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RESIDENTIAL CONSTRUCTION AND SEDIMENTATION AT KENSINGTON, MARYLAND*

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Abstract

Sediment transported in storm runoff near Kensington, Maryland, during the transformation of part of a 58-acre area from rural to residential land use was measured for 25 storm events from July 1959 to January 1962. These data were used with the water discharge record of nearby Rock Creek in a multiple regression analysis to show the magnitude and trend of sediment movement with time.

Total sediment discharged from the area affected by urbanization was 189 tons per acre for the entire period of construction and the subsequent return to a reasonably stable residential area. The high yield of sediment from the Kensington area is attributed to (1) the rolling topography, 3 to 25 percent slope, (2) a very friable soil and subsoil, (3) the construction of a street in the major drainage channel, (4) a tendency for construction methods to expose extensive areas of the soil for a long period of time, and (5) a substantial amount of the 42 inches of annual rainfall occurring at a rate in excess of the infiltration capacity of unprotected soil.

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Introduction

Population pressure in and around cities causes much urban construction which is tied to the mantle of soil and subsoil. This includes all the construction for the industrial, commercial, and residential developments including the necessary highways, streets and utilities. Some of the impact of urban growth on the general water regime was discussed by Savini and Kammerer (1961). The impact of urbanization on sediment accumulation in small reservoirs has been discussed by Guy and Ferguson (1962).

The pressure to occupy extensive land areas around our cities is mostly attributed to advances in agricultural technology and private transportation. Thus, the relatively high economic status of the urban population and relatively cheap transportation have combined to "price" the farmer off the land adjacent to cities. In many instances the use of more single instead of multiple family dwellings, larger parking lots, and single level school and commercial buildings causes an increase of urban land use per capita.

This paper deals with an example of the effects of residential construction on the sediment transported from a 58-acre drainage area at Kensington, Maryland--a part of the metropolitan area of Washington, D. C. The duration of the study is from July 1957 to April 1962.

The soil contains a considerable amount of sand and silt. The average size distribution of two subsoil samples in the basin is 14 percent clay, 30 percent silt, 43 percent sand and 13 percent gravel. Thus, the soil is very friable when acted upon by the erosive forces of raindrops and of the surface runoff flowing in sheets, rills, and larger channels. Under natural conditions the soil is well protected by vegetative cover.

Unaltered slopes in the basin range up to 25 percent, but in the construction area is only about 3 to 10 percent. Artificial slopes may be much steeper. The layout of streets in the basin is irregular. One of these streets is in the principle drainageway in the upper part of the basin.

The average annual precipitation on the area is about 42 inches. The average amount of stream runoff is about 16 inches of which about 4 inches is overland or surface runoff. Areas having little or no vegetative cover usually have a higher portion of the precipitation leaving the basin as surface runoff.

Basic Measurements

The determination of the amount of sediment transported from the basin was accomplished by a combination of actual observations and computation through correlations. The sampling was done on only selected storm events because the small size of the basin caused the surface runoff from the construction area to drain from the basin within a few minutes of the rain. Generally, several samples were obtained for the selected storms in order to define the variation of sediment concentration in transport. The samples were velocity-weighted over the cross section of flow moving through a drop spillway, and therefore represent the total sediment discharge. Such data were collected for 25 storm events plus some miscellaneous single observations during other storm periods. The first observations were made in July 1959 which is just prior to the time of maximum construction in the basin. The sediment transport determinations for the unmeasured storms was accomplished through correlation with water discharge of nearby Rock Creek.

The water discharge for the storms having sediment measurements was computed from hydrographs drawn from instantaneous observations of flow depth in the notch of the drop spillway. The stage-discharge relationship was established by measurements with a pigmy current meter. The unmeasured water discharge from the basin was determined by correlation with water discharge from nearby Rock Creek. All correlative relationships for both sediment and water were made on the storm event basis.

A precise record of the environmental conditions of the basin during the period of record was not attempted because of the effect of the varying stage of construction of a group of houses on the amount of sediment yield for a given storm characteristic and given season of the year. It is logical to assume that the maximum sediment yield occurred when the maximum 10 acres of construction was exposed. The total area exposed during the period of record can, however, be measured quite precisely from areal photographs. See figures 1 and 2. The total construction was for 89 single dwelling houses on 20.5 acres.

Figure 1. --Photograph taken August 28, 1957, outlining the area in the basin on which construction occurred during the period of record.

Figure 2. --Photograph taken May 7, 1961, showing completed residential construction. Stabilization of the drainage channels and the surface areas reduced sediment outflow for many months after this picture was taken.

Results for a Single Storm

The water discharge hydrograph and sediment concentration curves are shown in figure 3 for one of the larger storms (August 4, 1960).

Figure 3. --Runoff hydrograph and suspended-sediment concentration graph for storm of August 4, 1960, on a 58-acre area at Kensington, Maryland.

The streamflow hydrograph was drawn on the basis of four observations of water stage and the stage-discharge curve. The discharge near the peak rate of flow was checked by observations of float velocity moving through an 80-foot reach of the channel immediately upstream from the drop spillway.

Four depth-integrated suspended-sediment samples were obtained at the time of the water discharge measurements. A smooth concentration graph was drawn on the basis of these data and the concentration data for other lesser storms for which data have been obtained. The relative amount of sand in each concentration sample was determined by wet sieving the sediment. The percentage of sand in each sample in the order shown on figure 3 is 67, 80, 77, and 44, respectively. The amount of coarse sediment as contrasted with the amount of fine sediment in transport is considered indicative of the relative amount of sediment derived from channel erosion as contrasted with sheet erosion.

The hydrograph and concentration graph was subdivided as shown in table 1 for computation of water and sediment discharge. The table, the graphs, and the basic data provide information for summarizing the total and the peak intensity of rainfall, streamflow, and sediment as shown in table 2. This table allows more meaningful comparison of this storm with other storms and with other drainage areas.

Analysis of Data

The quantity of sediment discharged from the basin during the period of construction was computed by the following generalized steps:

(1) The amount of water and sediment discharged for each of the 25 sampled storm events was computed from sketches of the hydrographs and sediment concentration graphs. Figure 3 and table 1 provide an example for one of the 25 storms.

(2) The second step consists of listing variables associated with the storm-to-storm variation of sediment concentration or discharge. Due to the drastic changes of environment in the drainage basin, a measure of time M_t from the beginning of the record is essential. See figure 4.

Figure 4. --Mean sediment concentration of storm runoff from an area of residential construction at Kensington, Maryland, 1957 to 1962. Dashed line is estimated on basis of visual observations of construction area and the drainage channels.

TABLE 1. --Subdivision and computation of water and sediment discharge for storm the evening of August 4, 1960.

Time	Interval (hrs.)	Discharge (cfs)	Concentration (ppm)	Tons
9:00 - 9:06	1/10	6.5	7,000	0.5
9:06 - 9:12	1/10	39	28,000	12.3
9:12 - 9:18	1/10	74	43,000	37.1
9:18 - 9:30	1/5	84	51,200	100.3
9:30 - 9:36	1/10	79	51,700	47.7
9:36 - 9:42	1/10	56	49,000	32.0
9:42 - 9:48	1/10	34	41,500	16.5
9:48 - 10:00	1/5	13	27,000	7.9
10:00 - 10:12	1/5	4.7	14,400	1.5
10:12 - 10:42	1/2	1.7	6,000	.5
		50.04 (cfs-hrs.)		256.3

TABLE 2.--Summary of rainfall, streamflow and sediment discharge, both total and peak intensity, for storm of August 4, 1960.

Totals

Rainfall:	1.82 inches from 9:00 to 11:20 p.m. 1.68 inches from 9:00 to 9:33 p.m.
Streamflow:	2.1 cfs-days 0.87 inch
Sediment:	260 tons

Peak rates for maximum 12-minute period

Rainfall:	Estimated 4 inches per hour
Streamflow:	84 cfs (from 58 acres) 927 cfs per sq. mi. 1.44 inches per hour 51,200 parts per million
Sediment:	8.4 tons per minute (for 58 acres) 12,000 tons per day (for 58 acres) 132,000 tons per day per sq. mi.

As shown by the writer (----), some of the remaining storm-to-storm variation can be related to (a) the magnitude of the storm in terms of runoff quantity Q_w or rainfall quantity R_q, (b) the season or time of year which can be evaluated in terms of the mean air temperature T_a, (c) the storm intensity as measured by the relative peakedness of the hydrograph P_n, and (d) the antecedent condition of the basin measured in terms of the base flow in nearby Rock Creek. Tables 3 and 4 summarize the data for these variables for each of the 25 storms for the construction basin and for the Rock Creek basin, respectively.

(3) Graphical correlation was used in the third general step to determine the necessary transformation of the variables to yield linear relationships. The values of T_a can be used directly. The function for transformation of M_t is

$$\log\left(\frac{M_t - 5}{1.5}\right)^{\left(1 + \frac{M_t - 5}{10}\right)}$$

All other variables are transformed with log base 10. The values for Q_w are multiplied by 100 and the values for R_q and R_{qr} are multiplied by 10.

(4) Multiple regression analysis by computer was then used to obtain equations having a minimum standard error of estimate for predicting Log C and Log Q_w. These are:

1. $\text{Log } C = 4.935 - 0.506\, f(M_t) + 0.317 \log P_n - 0.294 \log 10\, R_q$ (S. E. = 0.141 log units)
2. $\text{Log } C = 3.741 + 0.109 \log Q_{wr} - 0.429\, f(M_t) + 0.0062\, T_a + 0.325 \log Q_{br}$ (S. E. = 0.172 log units)
3. $\text{Log } 100\, Q_w = -0.579 + 0.896 \log Q_{wr} + 0.0103\, T_a - 0.345 \log Q_{br}$ (S. E. = 0.271 log units)

TABLE 3.--Hydrologic and sedimentologic data by storm events from a drainage area affected by residential construction.

Date	Precipitation	Water discharge		Sediment		Peak flow	Mean air temp.
	R_q (inches)	Q_w (cfs-days)	(inches)	Discharge Q_s (tons)	Concentration C (ppm)	P_n (cfs)	T_a (°F)
1959							
July 1	1.7	0.81	0.332	128	59,200	25	74
Oct. 1	.9	.39	.160	60	54,500	9.0	61
Nov. 7	.8	.25	.103	14.7	21,800	1.8	48
Dec. 28	.44	.048	.020	5.0	37,200	2.0	35
1960							
Jan. 3	.8	.156	.064	14.3	32,800	5.0	33
Feb. 18	.7	.59	.242	73	46,700	11.1	34
Apr. 3	.4	.194	.080	20.3	38,700	1.6	49
May 8	1.5	.76	.312	55	26,800	6.0	61
May 21	.6	.23	.094	37	57,300	12	64
May 22	.6	.39	.160	72	65,300	15	64
July 11	.7	.158	.064	11.7	27,400	5.0	75
July 30	1.0	.53	.218	20.2	14,000	3.1	75
Aug. 3	.8	.52	.213	48	34,000	13	74
Aug. 4	1.8	2.08	.854	256	44,000	84	74
Sep. 12	4.1	2.68	1.102	123	17,000	20	68
1961							
Mar. 8	.4	.233	.096	6.0	9,600	7.8	41
May 7	.6	.149	.061	11.7	29,000	13.5	61
May 12	.3	.37	.152	12.6	12,700	9.0	61
June 9	.22	.032	.013	.7	7,700	2.1	69
June 14	1.0	.48	.197	18.9	14,600	22	70
July 24	.30	.042	.017	.8	6,900	3.3	75
Aug. 9	.6	.21	.086	4.1	7,350	12.9	74
Sep. 3	.30	.125	.051	1.4	4,200	12.3	70
Oct. 21	.5	.45	.185	4.4	3,550	3.4	54
1962							
Jan. 6	.6	.23	.094	.9	1,490	3.9	33

TABLE 4.--Hydrologic data for Rock Creek for storm events listed in table 3.

Date	Precipitation	Water discharge		Base flow	Peak flow
	R_{qr} (inches)	Q_{wr} (cfs-days)	(inches)	Q_{br} (cfs)	P_{nr} (cfs)
1959					
July 1	0.8	170	0.102	18	840
Oct. 1	1.0	135	.081	21	396
Nov. 7	.6	55	.033	33	164
Dec. 28	.6	65	.039	49	121
1960					
Jan. 3	.8	205	.123	41	443
Feb. 18	1.3	895	.536	75	1,080
Apr. 3	1.2	286	.171	110	330
May 8	1.9	323	.193	36	418
May 21	.8	128	.077	35	131
May 22	.5	175	.101	53	401
July 11	1.5	166	.099	19	386
July 30	1.5	171	.102	22	450
Aug. 3	.9	111	.066	18	890
Aug. 4	1.6	522	.312	30	1,750
Sep. 12	3.2	791	.473	28	1,200
1961					
Mar. 8	.3	124	.074	76	99
May 7	.5	160	.096	60	374
May 12	.4	215	.129	57	325
June 9	.2	35	.021	43	283
June 14	.5	148	.089	35	650
July 24	.6	34	.020	34	90
Aug. 9	.4	50	.030	21	194
Sep. 3	.2	12	.007	18	48
Oct. 21	1.8	268	.160	6	531
1962					
Jan. 6	.8	360	.216	28	480

The first equation is mostly of academic interest because water discharge and precipitation data were collected for only 25 storms during the period of observation; however, it does give a basis for evaluating the effectiveness of the other equations when used for determining sediment discharge of the unsampled storms.

From the time of the first observation in July 1959 to the end of the record in April 1962, the continuous recording from the Rock Creek gaging station shows a total of 124 storm events which could result in at least 0.011 inch of runoff or at least 0.2 ton of sediment. The sediment discharged for each of the 127 storm events was computed by

$$Q_s = 0.0027\ C\ Q_w \quad \text{when} \quad C < 32{,}000 \text{ ppm}$$

and

$$Q_s = 0.0028\ C\ Q_w \quad \text{when} \quad C > 32{,}000 \text{ ppm}$$

where C and Q_w are computed from the multiple regression equations 2 and 3. The computed results for C are presented for comparison with the measured values of C in figure 4 for the 25 storms for which data was obtained.

From July 1957, the beginning of construction, to the observation of the first storm event in July 1959, the data from Rock Creek shows an additional 63 storm events important to the determination of the sediment contribution from the construction area. The sediment discharged for these events was computed by use of the same formulas for Q_s and the third regression equation for Q_w but using an estimated value for C from figure 4. The value for Q_w was decreased by a factor to compensate for the trend of increasing storm runoff as the 20-acre construction area was cleared of its natural vegetative cover. The factor was varied with time from 0.62 in July 1957 to 1.00 in July 1959. During the sampling period from July 1959 to April 1962 no significant change in the relationship of runoff in the test basin Q_w to runoff in Rock Creek Q_{wr} took place.

These computations show that 4,000 tons of sediment in 22 inches of runoff was discharged from the 58-acre basin during the 4 3/4-year construction period from July 1957 to April 1962. The actual construction area on which 89 single family dwellings were built is 20 1/2 acres. The remaining 37 1/2 acres is mostly a residential area which was completed prior to this study and some undeveloped area. A liberal estimate of sediment discharge for the 37 1/2-acre portion of the basin would be 3/4 ton per acre per year or a total of about 130 tons. The net is then 3,880 tons from the construction area which is equivalent to 189 tons per acre of 121,000 tons per square mile.

Figure 5 shows the time trend of sediment discharge from the

Figure 5. --Cumulative sediment discharged from the construction area with time. Note the higher rates of accumulation during summer months.

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area during the construction area. The rate of sediment discharge accumulation was more during the summer months than during the remaining months of the year. The maximum year of accumulation was during 1959 when the average concentration of sediment in the runoff was a maximum (figure 4).

Discussion

Most of the construction in the 58-acre basin was located on or near the upper part of the basin. As noted in the introduction, one of the streets was built over the principle drainageway. The construction followed a pattern of development in subareas ranging in size sufficient for 5 to 20 houses with as many as 3 subareas exposed at one time. The lack of vegetative cover reduces the infiltration rate and hence causes an increase in surface runoff. Some of the subareas were exposed for as long as 2 years while others were exposed for only about 8 months. The relatively great areas of exposed slopes and channels therefore cause intensive sheet, rill, and channel erosion of sediments.

In the early stages of construction in 1957 and 1958, much of the sand eroded from the construction areas was deposited in the downstream channels giving them the appearance of a true sand-bed stream. In the last year of the record, most of the sand was transported from the channels. Thus, the channels returned to the more natural state with rock and gravel armoring of the bed and with heavy vegetative growth on the banks.

The 189 tons per acre or 121,000 tons per square mile determined from the Kensington area may be considerably greater than may be expected for average urbanization around Washington. Measurements of sediment accumulated in Lake Barcroft, also a part of the metropolitan Washington near Fairfax, Va., between 1938 and 1957 show an average of about 25,000 tons for each of the 9 1/2 square miles urbanized. The Lake Barcroft yield may be low since much of the housing development, at least in the vicinity of the lake, is "custom built", that is, only the small area for a single home is exposed at a given time and each area having little likelihood of being connected by channel with the surface drainage system. Also, in the Barcroft area, some sediment is stored in the channels and on the flood plains which drain the area to the lake.

It is reasonable to assume that the streams draining the area around metropolitan Washington will transport 20 million tons of sediment to the Potomac River in the next 20 years given the following:

1. That the population increases by 2 million.
2. That the present population density of 4,000 per square mile will continue.
3. That 500 square miles of rural area will therefore be urbanized.
4. That the sediment discharged to the streams will be 40,000 tons per square mile, or about 1/3 that measured at Kensington and yet more than that measured at Lake Barcroft.

The results of urbanization under these conditions amount to the movement by streams of 10 tons of sediment for each person added to the city.

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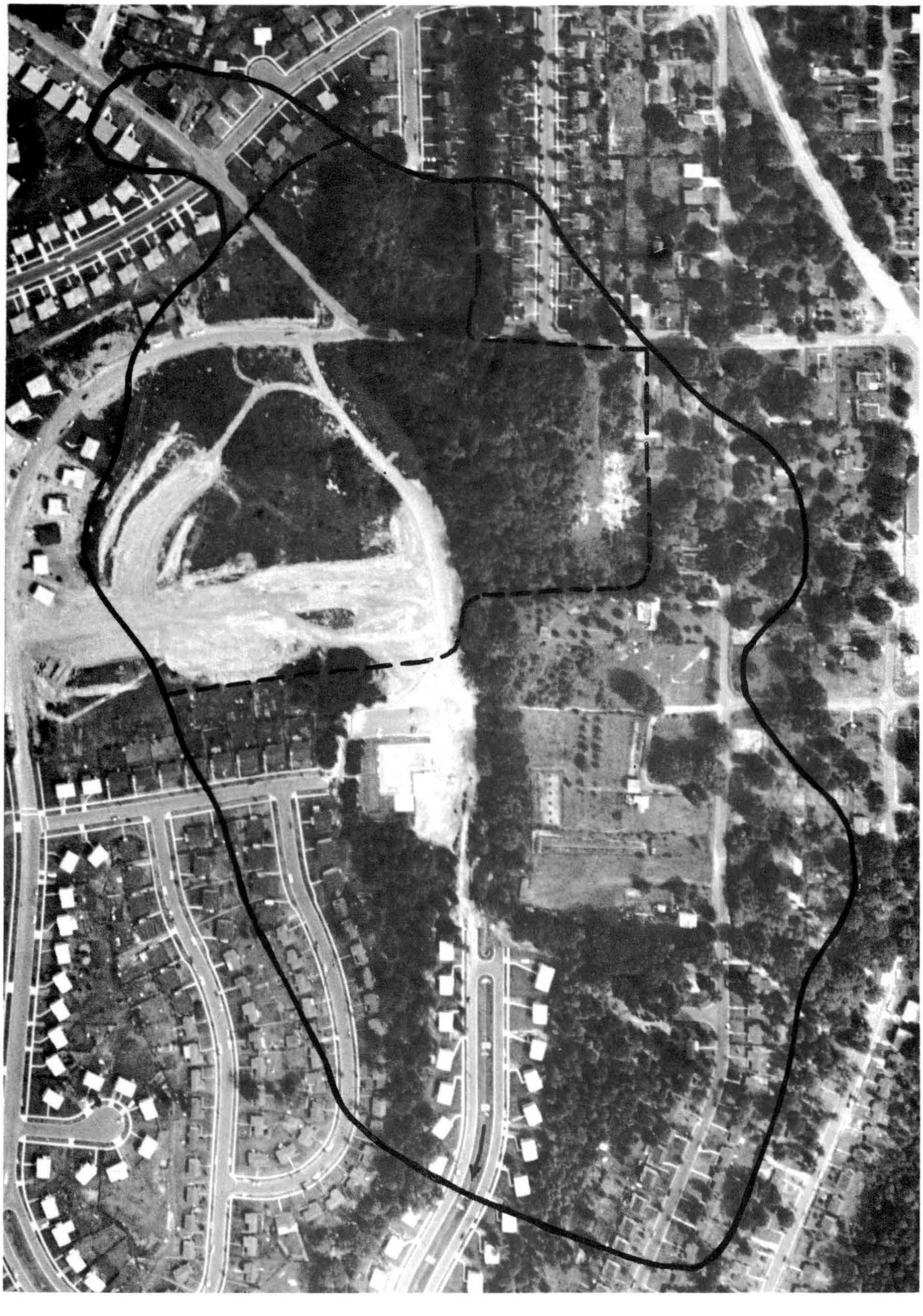

Figure 1. --Photograph taken August 28, 1957, outlining the area in the basin on which construction occurred during the period of record. Scale 303 ft per inch.

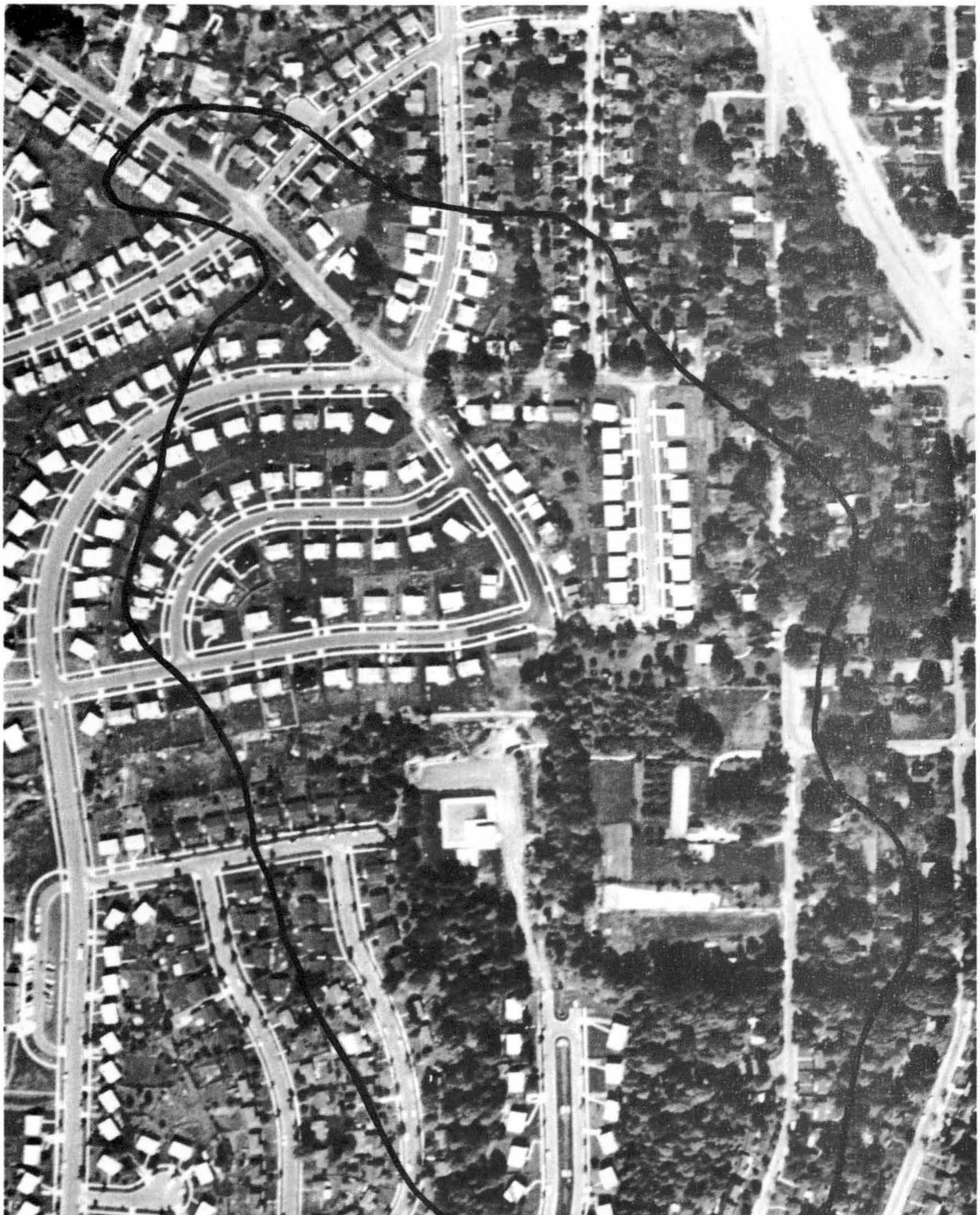

Figure 2. --Photograph taken May 7, 1961, showing completed residential construction. Scale 317 ft. per inch. Stabilization of the drainage channels and the surface areas reduced sediment outflow for many months after this picture was taken.

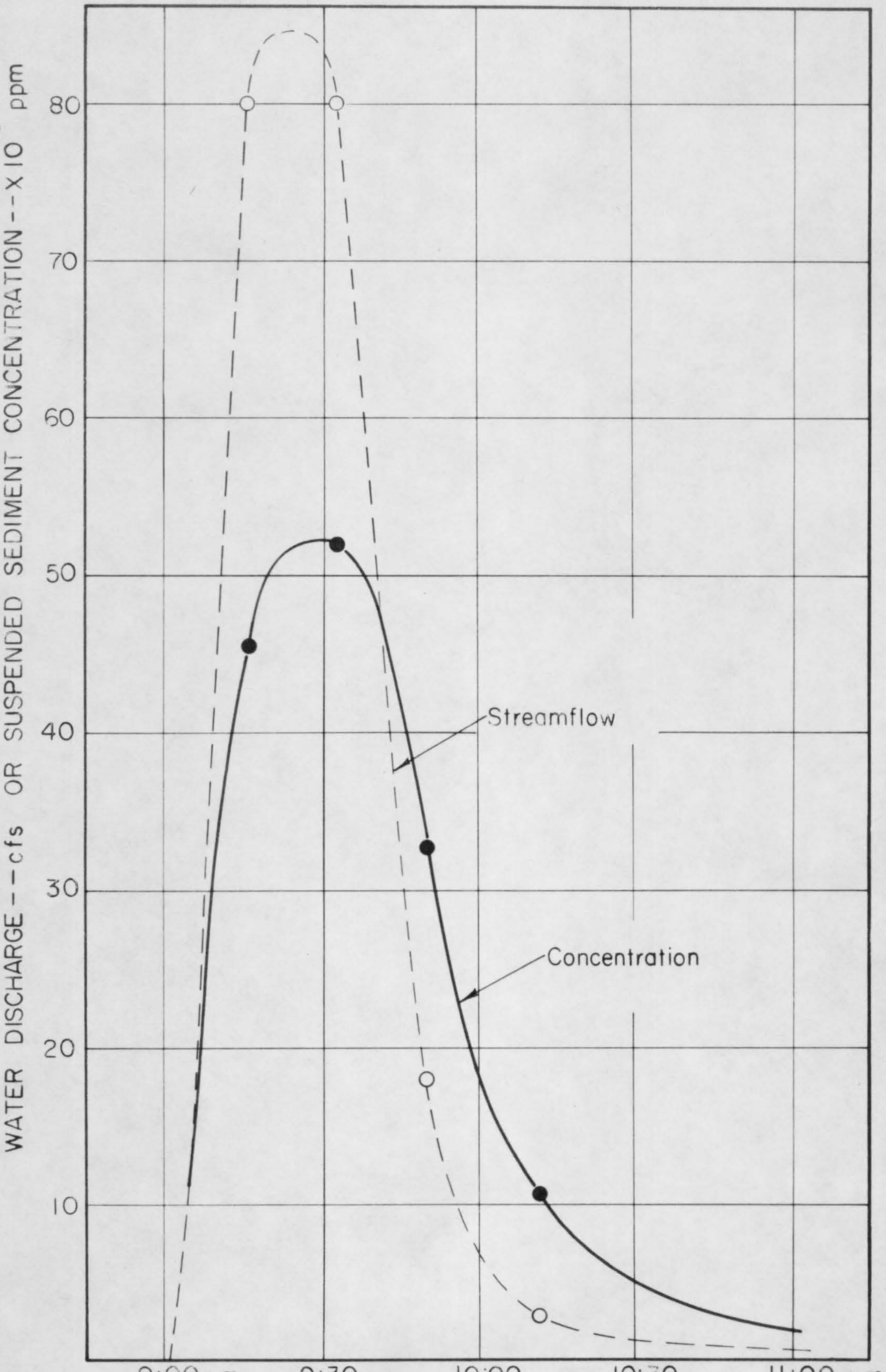

FIG. 3 RUNOFF HYDROGRAPH AND SUSPENDED - SEDIMENT CONCENTRATION GRAPH FOR STORM OF AUG. 4, 1960 ON A 58 - ACRE AREA AT KENSINGTON, MD.

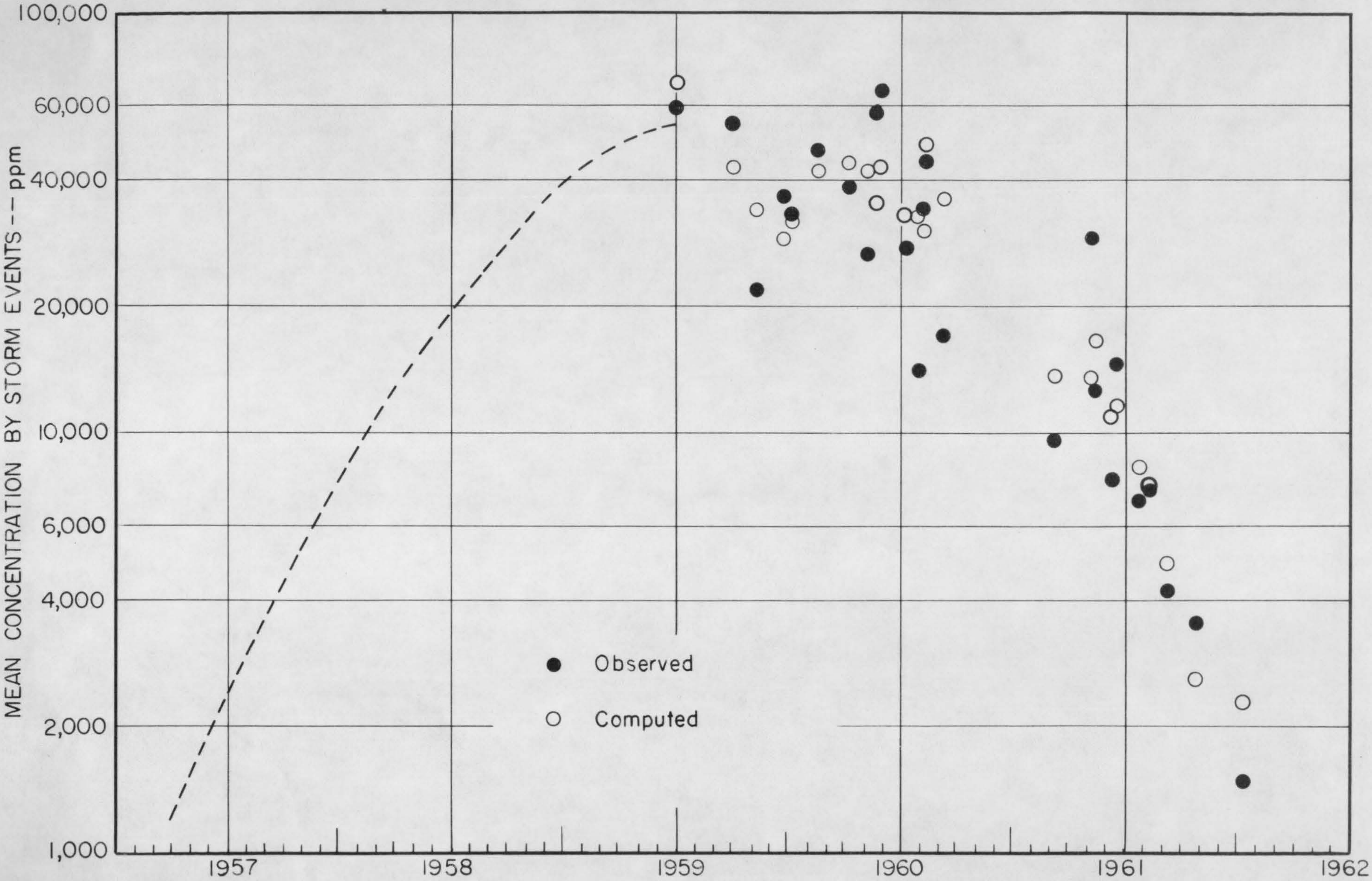

FIG. 4 MEAN SEDIMENT CONCENTRATION OF STORM RUNOFF FROM AN AREA OF RESIDENTIAL CONSTRUCTION AT KENSINGTON, MD. 1957 TO 1962. DASHED LINE IS ESTIMATED ON BASIS OF VISUAL OBSERVATIONS OF CONSTRUCTION AREA AND THE DRAINAGE CHANNELS.

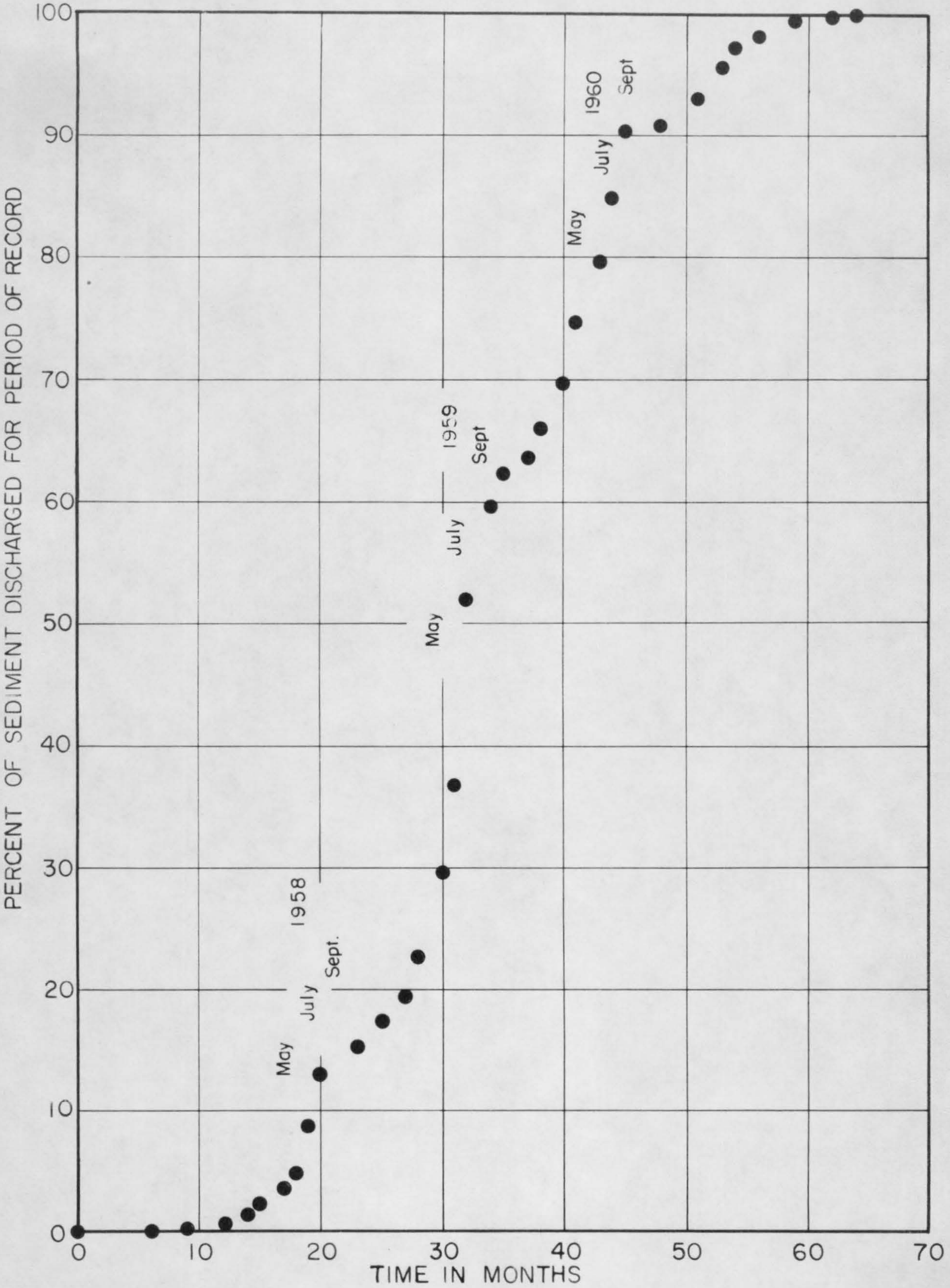

FIG. 5 CUMULATIVE SEDIMENT DISCHARGED FROM THE CONSTRUCTION AREA WITH TIME. NOTE THE HIGHER RATES OF ACCUMULATION DURING SUMMER MONTHS.