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A CYCLE OF SEDIMENTATION AND EROSION IN URBAN RIVER CHANNELS

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ABSTRACT. Historical evidence and contemporary measurements indicate in the Piedmont of Maryland that successive changes in land use have been accompanied by changes in sediment yield and in the behavior of river channels. Sediment yields from forested areas in the pre-farming era appear to have been less than 100 tons/sq.mi/year. Yields from agricultural lands in the same region at a later time range from 300 to 800 t/sq.mi. on large drainage areas. Subsequently, on lands marginal to expanding urban centers, a decline in active farming may be accompanied by a decline in sediment yield. In marked contrast, areas exposed during construction can produce sediment loads in excess of 100,000 t/sq.mi./year. Small channel systems become clogged with sand during this construction period. While sediment deposited in channels during construction is gradually removed by subsequent clearer flows, rates of removal are slow and hampered by deposition of debris. Increased runoff from urban areas coupled with a decline in sediment yields to values on the order of 50 to 100 t/sq.mi. promote continued bank erosion and channel widening. Maximum observed rates of bank erosion were on the order of 1.0 foot per year. Raw banks adjacent to coarse cobble bars and widespread deposits of flotsam and debris attest to the flood regimen of urban rivers. Canalization in concrete does not eliminate such debris nor does it eliminate deposition of sediment as local changes in gradient, excessive channel width, and debris accumulation foster deposition even in canalized reaches.

Equilibrium and a cycle of change

Students of geomorphology have long debated the meaning and value of concepts such as grade and equilibrium applied to the behavior of stream channels. These and similar phrases generally denote a condition of balance, stability, or both in the characteristics and behavior of a river channel. However, logical and semantic difficulties demand that phrases associated with the concept of equilibrium must be used with care and circumscribed by qualifications. Thus, progressive degradation over geologic time is inconsistent with a too rigid definition of equilibrium which implies stability in elevation, gradient, and channel form. At the same time, over somewhat shorter periods of time, slow but progressive degradation may yet be associated with near constancy or stability of channel form. With only small changes in inflow of water and sediment, channel form and even channel gradients may remain relatively stable.

While a universally applicable concept of equilibrium may be difficult to formulate because of the problems posed by varying time scales and rates of change of channel gradients and channel forms, the concept of equilibrium can be useful in dealing with the response of channel systems to significant changes in the values of the independent variables such as discharge and sediment load over shorter intervals of time. Under these conditions a reasonable working hypothesis, perhaps paraphrasing Mackin (1948), might be that over a period of years channel slope and form are adjusted to the quantity of water and to the quantity and characteristics of the sediment load provided by the drainage basin. Each of the independent variables, water and sediment, are in turn related to the soil, lithology, vegetation, and climate of the region. This statement of adjustment allows for momentary scour and fill and for short-term trends, measured in years, in channel behavior associated with high water or drought.

If a set of river channels are in equilibrium with prevailing conditions in a drainage basin, it follows that major disturbances on the drainage basin will result in changes in channel form and behavior. The process of urbanization of the landscape constitutes a major interruption of "prevailing" conditions on a watershed. If prior to urban development, a kind of equilibrium prevailed in which channel gradient and form were related to water

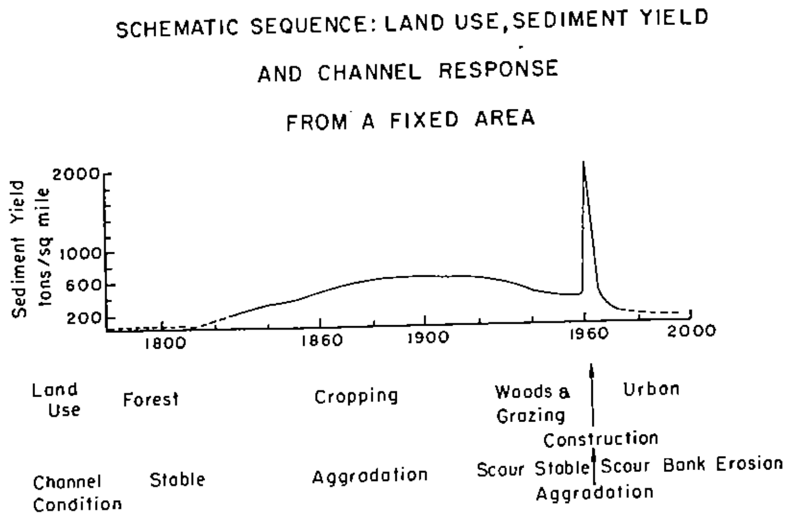


Figure 1. The cycle of land use changes, sediment yield, and channel behavior in a Piedmont region beginning prior to the advent of extensive farming and continuing through a period of construction and subsequent urban landscape.

and sediment derived from the watershed, then the sequential changes which occur as urban development takes place on the watershed can be expected to alter markedly the equilibrium forms and may result in the eventual establishment of new conditions of equilibrium. At the present time the disturbance of equilibrium can be documented, but as the data here will show, it is currently difficult to determine whether a new equilibrium will be established or whether instead a condition of disequilibrium will persist.

The process or cycle of urbanization on the watershed that is reflected in the river channels of a region consists of three stages; 1) an initial stable or equilibrium condition in which the landscape may either be primarily agricultural or dominated by forests, 2) a period of construction during which bare land is exposed to erosion, and 3) a final stage consisting of a new urban landscape dominated by streets, rooftops, gutters, and sewers. This theoretical cycle is sketched in Figure 1 along with estimates of the quantity of sediment derived from the watershed, the presumed channel behavior, and the sequence of land use. The data are based upon experience in the Middle Atlantic region of the United States. The conditions outlined in Figure 1 are described in the following paragraphs. These serve both as an outline and as a summary of the data presented and evaluated in the body of the paper.

In accord with the historical evidence, Figure 1 shows a modest yield of sediment prior to the farming era given here as beginning around 1700 A.D., and a significant increase in sediment yield during the farming period to an average value of about 600 tons/square mile. A decline in yields to a value of perhaps 300 tons/sq.mi. is shown for the period immediately preceding construction based on the observation that in the environs of some of the major urban centers much farmland may be put in grass or allowed to return to brush and forest while awaiting development. With the onset of clearing for construction sediment yields rise to perhaps several thousand or more tons/sq. mi. during a short interval of perhaps one to three years. The interval is short, of course, only where a single or isolated unit of land and channel is considered since progressive development of a large drainage area will affect downstream reaches of channel for a longer period. Following construction, if the entire area has been developed, sediment yields should be expected to decline to values as low as or lower than those experienced prior to the farming era. This condition is shown by a dashed line on Figure 1.

Changes in the watershed are accompanied by changes in channel characteristics. During the farming era historical evidence indicates considerable accumulation of sediment within channels (Gottschalk, 1945). Subsequently, in areas returned to brush and forest, much of the fine-grained sediment appears to have been removed returning the channels to a condition in which the channel bed was composed of gravel with lesser amounts of silts and sands. With the onset of construction large quantities of sand are delivered to channel systems and new sandbars and dunes may blanket the bed of the channel. If vegetation becomes established on the bars, channels are constricted, or locally banks may erode, accompanied by an increase in flooding at the channel constrictions. Upon completion of streets and sewerage systems sediment derived from the watershed decreases while the rapidity of runoff is increased. Channel bars and vegetation may be removed by flows of clear water. At the same time the absence of a fresh supply of sediment may result in progressive channel erosion without concomitant deposition.

While this general configuration of the process of urbanization and its effect on channel systems is reasonable, it is the purpose of this paper to review, add to, and evaluate the evidence for successive stages in the cycle. Because the economic consequences of these changes in the natural landscape are significant, it is hoped that a better understanding of the processes may be helpful in evaluating alternative methods of managing the land surface as well as the channel and riverine bottom lands.

Changes in sediment production

Sediment yields from agricultural and forested regions are well documented (U.S. Dept. of Agriculture, 1964) and are not repeated here. The upper part of Table 1 shows sediment yields for wholly forested regions as well as for areas of mixed farming and forests. Data from large areas wholly in forest are quite limited but current estimates suggest that yields may be less than 100 tons per square mile. In contrast the figure for the Gunpowder Falls at two successive intervals is of particular interest. From 1914 to 1943, a period of intense farming on the watershed, sediment yield was approximately 800 tons/sq. mi. During a later period when much land was returned to grazing and to forest in the immediate vicinity of the city of Baltimore, sediment yield declined to approximately 200 tons/sq. mi. or one-quarter of the earlier figure. The dip in the curve in Figure 1 is based upon this observation.

Sediment yields from areas undergoing construction may exceed by several hundred-fold the yields from lands in forests and grazing, or by several fold areas in agriculture. As the selected values in Table 1 show, yields may exceed 100,000 tons/sq. mi. over very small areas. On larger drainage basins in which the

Table 1. Sediment yield from drainage basins under diverse conditions.

RIVER AND LOCATION	DRAINAGE AREA SQUARE MILES	SEDIMENT YIELD TONS/SQ. MILE/YR.	LAND USE
BROAD FORD RUN, MD.	7.4	11	FORESTED: ENTIRE AREA
HELTON BRANCH, KY.	0.85	15	SAME
FISHING CREEK, MD.	7.3	5	SAME
GUNPOWDER FALLS, MD.	303	808	RURAL - AGRICULTURAL, 1914-1943, FARMLAND IN COUNTY 325,000 TO 240,000 AC.
SAME		233	RURAL - AGRICULTURAL, 1943-1961, FARMLAND IN COUNTY 240,000 TO 150,000 AC.
SENECA CREEK, MD.	101	320	SAME
BUILDING SITE, BALTO., MD.	0.0025	140,000	CONSTRUCTION: ENTIRE AREA EXPOSED
LITTLE FALLS BRANCH, MD.	4.1	2,320	CONSTRUCTION: SMALL PART OF AREA EXPOSED
STONY RUN, MD.	2.47	54	URBAN: ENTIRE AREA

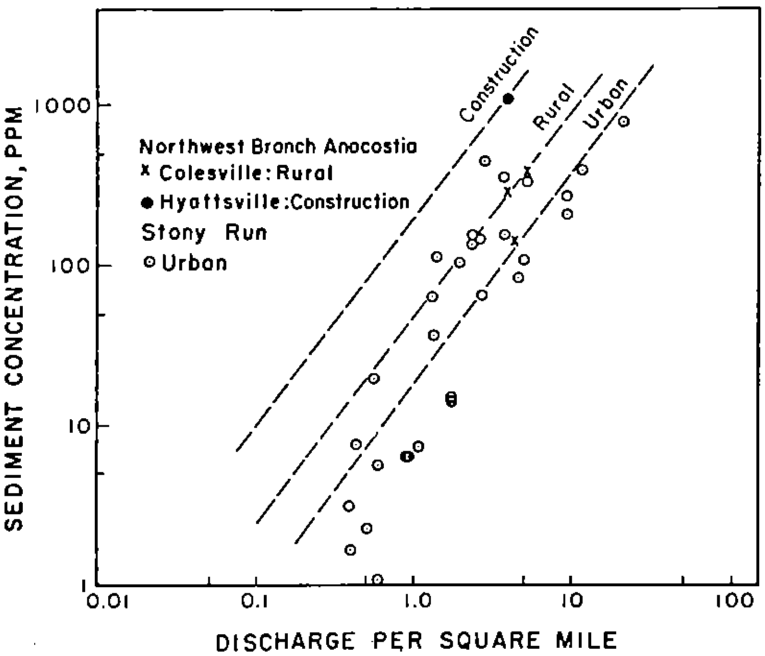
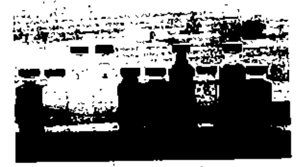


Figure 2. Curves relating sediment concentration and discharge in streams from three drainage areas differing in land use. The drainage area of the Northwest Branch of the Anacostia River above Colesville (21.3 sq.mi.) is rural, between Colesville and Hyattsville (45.2 sq. mi.) considerable land is exposed to construction, while Stony Run (2.5 sq.mi.) lies within the city of Baltimore. Curves suggest highest concentrations from areas undergoing construction with successively lower values for rural and urban watersheds.

entire area is not undergoing construction, yields may still exceed several thousand tons per square mile (Wolman and Schick, 1967).

Comparison of sediment rating curves also indicates that for a given discharge or frequency of flow, sediment concentrations may be twice or more than those from similar areas not subject to construction (Figure 2). Keller (1962) reports sediment loads 3 to 5 times as high. As one would expect, the quantity of sediment derived from the areas undergoing construction is a function of gradient, quantity and intensity of precipitation, characteristics of the soil, and topographic discontinuities at the construction site. However, even in the absence of precipitation, large quantities of suspended sediment may result from construction activities where heavy machinery operates directly in the stream channels. Thus on a clear day without precipitation concentrations in a local channel reached 3300 ppm and sediment load followed a diurnal cycle in accord with the variation in construction activity (Figure 3). While the total load derived from this source may be small, the turbidity created in the flow is significant.

The yield of sediment from urban areas following completion of construction is less



CONCENTRATION OF SOLIDS IN STREAM SAMPLES 24 HOUR PERIOD, APRIL 27 - APRIL 28, 1965

BOTTLE NUMBER	TIME	DATE	TOTAL SOLIDS-PPM
1	6:00 PM	APRIL 27	670
2	11:00 PM	"	300
3	7:15 AM	APRIL 28	290
4	9:00 AM	"	260
5	10:30 AM	"	1250
6	12:00 NOON	"	2300
7	1:30 PM	"	3340
8	3:00 PM	"	310
9	4:40 PM	"	2610
10	6:00 PM	"	1250

Figure 3. Diurnal variation in sediment concentration observed in Herring Run on a clear day as a result of construction activity within the channel. (Data from Whitman, 1965).

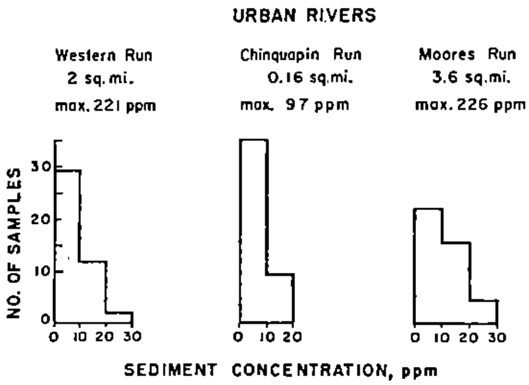


Figure 4. Histograms showing concentrations of suspended solids in three streams in the Baltimore Metropolitan Area. Location of these streams is shown on the map in figure 5.

well documented. In most large cities where measurements have been made construction has continued at successive locations on the drainage area above the measuring site. However, some data are available for streams in the Baltimore area.

Periodic spot observations in three streams in the Baltimore area suggest the order of magnitude of average sediment yields and concentrations in urban areas (Figure 4). The drainage basins of both Western Run and Chinquapin Run are underlain by crystalline rocks of the Piedmont while Moores Run is primarily in

Figure 5. Map showing streams in the Baltimore Metropolitan region referred to in the text.

the Coastal Plain (Figure 5). (The channel of Chinquapin Run is pictured below in Figure 8). None of these samples were collected during storms, and hence concentrations are probably somewhat too low. Nevertheless the values are low and average sediment yields from these urban areas appear to be small.

More detailed observations on both low and storm flow in streams in the Baltimore area show similarly low concentrations of suspended sediment (Brosky, 1966). During a summer storm with a peak flow of 17 cfs from a drainage area of 2.5 square miles (a flow equaled or exceeded about one percent of the time) the peak concentration of suspended solids was only 439 ppm (Figure 6). A maximum concentration of 793 ppm was observed for a flood flow with a recurrence interval of approximately 1.5 years. Brosky noted that in the absence of construction sites on the watershed, suspended solids were almost exclusively granular and without clays characteristic of samples of suspended solids from areas undergoing construction.

A rough estimate indicated that the average fallout of dry solids on the watershed, measured by the city nearby, of 58.7 tons/month in summer and 117 tons/month in winter exceeded the quantity of material removed in solution and suspension. For the storm shown in Figure 6 suspended solids amounted to about 77 percent of the dissolved load. Preliminary estimates indicate that the amount of sediment removed from the basin may be considerably less than the dry fallout but available data is not sufficiently accurate to warrant detailed comparison. However, concentrations are low even in storm periods and a crude computation suggests that average annual clastic load is on the order of 50 t/sq.mi.

Evidence of the reduction of sediment supply from urban areas is provided by a survey of sediment in large culverts draining new developments. Of 14 drains surveyed in the suburban region, only 3 showed 20 per cent or more of the end or cross-sectional area of the culvert occupied by sediment. Furthermore, at two of these three, the surrounding suburban development had only been completed within the preceding year. Where development had been completed five or more years, sediment covered 10 per cent or less of the culvert cross-section.

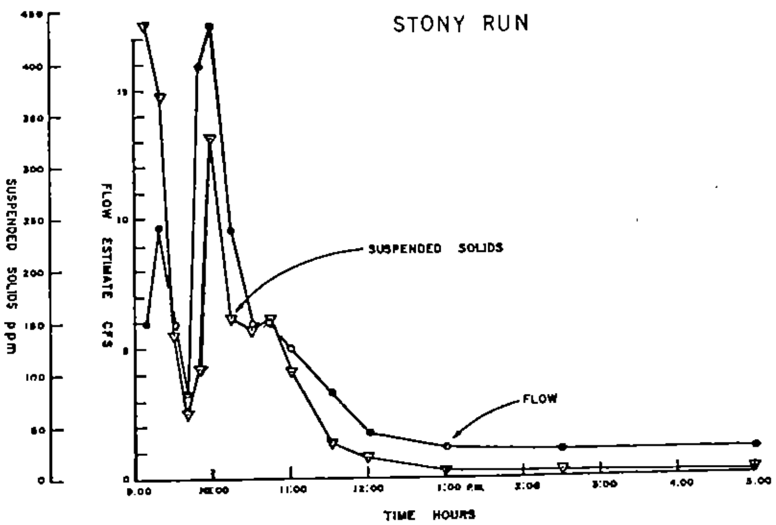


Figure 6. Hydrograph showing variations in flow and in concentration of suspended solids in Stony Run during a storm on July 29, 1964. Peak discharge represents a flow equaled or exceeded on the order of 1% of the time or about three days per year.

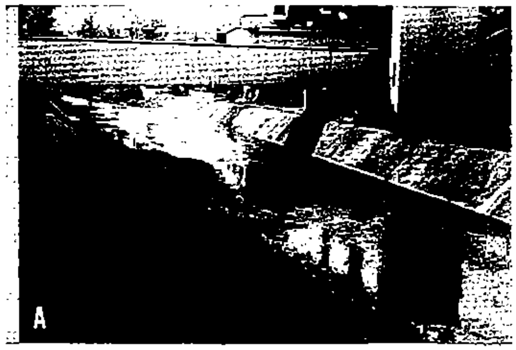
To permit rapid removal of runoff, storm drainage culverts are often placed on high gradients. In addition, a number of estimates indicate that peak runoff from impervious areas (Carter, 1961) may exceed by 2 to 6 times the peak runoff from the same area prior to urban development. Thus it is not surprising that sediment is progressively removed from culverts following completion of construction. The rate of removal should depend upon the timing and magnitude of the runoff, the capacity and gradient of the drain. These observations all indicate that the inflow or renewal of sediment is reduced allowing the flow to remove from the drains sediment accumulated during the period of construction.

Data representing the full transition from "natural" or agricultural conditions, through construction, to a completely urbanized watershed at a single location were not available to the author. Therefore curves relating suspended sediment concentration to discharge for three locations on two different streams are compared. The watershed of Stony Run lies within Baltimore City (drainage area 2.5 sq. mi.) and contained no area exposed to construction. In contrast most of the area on the Northwest Branch of the Anacostia above Colesville (drainage area 21.3 sq.mi.) is rural and agricultural while extensive areas are undergoing construction in the intervening region between Colesville and Hyattsville (drainage area 45.2 sq. mi.). A straight line was fitted by eye to the data for Stony Run and curves parallel to it were drawn for the Northwest Branch of the Anacostia at Colesville and at Hyattsville. Thus the slopes of the curves differ from those originally drawn by Keller (1962). Three points including an especially low concentration are shown for the Colesville station for comparison. As Keller (1962) pointed out initially, the curves indicate that for a given flow, concentrations from the areas undergoing construction may be 5 times greater than from the rural areas. In addition, the curve added here for the completely urban watershed appears to lie below that of the rural area. Eighty-five per cent of the points for the "urban river" fall below the Colesville or "rural" curve (see Fig. 2).

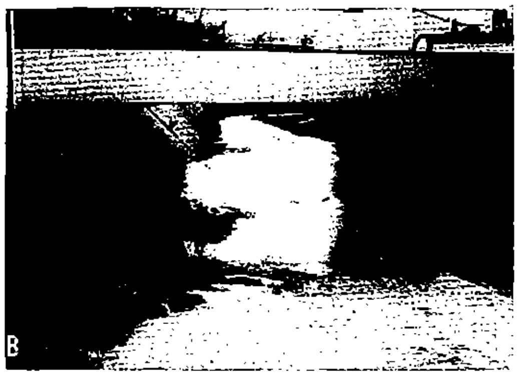
In summary, the data appear adequate to support the contention that sediment yields during construction exceed yields not only from forests but from agricultural lands as well. Less well documented but suggestive is the evidence that sediment yield several years after completion of urban development is very low, perhaps as low as or lower than sediment yields from completely forested areas.

Channel behavior

In forested regions where sediment yields are low, stream channels in the crystalline Piedmont flow on beds of cobble gravel interspersed with finer grained deposits and occasional bedrock outcrops and within banks generally



1963



1966

Figure 7. Successive photographs of sand bars developed in the channel of Jones Falls 100 yards downstream from major highway construction completed in 1963. Vegetation on bars appears during summer months but has not become established as shown by the winter picture in 1966.

composed of silty or sandy loam. An influx of sediment laden water derived from construction on the watershed can be expected to result in extensive deposition of sand bars and dune sand generally coarser than the finer sediments carried in suspension prior to the advent of construction. Such a generalization would not be true, of course, if the inflow of sediment was small relative to the transporting capacity of the receiving channel, i.e., 100 acres of exposed land contributing sediment directly to the Mississippi River is unlikely to create new channel forms within the Mississippi. Virtually every large metropolitan center in the region, however, contains a myriad of small streams which may be affected. In metropolitan Baltimore the formation of deltas at the confluence of two channels, of sand bars, and banks of sand dunes over pre-existing gravel beds have been observed (Wolman and Schick, 1967). Less clear is the progression of channel changes following completion of construction.

Comparison of photographs of the channel of Jones Falls at the time of completion of a super-highway, which involved massive earth-moving, with the same reach three years later (Figure 7) shows little or no change in the size of bars. The reach shown is 100 to 200 yards downstream from the highway construction. Upstream from the reach the area is primarily rural. Further downstream, however, within the urban area, comparison of photographs taken four years apart indicates that some bars may have been removed from mid-channel and from the outside of bends, but in general the channel continues to contain extensive sand deposits particularly where piles of debris and bridge piers encourage deposition. Photographs of nearby Roland Run, taken $3^1/_2$ years apart, indicated that with lessening of suburban development on the watershed, some sand and gravel deposits have been scoured from an upstream reach. In a reach 300 yards downstream deposition appears to have increased upstream from a small bridge opening. The intervening steeper channel contains little or no fresh deposits of gravel and sand.

Colby (1964) has shown that at a depth of one foot and a velocity of 2 feet per second the rate of sand transport will be about 5 tons per day per foot of width. In an urban channel at a drainage area of 2 square miles these conditions are reached on the order of one percent of the time. Assuming a deposit of sand 0.5 foot thick over a reach $^1/_4$ mile long and a unit weight of 100 pounds per cubic foot, without additional inflow of sand, removal of the deposit would require about 7 days or two years. This figure is of course hypothetical but observation of streams in the Baltimore area suggest that the period will be considerably longer. Some observers (Guy, 1963, Wolman and Schick, 1967), noted that channels may be cleared of sediment in 5 to 7 years. However, continuing observations indicate that channel curvature, local flattening of slope, establishment of vegetation, and particularly trash and debris may inhibit removal of sediment for even longer periods.

Both the expected increase in runoff from urban areas and the absence of sediment should contribute to an increase in channel erosion and to an increase in channel width. An increase in the number of peak flows particularly would tend to increase the amount of bank erosion. With a decrease in the available sediment, deposition would not keep pace with erosion, as it might under "normal" conditions of flood-plain formation, thus promoting progressive widening of the channel.

Exposure of raw banks in miles of urban river channels suggests bank erosion. As Hadley and Schumm (1961) have observed, however, raw banks are not prima facie evidence of high rates of bank erosion. Detailed observations of 7200 feet of the channel of Western Run in northwest Baltimore indicate that active bank erosion is occurring along a distance of about 580 feet of the total length of 14,400 feet of channel bank. The channel was straightened and deepened beginning about ten years ago to an average gradient of one per cent. Maximum observed erosion was about 2.2 feet on the outside of an aligned curve constructed $3^{1}/_{2}$ years ago. With the exception of irregularities at tree roots, at points adjacent to gravel bars, and at junctions of concrete culverts, average erosion is probably less than one foot per year. Some slumping can be seen near the top of the higher banks but the result appears to be a gentler side slope not yet attacked by the shallow flow at the base.

As the photographs of Chinquapin Run (Figure 8) show, little or no vertical buildup of point bars is taking place in the urban channels. Similar conditions were observed on Western

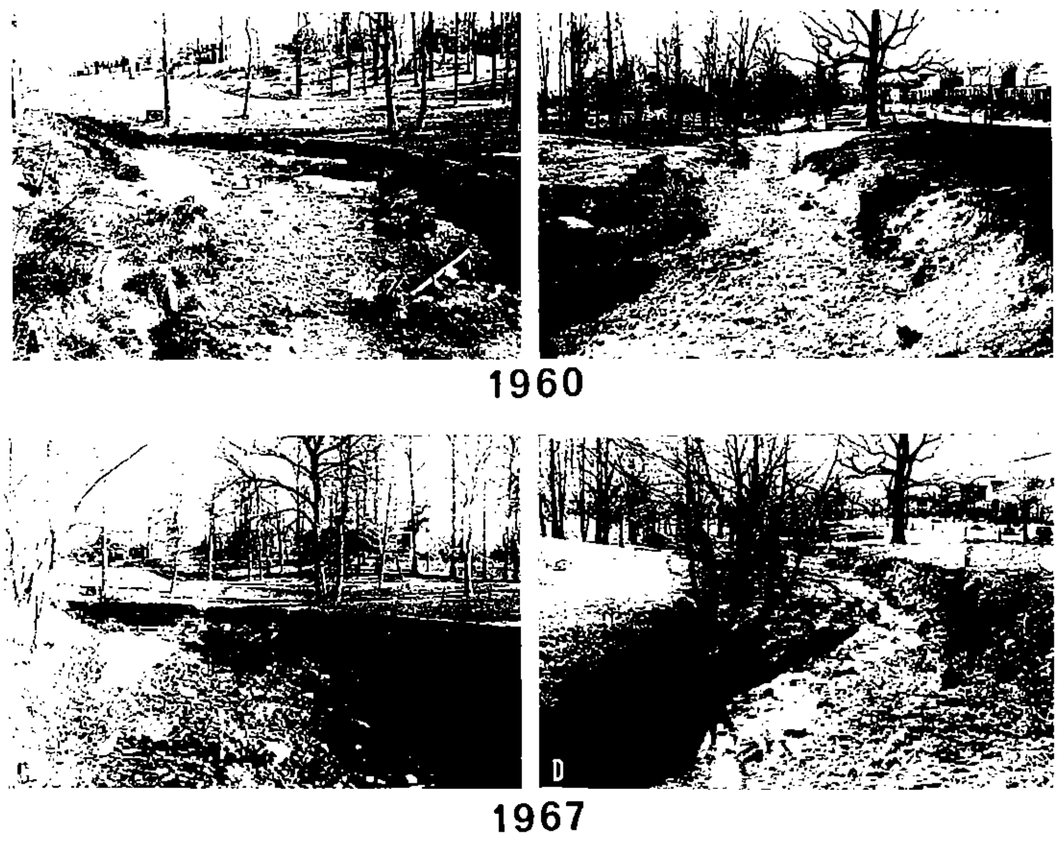


Figure 8. Photographs of Chinquapin Run north of Northern Parkway in Baltimore City. Photographs in 1967 show development of vegetation, particularly establishment and growth of locust trees. Comparison of photographs B and D reveals some deposition along the left bank with erosion of 2 to 3 feet along the near vertical right bank. Comparison of photographs A and C suggest scouring of sand on the point bar as well as some channel erosion just downstream from the point bar. Some channel widening is in evidence in both photographs.

Run. Locust trees and grass have become established adjacent to and on the low bar along the left margin of the channel in Figure 8D. Lateral deposition to a height of 1.5 feet or less is also evident. The right bank is steeper in 1967 than in 1960 and has receded about 3 feet in the 7-year period. Comparison of Figures 8A and 8C over the same time interval indicates that the channel has widened particularly in the bend by removal of the sands on the point bar and by erosion downstream from the point bar along the left bank (left foreground of the photograph 8C). A locust tree about 3 years old has become established adjacent to the left or concave bank suggesting some stability at that point. Nearby some slump is also evident along the concave bank at the right edge of the photograph. One hundred yards downstream from the reach in Figure 8 on the outside of a bend, highwater (estimated frequency once or twice per year) on January 26, 1967, undermined a tree 18 inches in diameter resulting in local lateral erosion of about one foot. These observations establish the fact that erosion is taking place albeit at a relatively slow pace. However, because such erosion is progressive and unaccompanied by comparable accretion, a net widening appears to be taking place above the elevation of the coarse cobble bed. Because continued widening will reduce

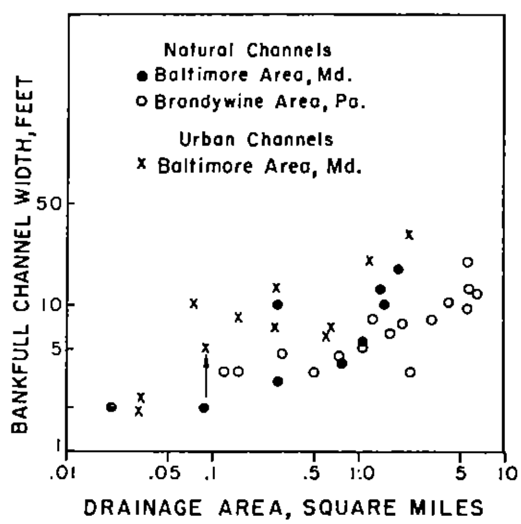


Figure 9. Comparisons of drainage area and channel width for streams in the Piedmont region under rural and urban conditions. Data indicate that at least some of the urban channels show an expected increase in width.

the depth of flow for a given discharge, the rate of lateral erosion should be expected to decline. Nevertheless, in the absence of an equivalent inflow of sediment, a new equilibrium in transport will not be established.

Because of the great variability of natural channels, it is difficult to make statistically adequate comparison of channel shape and size before and after urbanization. Figure 9 is an attempt at such a comparison and the data suggest that the width of channels in urban areas may be somewhat larger than in comparable channels in "natural" or agricultural areas.

The erosion and flood characteristics of the urban river may be better demonstrated by the visual, subjective, impression of the channel than by any current objective or measurable parameters. The combination of raw banks, exposed cobble bars, and debris including flotsam strewn about the floodplain and channel margins all convey the impression of frequent flooding and the transient character of the alluvial features. Thus, the comparative photographs in Figure 10 show two aspects of the results of flooding in two completely different environments. The top photographs (Figures 10A and 10B), were taken immediately after the record hurricane flood of August, 1955, in Connecticut. They show the abrupt channel widening which commonly results from the deposition of coarse cobble bars and the characteristic flotsam and debris deposited on the channel margins by the floodwaters. The lower photographs show precisely the same erosion features and ubiquitous debris in several urban rivers in the Baltimore metropolitan region. Similar exposed banks coupled with tangles of debris on the margins of the channel can be seen over many miles of urban river channel. While attempts have been made to quantify this evidence, no readily mappable parameters have described these conditions as well as the overall visual impact. The existence of market carts and tricycles with densities up to 14 per linear mile is not an uncommon measurable parameter but perhaps one of dubious comparative significance.

Flood debris, eroding banks, scour holes, and exposed bars all appear to suggest the development of an erosive regimen in the urban river channel following completion of development on the watershed. These effects

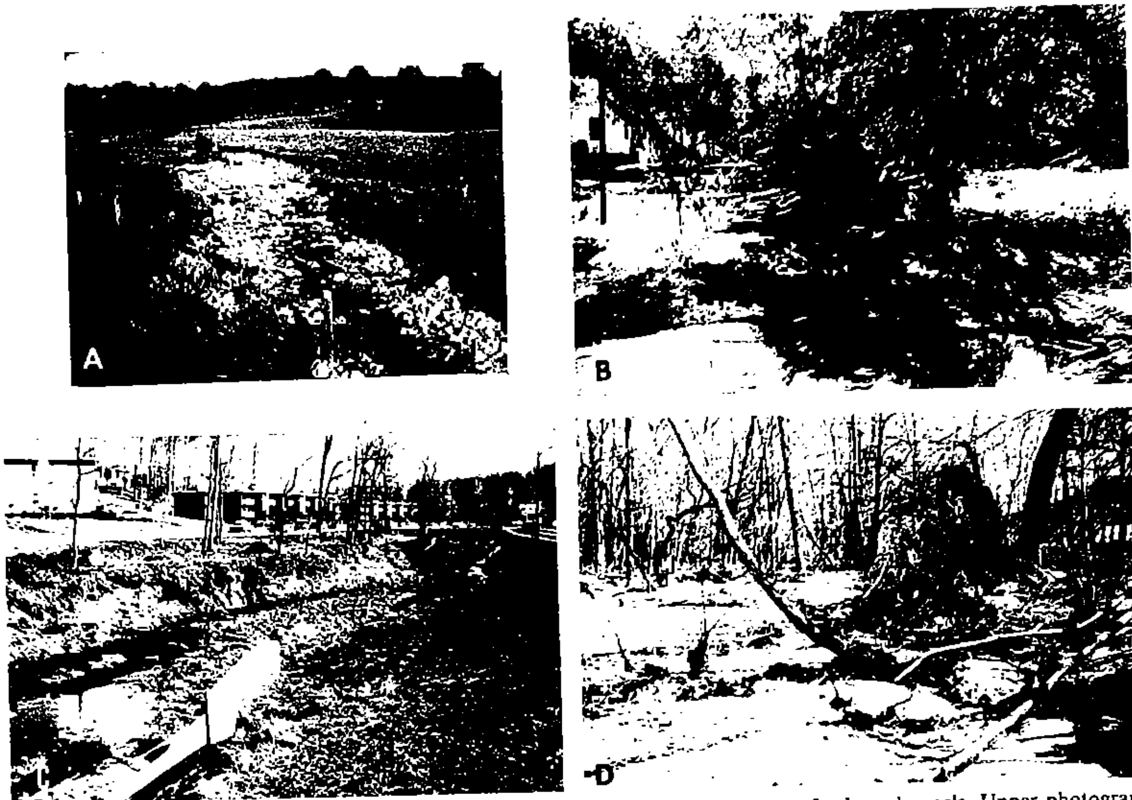


Figure 10. Comparative photographs illustrating the apparent flood regimen of urban channels. Upper photographs were taken following the hurricane flood of August, 1955, in Connecticut. Photograph A at Lewis Atwood Brook near Waterbury, Connecticut, shows characteristic widening associated with deposition of coarse cobbles following the flood. Comparable deposition and channel widening is shown on Western Run below Simmonds Avenue in Baltimore, Maryland. Photograph B, Farmington River near Unionville, Connecticut, shows characteristic debris deposited by flood waters comparable to debris illustrated by the photograph (D) of Herring Run at Pioneer Drive in Baltimore, Maryland.

may be attributed to the combined action of an increase in the magnitude and number of peak flows as well as to a decrease in the availability of sediment derived from the watershed.

Social response to changing channel behavior

Recognizing the potential value of river bottom lands for recreational use, a number of metropolitan areas in the United States have been moving toward reservation of floodplain lands for parks and open spaces. Where such use is contemplated an effort has also been made to avoid canalizing stream channels with concrete or other materials in order to preserve a more natural environment.

Accompanying this trend toward reservation of open spaces in a natural condition, however, has been a public demand for maintenance of urban steram channels against the ravages of erosion and the accumulation of rat-infested debris. One rather common response to this demand, and in the eyes of some a response completely at odds with preservation of the natural scene is the canalization of extensive reaches of channel in concrete. Several assets of such concrete channels are assumed to be rapid dispersal of storm drainage, an increased potential for self-cleaning, and low maintenance costs. Aside from aesthetic considerations it is important to recognize that deposition and erosion may be subject to the same controls in floodways as in the preexisting alluvial channels. Abrupt flattening of gradients in broad floodways and the accumulation of debris may induce deposition at precisely those locations where such deposition previously occurred. Careful and sometimes expensive designs may mitigate such problems, but in many cases it is likely that removal of sediment and debris and continuous channel maintenance will be required regardless of design.

Because the urban river poses both opportunities for recreational land use as well as problems in control and maintenance, it is important that alternative plans for control and use of these rivers be developed in accord with some understanding of the principles of their behavior. The evidence suggests that even in the relatively restricted field of erosion and sedimentation in alluvial channels there are significant physical consequences resulting from urban development of entire watersheds. Recognition of these consequences, while it solves no problems, can perhaps serve a purpose in demonstrating the need for forethought in planning for the appropriate use of the riverine environment. As always, the appropriate combination of aesthetics, economics, and physical limitations is not a constant but must vary from city to city and from river to river.

Acknowledgement

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