Bulletin 98

Evaluation of Sediment Yields Due to Urban Development

Chin Y. Kuo

Bulletin 98
September 1976

Evaluation of Sediment Yields Due to Urban Development

Chin Y. Kuo
Department of Civil Engineering
Old Dominion University
Norfolk, Virginia

The work upon which this report is based was supported by funds provided by the Research Division, Virginia Polytechnic Institute and State University.

Project D-009-VA
VPI-VWRRC-BULL 98

A publication of
Virginia Water Resources Research Center
Virginia Polytechnic Institute and State University
Blacksburg, Virginia 24061

PREFACE

Urban sedimentation is one of the most pervasive and most destructive elements of non-point pollution in areas undergoing new residential, industrial, and commercial developments. Intensive and massive stripping of vegetation and topsoil from construction sites produces higher erosion rates. The increased volume of sediments deposited in nearby streams and lakes frequently results in adverse impacts, and expensive remedial measures are required to correct the situation. A recognition of sediment problems and their solutions in urban areas is necessary if people are to have an acceptable environment.

In coastal areas such as the Tidewater region, even more adverse effects are apparent. Sediments serve as vehicles which transport contaminant materials throughout the estuary. Sediments in agricultural or urban areas absorb pollutant materials such as harmful bacteria and toxic chemicals and carry them to tidal waters by means of surface runoff. Due to the deposition of suspended sediment or resuspension of bottom sediments, sediment density layers of considerable thickness may flow under tidal current into spawning, nursery, and habitat areas. This condition may force closing of oyster beds. If these layers settle in vital areas, normal food chains may be disrupted and natural ecological balance destroyed. On the other hand, sediment may be beneficial if it sorbs the contaminant and then deposits it someplace where it is harmless. Without the sediment, the contaminant may cause much damage as it moves through the water system.

The consequences of urban sedimentation can be seen at Lake Pembroke in Virginia Beach. Massive fish kills in 1973 were credited to excess sediment from the surrounding construction areas. At that time, insufficient data existed for decisionmaking on such remedial measures as a sediment basin, storm drainage, and dredging.

The current project is focused on coastal urban areas in Virginia Beach, Virginia. Cedar Hill subdivision, an area undergoing housing development, was chosen for study of soil erosion rate, sediment yield, and sediment delivery ratios. The results of this study will be helpful in determining appropriate erosion-control methods for the area. Findings also should be applicable to other similar coastal urban areas.

This research was sponsored by the Virginia Water Resources Research Center, Blacksburg, Virginia. Consultation and review of the manuscript by Harold P. Guy, U. S. Geological Survey, Reston, Virginia, is appreciated. Acknowledgment also is made to Vernon O. Shanholtz of Virginia Polytechnic Institute and State University and C. A. Onstad of the U. S. Department of Agriculture for their review of the manuscript.

Trade names are used in this report solely for the purpose of providing information. The mention of a trade name does not constitute a guarantee of the product nor an endorsement over other similar products.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

This research project sought to determine sediment yields in the Cedar Hill area, Virginia Beach, Virginia. Using a modified Universal Soil Loss Equation, soil-erosion rates were estimated at construction, semi-construction, and well-developed sites in this area. Sediment yields then were measured at the three sites and at a downstream monitoring station and compared with the estimates. Dilution factors also were studied as a function of rainfall intensities, and are believed to correlate with the characteristics of the area undergoing construction. The dilution factor was defined as the ratio of suspended-sediment concentration on the site compared to that for an off-site specific downstream station at the peak hours of runoff hydrographs. The dilution factor was found to increase as rainfall intensity decreased, and on-site soil erosion rates varied according to the stage of construction.

INTRODUCTION

The tremendous volume of urban-construction erosion and its impact on society has become a major cause for public concern. Soil sediments are considered non-point pollutants when they interfere with the use of water for domestic use, navigation, drainage, recreation, agriculture, and biological or ecological functions. Sediments, including nutrients and pesticides adsorbed on and associated with sediments, influence water quality and affect the growth of organisms in lakes, rivers, estuaries, and marine environments. Sediments may affect public health in a number of ways. Economic loss may result from actions such as the closing of oyster beds due to high concentrations of sediment. Unless urban construction and development are well planned and carefully managed, the total environment will be degraded as the result of urban sediment erosion, transportation, and deposition.

It is desirable that planners and designers understand the general nature of the problem, the mechanics of soil erosion, sediment transport and deposition, the availability of erosion-control guidelines and technology, and legislative measures such as erosion and sediment control laws and local ordinances. Numerous publications are available [Environmental Protection Agency, 1973; Guy, 1970; Guy and Jones, 1972; Guy, 1974; Guy, 1975a; Guy, 1975b; Heinemann and Piest, 1975] in the general areas, and these have led to more specific literature. It is beyond the scope of this report to review the entire urban sediment problem. This bulletin presents some findings of a project of evaluation of stream sediment yield in a housing construction area of Cedar Hill subdivision, Virginia Beach, Virginia.

The development of Virginia Beach differs from other Tidewater Virginia cities. The city's rapid growth primarily is due to activities related to beach resorts, seaports, naval bases, large industries, and commercial enterprises. Urban construction, involving the change from farm lands to residential areas, has accelerated in recent years. It is desirable as one aspect of coastal resources management to insure acceptable water quality by minimizing the impact of the urban sediment problem.

Although the city has an erosion and sediment control ordinance, its effective implementation requires better understanding of the erosion, transport, and deposition processes in this part of the coastal plain. Practically no streamflow-gaging or sediment-measurement stations have been established in this area, since most of the creeks are in the tidal region and non-tidal creeks are small and short in length. The applicability of the Universal Soil Loss Equation for either rural areas or its slightly modified form for construction areas needs to be studied in the context of the flat topography.

THE WATERSHED

Figures 1 and 2 show the location of the study area. Because of the flat terrain in the coastal plain, watershed boundaries normally are difficult to identify. Once identified, it is likely that the area is too large for an efficient sediment-yield study due to the comparatively small size of construction sites. Upstream of gaging Station A (Figure 1), the drainage area is relatively big and flat, with significant coverage by small swamps, storage ponds, and tall vegetation. Consequently, the time of concentration for surface runoff at Station A is long, the runoff volumes and peak discharges are small, and the suspended sediment concentrations are low. On the other hand, the drainage area between Stations A and B is well developed, with Cedar Hill being the only site subjected to the severe soil disturbances of housing construction. At Station B, the time of concentration, runoff volume, and suspended-sediment concentration are quite different from Station A. These features suggest selection of Point A as the reference station (rural conditions) and Point B as the monitoring station for the runoff and sediment measurements of the residential and construction areas. Cedar Hill Creek, which runs through the area, is a non-tidal stream with an average width of 6.1 m, embankment height of 1.83 m, and slope of 0.0033 for this reach.

The drainage area between the two stations is 1.17 km^2. Cedar Hill subdivision has an area of 0.39 km^2. The surface coverage in August 1974 within the drainage area is classified as follows: 7.4 percent woods; 3.1 percent pond; 1.7 percent exposed soils; 23.3 percent impervious surface including roofs, driveways, and streets, and 64.4 percent percent semi-exposed area including lawns, gardens, farm land, and stripped but unconstructed land with some vegetation.

The land use of the construction site formerly was agricultural. The subdivision was laid out in 1971 and house construction began late in that year. The neighboring subdivision inside the sub-drainage area was develoed in the mid-1960's. Generally, only four to five single-family houses have been under construction at a given time. Hence, the size of the exposed area undergoing active construction has remained relatively constant. The building permit was issued before approval of the city erosion and sediment ordinance, so no sediment-control measures have been taken. Most of the eroded sediments have been carried to the creek through the storm drainage system via street-drain inlets.

SOIL AND SEDIMENT INFORMATION

Soil types were obtained from the local Soil Conservation Service. The dominant soils were Woodtown and Othello. Woodtown is a moderately well-drained soil with fine sandy loam and loamy sand substrata, a high seasonal water table, permeability of 5.08 to 15.24 cm/hr, and available moisture capacity of 0.14 to 0.19 cm/cm of depth. Othello is poorly drained, has a high seasonal water table, fine sandy loam and loose fine sand, permeability of 1.6 to 5.08 cm/hr, and available moisture capacity of 0.16 to 0.23 cm/cm of depth. Othello is the soil at the construction site. Particle size distributions for this soil and the streambed material are shown in Figure 3. Only 0.5 percent of the riverbed sediment is in the range of silt and clay sizes (less than 0.062 mm), whereas 23 percent of the soil at the construction site falls in this range. Nearly all the suspended sediment moving at the monitoring Station B was of silt and clay sizes. The sand sizes discharged from the storm drains are not being deposited upstream of Station B. The suspended-sediment sampling zone was representative of the entire flow depth. Thus, the sediment sampled was primarily wash-load from land erosion, not channel erosion.

Analysis of suspended-load, channelbed and construction-site materials for grain size were made following standard methods specified by the American Society for Testing Materials (ASTM).

DATA COLLECTION

Water and sediment-discharge measurements were made at gaging Stations A and B (Figure 1). Stream stages were continuously recorded with Stevens A-35 recorders. Steamflow ratings were established with a Pygmy Type F-583 water-current meter from Weather Measure Corporation. Suspended-sediment samples were collected at both stations during storm periods using a USDH-48 sampler. Concentrations of suspended sediment were determined using the evaporation method specified in the U.S. Geological Survey series on techniques for water resources investigations [Guy, 1969]. Type P501-I remote recording rain gauge with Type P521 event recorder, both from Weather Measure Corporation, were installed for rainfall data collection at the midpoint between Stations A and B, near the center of the drainage area. Suspended-sediment samples were also collected at the street-drain inlets draining well-developed areas, construction sites, and semi-construction areas where the land was stripped but unconstructed. Concentration data at the street-drain inlets were obtained: (1) to define the variation of sediment concentration with respect to time at the three sites, and (2) to study the effect of dilution. Samples also were collected for these purposes at the peak hour of river stage at both the downstream and the upstream stations.

RESULTS AND ANALYSIS

I. Flowrates and Suspended Sediment Concentrations

A summary of the recorded hydrologic and sediment data is presented in Table 1 Typical data obtained can be seen from the results of a particular storm on March 30, 1975. Suspended-sediment concentrations and discharges upstream (Station A) and downstream (Station B) as a function of time are plotted for this storm in Figure 4, with rainfall data inserted for reference. The extremely low and stable streamflow and suspended-sediment concentration at Station A, verify the observation previously made on the characteristics of the drainage area upstream from this point.

The response of Station B to the surface runoff and sediment load from the drainage area undergoing construction is dramatic. The net suspended-sediment concentration and discharge between the two stations represent contributions from the drainage area under consideration. The peak time for the runoff hydrograph is a reflection of the rainfall pattern and reveals that the time of concentration for the drainage area between Stations A and B is estimated to be less than 20 minutes. Rainfall data are used for the calculation of erosive energy, whereas the hydrograph and sedimentgraph are used for the computation of water and sediment yield. Both results are used in conjunction with the estimation of soil erosion rate and sediment-delivery ratio. Curves for the sediment concentration/streamflow rating for storms of January 11 and March 30, 1975 are shown in Figure 5. Each data point indicates the flowrate and suspended-sediment concentration at a given time. In general, the time rate of change for both suspended-sediment concentration and discharge is large for the period of stage rise.

During the fall and early winter of 1974 and 1975, the weather was extremely dry, with only occasional light showers and drizzles. In contrast with data given in Figure 4, Figure 6 indicates a very small difference in discharge and sediment concentration between the two stations, due to the light intensity, long-duration rainfall during the period observed. The amount of sediment washed away from the construction land is relatively insignificant and unmeasurable. These data document the effect of rainfall intensity as the active agent of soil erosion.

For a rainfall of 16 minutes' duration and a uniform rate of 4.5 mm/min on March 24, 1975, the sediment concentration for the samples collected at street drain inlets is plotted in Figure 7 as a function of time. This shows the on-site erosive phenomena—that is, how fast the soil at different sites is eroded and transported along the gutter to the street-drain inlet. In Figure 7, the magnitude of sediment concentration at each location except C-1, a well-developed area, is relatively high at the beginning of the rain and decreases thereafter. The time rates of change of sediment concentration are almost the same, except for C-1. The average sediment concentration occurs approximately when the runoff hydrograph at Station B reaches its peak. This also corresponds approximately to the peak of the sedimentgraph.

TABLE 1

Summary of Hydrologic and Sediment Data Recorded

Storm Date 1975	Total Rainfall (mm)	Rainfall Duration (min)	Maximum Rainfall Intensity Near Time of Peak Discharge (mm/min)	Peak Net Discharge, $Q_B - Q_A$ (cms)	Peak Concentration of the Net Suspended Sediment, $C_B - C_A$ (mg/l)	Mean Concentration of Suspended Sediment at Street-Drain Inlet at Construction Site (mg/l)
1-4	6.8	255	0.027	0.09	≈0	600
1-11	16.8	70	0.8	1.1	3280	1816
2-16	24	180	0.16	0.22	320	3796
2-24	26.4	90	1.68	1.4	3600	3144
3-13	5.6	25	0.4	0.08	112	897
3-14	12.4	95	0.373	0.3	180	1517
3-17	22	85	0.27	1.05	203	1376
3-19	49.6	285	0.293	0.91	840	2797
3-30	23.6	225	0.627	1.01	1600	1445
5-27	16.4	35	0.47	0.45	960	7207
6-18	14	52	0.27	0.17	750	3700
7-4	8	90	0.09	0.03	81	305
7-12	68.8	210	1.23	2.0	2950	3154
7-13	20	60	0.33	0.78	100	1716
7-13	18.4	23	0.8	1.05	222	1523
7-14	5.6	23	0.243	0.9	400	2337
7-16	16.8	102	0.53	0.33	326	4713
8-21	8	15	0.53	0.23	1311	1334
8-24	24	35	1.0	0.99	2160	3255
9-1	10.8	15	0.72	0.48	385	2156
9-21	13.6	90	0.33	0.03	370	2725
9-23	10.8	75	0.53	0.03	758	4484
9-26	24	55	1.33	0.51	1862	2926

II. Dilution Factor

For practical and convenient purposes, the term "dilution factor" in this study is defined as the ratio of suspended-sediment concentration on the construction site compared to that of a specific off-site downstream station at the peak time of the sedimentgraph. The specific downstream station refers to a point in the immediate vicinity where the drainage system enters the natural drainage watercourse. This requirement is necessary to assure that the construction site of interest is similar to the present case, with a relatively short-time concentration for surface runoff. The dilution factor is a lump-sum representation of the characteristics of the sediment-transport pattern in a drainage area undergoing construction. It is evident that the dilution factor may be a function of many parameters related to the sediment delivery processes, such as drainage system, sediment properties, rainfall, and runoff.

Figure 8 shows a simple relationship between the dilution factor and rainfall intensity for 18 storm events. The general tendency is for the dilution factor to increase as rainfall intensity decreases. For high-rainfall intensity, the dilution factors are expected to approach unity. The scatter in Figure 8 may be due to inexact timing of sampling, and possibly to some difficulty with the definition of the dilution factor. Semi-log or log-log plots do not result in a better presentation of the information in this figure.

III. Soil Erosion, Sediment Yield, and Sediment-Delivery Ratio

In addition to the data shown, samples collected at street-drainage inlets in each of the semi-construction and unconstructed sites were similarly analyzed and the results presented in Figure 9. The concentration for each storm and the sample location varies as rainfall intensity changes. The average proportionality among the three concentrations for the three sites for a particular rainfall intensity is about 40:10:1. Concentrations at the three sites for a given rainfall intensity are not the same, even though each site probably had the same erosive energy for that rainfall event. One factor producing the proportionality was the surface coverage at the three sites. Based on this analysis, the proportionality for the soil erosion control practice factor, C, in the modified Universial Soil Loss Equation for three sites is thus estimated as:

$$C_1:C_2:C_3 = 0.025:1.0:0.25$$

where subscripts 1, 2, and 3 refer to nonconstruction, construction, and semi-construction sites, respectively.

The modified form of the Universal Soil Loss Equation as suggested by Chen [1974] is as follows:

$$q_c = RKLSC$$

where:

q_c = the rate of soil erosion from a construction site;
R = the rainfall erosive energy;
K = the soil erodibility;
LS = the length of steepness of slope, and
C = the control practice.

The C factor can be evaluated as the product of the control factors associated with each of the individual sediment control measures. Thus:

$$C = C_s \cdot C_r \cdot C_t \cdot C_e \cdot C_o$$

where:

C_s = the control factor due to surface stabilizing or protecting treatment;
C_r = the control factor due to runoff reduction practices;
C_t = the control factor due to sediment trapping measures;
C_e = the control factor due to restricting the spatial and/or temporal exposure of the denuded site to the rainfall and runoff erostion, and
C_o = other practices that are not included.

The Virginia Beach Erosion and Sediment Control Ordinance [1973] suggests a value for average annual erosive energy of the rainfall (R) to be R = 300. The K value for the C horizon of Othello soil is 0.28. Because no sediment-control measures were taken in this case, the C value is taken as unity at the construction site. For most of the lots in the subdivision, the slope length is 15 to 30 meters, slope is 8 to 10 percent, and the erosion rate is estimated to be 14,800 metric tons/km^2/yr. This soil erosion rate, illustrated in Figure 10, falls into the same data band as indicated by Chen [1974].

To estimate the lump-sum control practice factor, C, for the semi-exposed area previously mentioned, the area is broken into two categories. One is for lawns and gardens (40.3 percent of the drainage area), and the other is the stripped but unconstructed land with some degree of vegetation growth (24.1 percent of the area). It is assumed that soil erosion from impervious surfaces, ponds, and woods is practically nill. The C values for lawns and unconstructed areas can be deduced from the previous results as 0.25 and 0.25 respectively. It follows that soil-erosion rates from these two types of surface coverage are 3,600 metric tons/km^2/yr for a semi-constructed area, and 360 metric tons/km^2/yr for a well-developed area. The erosion rate for the well-developed area falls into the data band of non-construction land shown in Figure 10.

The sediment yield, Q_s, in tons, at a downstream location (Station B) can be expressed as:

$$Q_s = D\left[q_c\left(\frac{A_c}{A}\right) + q_s\left(\frac{A_s}{A}\right) + q_u\left(\frac{A_u}{A}\right) + q_o\ 1-\left(\frac{A_c + A_s + A_u}{A}\right)\right] A$$

where:

D	=	the sediment delivery ratio, defined as the ratio of the percentage of sediment delivered to a specific location in watershed to the soil erosion from the source area.
q_c, q_s, q_u, q_o	=	the soil erosion rates in tons per acre per year, from construction site, semi-construction site, nonconstruction site, and other surfaces ($q_o = 0$).
A_c, A_s, A_u, A	=	the area in acres of construction site, semi-construction site, non-construction site, and total drainage area.

Based on the recommended curves for the sediment-delivery ratio as a function of drainage area for Maryland and the southeastern U.S. [Chen, 1974], the sediment yield is estimated as about 3,500 metric tons/km^2/yr when the sediment-delivery ratio is estimated to be 45 percent. This indicates that the drainage area undergoing construction is in the high-dilution category as classified by Wolman and Schick [1967] and illustrated in Figure 11.

In order to better understand the sediment-delivery ratio for this area, the thunderstorm of March 30, 1975, was analyzed. Rainfall intensities were 3.4 mm/hr for the first 60 minutes and 4.7 mm/hr for the next 30 minutes, this being equivalent to a recurrence interval of one year. The rainfall erosion energy, R, for this single storm event was calculated to be 11.9, and soil-erosion at the construction site for this storm was estimated to be 580 metric tons/km^2. Data on water discharge and suspended-sediment concentrations observed at Station B indicated that the sediment yield was 5.4 metric tons and that the sediment-delivery ratio was ony 3.2 percent. This discrepancy between the estimated and observed value of the ratio might be due to the occurrence of five rains of moderate-to-heavy intensity during the previous two weeks and the fact that the construction site was not newly disturbed during the period. This implies that the soil-erosion rate sometimes may be overestimated with the use of the Universal Soil Loss Equation. It seems evident that the impact of the previous rainfall events on soil conditions, such as compactness and moisture content, must be taken into account in computations to estimate the soil-erosion rate. A study of sediment-delivery ratios for other storms based on computed rainfall erosion energy indicated that the ratios ranged from 0.14 percent to 9.5 percent. The sediment-delivery ratios, as computed by the modified Universal Soil Loss Equation, are relatively low in the study area compared with other watersheds described in the literature [Chen, 1974]. If a mean sediment-delivery ratio of 4.5 percent is used for Cedar Hill, the sediment yield is estimated as about 350 metric tons per km^2 per year. The sediment yield for the construction site is indicated in Figure 12.

IV. Sediment Yield for Different Construction Stages

Figures 12 and 13 are similar to Figure 9 except each of them represents the data obtained during different time periods. C-1 identifies the well-developed area, C-2 the semi-construction area, and C-3 the construction site. Comparison of Figures 9, 12, and 13 reveals that the change of suspended sediment concentration of the samples collected at street inlets varies as the stage of the construction activities. Site C-1 remained undisturbed throughout the study period and therefore the samples collected at the street-drain inlet yielded the same relationship between the suspended-sediment concentration and the rainfall intensity. Site C-3 was subjected to sidewalk construction during the summer of 1975. The suspended-sediment concentration tended to increase somewhat after summer. Housing construction was active at Site C-2 during the time period of January to May 1975. The sidewalk here was constructed in late summer of 1975. It is clearly shown in Figures 9, 12, and 13 that the soil erosion decreased rather quickly, as indicated by the sediment concentration of the samples collected at the street drain inlet. Two data points for C-2 in Figure 13 deviated considerably from the general trend sketched. This reflected the disturbances due to sidewalk construction.

As the development progressed, the construction was moved from Site C-2 to the neighboring lots within a court. Samples were collected at four street drain inlets—C-4, C-5, C-6, and C-7—with C-4 being located at the lowest ground elevation. The data shown in Figures 14 and 15 indicate the magnitude of suspended-sediment concentration for each specific site inside this court. Within the four-to-five month period, no significant change was found for the relationship between the suspended-sediment concentration and the rainfall intensity.

SUMMARY

The modified Universal Soil Loss Equation is considered to be adequate to estimate the soil erosion rate at the construction site. The soil erosion rate at Cedar Hill, Virginia Beach, is estimated to be 14,800 metric tons/km^2/year. The sediment yield is estimated as 3,500 metric tons/km^2/year based on the sediment-delivery ratio of 45 percent for areas in the southeastern U.S. The observed sediment yield is, in general, less than this estimated value. The sediment-delivery ratios for the study area range from 0.14 percent to 9.5 percent due to the flatness of ground slope in coastal areas. The proportionality for soil erosion rate among construction, semi-construction, and well-developed sites is found to be 40:10:1 based on an analysis of sediment samples collected at street-drain inlets. The dilution factor (defined as the ratio of suspended-sediment concentration at the construction site compared to that of a specific off-site downstream station at the peak time of the sedimentgraph) is found to increase as rainfall intensity decreases. The dilution factor is a lump-sum indicator of the characteristics of the sediment-transport pattern in a drainage area undergoing construction. The on-site erosion rate varies according to the construction stage as indicated by the suspended-sediment concentration of the samples collected at the street-drain inlets.

REFERENCES

Chen, C. N., 1974. "Evaluation and Control of Soil Erosion in Urbanization Watersheds." In *Proceedings of National Symposium on Urban Rainfall and Runoff and Sediment Control.* School of Engineering, University of Kentucky.

Environmental Protection Agency, 1973. *Processes, Procedures, and Methods to Control Pollution Resulting from All Construction Activity.* EPA 430/9-73-007. Washington, D. C.

Guy, Harold P., 1969. *Laboratory Theory and Methods for Sediment Analysis.* U.S. Geological Survey, Series on Techniques of Water Resources Investigations.

Guy, Harold P., 1970. *Sediment Problems in Urban Areas.* U. S. Geological Survey Circular 601-E.

Guy, Harold P., 1974. "An Overview of Urban Sedimentology." In *Proceedings of National Symposium on Urban Rainfall and Runoff and Sediment Control.* School of Engineering, University of Kentucky.

Guy, Harold P., 1975. "An Overview of Non-Point Sources of Water Pollution from Urban-Suburban Areas." In *Proceedings of Southeastern Regional Conference on Non-Point Sources of Water Pollution.* Virginia Water Resources Research Center, Virginia Polytechnic Institute and State Univeristy.

Guy, Harold P. and Jones, D. Earl, Jr., 1972. "Urban Sedimentation in Perspective." *Journal of the Hydraulic Division, ASCE.* Vol. 98, No. HY12.

Heinemann, H. G. and Piest, R. F., 1975. "Soil Erosion—Sediment Yield Research in Progress." In *Transactions, American Geophysical Union.* Vol. 56, No. 3.

Ordinance No. 485, Erosion and Sediment Control, Article II, Chapter 31. *Code of the City of Virginia Beach.*

Task Committee of Sedimentation Committee, Hydraulic Division, 1975. "Urban Sediment Problems: A Statement on Scope, Research, Legislation, and Education," *Journal of the Hydraulic Division, ASCE.* Vol. 101, No. HY4.

Wolman, M. G. and Schick, A. P., 1967. "Effects of Construction on Fluvial Sediment, Urban and Suburban Areas of Maryland." *Water Resources Research.* Vol. 3, No. 2.

FIGURES

FIGURE 1
Drainage Area Under Study

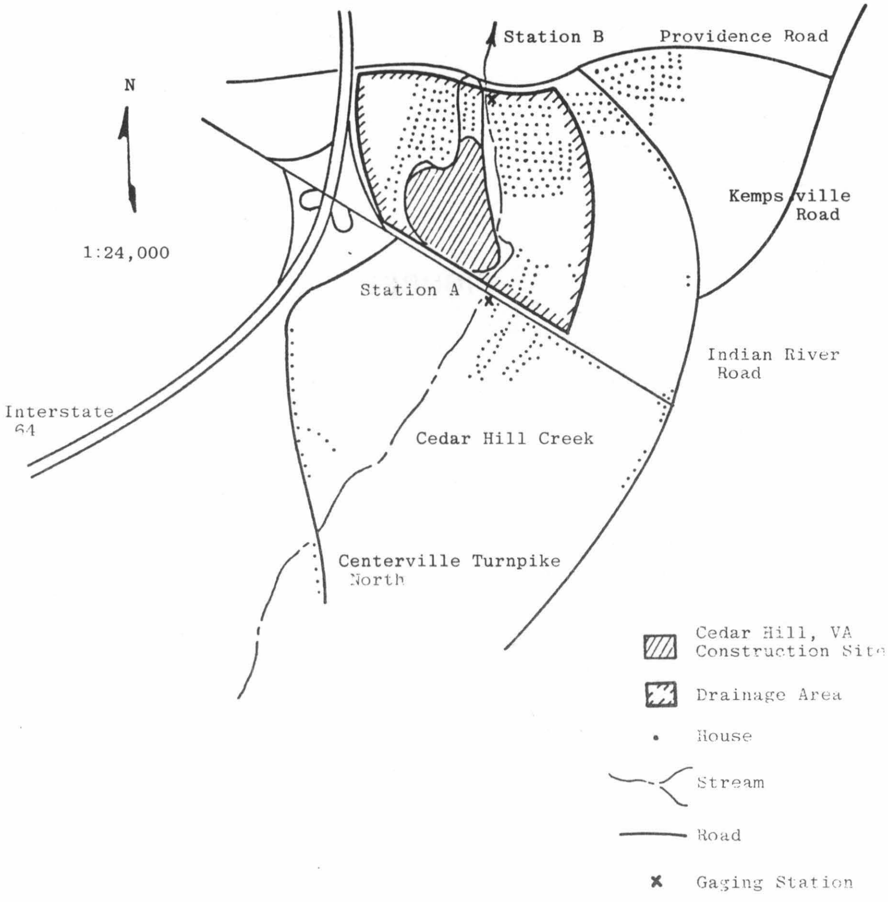


FIGURE 2
Aerial Photograph of the Study Area on August 12, 1974

FIGURE 3

Particle Size Distributions for Soils at Streambed and Construction Site

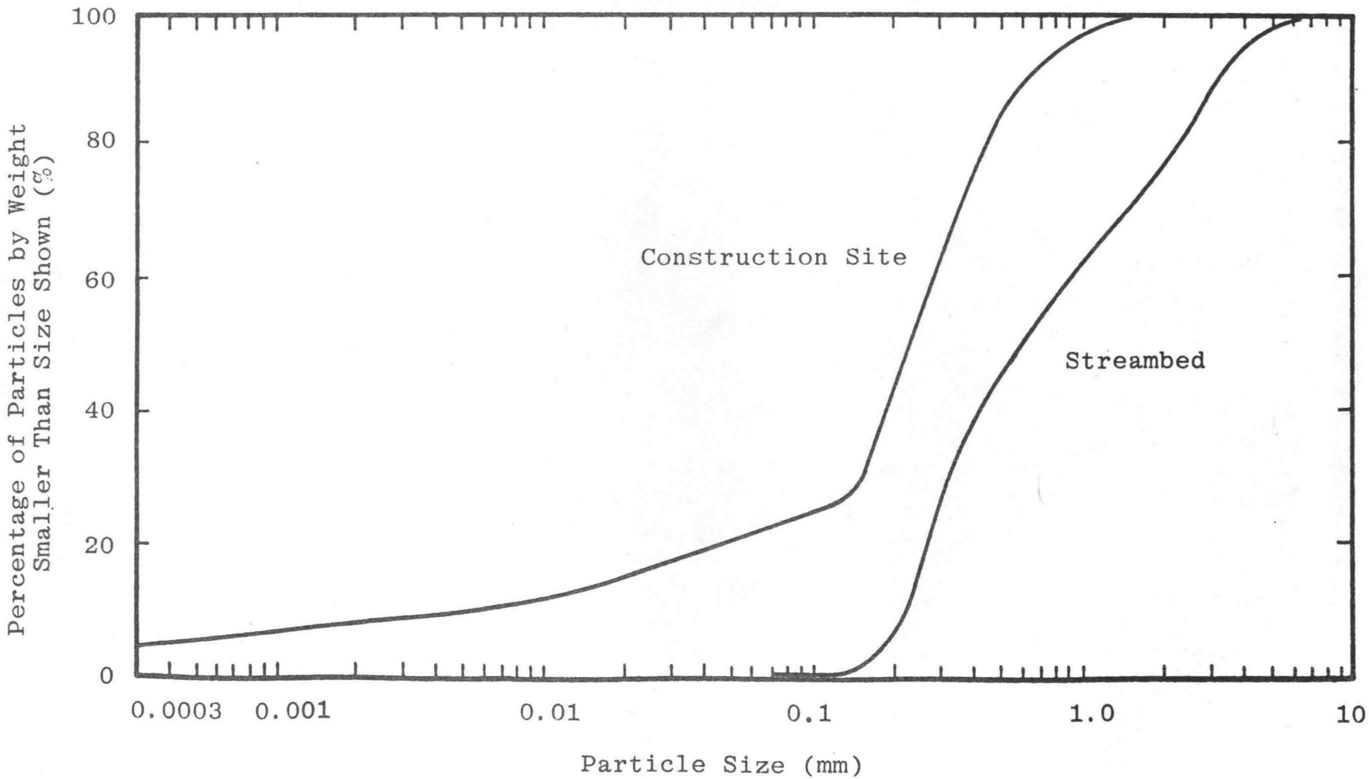


FIGURE 4

Data for Streamflow and Suspended-Sediment Concentration Due to Storm on March 30, 1975

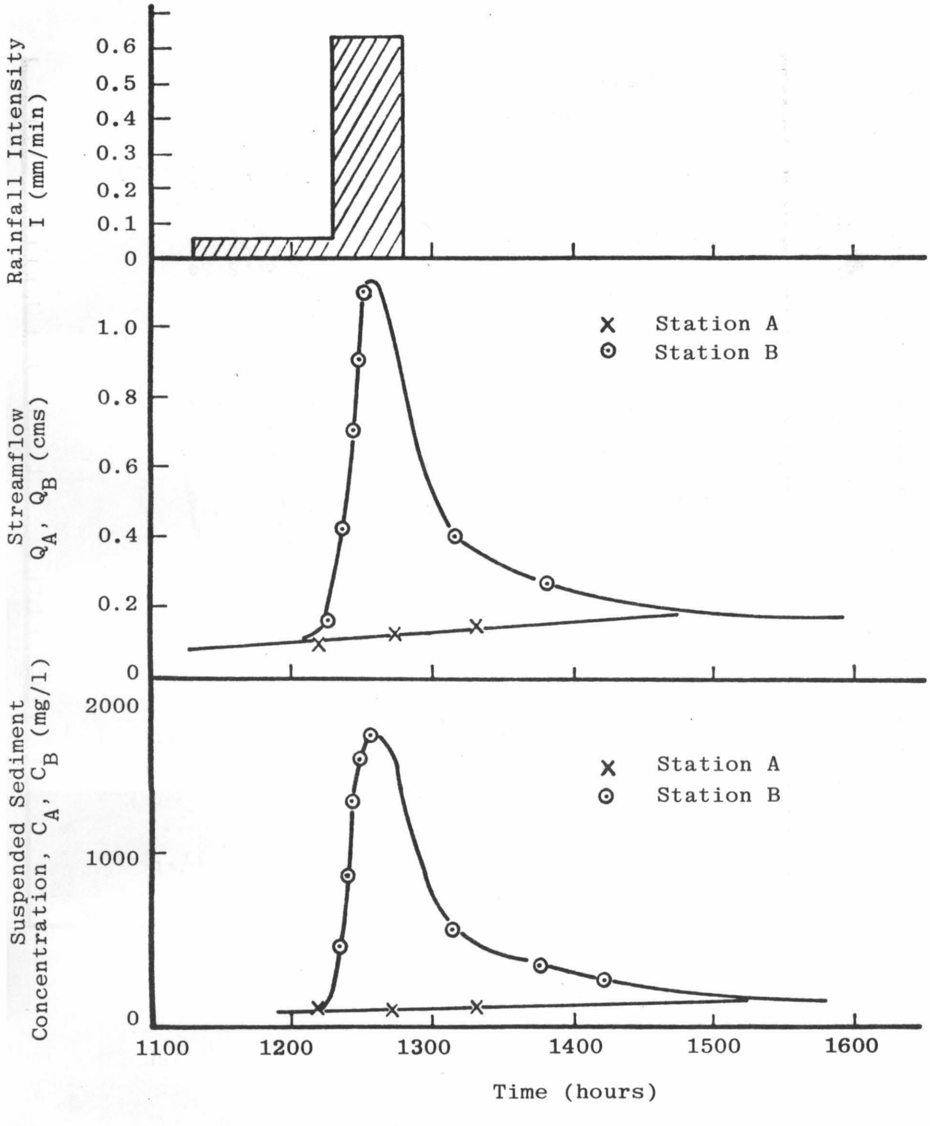


FIGURE 5
Sediment Concentration/Streamflow Rating for Storms on January 11 and March 30, 1975

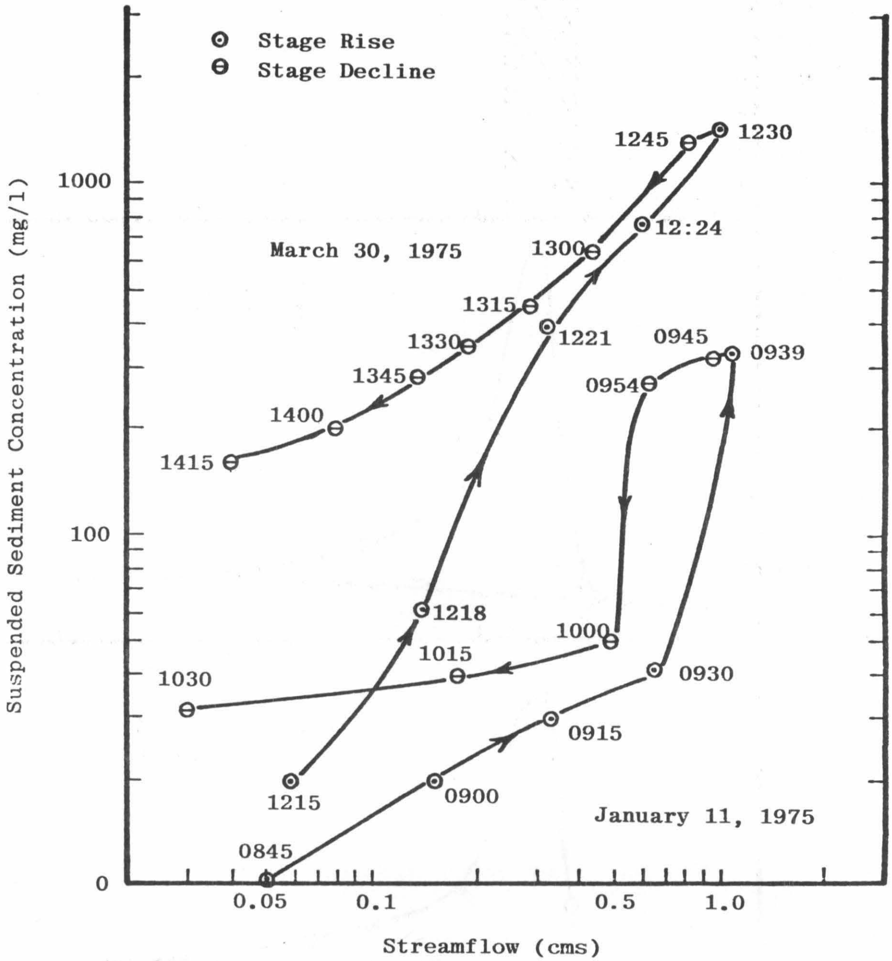


FIGURE 6

Data for Streamflow and Suspended Sediment Concentration Due to Light Rain, January 4, 1975

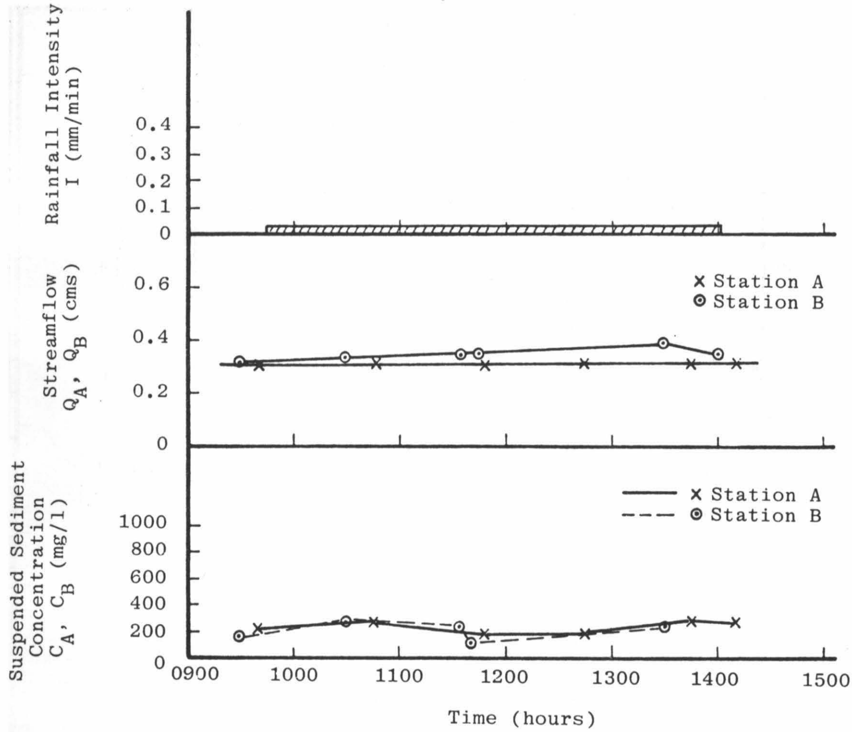


FIGURE 7

Time Rate of Change of Suspended-Sediment Concentration at Street-Drain Inlets for Storm of March 24, 1975 for a Duration of 16 Minutes and an Intensity of 4.5 mm/min

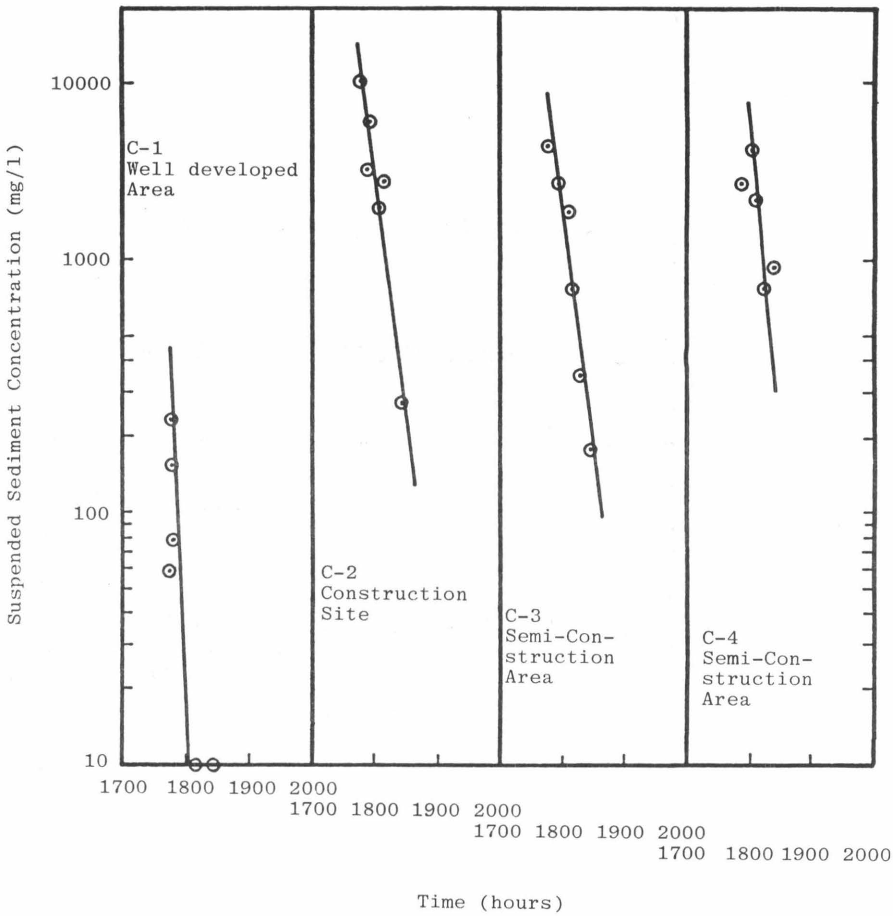


FIGURE 8
Relationship Between the Rainfall Intensity and the Dilution Factor

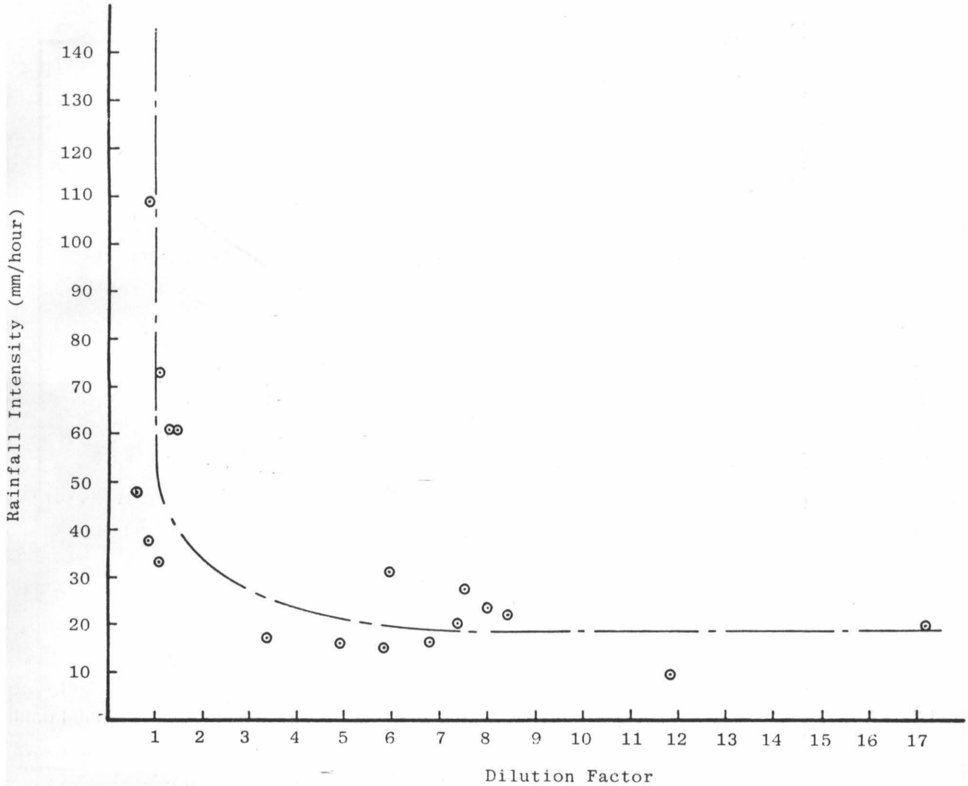


FIGURE 9

Spatial Variation of Suspended-Sediment Concentration at Street-Drain Inlets (January to May 1975)

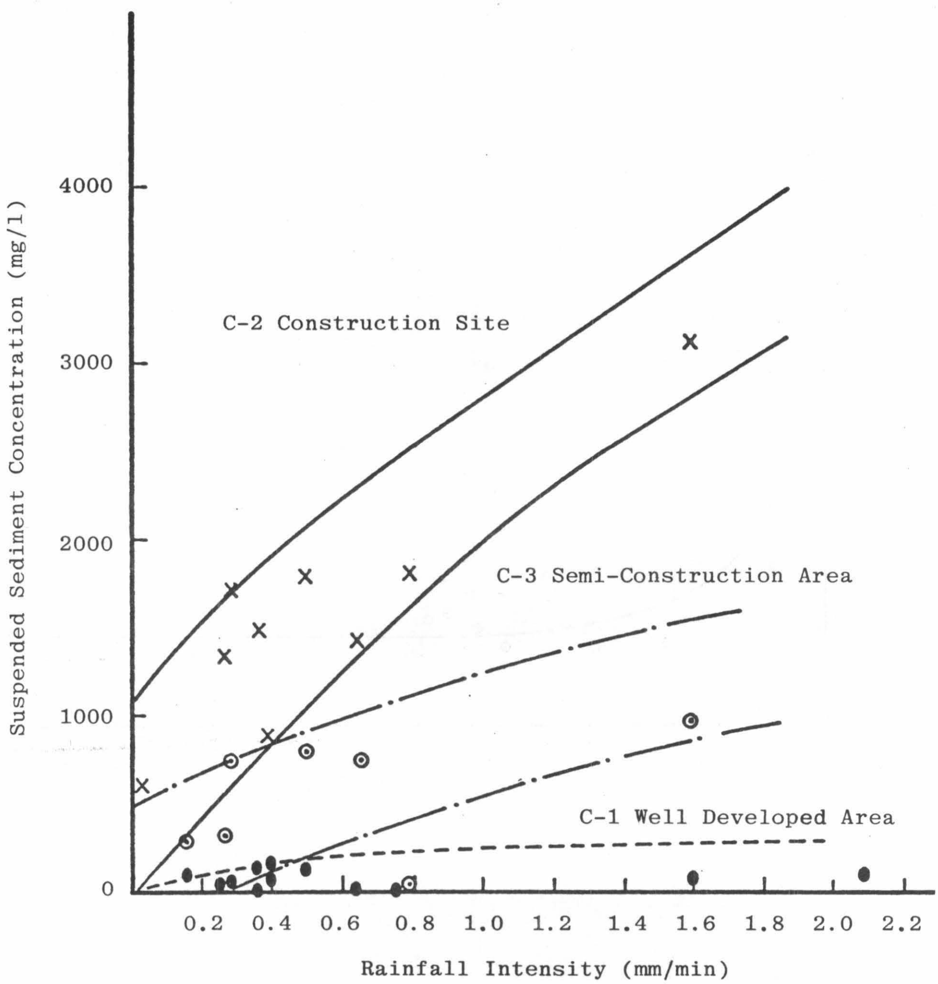


FIGURE 10

Soil Erosion Rates from Construction and Non-Construction Lands

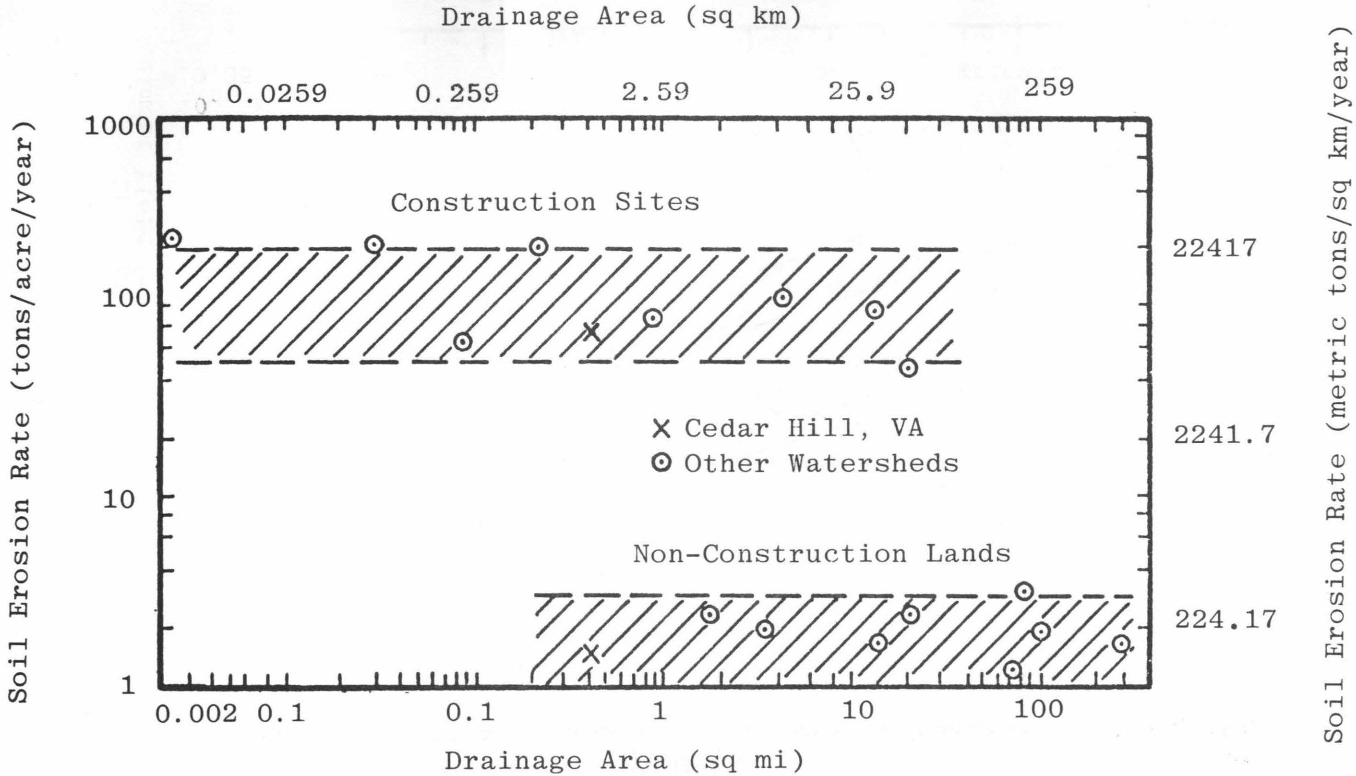


FIGURE 11

Effect of Construction Intensity and Drainage Area on Sediment Yield (From Wolman and Schick, 1967)

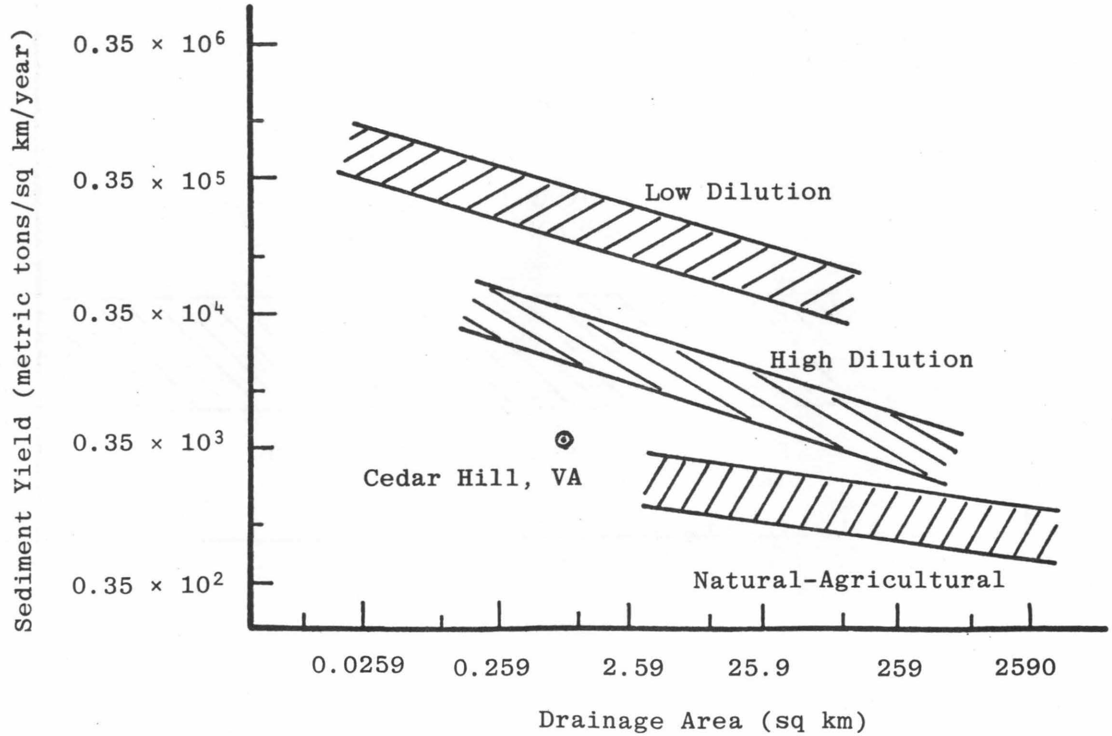


FIGURE 12

Spatial Variation of Suspended-Sediment Concentration at Street-Drain Inlets (June to August 1975)

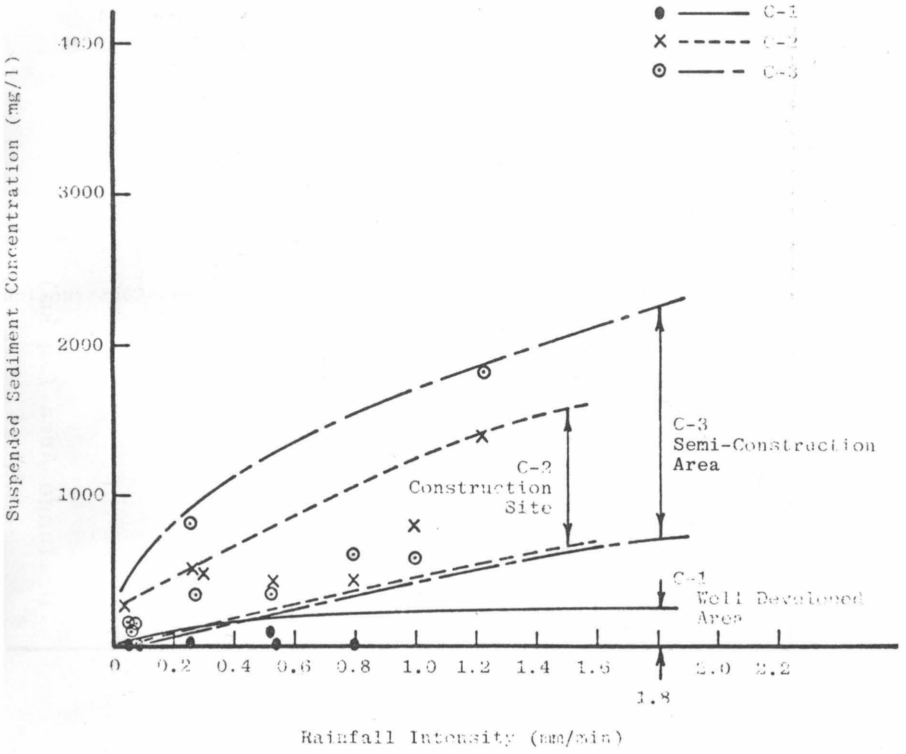


FIGURE 13

Spatial Variation of Suspended-Sediment Concentration at Street-Drain Inlets (September to December 1975)

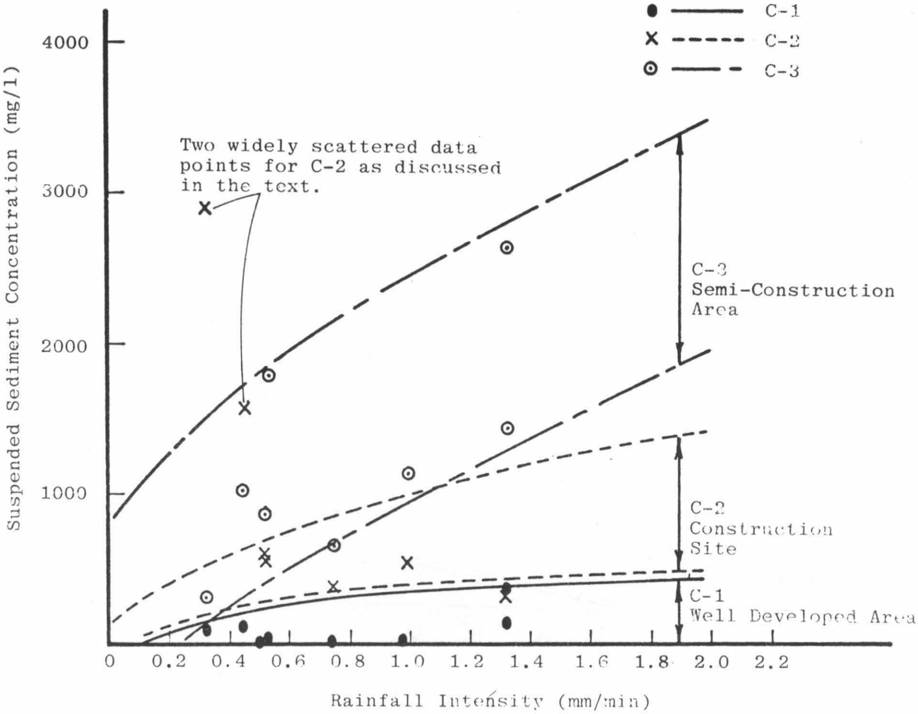


FIGURE 14

Variation of Suspended-Sediment Concentration at Street-Drain Inlets at the Construction Site (June to August 1975)

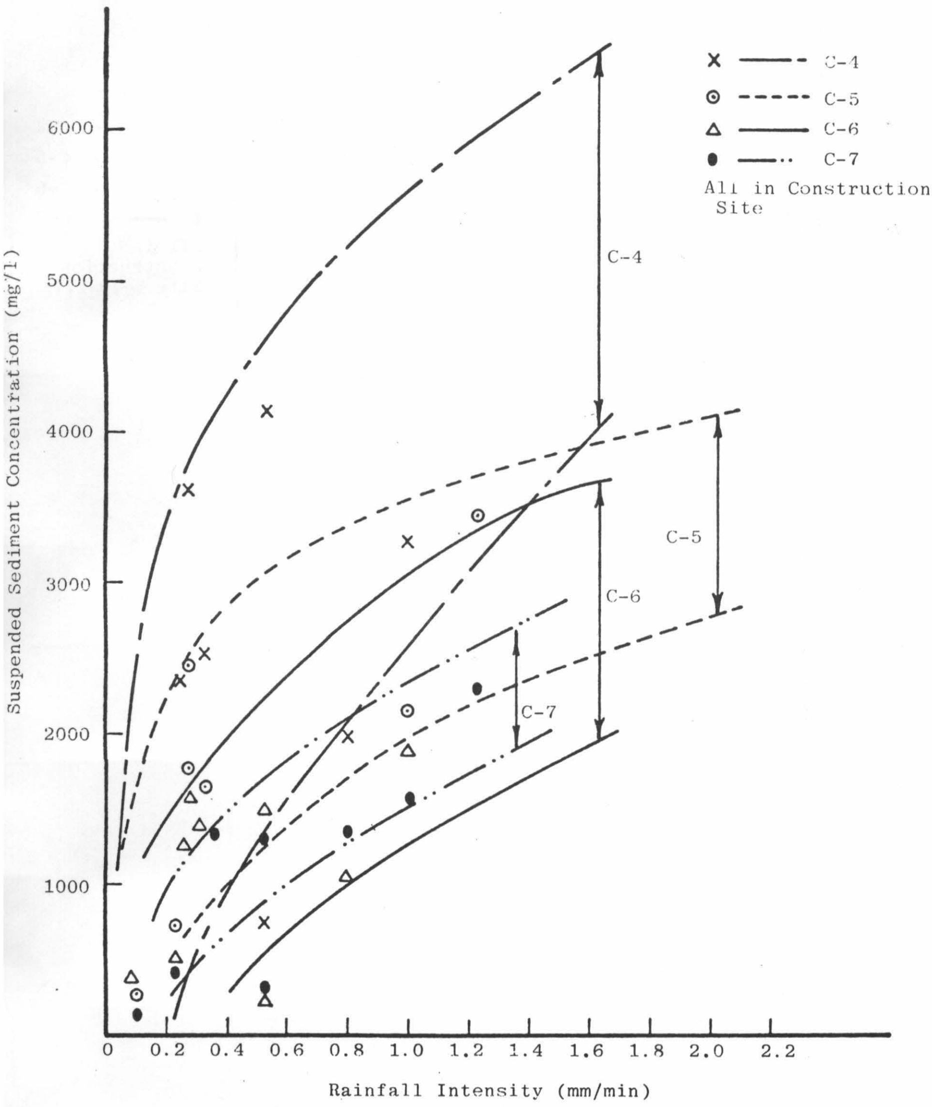
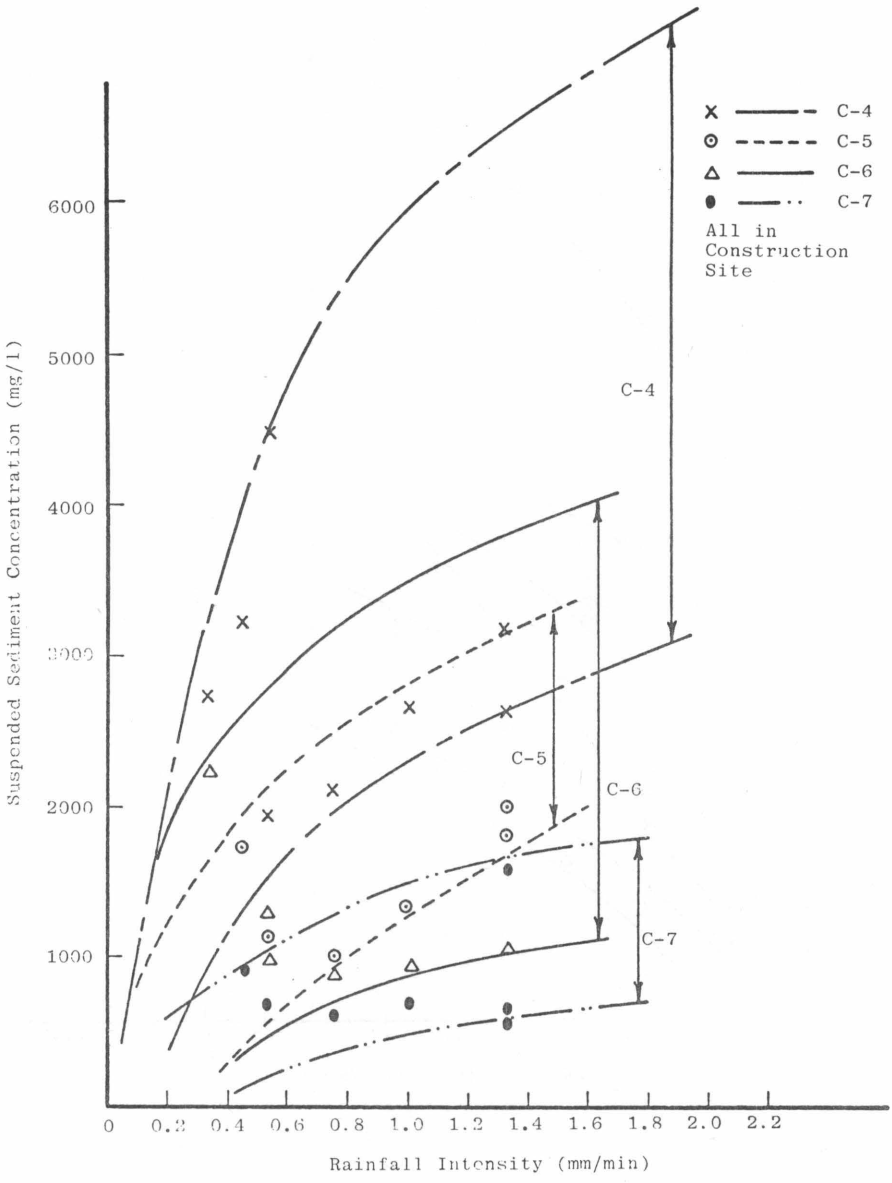


FIGURE 15

Variation of Suspended-Sediment Concentration at Street-Drain Inlets at the Construction Site (September to December 1975)



VIRGINIA WATER RESOURCES RESEARCH CENTER
BLACKSBURG, VIRGINIA 24061