J. ENVIRONMENTAL SYSTEMS, Vol. 6(4), 1976-77

ADAPTED TECHNIQUES FOR URBAN STREAM STRUCTURE ANALYSIS

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ABSTRACT

Land surface changes accompanying urbanization cause modifications of the natural processes of erosion and sedimentation. These modifications result in the altered structure of streams in or adjacent to urban areas. This study is intended to identify the effect of urbanization on stream structure. The hypothesis is that changes in stream structural parameters act as gauges reflecting the impact of the much larger changes occurring on the watershed.

The study employs simple and inexpensive techniques which may be easily applied by researchers. Discussion and representation of data collected by the author are included in the narrative. It is concluded that there is a close correlation between the degree and intensity of urban land use change and the variability of data collected.

As more and more of the land surface is transformed into urban-suburban areas, the need to develop an awareness of the effect of alterations on the environment becomes more important. At times, gross manifestations of the alteration of natural processes are visible in the form of greatly enlarged gullies, a lack of black top soil, etc. More typically, however, land use changes occur over a long enough time period so as not to draw attention to the impact until the gross manifestations mentioned above become perceptible.

This study introduces easy and inexpensive data collection procedures which can be used by researchers to determine the impact of land use and land use modifications. The methods employed are based on studies by Wolman, who examined the physical effects on streams resulting from urban development of

doi: 10.2190/WPHH-8JL9-EC6P-LMQF
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entire watersheds; Hammer, who quantified the effect of urbanization on stream channel enlargement, and Hack, who investigated rural stream slope and bed material [1-3]. Based on data collected from a recently urbanized watershed, the scientific bases for these procedures are developed and discussed, and a few methods of representing and analyzing data are illustrated.

Hypothesis

The hypothesis of this study is that a close relationship exists between urban land use change and changes in stream structural parameters, and that changes in stream structural parameters directly reflect the much larger surface structural changes occurring on the remaining watershed. Hence, stream structural parameters may be used as gauges to define what is occurring, on a much larger scale, in the watershed itself.

Previous Stream Research Techniques

Systematic changes in rural areas have been reported by Hack. Hack studied the longitudinal profiles of fifteen streams in Maryland and Virginia. The streams were located in different physiographic regions. He found that: ". . . the slope as area increases appears to be constant for streams in the same geologic region [2, p. 69]." The slope of the longitudinal profile is determined by the corrosive power of the stream, bed resistance and structure, and the median size of the intermediate axis of coarse streambed material. (Pebbles taken from a stream bed tend to have three axes: the second largest is termed the "intermediate" or "B" axis, and is usually employed as the standard reference in examinations of stream materials.) Hack also found that samples taken from rural streams tend to decrease or increase in median size as the researcher progresses downstream. Whether there is a decrease or increase depends on slope and underlying geology. The key factor, however, is that changes in size occur systematically.

Urban watersheds have been examined by Hammer, who did an extensive study of seventy-eight watersheds in the Pennsylvania portion of the Philadelphia metropolitan area. All of the watersheds were located in the Piedmont physiographic province, and twenty-eight contained only rural land uses. Hammer states:

> . . . the effect of urbanization, particularly in the short run, is to increase this variability (i.e., variability in width, depth, cross-sectional area, etc. over a given channel reach). The scour, deposition, and overall

> channel enlargement which results from increased peak flows seem to proceed at different rates in different locations [3, p. 23].

Therefore, increased variability of various dimensions within a single stream and cross-sectional enlargement should be expected changes due to urbanization.

Study Area

Located in Maryland, northeast of Washington, D.C., the Northeast Branch Basin of the Anacostia River encompasses an area of 72.8 square miles (see Figure 1). Three-quarters of the basin are situated in the Coastal Plain physiographic province. The remaining portion is in the Piedmont. The nearby Chesapeake Bay tempers the extremes of summer heat and winter cold; the average annual precipitation is 42 inches. Precipitation occurs in a fairly uniform monthly distribution with the highest intensities measured in Spring and Summer thunderstorms.

A diversity of land uses are found in the basin. Some areas are rural and have for a long time been protected by the U.S. Park Service and the U.S. Department of Agriculture. Other areas are highly urbanized. Lazaro reported that in the thirty-year period from 1940 to 1970, the watershed experienced a 616 per cent increase in population density, from a rural average of 339 persons per square mile, to an urban average of 2,429 persons per square mile [4].

Methods and Data Collection

For study purposes, the Northeast Branch watershed was divided into its tributary watersheds. Data from these areas were compared for:

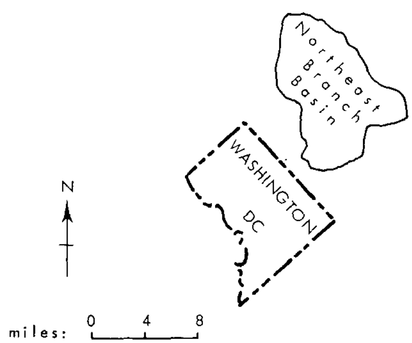

Figure 1.

1. dispersion of coarse riverbed particles,
2. median diameter of their intermediate axes, and
3. stream cross-sectional area.

Thirteen sampling stations were selected. The location of each station was determined by following Hammer's methodology. Only areas that were as close as possible to a natural state were considered. They were also required to have a flat bed and show no evidence of deep ponding or silting. An additional requirement was location in portions of the stream that were removed from bends and which experienced a perceptible stream flow.

Once these testing areas were identified, the stream cross-section was defined. This was accomplished by placing a stake at the first point in each bank where perennial vegetation began to grow. A string was tied to the stakes and height measurements were taken from the string downward to the streambed at two-foot intervals.

Following methods adapted from Hack and Wolman, a string reference grid was set up over the streambed [2, 5]. The grid was established by hanging ten strings equidistant from each other a foot above the stream, with five lines parallel to the stream flow and five perpendicular to the stream flow. The grid formed in this manner served as twenty-five random sampling squares over the streambed, including the bank portions. Each square was numbered, and a random number table was used to determine the square from which a riverbed sample would be collected. For example, reading a twenty-five from the random number table, the researcher would go to the square with a perpendicular coordinate of two and a parallel coordinate of five and pick a sample by placing a hand in the stream and, with eyes averted, picking up the first pebble touched. One hundred such samples were collected in this manner.

DATA ANALYSIS BY LAND USE AND SCIENTIFIC BASIS FOR CONCLUSIONS

Figure 2 displays the histograms of coarse riverbed samples, their median sizes, and the type of land use above each sampling station.

Three sampling stations, numbers 4, 5, and 10, were located below the drainage area of recently urbanized areas. They are labeled U1 in Figure 2. Samples collected at these stations exhibited high medians and wide histogram dispersions. This seems to be correlated with research reported by Wolman.

> . . . 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 [1, p. 391].

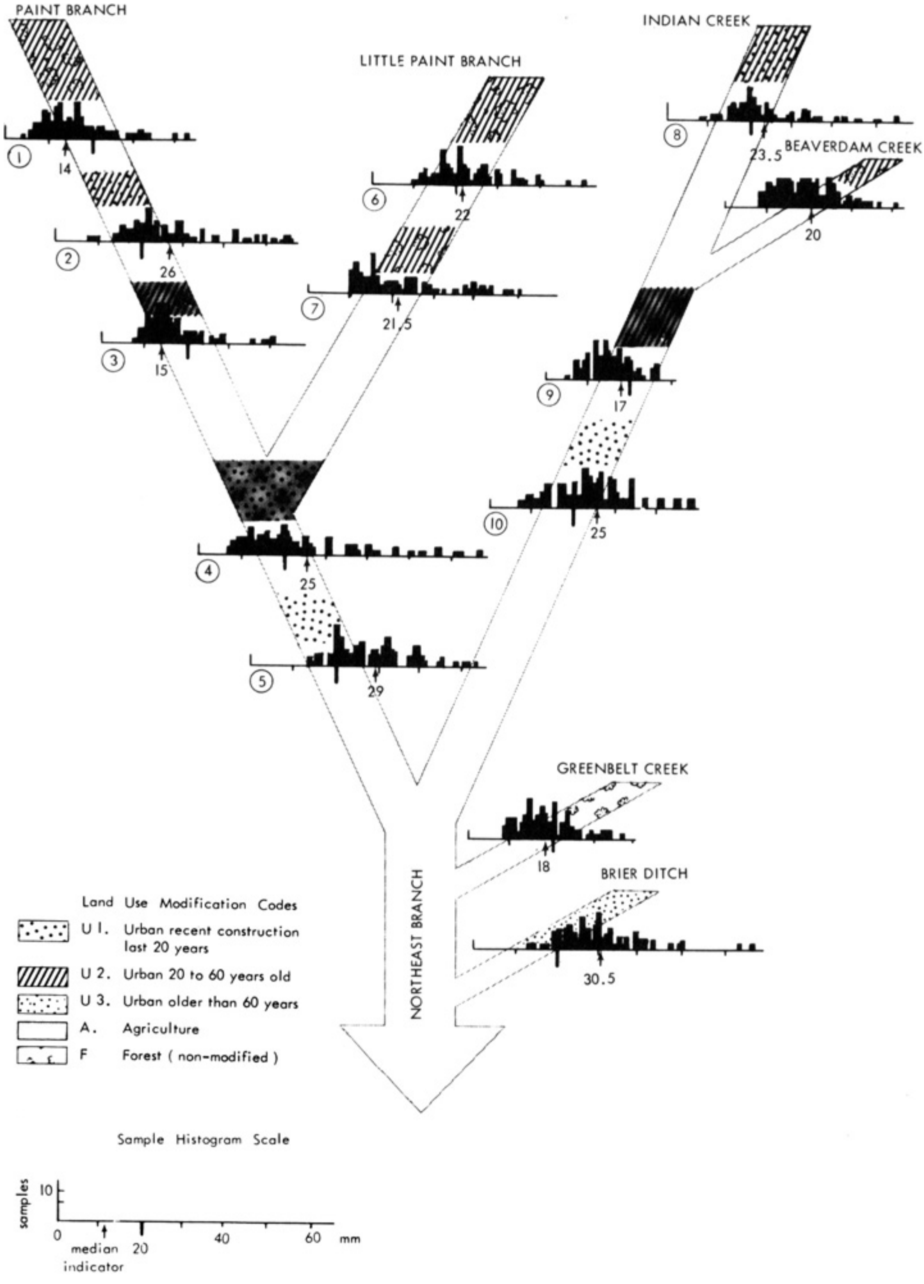

Figure 2. Histograms of coarse riverbed material intermediate axes.

Similar findings were reported by Guy and Keller, who noted the tremendous increase in sediment discharge during construction in an adjacent watershed, the Northwest Branch of the Anacostia River [6, 7].

Forested areas drain into streams above four stations, numbers 1, 6, and 7 and the Greenbelt Creek station (see Code F in Figure 2). Samples collected here had small medians and narrow dispersions. These drainage areas have undergone the least amount of urban development.

In areas protected by the U.S. Department of Agriculture (Code A) and older urban areas (Code U2), samples registered the lowest medians and narrowest histogram dispersions. On Code A lands, the Department of Agriculture exercises strict controls over land use. Type U2 land use is primarily devoted to individual homes built during a time when the study area's population was growing at a much slower rate and land clearing was done on a smaller area with separations of the indigenous vegetation between houses.

Brier Ditch drains an area which has been urbanized more than sixty years (Code U3). In many respects—underlying geology, stream length, and drainage area—it is similar to the adjacent watershed, Greenbelt Creek. Land use, however, is different. Greenbelt Creek drains a stable forest area which is protected by the National Park Service; Brier Ditch drains the oldest heavily urbanized area in the basin. It has had a population density of at least 3,000 persons per square mile for the sixty years prior to this report. Differences in land use are reflected in the samples. Cross-sections of Brier Ditch registered the highest median and widest histogram dispersion—a 180mm coarse riverbed sample was measured. Greenbelt Creek had the fourth lowest median and a much narrower histogram dispersion. Thus, the increased imperviousness created by intensive urban land use modification within the Brier Ditch drainage area appears to be reflected in the wider dispersion and larger median size of the coarse riverbed samples.

Table 1 lists the measured and computed cross-sectional areas at each of the thirteen data collection points. Cross-sectional areas for Little Paint Branch and Indian Creek increase as drainage area becomes larger in a downstream direction. Those of Paint Branch decrease.

Of all the information obtained from the six tributaries, data collected at Paint Branch show the greatest variability. This suggests that the structural function of the entire Paint Branch drainage system has been distorted in a complex manner by irregular spatial and temporal land use modifications. Remaining tributary data suggest lesser variability.

Table 1. Northeast Branch Tributary Cross-sectional Areas

Stream cross-section	*Drainage area (above cross section) in sq. miles*[a]	*Cross-sectional area (sq. feet)*[b]
Paint Branch (1)	6.7	431
Paint Branch (2)	10.5	429
Paint Branch (3)	13.3	142
Paint Branch (4)	23.3	356
Paint Branch (5)	26.2	330
Little Paint Branch (6)	7.0	80
Little Paint Branch (7)	8.3	130
Beaverdam Creek	6.5	60
Indian Creek (8)	6.8	76
Indian Creek (9)	23.0	141
Indian Creek (10)	26.7	288
Brier Ditch	3.9	312
Greenbelt Creek	2.9	77

[a] J. O. Duru, Storm Water Management Study: Northeast-Northwest Branch, Anacostia River. Prince Georges County, Department of Planning, September, 1973. Figure 5.
[b] Computed by author by forming a trapezoid.

Conclusions

In summary, then, data collected from drainage areas with rural and a mixture of rural-urban (U2) land use modifications displayed:

a. smaller histogram dispersions,
b. smaller medians, and
c. increased cross-sectional areas as drainage area increased.

Data from Brier Ditch, the oldest urbanized area studied, displayed:

a. the largest dispersion,
b. the largest median, and
c. a cross-sectional area that was very large for the area drained (when compared to Greenbelt Creek).

These facts suggest that there is a close correlation between the degree and intensity of urban land use modifications and the variability of stream data collected. The more recent and intense the land use modification, the wider the histogram dispersion, the larger the median of the coarse riverbed intermediate axis, and the more irregularly defined the tributary cross-sectional areas.

In order to minimize upset in the functional balance between stream structure and drainage areas, development should be planned to achieve a proper mixture of urban-rural land uses. Utilization of methods adapted in this study should aid in the detection and avoidance of drainage area structural upset.

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