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ENVIRONMENTAL ASPECTS OF RUN-OFF AND SILTATION IN THE ANACOSTIA BASIN FROM HYPERALTITUDE PHOTOGRAPHS

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by

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ABSTRACT

An analysis has been made of the effects of urbanization and highway construction on run-off, erosion and siltation on the Anacostia watershed. The analysis is based on changes in land use patterns as determined from aerial photographs as well as geologic and hydrologic data for the region.

Two selected subwatersheds of Indian Creek and one of Little Paint Branch of the Northeast Branch of the Anacostia were studied in terms of three hypothetical storms of different magnitudes. It was determined that an approximately 10 percent increase in impervious surface could bring about a 12 percent increase in the peak discharge for storms of the magnitude of tropical storm Agnes, a 20 percent increase in peak discharge for 10 hours storm and as much as a 150 percent increase in peak discharge for a typical thunderstorm. Also the early hourly incremental discharge from a storm of Agnes' magnitude could be increased by as much as 100 percent. Correspondingly large effects were observed in soil erosion and siltation from bare construction sites which show sediment yields of up to hundreds of thousands of tons per square mile per year.

The effects of rapid run-off, erosion and siltation are interrelated with other environmental problems such as sewage, oil and chemical pollution and lack of adequate public transportation. The net result is one of a steady degradation of the urban and suburban environment and of the estuary and bay into which this river flows.

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INTRODUCTION

It is now generally recognized that urbanization involves a complex of interacting factors which determine the environmental quality of a watershed or river basin. To what extent these factors determine the carrying capacity* of the basin with respect to population and technology is less clear but has become a pressing question.

In the process of urbanization, river basins are degraded through increased biological and chemical pollution from such sources as industries, commerce, residences and transportation systems. Part of the chemical load is attributable to nutrients which result from greatly increased sewage flows, since the effluent from sewage treatment plants is characteristically discharged into streams. Superimposed on this biological and chemical pollution are the effects of rapid water run-off and sediment from paved and eroding vegetation denuded land. In the headwaters and interstream area, soils are washed away at catastrophic rates, frequently leaving sterile and impermeable subsoils of increased erodability. On the floodplains, whose capacities become too small to contain the augmented floodwaters, coarse gravels and silts now cover the former fertile deposits of the pre-technological period or cut across them in newly eroded channels. At the same time stream banks bereft of their former mesh of protecting vegetation and roots, are more subject to erosion than in their natural state. Characteristically also the water storage capacity of floodplains is diminished by filling and construction. Thus flooding may be aggravated in both upstream and downstream reaches due to poorly designed road embarkments and other structures. Bank caving, flooding of residences, and destruction of roads, and bridges is the order of the day. Although some sediment which clogs the stream channels may be removed by dredging operations, most of fine material is transported into esturaries and bays where it contributes to fouling of shellfish beds, fish spawning grounds, wildlife habitat, and recreational waters. All along these urban rivers oil slicks line the banks and mud flats and obstruct the flow of raw or poorly treated sewage and solid debris. Frequently the worst of these effects occur in the most densely populated areas and deny the inhabitants even a modicum of water recreation.

* We are concerned here with a restricted version of carrying capacity that is defined in relation to certain indexes of environmental quality or levels of pollution. By contrast the ultimate carrying capacity of the Earth depends on available resources and total environmental factors.

In addition to the environmentally detrimental effects of rapid water run-off is the loss of a valuable resource. The multiplication of impermeable surfaces through urbanization increases rot only the peak discharge of storms but also the absolute quantity of water lost to the watershed throughout the year. Thus there is a general dehydration effect of urbanization. Water which is lost is prevented from recharging the ground water table and aquifers. Consequently more water must be imported into the area or shortages will be felt. This in turn places stress on neighboring regions which are called upon to supply this water.

Most or all of the effects listed above have been identified in the Anacostia Basin and in the Potomac Estuary into which the Anacostia discharges (Mueller and Lahn, 1970; Jaworski Clark and Fiegner, 1970). Of particular weight in the Anacostia Basin is a transportation system which is centered on the private automobile. This large automobile population in the basin gives rise to a continuous seepage of oil into streams from highways, parking lots and service stations. The oil pollution from automobiles has its complement in the silt, concrete spoils and gravel pits which result from the construction of highways to serve these vehicles. The proliferation of highways and their associated impermeable surfaces in turn cause greatly accelerated run-off and water loss to the basin. By and large the various forms of environmental degradation reinforce each other so that the cumulative effect is greater than the sum of its parts.

The purpose of this study is to determine the local and regional effects of urbanization on the hydrology and related factors of a drainage basin. In particular the effects of urbanization on run-off, stream discharge, and sediment yield are evaluated and compared for different storm events and for varying degrees of urbanization. We feel that such studies as these, conducted by responsible public agencies should be required to precede any future major construction and should form a logical part of the environmental impact statement of the project.

METHODS

Aerial photographs of three sub-drainage basins of the Anacostia Watershed (Figure 5) taken in 1964 and 1971 were compared for purposes of determining the change in land use patterns (Figures 1, 2, Table 15). Black and white aerial photography was utilized for this purpose and was supplemented with high altitude infrared photography which was especially useful in determining badly eroded and bare or exposed areas. Earth Resources Technology Satellite (ERTS) Imagery was used for studying the overall regional land use relationships of the Anacostia watershed. Geology, land use patterns and the soil cover associated with a given land use are the predominant factors which influence the hydrology of a given basin. The geology is shown in Figure 3 and in Table 16. A soil map (Figure 4) of the Little Paint Branch, and a sub basin of Indian Creek Basin, which reflect the textural characteristics of the various soils, was compiled from the Prince George's and Montgomery County soil surveys of 1967 by mapping together those units whose textural classes were the same or very similar. Hydrologic characteristics of the soils were then determined. The hydrologic characteristic of a particular soil and its susceptibility to erosion is determined by the rate of infiltration of water when it is thoroughly wet.

Presented below are the hydrologic characteristic categories developed by the Soil Conservation Service (SCS) and used in this report (Soil Conservation Service Handbook, 1954):

A. (Low run-off potential). Soils having high infiltration rates even when thoroughly wetted and consisting of deep, well to excessively drained sands and gravels. These soils have a high rate of water transmission.

B. Soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to coarse textures. These soils have a moderate rate of water transmission.

C. Soils having slow infiltration rates when thoroughly wetted and consisting chiefly of soils with a layer that impedes downward movement of water, or soils with moderately fine to fine texture. These soils have a slow rate of water transmission.

D. (High run-off potential). Soils having very slow infiltration rates when thoroughly wetted and consisting chiefly of clays with a high swelling potential, soils with a permanently high water table, soils with a claypan or clay layer at or near the surface and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission.

Most of the soils in the area under study range between well to moderately drained. This means excess water in the soil profile is readily removed. However, the presence of fragipan in the subsoil negates to a large degree the beneficial effects of the well to moderately drained character of the surface soils. In order to simplify calculations and at the same time place conservative bounds on values obtained for run-off and discharge an average hydrologic condition of "B" was chosen for all of drainage basins under study. B was chosen because of the variation in permeability of the subsoils, different susceptibility to erosion of the soils and other factors. A detailed analysis of individual soils in the basins would show that the majority of hydrologic conditions lie between B and C with a few in the A category. Using the hydrologic condition of the soil and the land use associated with a given soil (Figures 1 and 2) run-off curve numbers were next determined (Figure 7). The equations utilized for the determination of run-off and soil erosion are the following:

Equation (1) $Q = (P - 0.2S)/(P + 0.8S)$ (SCS Handbook, 1951)

X = area of the watershed
P = amount of rainfall in inches
S = Potential maximum retention the intial abstraction
Q = direct runoff

Equation (2) $Q_p = 484\,XQ/(d/2 + 0.6\,t_c)$ (SCS Handbook, 1954)

Q_p Peak discharge
d = duration of effective rainfall
t_c = time of concentration
t_p = time to peak discharge
t_b = time to base

$t_p = d/2 + 0.6t_c$

$t_b = 2.67\,t_p$

Equation (3) A = Krlscp (Agri. Handbook 282, 1962)

A = average annual soil loss in tons/acre
K = erodability factor
ls = slope length factor
c = cropping management
p = conservation practice
r = rainfall factor

Note: For estimating sediment yield from construction sites and other denuded areas, c and p were set = to 1. This is analogous to lands lying fallow.

The curve number (CN) is a value which reflects the probability of precipitation becoming subsurface flow or overland flow. i.e., the higher the curve number, the more likely precipitation over an area will become surface runoff. The curve numbers are then used to find a graphical solution to the runoff equation (Equation 1, Figure 7). The direct runoff, which is the depth in inches to which an acre of land would be covered if the water were evenly distributed, is then used in equation 2 which provides the peak discharge in cubic feet per second. For storms of long duration, hourly hydrographs of discharge versus time were compiled using eq. 2 with d equal to one hour. These incremental hydrographs were then combined into a composite hydrograph for the entire storm.

Equation 3, the universal soil loss equation was used to estimate sediment yield from construction sites and other areas where vegetative cover has been removed and the soils disturbed. Such areas combined with bank erosion are the major source of sediment pollution. For these areas, the c and p factors were assigned a value of 1; this indicates that no measures have been taken to reduce the effects of erosion and this is true of most construction sites.

In evaluating the changes in run-off potential due to urbanization three hypothetical storm events were utilized. The storm events used were: 1) The first thirteen hours of a storm with the characteristics of hurricane Agnes, the last major storm over this area. Total precipitation from Agnes in this area was 6.28 in. (16cm) of which 5.28 inches (13.cm) fell within the first thirteen hours. 2) A storm of 10 hrs. duration and 3) A thunderstorm of 1 inch per hr. (2.54cm) typical of the type of storm this area is subject to during the summer months.

The data on runoff and discharge are based on these hypothetical storm events over the basins, given the land use patterns as they existed in 1964 and 1971. The category "impervious surfaces" (IV) includes all paved surfaces and all surfaces which for practical purposes behave as impervious surfaces. Also the headings "effects on runoff "and" sediment yield and discharge" refer to the probable effect caused by the change in land use. Values for time of concentration and soil erodability factor, K were obtained from the monograph and curves developed by the Soil Conservation Service (SCS Handbook, 1954).

DESCRIPTIONS OF BASINS

Basin I - Little Paint Branch

Dimensions - The reach extends from the intersection of Spencerville Road and Route 29 in the north to a point 200 ft. (61m) south of where Sellman Road crosses the stream and is 6 miles (9.7Km) in length (Figure 5). The area drained is approximately 9 square miles (23Km^2). The elevation differences between the highest and lowest point in the basin is 320 ft. (98m) and the topography can be described as rolling. The slopes (Figure 6) range generally from 0-25%; the steepest slopes being located along tributaries and the main stream. The flood-plains along the main stream (Little Paint Branch) are relatively narrow in the upper portion of the basin and broaden as the stream crosses from the piedmont into the coastal plain province. The widening of the flood plains in this basin begins in the Beltsville area. The basin is bounded on the north by Spencerville Road, which forms part of the divide between the Anacostia and Patuxent watersheds, on the west and southwest by Columbia and Cherry Hill Road and on the east by Old GunPowder Road, which is the divide between Little Paint Branch and Indian Creek.

Geolcgy- (Cooke, and Cloos, 1951, 1953) The basin lies in both the piedmont and coastal plain geologic provinces (Figure 3). The geologic formations underlying the basin are the Wicomico, Patuxent, Laurel Gneiss and Wissahickon Schist. The Patuxent formation dominates the geology of this basin and the two other basins under study, and consists of deposits of unconsolidated sand, gravel, clay and silt; the percentage of each varying with location. The Laurel Gneiss and Wissahickon Schist underly the headwater and tributary regions of the basin with the Patuxent occupying the divides between the tributaries in this region (Figure 3). Quanternary and younger deposits of sand, silt and gravel form the flood plains at the southern tip of the basin (Figure 3).

Soils- (Prince Georges County Soil Survey, 1967) The major soil associations within the drainage area are Leonardtown - Chillum, Beltsville and the Bibs tidal marsh associations. The first association is the predominant one in the basin with the Beltsville soil series being the major constituent. The Leonard Town occupies depressions and low places and makes up approximately 14% of the series and the Chillum and other minor soils comprise the rest of the series.

The soils differ in varying degrees with respect to drainage and other aspects but they all have in common a fragipan of varying permeability in the subsoil. Some of the characteristics of the predominant Beltsville soil area are as follows: moderately well drained but with moderate effective depth, thick and very compact fragipan in the subsoil, clay content ranges from 18-35 percent, with a seasonally perched water table. The Prince George's county soil survey also points out that the Beltsville soils pose special problems for residential use and that they are best suited for park and recreational development. The Bibb series consists of poorly drained soils on the flood plains along the streams of the coastal plain. These soils are confined to the Beltsville-Calverton area in this basin. Because of the poor drainage and flooding problems associated with these soils, residential use of the soils is limited. However, a substantial portion of those soils in the basin have undergone some development (Figure 4).

Land Use Patterns - The land use patterns based on the analysis of 1971 photography are as follows: High density suburban complexes, and paved roads comprise approximately 14.4%. The high density housing areas are concentrated towards the southern end of the basin near the Capital Beltway and along the Interstate 95 highway (I-95) (Figure 1). Most of the high density areas are made up of single family homes of the Calverton housing development and parts of the city of Beltsville as well as I-95. Denuded land, gravel pits, medium density suburban complexes together comprise 8 percent of the basin. The gravel pits are scattered throughout the area with most of them located adjacent to I-95. Grassland and lawns associated with low density housing areas, cropland and medium to lightly wooded areas comprise approximately 40% of the area. Comparatively little land is presently used for farming in the basin. Low density housing is distributed between Route 29 and Columbia Road along the west side of the basin. The rest of the area consists of relatively heavily wooded areas. Since 1964 the major changes within the basin have been the construction of I-95 and approximately 50% additional housing and roads in the Calverton-Beltsville area. (Figure 1 and 2).

Effects on Runoff and Discharge - A comparison between land use in 1972 and 1964 (Figs. 1 and 2) shows the following changes in the Little Paint Branch basin: (1) An increase from 271 acres of impervious surfaces or surfaces that for practical purpose can be considered impervious to 847 acres of impervious surfaces. This additional 576 acres is due chiefly to construction of Interstate 95 and the addition of housing and roads to the Calverton Area. Over 300 acres of the new construction occurred at the expense of wooded areas. (2) Thus occurred a reduction of the heavily wooded areas from 2757 acres to 2217 acres and a decrease in bare or exposed surfaces from 580 acres to 472 acres. The latter includes sand & gravel areas, and those areas which are easily eroded.

It can be seen from Tables 1 to 6 that the most significant factor affecting total runoff is the area of impervious surfaces relative to those of low runoff potential, especially those which are heavily wooded. For the hypothetical storm of Agnes' magnitude, peak discharge would increase from approximately 1650 to 1850 cfs (45 to 53 cms) (Figure 8). This is approximately a 12% increase in peak discharge. For the hypothetical 10 hour storm the increase in discharge is approximately 20% (Figure 9) and for a thunderstorm the increase in discharge is 150% (Tables 13 and 14). This increase in the percentage of discharge with decrease in storm magnitude can be attributed to the fact that for long duration, high intensity storms maximum infiltration rates are quickly attained and all surfaces act as relatively impervious surfaces, whereas for the less intense storms of shorter duration, runoff from impervious surfaces begins immediately while all of the precipitation occurring on low runoff potential areas may be taken up by infiltration (Yorke and Davis, 1972). The increase in rates of runoff and discharge can be attributed to the 10% increase of impervious surface in the basin. Computed rates of discharge would be substantially higher if account were taken of the effect of sewer drains and other structures which facilitate runoff since these structures decrease the time of concentration.

Also, the most detrimental effects of this increased discharge will be on those tributaries closest to the urbanized areas. For instance, those tributaries which drain the Calverton area are now being subjected to flooding due to thunderstorms whereas before urbanization, such storms did not pose a threat.

Although the relative change of peak discharge is most pronounced for the smaller storms there is a marked increase in incremental discharge for the larger storms from 1964 to 1971. In particular this is apparent from the storm of Agnes' magnitude. Figure 8 shows that the discharge for the 10th hour was increased by more than 100 percent as a result of urbanization. Such effects greatly increase flooding and damage during early stages of the storm.

Effects on Sediment Yield - Urbanization affects sediment yield in two major ways: (1) by denuding land of vegetative cover and therefore making soil susceptible to removal by runoff and (2) the increase in discharge due to urbanization increases a stream's ability to erode its banks and bed. Only the sediment yield from construction and other bare and denuded areas will be considered here since these areas contribute the bulk of the sediment delivered to the stream channels (Guy and Ferguson, 1964). Storm runoff will have its most adverse erosional effects during periods of construction when the land is bare for long periods of time. On a yearly basis sediment yield from construction areas within the basin may range from 137 metric tons/acre to 300 metric tons/acre.

From Eq. 3 we find that for a single storm which drops 3 inches (7.6 cm) of rain in ten hours the sediment yield is approximately 40 tons/acre. Of the total gross eroded sediment during storm events at least 30% finds its way into the main channel immediately and the percentage becomes higher as the proximity of construction to tributaries become closer. In particular such was the case during the expansion of the Calverton area where tributarties run directly through the construction (Figure 5). Consequently as much as 50 to 60% of the gross erosion from this site may have found its way into the stream channels during storm events. Furthermore, these soils were classified prior to construction as being moderately to severely eroded so that further disturbance of the soils in this area would probably increase the soil erodibility factor far above 0.32 which is the average for the basin. Therefore sediment yield for this area might have been as high as 250 metric tons/acre/yr. Likewise, the sediment yield from certain areas associated with the construction of I-95 probably was higher than the average of 137 metric tons/acre/yr. This is true because slopes within the construction area range between 15-25% and the fact that the soils in this area were classified as being moderately eroded prior to disturbance.

Basin II - Indian Creek

Dimensions - The basin is drained by a segment of Indian Creek which extends from a point 2000 ft. (620 m) north of where Indian Creek crosses I-95 to the intersection of the creek with Sunnyside Avenue in Beltsville (Figure 5). This is a total length of about six miles (9.7Km). Total drainage area is approximately 10 square miles ($26Km^2$).

Geology - (Cooke and Cloos, 1951, 1953) The basin lies entirely within the Coastal Plain geologic province, and is underlain by the Patuxent, Anne Arundel Clay and Wicomico Formations. The Patuxent Formation underlies over 80% of the basin with the Anne Arundel Clay making up 17% (Figure 3).

Soils (Prince George's County Soil Survey, 1967) The major soil associations in the basin are the Christiana - Sunnyside-Beltsville, Beltsville-Leonardtown-Chillum, and Bibbs tidal marsh. The dominant soil series within the basin is the Christiana-Sunnyside-Beltsville series. Most of the urban development has taken place on these and the Bibbs tidal marsh soils. Some of the characteristics of the Christiana-Sunnyside association are: (1) well-to moderately drained with compact subsoil, (2) soils tend to cave, (3) to slump and flow when wet or under load of buildings; and (4) septic tanks do not function well in these soils.

Topography - This is essentially the same as that of the adjacent Little Paint Branch basin.

Land Use - Land use patterns in 1971 were as follows (Figure 1): High density areas made up approximately 19% of the basin and are concentrated close to the beltway. These areas include part of the city of Beltsville and portions of I-95 and industrial sites located along route 1 and adjacent to the Baltimore and Ohio railroad. Denuded land mostly in the form of operational gravel pits comprises 17-1/2 percent of the basin. The remaining area is comprised mostly of wooded areas and cropland of the U.S. Department of Agriculture research center, with the heavily wooded areas making up approximately 50% of the basin. The major changes within the basin since 1964 have been the addition of I-95 and expansion of sand and gravel operations (Figure 2). Also residential housing and industrial areas have been added in the Beltsville areas.

Effects on Runoff and Discharge - The significant changes are as follows: (1) increase of impervious surfaces from 956 to 1200 acres, (2) increase in gravel and sand operations from 335 acres to 475 acres and a decrease by 150 acres of heavily wooded areas. The result of these conversions represents a 3% increase in urbanization since 1964. For the first thirteen hours of storm of Agnes' magnitude, the peak discharge increases by approximately 9%. For the ten hour storm, discharge would increase by 25%. (Tables 9, 10, 13, 14). Although the increase in discharge for the storms of long duration is relatively low, the 27% increase in discharge for thunderstorm may prove significant, especially in those areas of Beltsville located along the flood plains. Also since the incidence of such storms as Agnes and the 10 hour storm may be 50 and 2 years respectively, the effect of local thunderstorm is relatively more important. For example, the Arlandria area of Northern Virginia is quite frequently subject to flooding due to local thunderstorms. The inability of Four Mile Run to contain the increased discharge due to rapid urbanization in that area accounts for the frequent floods to which it is subject.

Effects on Sediment Yield - In 1971 the Indian Creek basin had approximately 200 to 400 acres of land in the form of sand and gravel pits and other unreclaimed areas associated with construction of I-95. Using equation 3 we see that sediment yield from this area ranges between 50 to 150 thousand tons per yr. However, the major localized erosional damage occurred during the period of time that the 80 acres of land associated with I-95 lay bare of vegetation. As was the case in the adjacent Little Paint Branch Basin, most of the soils on which I-95 was constructed were classified as moderately eroded (Prince Georges County Soil Survey, 1967). With the denuding of the land, the susceptility of these soils to erosion increased greatly. Assuming that the K value after removal of vegetative cover was 0.43, and using eq.(3), sediment yield from this area would have amounted to approximately 200 metric tons/acre/year.

Considering the fact that the construction site lay bare of vegetation from 6 months to 1 year, this amounts to 12,500 to 25,000 metric tons from that portion of I-95 which crosses the basin.

Basin III - Indian Creek

The third basin studied is a sub-basin of Indian Creek. This basin was chosen in order to minimize variations of soil, geology, topography andthe other parameters which affect the hydrology. Also virtually all of the impervious surfaces within the basin were of one source and location (I-95).

Dimensions - The reach extends from headwaters of Indian Creek to a point 1000 ft. (300 m) below the intersection of I-95 and Indian Creek (Figure 5). The total drainage area is approximately 1.6 square miles ($4.15 Km^2$).

Geology - (Cooke and Cloos, 1951, 1953) Deposits of the Patuxent formation underlie the entire basin.

Soils - (Prince Georges County Soil Survey 1967) Over 90% of the soils in the basin are made up of the Beltsville and Mattapeake soils. The Beltsville soils have been described previously. The Mattapeake soils are mostly silt loams, moderately to severely eroded, with clay content varying from 18 to 30% (Figure 4). Slopes in the basin vary from 5 to 25% with most of those associated with I-95 falling in the 10 to 15% range (Figure 6).

Land Use - Land use in 1964 was as follows (Figure 1, 2): 400 acres medium to heavily wooded, 300 acres in grass or meadow land, 300 acres of bare eroded and denuded land in the form of gravel pits. The only change in land use since 1964 has been a converison of 50 acres of woodland as a result of the construction of I-95. This change represents 5% of the drainage basin.

Effect on Runoff and Discharge - Considering a storm of Agnes' magnitude, the change in peak discharge would be approximately 25%, for the 10 hour storm the peak discharge would increase by approximately 40%, and for a thunderstorm, peak discharge rises by approximately 110%.

Effects on Sediment Yield - The sediment contribution from the sand and gravel pits and the construction phase of I-95 has been estimated previously in discussing the larger Indian Creek basin, but it is interesting to calculate the sediment eroded from the 50 acres of the I-95 right of way during construction.

In this case K = 0.5, ls = 2.0. If we utilize these values in eq. 3 and utilize the yearly rainfall factor we obtain 200 metric tons/acre/yr. For a severe thunderstorm A = 40 metric tons/acre/yr. or a total of 2000 metric tons of sediment eroded from a 50 acre segment of I-95. This illustrates further the effects of denuding wooded and other low yield areas.

SUMMARY AND CONCLUSIONS

The analysis of the effects of three hypothetical storms, particularly based on the hydrographs (Figures 8 and 9), indicates that the degree of urbanization which took place in the Anacostia Basin between 1964 and 1971 greatly enhanced flood peaks of thunderstorms and the early hourly incremental run-off of large storms such as tropical storm Agnes. As a result of these effects local flooding and flood damage of such storms probably increased significantly. It is likely for example that the effect of the actual storm Agnes was considerably greater than if it had occurred in 1964 rather than in 1972. Although these results were obtained from selected basins of the Northeast Branch of the Anacostia similar effects also occur throughout the Basin where a corresponding degree of urbanization prevails. Thus, it was documented recently (Cohen, 1972) that extensive damage to property values occurred at the George Washington Cemetery on the Northwest Branch of the Anacostia due to rapid run-off from the Capital Beltway (Interstate Highway 495) and newly urbanized areas upstream. Damage in this one small area was placed at one million dollars.

In addition to the effects of erosion, siltation and flooding, urbanization brings about a serious loss of water resources throughout the year. This loss is particularly great in the case of the frequent summer thunderstorms because for such storms there is a great potential for infiltration in non-urbanized areas since the ground usually does not become saturated during the short period of the storm. However with the spread of impermeable areas this short term capacity for water retention is lost. However Figures 8 and 9 show that even for the larger storms absolute water loss is increased substantially by impervious surfaces since apparently substantial infiltration can occur during the period of the storm even though the ground is kept saturated.

We may also extend our results on erosion and siltation to the entire Anacostia Basin. Thus the U.S. Geological Survey has made a conservative estimate that sediment deposition in the Potomac Estuary is approximately 2.1 million yd^3 annually (Wark and Keller, 1963). Of this amount approximent 12 percent or 251,000 yd^3 is contributed by the Anacostia River. The major sources of this sediment are those areas which are undergoing urbanization similar to those described in this report. We estimate from aerial photographs and ERTS data that about 5 percent of the Anacostia Basin fits this category. According to equation 3 the sediment yield from this area should amount to approximately 400,000 yd^3 annually. Considering the uncertainties in such figures this is in essential agreement with the Geological Survey result.

The qualitative and quantitative assessment presented here for run-off, erosion and siltation in the Indian Creek and Little Paint Branch watersheds may also, with proper qualifications, be generalized to other basins with similar geologic and hydrologic conditions. The remote sensing data, here largely obtained from aerial photographs, may also be expanded to include earth satellite data which might then be used to integrate and interpolate in larger basins, particularly in the coastal plain.

Because the Anacostia River is a good prototype of an urban river and because its water flows into the Potomac Estuary and eventually into Chesapeake Bay, studies of the effects of urbanization on this River can contribute materially to assessing the larger impact of urbanization on urban populations and coastal waters. For example these results can be extended to other nearby urbanized regions such as Baltimore if account is taken of the larger industrial sector in that region. In particular the adverse effects of chemical pollution, oil, sewage, and sediment which emanate from such urbanized watersheds illustrates that waters such as Chesapeake Bay cannot be protected without considering all pollutant loadings on every watershed which drains into them. Indeed past and current policies with regard to Chesapeake Bay fail seriously in this regard. Also such studies illustrate that the quality of urban rivers and of the lives of those living along them depend greatly on what occurs in headwater regions, frequently in the suburban and rural areas.

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Table I
Basin I, Little Paint Branch
Storm: First thirteen hours of Agnes
Total Rainfall 5.28 inches

P hourly accumulated rainfall														
		(1.78) 0.07	(1.17) 0.46	(2.02) 0.80	(2.3) 0.90	(2.3) 0.90	(3.0) 1.19	(4.2) 1.65	(7.1) 2.70	(9.9) 3.90	(10.6) 4.16	(13) 5.09	(13.2) 5.17	(13.6) 5.28
I.U.C.	CN	Q = Accumulated Direct Run-off												
I	55								(0.254) 0.1	(1.27) 0.5	(1.52) 0.6	(2.54) 0.1	(2.79) 1.1	(2.92) 1.15
II	65							(0.203) 0.08	(1.02) 0.4	(2.54) 1	(2.79) 1.1	(4.32) 1.7	(4.45) 1.75	(4.70) 1.85
III	82				(0.38) 0.15	(0.38) 0.15	(0.51) 0.2	(2.03) 0.8	(3.05) 1.2	(5.08) 2.0	(5.59) 2.2	(7.62) 3	(8.13) 3.2	(8.64) 3.4
IV	100	(0.178) 0.07	(1.17) 0.46	(2.03) 0.80	(2.29) 0.90	(2.29) 0.90	(3.04) 1.2	(4.19) 1.65	(6.86) 2.70	(9.91) 3.70	(10.54) 4.16	(12.93) 5.09	(13.3) 5.17	(13.41) 5.28
Acres		Acres XQ (71) - Potential run-off in acre-in in hectare-cm.												
I (897) 2217									(227) 222	(1137) 1108	(1161) 1330	(2286) 2217	(2509) 2430	(2630) 2560
II (955) 2359								(1[illegible]4) 190	(971) 945	(2408) 2359	(2651) 2600	(4128) 4000	(4244) 4120	(4462) 4350
III (191) 472					(73) 71	(73) 71	(96) 94	(330) 330	(575) 565	(963) 944	(1068) 1040	(1457) 1420	(1540) 1510	(1639) 1600
IV (343) 847		(59) 58	(401) 390	(749) 730	(781) 760	(781) 760	(1028) 1015	(1416) 1395	(2307) 2280	(3330) 3300	(3651) 3500	(4411) 4390	(4512) 4390	(4570) 4450
Acres		Acres XQ (64) Potential run-off in acre-in in hectare-cm.												
I (1042) 2575									(265) 258	(1319) 1285	(1578) 1540	(2630) 2575	(2894) 2830	(3035) 2960
II (999) 2469								(202) 197	(1008) 980	(2529) 2469	(2772) 2700	(4249) 4150	(4411) 4300	(4694) 4550
III (235) 580					(89) 87	(89) 87	(119) 116	(417) 405	(714) 695	(1102) 1160	(1316) 1280	(1789) 1740	(1912) 1860	(2025) 1970
IV (110) 271		(19) 19	(129) 124	(238) 232	(250) 243	(250) 243	(334) 325	(457) 445	(750) 730	(1089) 1060	(1151) 1120	(1414) 1375	(1439) 1400	(1410) 1430

Relationship between precipitation, land use classification (L U C) curve numbers (CN) and acreage associated with each hydrologic complex. Complexes are coded as follows

I - Heavily wooded areas

II - Grass or meadow type areas, farmland, medium to lightly wooded areas, low density residential housing areas

III - Bare, denuded areas susceptible to erosion, medium density housing areas.

IV - Impervious surfaces such as roads and high density suburban industrial areas and those areas that can be considered to have curve number 85

Figures in parentheses are metric values hectares, centimeters and hectares cm

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Table 2
Basin I, Little Paint Branch
Storm: 10 hrs., total rainfall 3 inches

		P = hourly accumulated rainfall									
		(0.762) 0.3	(1.52) 0.6	(2.29) 0.9	(3.05) 1.2	(3.81) 1.5	(4.57) 1.8	(5.33) 2.1	(6.10) 2.4	(6.86) 2.7	(7.62) 3.0
L.U.C.	CN	Q = accumulated direct run-off									
I	55								(0.127) 0.05	(0.254) 0.1	(0.508) 0.2
II	65					(0.076) 0.03	(0.254) 0.1	(0.457) 0.18	(0.686) 0.27	(0.940) 0.37	(1.27) 0.50
III	82			(0.254) 0.1	(0.533) 0.21	(0.889) 0.35	(1.40) 0.55	(1.78) 0.70	(2.41) 0.95	(2.92) 1.15	(4.83) 1.9
IV	100	(0.762) 0.3	(1.52) 0.6	(2.29) 0.9	(3.05) 1.2	(3.81) 1.5	(4.57) 1.8	(5.33) 2.1	(6.10) 2.4	(6.86) 2.7	(7.62) 3.0
Acres		Acres XQ (71) = potential run-off in acre-in and in hectare-cm									
I (896) 2217									(113) 110	(228) 222	(456) 444
II (955) 2359						(73) 71	(242) 236	(437) 425	(653) 635	(894) 870	(1212) 1179
III (191) 472				(48) 47	(102) 99	(170) 165	(257) 250	(339) 330	(463) 450	(555) 540	(925) 900
IV (343) 847		(261) 254	(524) 510	(786) 765	(1049) 1020	(1306) 1270	(1562) 1520	(1830) 1780	(2076) 2020	(236) 2300	(2611) 2540
Acres		Acres XQ (64) = Potential run-off in arce-in and in hectare-cm									
I (1042) 2575									(141) 137	(265) 258	(531) 516
II (1000) 2469						(76) 74	(254) 247	(457) 445	(684) 665	(935) 910	(126) 1230
III (235) 580				(59) 58	(125) 122	(209) 203	(329) 320	(416) 405	(565) 550	(684) 665	(1131) 1100
IV (109) 271		(83) 81	(168) 163	(251) 244	(335) 326	(416) 405	(504) 490	(586) 570	(669) 650	(750) 730	(832) 810

Relationship between precipitation, land use classification (L.U.C.) curve numbers (CN) and acreage associated with each hydrologic complex. Complexes are coded as follows:

- I – Heavily wooded areas.
- II – Grass or meadow type areas, farmland, medium to lightly wooded areas, low density residential housing areas.
- III – Bare, denuded areas susceptible to erosion, medium density housing areas.
- IV – Impervious surfaces such as roads and high density suburban industrial areas and those area that can be considered to have curve numbers > 85.

Figures in parentheses are metric values: hectares, centimeters and hectare-cm.

Table 3
Basin II Indian Creek
Storm: First 13 hrs. of Agnes
Total Rainfall 5.28 inches

		P - hourly accumulated rainfall												
		(0.178) 0.07	(1.17) 0.46	(2.03) 0.80	(2.3) 0.90	(2.3) 0.90	(3.0) 1.19	(4.2) 1.65	(7.1) 2.70	(9.9) 3.90	(10.5) 4.15	(13) 5.09	(13.2) 5.17	(13.6) 5.28
[illegible]	CN	Q - accumulated direct run-off												
I	[illegible]								(0.254) 0.1	(1.27) 0.5	(1.52) 0.6	(2.54) 1	(2.79) 1.1	(2.92) 1.15
II	65							(0.203) 0.08	(1.02) 0.4	(2.54) 1	(2.79) 1.1	(4.32) 1.7	(4.45) 1.75	(4.70) 1.85
III	[illegible]				(0.38) 0.15	(0.38) 0.15	(0.51) 0.2	(2.03) 0.7	(3.05) 1.2	(5.08) 2.0	(5.59) 2.2	(7.62) 3	(8.13) 3.2	(8.64) 3.4
IV	100	(0.178) 0.07	(1.17) 0.46	(2.03) 0.80	(2.29) 0.90	(2.29) 0.90	(3.04) 1.2	(4.19) 1.65	(6.86) 2.70	(9.91) 3.90	(10.54) 4.15	(12.93) 5.09	(13.3) 5.17	(13.41) 5.28
[illegible]		Acres XQ (71) Potential run-off in acre-in and in hectare cm												
I [illegible]									(337) 328	(1686) 1640	(2016) 1960	(3367) 3275	(3700) 3600	(3906) 3800
II [illegible]								(123) 120	(617) 600	(1542) 1500	(1696) 1650	(2631) 2560	(2703) 2630	(2878) 2800
III [illegible]					(75) 73	(75) 73	(98) 95	(341) 332	(586) 570	(977) 950	(1079) 1050	(1470) 1430	(1513) 1530	(1696) 1650
IV [illegible]		(86) 84	(565) 550	(1064) 1035	(1110) 1080	(1110) 1080	(1490) 1450	(2117) 2060	(3331) 3240	(4832) 4700	(5140) 5000	(6270) 6100	(6373) 6200	(6527) 6350
[illegible]		Acres XQ (64) Potential run-off in acre-in and in hectare cm												
I [illegible]									(370) 360	(1850) 1800	(2220) 2160	(3694) 3594	(4112) 4000	(4266) 4150
II [illegible]								(126) 123	(632) 615	(1591) 1548	(1747) 1700	(2693) 2620	(2775) 2700	(2930) 2850
III [illegible]					(51) 50	(51) 50	(69) 67	(242) 235	(411) 400	(689) 670	(761) 740	(1028) 1000	(1100) 1070	(1172) 1140
IV (387) [illegible]		(69) 67	(452) 440	(843) 820	(884) 860	(884) 860	(1172) 1140	(1614) 1570	(2652) 2580	(3824) 3720	(4070) 3960	(4985) 4850	(5088) 4950	(5191) 5050

Relationship between precipitation, land use classification (L.U.C.), curve numbers (CN) and acreage associated with each hydrologic complex. Complexes are [illegible] as follows:

I - Heavily wooded areas
II - Grass or meadow type areas, farmland, medium to lightly wooded areas, low density residential housing areas
III - Bare denuded areas susceptible to erosion, medium density housing areas
IV - Impervious surfaces such as roads and high density suburban industrial areas and those areas that can be considered to have curve numbers 85

Figures in parentheses are metric values: hectares, centimeters and hectare-cm

Table 4
Basin II
Storm· 10 hrs. Total rainfall, 3 inches

		P = hourly accumulated rainfall									
		(0.762) 0.3	(1.52) 0.6	(2.29) 0.9	(3.05) 1.2	(3.81) 1.5	(4.57) 1.8	(5.33) 2.1	(6.10) 2.4	(6.86) 2.7	(7.62) 3.0
L.U.C.	CN	Q = accumulated direct run-off									
I	55								(0.127) 0.05	(0.254) 0.1	(0.508) 0.2
II	65					(0.076) 0.03	(0.254) 0.1	(0.457) 0.18	(0.686) 0.27	(0.940) 0.37	(1.27) 0.50
III	82			(0.254) 0.1	(0.533) 0.21	(0.889) 0.35	(1.40) 0.55	(1.78) 0.70	(2.41) 0.95	(2.92) 1.15	(4.83) 1.9
IV	[illegible]	(0.762) 0.3	(1.52) 0.6	(2.29) 0.9	(3.05) 1.2	(3.81) 1.5	(4.57) 1.8	(5.33) 2.1	(6.10) 2.4	(6.86) 2.7	(7.62) 3.0
Acres		Acres XQ (71) = potential run-off in acre-in and in hectare-cm									
I (1330) 3275									(168) 163	(337) 328	(777) 756
II (607) 1500						(4[illegible]) 4[illegible]	(154) 150	(278) 270	(411) 400	(565) 550	(771) 750
III (192) 475				(49) 48	(103) 100	(170) 165	(267) 260	(339) 330	(463) 450	(566) 550	(925) 900
IV (486) 1200		(370) 360	(730) 710	(1100) 1070	(1439) 1400	(1850) 1800	(2220) 2160	(2570) 2500	(2981) 2900	(3392) 3300	(3803) 3700
Acres		Acres XQ (64) = Potential run-off in acre-in and in hectare-cm									
I (1470) 3621									(185) 180	(372) 362	(744) 724
II (627) [illegible]						(46) 45	(159) 155	(269) 262	(401) 390	(555) 540	(750) 730
III (135) 336				(35) 34	(64) 62	(106) 103	(166) 162	(210) 204	(288) 280	(350) 340	(575) 560
IV (387) 956		(295) 287	(591) 575	(884) 860	(1182) 1150	(1470) 1430	(1768) 1720	(2056) 2000	(2364) 2300	(2673) 2600	(2981) 2900

Relationship between precipitation, land use classification (L.U.C.) curve numbers (CN) and acreage associated with each hydrologic complex. Complexes are coded as follows

I – Heavily wooded areas.

II – Grass or meadow type areas, farmland, medium to lightly wooded areas, low density residential housing areas

III – Bare, denuded areas susceptible to erosion, medium density housing areas.

IV – Impervious surfaces such as roads and high density suburban industrial areas and those areas that can be considered to have curve numbers · 85.

Figures in parentheses are metric values: hectares, centimeters and hectare-cm.

Table 5
Basin III
Storm: First 13 hrs of Agnes
Total Rainfall 5.28 inches

L.U.C.	CN													
P hourly accumulated rainfall														
		(0.178) 0.07	(1.17) 0.46	(2.02) 0.80	(2.3) 0.90	(2.3) 0.90	(3.0) 1.19	(4.2) 1.65	(7.1) 2.70	(9.9) 3.90	(10.6) 4.15	(13) 5.09	(13.2) 5.17	(13.5) 5.28
L.U.C.	CN	Q accumulated direct run-off												
I	55								(0.254) 0.1	(1.27) 0.5	(1.52) 0.6	(2.54) 1	(2.79) 1.1	(2.92) 1.15
II	65							(2.03) 0.08	(1.02) 0.4	(2.54) 1	(2.79) 1.1	(4.32) 1.7	(4.45) 1.75	(4.70) 1.85
III	82				(0.38) 0.15	(0.38) 0.15	(0.51) 0.2	(2.03) 0.7	(3.05) 1.2	(5.08) 2.0	(5.59) 2.2	(7.62) 3	(8.13) 3.2	([illegible]) 3.1
IV	100	(0.178) 0.07	(1.17) 0.46	(2.03) 0.80	(2.29) 0.90	(2.29) 0.90	(3.05) 1.2	(4.19) 1.65	(6.86) 2.70	(9.91) 3.90	(10.54) 4.15	(12.93) 5.09	([illegible]) 5.17	([illegible]) 5.28
Acres		Acres NQ (71) Potential run-off in acre-in and in hectare-cm												
I (121) 300									(62) 60	(217) 210	(278) 270	(432) 420	(463) 450	([illegible]) [illegible]
II (142) 350									(72) 70	(288) 280	(322) 314	(504) 490	(540) 525	(590) 525
III (121) 300					(46) 45	(46) 45	(62) 60	(216) 213	(370) 360	(617) 600	(678) 660	(925) 900	(987) 960	(1030) 1002
IV (20) 50			(23) 23	(45) 11	(46) 45	(46) 45	([illegible]) [illegible]	(85) [illegible]	(139) 135	(200) 195	(210) 201	([illegible]) 254	([illegible]) 260	([illegible]) 264
Acres		Acres NQ (61) Potential run-off in acre-in and in hectare-cm												
I (142) 350									(36) 35	(180) 175	(216) 210	(360) 350	(391) 380	(412) 400
II (142) 350									(72) 70	(288) 280	(323) 314	(504) 490	(540) 525	(540) 525
III (121) 300					(46) 45	(46) 45	(62) 60	(216) 210	(370) 360	(617) 600	(678) 660	(925) 900	(987) 960	(1030) 1002

Relationship between precipitation, land use class [illegible] (L.U.C.), curve numbers (CN) and acreage associated with each hydrologic complex. [illegible] are as follows:

I - Heavily wooded areas
II - Grass or meadow type areas, farmland, medium to lightly wooded areas, low den[illegible] residential housing areas
III - Bare, denuded areas susceptible to erosion, medium density housing areas
IV - Impervious surfaces such as roads and high density suburban industrial areas and those areas that can be considered to have curve numbers [illegible] 85

Figures in parentheses are metric values: hectares, centimeters and hectare-cm

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Table 6
Basin III
Storm: 10 hrs. total rainfall, 3 inches

P = hourly accumulated rainfall											
		(0.762) 0.3	(1.52) 0.6	(2.29) 0.9	(3.05) 1.2	(3.81) 1.5	(4.57) 1.8	(5.33) 2.1	(6.10) 2.4	(6.86) 2.7	(7.62) 3.0
L.U.C.	CN	Q = accumulated direct run-off									
I	55								(0.127) 0.05	(0.254) 0.1	(0.508) 0.2
II	65					(0.076) 0.03	(0.254) 0.1	(0.457) 0.18	(0.686) 0.27	(0.940) 0.37	(1.27) 0.50
III	82			(0.254) 0.1	(0.533) 0.21	(0.889) 0.35	(1.40) 0.55	(1.78) 0.70	(2.41) 0.95	(2.92) 1.15	(4.83) 1.9
IV	100	(0.762) 0.3	(1.52) 0.6	(2.29) 0.9	(3.05) 1.2	(3.81) 1.5	(4.57) 1.8	(5.33) 2.1	(6.10) 2.4	(6.86) 2.7	(7.62) 3.0
Acres		Acres XQ (71) potential run-off in acre-in and in hectare-cm									
I (121) 300									(15) 15	(31) 30	(62) 60
II (142) 350						(11) 11	(36) 35	(65) 63	(98) 95	(134) 130	(180) 175
III (121) 300				(31) 30	(65) 63	(108) 105	(170) 165	(216) 210	(293) 285	(355) 345	(586) 570
IV (20) 50		(15) 15	(31) 30	(46) 45	(62) 60	(77) 75	(93) 90	(108) 105	(123) 120	(139) 135	(154) 150
Acres		Acres XQ (64) = potential run-off in acre-in and in hectare-in									
I (142) (350)									(19) 18	(36) 35	(72) 70
II (142) 350						(11) 11	(36) 35	(65) 63	(98) 95	(134) 130	(180) 175
III (121) 300				(31) 30	(65) 63	(108) 105	(170) 165	(216) 210	(293) 285	(355) 345	(586) 570
IV0											

Relationship between precipitation, land use classification L C U , curve numbers, (CN) and average associated with each hydrologic complex. Complexes are coded as follows:

- I – Heavily wooded areas.
- II – Grass or meadow type areas, farmland, medium to lightly wooded areas, low density residential housing areas
- III – Bare, denuded areas susceptible to erosion, medium density housing areas.
- IV – Impervious surfaces such as roads and high density suburban industrial areas and those areas that can be considered to have curve numbers · 85.

Figures in parentheses are metric values hectares, centimeter and hectare-cm

Table 7
BASIN I
Little Paint Branch, Storm: First 13 hrs of Agnes (9.2 mi.^{2}) (23.7 Km^2)

ACC Q		Q		Q_p in Cfs and cm	
64	71	64	71	64	71
0	0				
0.003 (0.0076)	0.01 (0.025)	0.003 (0.0076)	0.01 (0.0254)	4 (0.113)	13 (0.368)
0.021 (0.053)	0.065 (0.165	0.018 (0.046)	0.064 (0.163)	23 (0.65)	82 (2.32)
0.039 (0.099)	0.14 (0.36)	0.018 (0.046)	0.049 (0.124)	23 (0.65)	63 (1.78)
0.056 (0.142)	0.14 (0.36)	0.017 (0.043)	0	22 (0.623)	0
0.056 (0.142)	0.19 (0.483)	0	0.05 (0.127)	0	64 (1.81)
0.075 (0.191)	[illegible] (0.584)	0.019 (0.048)	0.04 (0.101)	24 (0.680)	51 (1.44)
0.178 (0.452)	0.685 (1.74)	0.103 (0.33)	0.46 (1.17)	131 (3.71)	590 (16.7)
0.452 (1.15)	1.31 (3.38)	0.274 (0.696)	0.64 (1.63)	350 (9.91)	820 (23.2)
1.01 (2.56)	1.44 (3.66)	0.556 (1.41)	0.11 (0.279)	710 (20.1)	140 (3.96)
1.126 (2.86)	2.04 (5.18)	0.118 (0.300)	0.60 (1.62)	150 (4.25)	770 (21.8)
1.67 (4.24)	2.13 (5.41)	0.543 (1.38)	0.09 (0.229)	690 (19.5)	115 (3.25)
1.76 (4.47)	2.22 (5.64)	0.094 (0.239)	0.09 (0.229)	120 (3.40)	115 (3.25)
			0.01 (0.0254)		13 (.368)

$$k = \frac{484 \times 9.2}{3.5} = 1275, \quad Q_p = Q \times k$$

Accumulated run-off and peak discharge for storm of Agnes' magnitude. The accumulated Q are weighted values obtained from Table 1 by adding vertically the acres xQ for each hourly increment and dividing by total drainage area. The corresponding metric values are in parentheses.

Table 8
BASIN I
Storm: 10 hrs rainfall 3 inches

ACC Q		ΔQ		Q_p in CfS and cms	
64	71	64	71	64	71
0.014 (0.090)	0.043 (0.109				
		0.014 (0.036)	0.044 (0.112)	18 (31.65)	56 (1.59)
0.028 (0.071)	0.087 (0.221)				
		0.024 (0.061)	0.051 (0.130)	30 (0.849)	65 (1.84)
0.051 (0.130)	0.138 (0.351)				
		0.025 (0.064)	0.052 (0.132)	31 (0.878)	67 (1.90)
0.076 (0.193)	0.190 (0.483)				
		0.040 (0.102)	0.067 (0.170)	51 (1.44)	85 (2.41)
0.116 (0.294)	0.255 (0.648)				
		0.064 (0.163)	0.085 (0.216)	81 (2.29)	108 (3.06)
0.179 (0.454)	0.340 (0.863)				
		0.072 (0.183)	0.090 (0.229)	91 (2.58)	115 (3.26)
0.241 (0.612)	0.430 (1.09)				
		0.099 (0.251)	0.115 (0.292)	126 (3.57)	147 (4.16)
0.340 (0.864)	0.545 (1.38)				
		0.095 (0.241)	0.122 (0.310)	122 (3.45)	156 (4.42)
0.435 (1.10)	0.667 (1.69)				
		0.185 (0.470)	0.192 (0.488)	230 (6.51)	246 (6.96)
0.620 (1.57)	0.859 (2.18)				

Accumulated run-off and peak discharge for storm of magnitude 3 inches in ten hours. The accumulated Q are weighted values obtained from Table 2 by adding vertically the acres xQ for each hourly increment and dividing by total drainage area. Definitions are as for Table 7.

Table 9
BASIN II
Indian Creek, Storm: First 13 hrs. of Agnes
(10 mi^2) (26 Km^2)

ACC Q		Q		Q_p in CfS and cms	
64	71	64	71	64	71
0	0				
		0.01 (0.0254)	0.013 (0.033)	14 (0.011)	18 (0.510)
0.01 (0.0254)	0.013 (0.033)				
		0.058 (0.147)	0.073 (0.185)	70 (1.98)	100 (2.83)
0.068 (0.173)	0.086 (0.218)				
		0.059 (0.150)	0.074 (0.188)	83 (2.35)	105 (2.97)
0.127 (0.323	0.160 (0.406)				
		0.017 (0.043)	0.02 (0.051)	14 (0.011)	28 (0.793)
0.141 (0.358)	0.18 (0.457)				
		0	0	0	0
0.141 (0.358)	0.18 (0.457)				
		0.046 (0.117)	0.05 (0.127)	70 (1.98)	83 (2.35)
0.187 (0.475)	0.23 (0.584)				
		0.113 (0.287)	0.15 (0.38)	151 (4.28)	208 (5.89)
0.300 (0.762)	0.380 (0.465)				
		0.315 (0.800)	0.36 (0.914)	450 (12.74)	500 (14.16)
0.615 (1.56)	0.735 (1.87)				
		0.585 (1.49)	0.625 (1.59)	167 (4.73)	865 (24.49)
1.20 (3.05)	1.36 (3.45)				
		0.16 (0.406)	0.14 (0.356)	610 (17.27)	195 (5.52)
1.360 (3.45)	1.50 (3.81)				
		0.19 (1.24)	0.54 (1.37)	790 (22.37)	750 (21.24)
1.850 (4.70)	2.04 (5.18)				
		0.120 (0.305)	0.13 (0.330)	139 (3.94)	180 (5.10)

$$k = \frac{484 \cdot 10}{3.5} = 1390, \quad Q_p = Q \cdot k$$

Accumulated run-off and peak discharge for storm of Agnes' magnitude. The accumulated Q are weighted values obtained from Table 3 by adding vertically the acres xQ for each hourly increment and dividing by total drainage area. The corresponding metric values are in parentheses.

Table 10
BASIN II
Storm: 10 hrs, rainfall 3 inches

ACC Q		Δ Q		Q_p in CfS and cms	
64	71	64	71	64	71
0.044 (0.284)	0.056 (0.142)				
		0.045 (0.114)	0.054 (0.137)	63 (1.78)	75 (2.12)
0.089 (0.226)	0.110 (0.279)				
		0.049 (0.124)	0.063 (0.160)	68 (1.93)	68 (1.93)
0.138 (0.351)	0.173 (0.439)				
		0.050 (0.127)	0.060 (0.152)	70 (1.98)	83 (2.35)
0.188 (0.478)	0.233 (0.592)				
		0.057 (0.145)	0.079 (0.201)	79 (2.24)	110 (3.11)
0.245 (0.622)	0.312 (0.792)				
		0.071 (0.180)	0.086 (0.218)	100 (2.83)	120 (3.40)
0.316 (0.803)	0.398 (1.00)				
		0.066 (0.168)	0.083 (0.211)	66 (1.87)	115 (3.26)
0.382 (0.970)	0.481 (1.22)				
		0.106 (0.269)	0.126 (0.320)	147 (4.17)	175 (4.96)
0.488 (1.24)	0.607 (1.54)				
		0.108 (0.274)	0.126 (0.320)	150 (4.25)	175 (4.96)
0.596 (1.51)	0.733 (1.86)				
		0.166 (0.422)	0.214 (0.544)	230 (6.51)	300 (8.50)
0.762 (1.94)	0.947 (2.41)				

Accumulated run-off and peak discharge for storm of magnitude 3 inches in ten hours. The accumulated Q are weighted values obtained from Table 4 by adding vertically the acres xQ for each hourly increment and dividing by total drainage area. Definitions are as in Table 9.

Table 11
BASIN III Indian Creek, Storm: First 13 hrs of Agnes
(1.6 mi^2) (4.15 Km^2)

ACC Q				Q				Q_p in CfS and cms			
64		71		64		71		64		71	
0		0									
				0		0.003	(0.008)	0		0	
0		0.003	(0.008)								
				0		0.020	(0.051)	0		0	
0		0.023	(0.058)								
				0		0.021	(0.053)	0		16	(0.453)
0		0.044	(0.112)								
				0		0.046	(0.117)	0		14	(0.396)
0		0.090	(0.229)								
				0		0		0		31	(0.878)
0		0.090	(0.229)								
				0		0.03	(0.076)	0		0	
0		0.120	(0.305)								
				0		0.173	(0.439)	0		20	(0.566)
0.08	(0.203)	0.293	(0.744)								
				0.08	(0.203)	0.432	(1.10)	45	(0.036)	112	(3.17)
0.4	(1.02)	0.625	(1.59)								
				0.32	(0.813)	0.690	(1.75)	178	(5.04)	300	(8.50)
0.9	(2.29)	1.315	(3.34)								
				0.5	(1.27)	0.133	(0.338)	280	(7.93)	475	(13.45)
1.1	(2.79)	1.448	(3.68)								
				0.02	(0.051)	0.616	(1.56)	11	(0.311)	90	(2.55)
1.5	(3.81)	2.064	(5.24)								
				0.4	(1.02)	0.131	(0.333)	224	(6.34)	425	(12.03)
1.8	(4.57)	2.195	(5.58)								
				0.3	(0.762)	0.046	(0.117)	168	(4.76)	85	(2.41)

$$k = \frac{484 \quad 1.55}{1.1} = 685 \quad Q_p = Q \cdot k$$

Accumulated run-off and peak discharge for storm of Agnes' magnitude. The accumulated Q are weighted values obtained from Table 5 by adding vertically the acres xQ for each hourly increment and dividing by total drainage area. The corresponding metric values are in parentheses.

Table 12
BASIN III
Storm: 10 hrs rainfall 3 inches

ACC Q		ΔQ		Q_p in CfS and cms	
64	71	64	71	64	71
0	0.015 (0.038)				
		0	0.015 (0.038)	0	10 (0.283)
0	0.030 (0.076)				
		0.030 (0.076)	0.045 (0.114)	20 (0.566)	31 (0.878)
0.030 (0.076)	0.075 (0.190)				
		0.033 (0.084)	0.048 (0.122)	23 (0.651)	33 (0.93)
0.063 (0.160)	0.123 (0.312)				
		0.053 (0.135)	0.068 (0.173)	36 (1.02)	47 (1.33)
0.116 (0.294)	0.191 (0.485)				
		0.094 (0.239)	0.099 (0.251)	64 (1.81)	68 (1.93)
0.210 (0.534)	0.190 (0.485)				
		0.063 (0.160)	0.088 (0.224)	43 (1.22)	60 (1.70)
0.273 (0.694)	0.378 (0.960)				
		0.035 (0.089)	0.137 (0.348)	24 (0.680)	94 (2.66)
0.308 (0.783)	0.515 (1.31)				
		0.192 (0.487)	0.115 (0.292)	131 (3.71)	80 (2.27)
0.500 (1.27)	0.630 (1.60)				
		0.315 (0.800)	0.325 (0.825)	216 (6.12)	222 (6.29)
0.815 (2.07)	0.955 (2.42)				

Accumulated run-off and peak discharge for storm of magnitude 3 inches in ten hours. The accumulated Q are weighted values from Table 6. by adding vertically the acres ΔQ for each hourly increment and dividing by total drainage area. Definitions are as for Table 11.

Table 13
Peak discharge of thunderstorms for the three basins in 1971

BASIN I							
L.U.C.	CN	Acres		Q		A × Q	
I	55	2217	(897)	0			
II	65	2359	(954)	0			
III	82	472	(191)	0.15	(0.38)	71	(73)
IV	100	847	(343)	1	(2.54)	847	(870)
						918	

$Q_P = 1275 \times 0.156 = 200$ cfs (5.66cms)

weighted $Q = \frac{918}{5895} = 0.156$

BASIN II							
L.U.C.	CN	Acres		Q		A × Q	
I	55	3275	(1320)	0			
II	65	1500	(607)	0			
III	82	475	(192)	0.15	(0.38)	71	(73)
IV	100	1200	(486)	1	(2.54)	1200	(1230)
						1271	

$Q_P = 1390 \times 0.198 = 275$cfs (7.79cms)

weighted $Q = \frac{1271}{6450} = 0.198$

BASIN III							
L.U.C.	CN	Acres		Q		A × Q	
I	55	300	(121)			0	
II	65	350	(142)			0	
III	82	300	(121)	0.15	(0.38)	45	(46)
IV	100	50	(20)	1	(2.54)	50	(52)
						95	

$Q_P = 685 \times 0.095 = 65$cfs (1.84cms)

weighted $Q = \frac{95}{1000} = 0.095$

Table 14
Peal. discharge of thunderstorms for the three basins in 1964

BASIN I

L.U.C.	CN	Acres		Q		A × Q	
I	55	2575	(1040)	0		0	
II	65	2469	(1000)	0		0	
III	82	580	(235)	0.15	(0.38)	87	(90)
IV	100	271	(110)	1	(2.54)	271	(278)

Q_p = 75cfs
(2.21cms)

BASIN II

L.U.C.	CN	Acres		Q		A × Q	
I	55	3621	(1470)	0		0	
II	65	1548	(627)	0		0	
III	82	335	(136)	0.15	(0.38)	50	(52)
IV	100	956	(387)	1	(2.54)	956	(992)

Q_p = 217cfs
(6.14cms)

BASIN III

L.U.C.	CN	Acres		Q		A × Q
I	55	400	(162)	0		
II	65	300	(121)	0		
III	82	300	(121)	0.15	(0.38)	0.045
IV	100	0				

Q_p = 31 cfs
(0.87cms)

Table 15
Key Land Use

1. Town of Beltsville, - high density detached houses, very light vegetative cover
2. Large light industrial warehouse and commercial area located adjacent to B&O railroad.
3. Light woods and brush
4. Denuded land
5. Medium heavily wooded areas along flood plain and tributaries of Indian Creek.
6. Cropland, land under cultivation
7. Medium density housing
8. Cleared land
9. Baseball field
10. Cleared land practically devoid of vegetative cover
11. Lowland subject to inundation
12. Cleared lowland area
13. Medium to heavy wooded areas
14. Light density suburban area
15. Industrial Park storage and warehouse area
16. Badly eroded area devoid of vegetation cover
17. Light woods on flood plain
18. Sand and gravel
19. Denuded area undergoing construction
20. Industrial Park
21. Low density rural area
22. Baseball Field
23. Under construction
24. Powerline right of way

Table 15 (Continued)
Key Land Use

25. Heavily wooded lowland
26. Multi-family dwellings
27. Multi-family dwellings
28. Farmland
29. Under construction
30. Low density housing
31. Junkyard
32. Cemetery
33. Medium wooded area
34. Heavily wooded (Evergreen)
35. Medium to lightly wooded areas
36. Farmland
37. Farmland
38. Sand and gravel operations
39. Farmland
40. Meadows
41. Inoperational sand and gravel pit
42. Sand and gravel pit
43. Medium density Suburban Housing area (single family)
44. Farmland
45. Heavy woods
46. Powerline
47. Eroded area
48. Meadow/grassland
49. Partially filled reservoir
50. Sand and gravel pits and processing area

Table 15 (Continued)
Key Land Use

51. Small stand of trees
52. Farmland
53. Pond
54. Sand and gravel pit
55. Badly eroded area or old gravel pit
56. Sub station
57. Sand and gravel pit
58. Under construction
59. Powerline
60. Farmland
61. Golf course
62. Sand and gravel pits
63. Low density single family homes
64. Low density single family homes
65. Farmland
66. Meadows
67. Farmland
68. Sand and gravel operations
69. I-95 and Interchange
70. Low density single family homes
71. Heavily wooded area
72. Industrial Park
73. High density multi-family housing units
74. School
75. High density single family homes
76. Orchards/plant research

Table 15 (Concluded)
Key Land Use

77.	Construction site
78.	High density single family detached homes
79.	Low density single family homes
80.	Non-operational sand and gravel pits
81.	Denuded area
82.	Baseball field
83.	Low density single family homes
84.	Farmland
85.	Low medium density single family homes
86.	Golf course
87.	Woods
88.	Low density single family detached homes
89.	Denuded area
90.	Meadow
91.	Large estate
92.	School grounds
93.	Large estate
94.	Farmland
95.	Low density single family detached homes
96.	Low density single family detached homes
97.	Medium density housing areas
98.	Woods
99.	Medium density housing
100.	School grounds
101.	Low density housing

Table 16
Geology (Cooke, and Cloos, 1951, 1953)

Qw

Wicomico formation (Gravel, sand, and silt, stream deposits passing upward into estuarine deposits to a maximum altitude of 140 feet above sea level, about 30 feet thick.)

Tb

Brandywine gravel (Ancient alluvial fans sloping gently downward from an altitude of apprx. 300 ft. above sea level. The Potomac fan includes many pebbles of chert, about 40 ft. thick.)

Kp

Patapsco formation and Arundel clay (undifferentiated) (Dark-gray massive clay containing lignitized wood and saurian bones overlain by massive maroon clay and varicolored sand and clay, probably an outwash deposit; about 300 ft. thick.)

Kpx

Patuxent formation (Large round pebbles, fine white pink, or yellow sand, and thin lenses of white or iron-stained clay and kaolin. The sand beds commonly contain disseminated kaolin, probably an outwash deposit, about 100 feet thick.)

lm

Laurel migmatite (Intensely granitized schist mixed with impure granite, muscovite and biotite granite)

Pzwo

Wissahickon oligoclase-mica schist

Figure 1. Land use patterns in Little Paint Branch (Basin I) and Indian Creek (Basin II, III) in 1971. See Table 15 for annotations. Approximate Scale 1: 56, 250.

Figure 2. Change in land use patterns since 1964, (1) Former wooded areas, (2) Former denuded areas, (3) Former meadow or grass areas Approximate Scale 1: 56, 250.

Figure 3. Geology map - see Table 16 for description of Geology. Note extent of Patuxent Formation (KPx) which is a major aquifier. Approximate Scale 1: 56, 250.

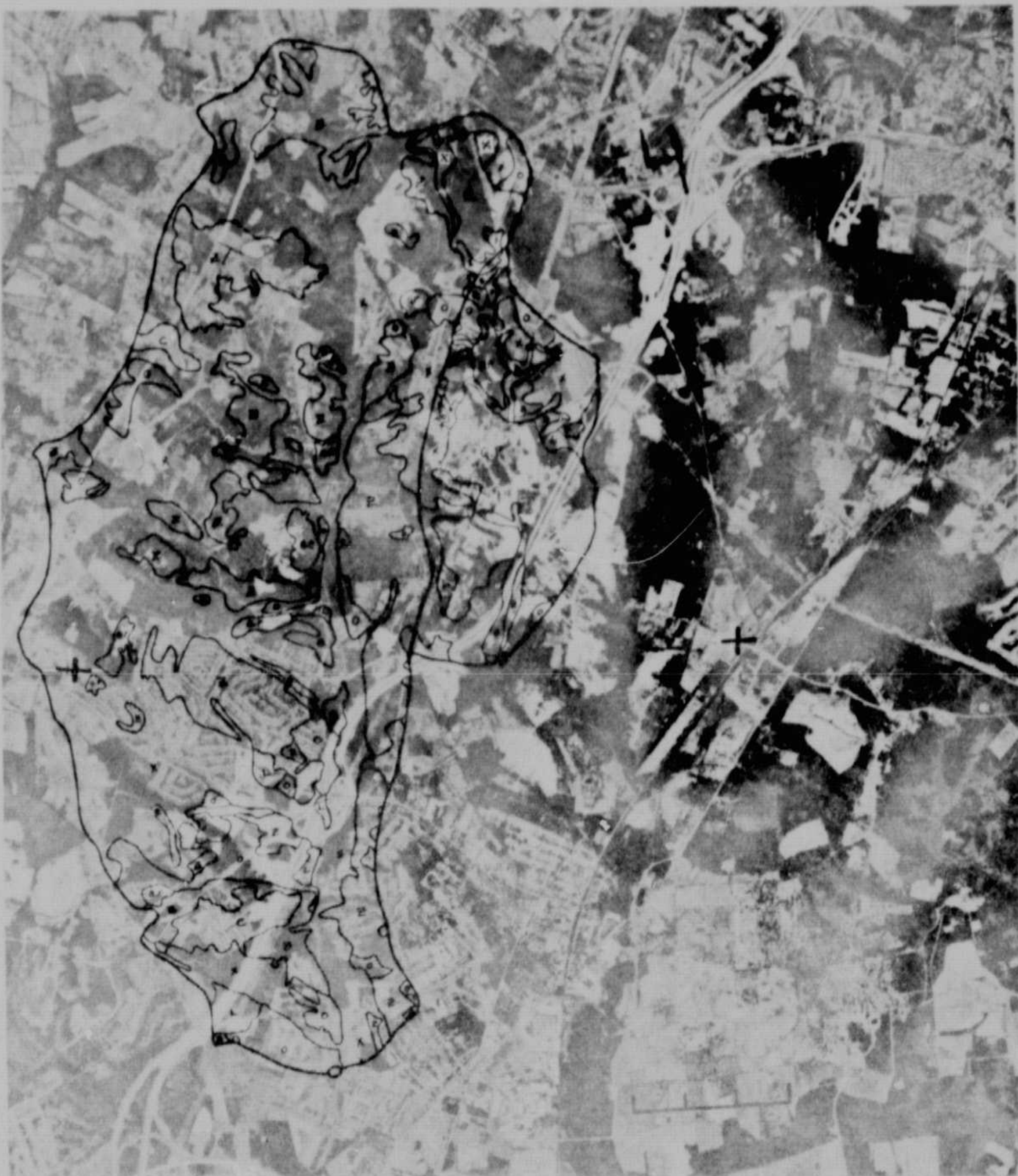

Figure 4. Soils map based on textural similarities. X = Silt Loam, Z = Gravelly sand, L = Loam, C = Urban land complex, CL = Clayey sand, O = sandy loam, G.P. = gravel pit. Approximate Scale 1: 56, 250.

Figure 5. Drainage map - Annotations I, II, III, refer to Little Paint Branch, Indian Creek, and a sub-basin of Indian Creek respectively Approximate Scale 1: 56, 250.

Figure 6. Slope map of Little Paint Branch and Sub-basin of Indian Creek, A = 0 to 2 percent, B = 2 to 5 percent, C = 5 to 15 percent, D = 15 to 25 percent. Approximate Scale 1: 56, 250.

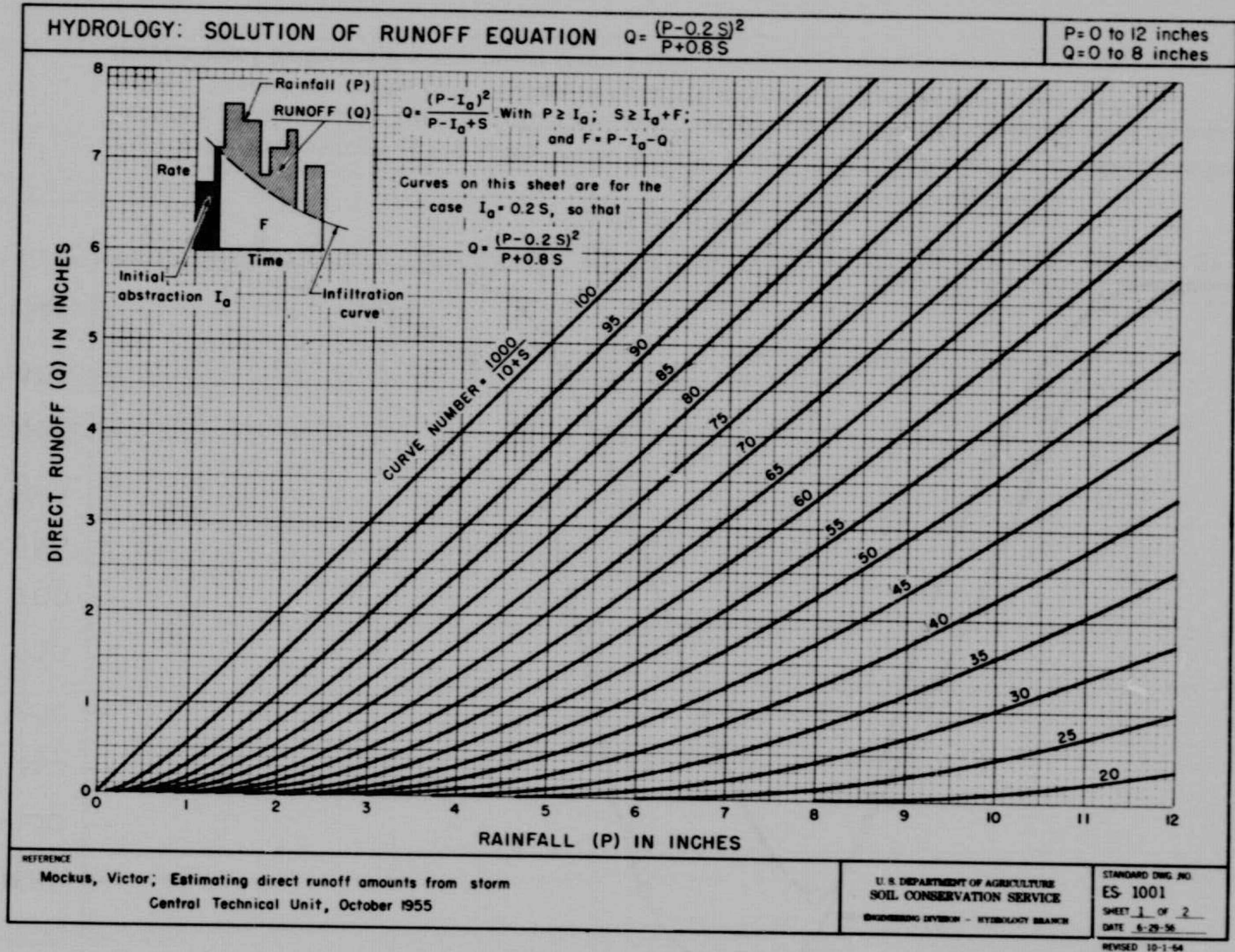

Figure 7. Illustration of solution to run-off equation and showing curve numbers (CN).

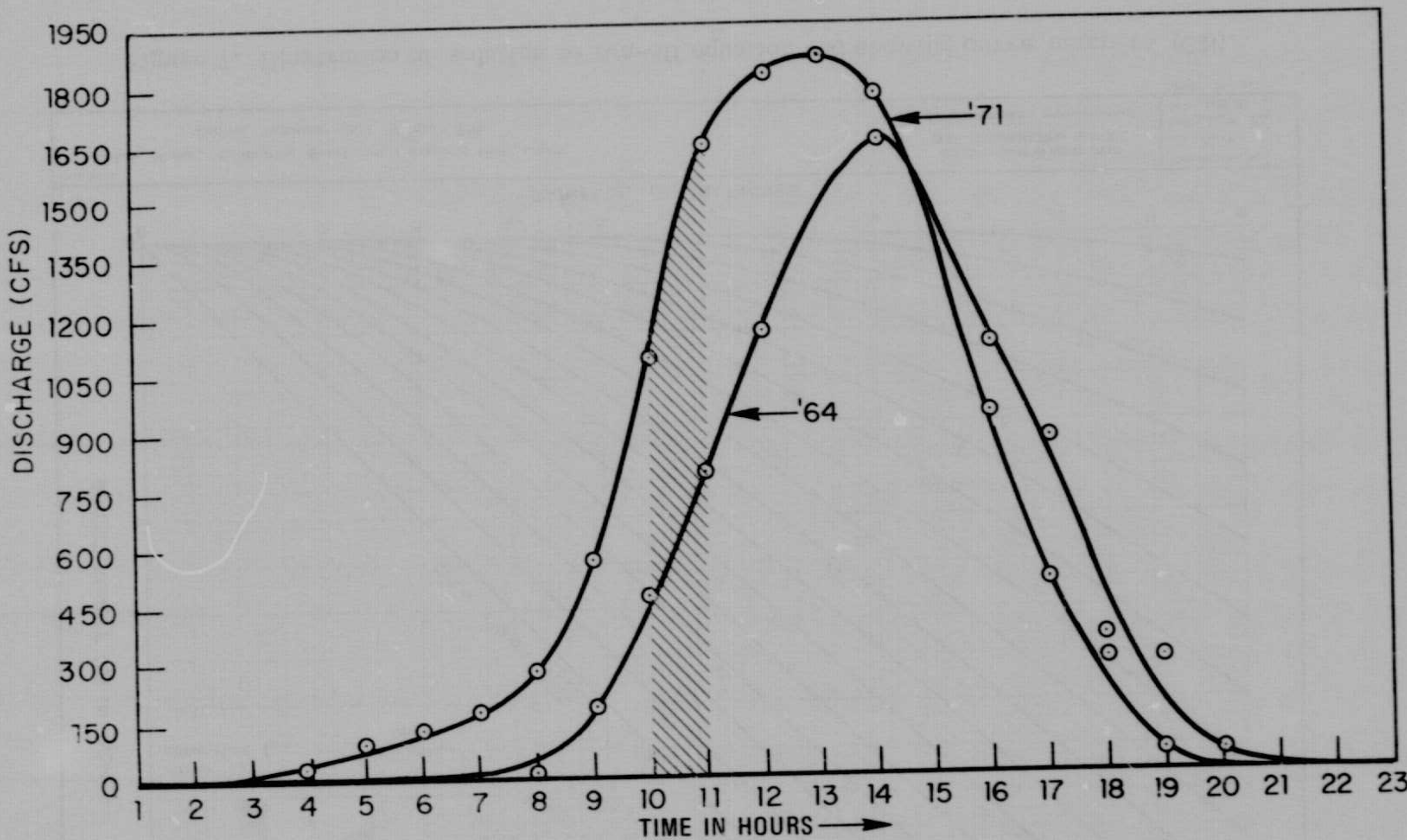

Figure 8. Hydrograph of the Little Paint Branch Basin showing change in run-off characteristics between 1964 and 1971 for a hypothetical storm of the magnitude and duration of Tropical Storm Agnes. Shaded areas indicate change in hourly incremental discharge for the 10th hour. Data for incremental hydrographs are taken from Table 7.

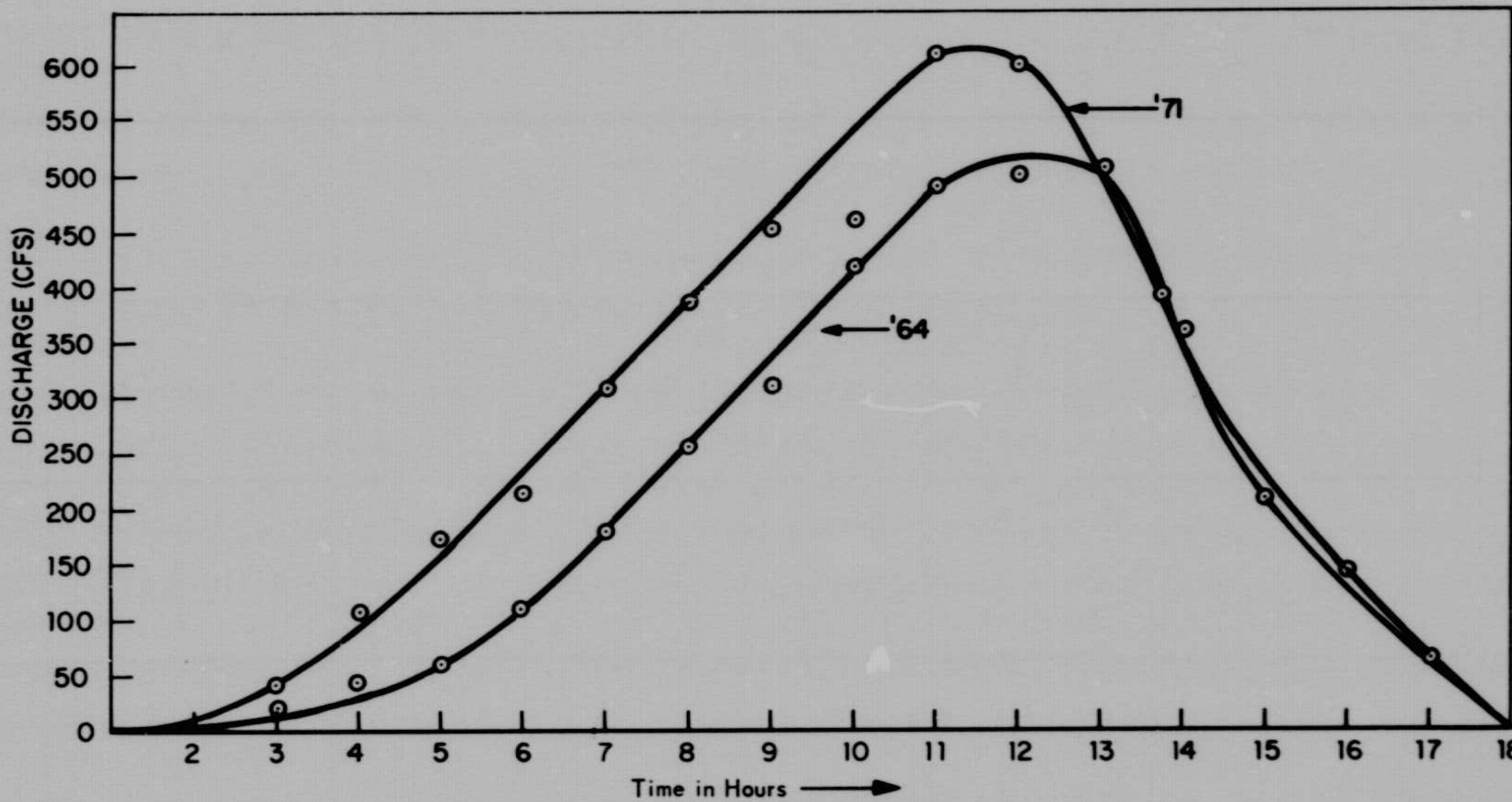

Figure 9. Hydrograph of the Little Paint Branch Basin showing change in run-off characteristics between 1964 and 1971 for a hypothetical ten hour storm. Data for incremental hydrographs are taken from Table 8.