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PLANNING AIDS TO MEASURE THE PHYSICAL IMPACT OF URBANIZATION

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ABSTRACT

Urbanization causes rapid land use changes. These modifications alter the surface structure of the landscape and its hydrologic responses. The analysis of data from a natural region (a watershed) in the process of urbanizing can indicate the physical impact of these land use changes. This paper outlines several applied analytical techniques, and suggests that if these methods were employed on a variety of watersheds, the collection of these studies would prove useful as a planning aid for the physical planner.

The methodology consists of examining growths in population and defining the consequent change in surface structure (using aerial photography). Next, hydrologic techniques along with a distribution-free test are employed to analyze the modified hydrologic response. The ultimate manifestation of the rapid land use changes, the greatly decreased flood return period, is illustrated graphically by the results of the California method.

Urbanization and its concomitant land use alterations such as parking lots and added roof tops of buildings have caused rapid changes in land use. These physical changes render more and more surface impervious to incoming rainfall and upset the natural runoff processes of the area. This paper proposes a hydrologic approach in the development of quantitative planning aids which may be utilized to determine the physical impact of these structural modifications.

The methodology consists of first defining the urbanizing period and then studying the changes in population and land use. Finally,

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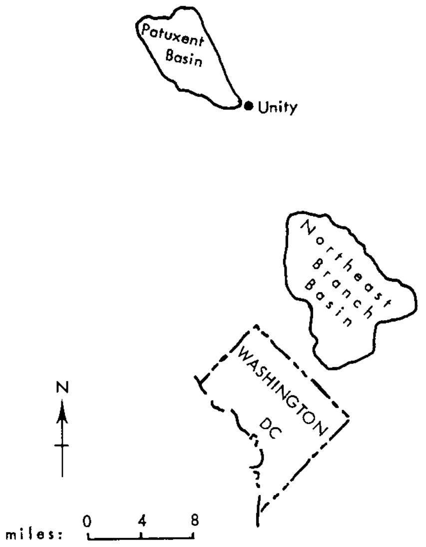

Figure 1.

simple hydrologic techniques are utilized along with non-parametric statistics to analyze the significance of the altered hydrologic response of a natural region—a watershed. It is the belief of the author that, if these methods were employed on all urbanized watersheds, the collection of these studies would become an invaluable planning aid for the physical planner. For example, a planner anticipating future urbanized land use changes need only observe the results of such changes elsewhere and thereby better predict what the consequences of this development would be for his area. He could recommend the allocation and intensity of proposed land use changes more rationally.

Study Region

The study region is in the Maryland suburbs of Washington, D.C. and is the river basin of the Northeast Branch of the Anacostia River which encompasses 72.8 square miles of diversified land use (Figure 1). 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.

Definition of Urbanizing Period

Upon examination of census data over the last century, it was observed that the largest increases in population occurred after

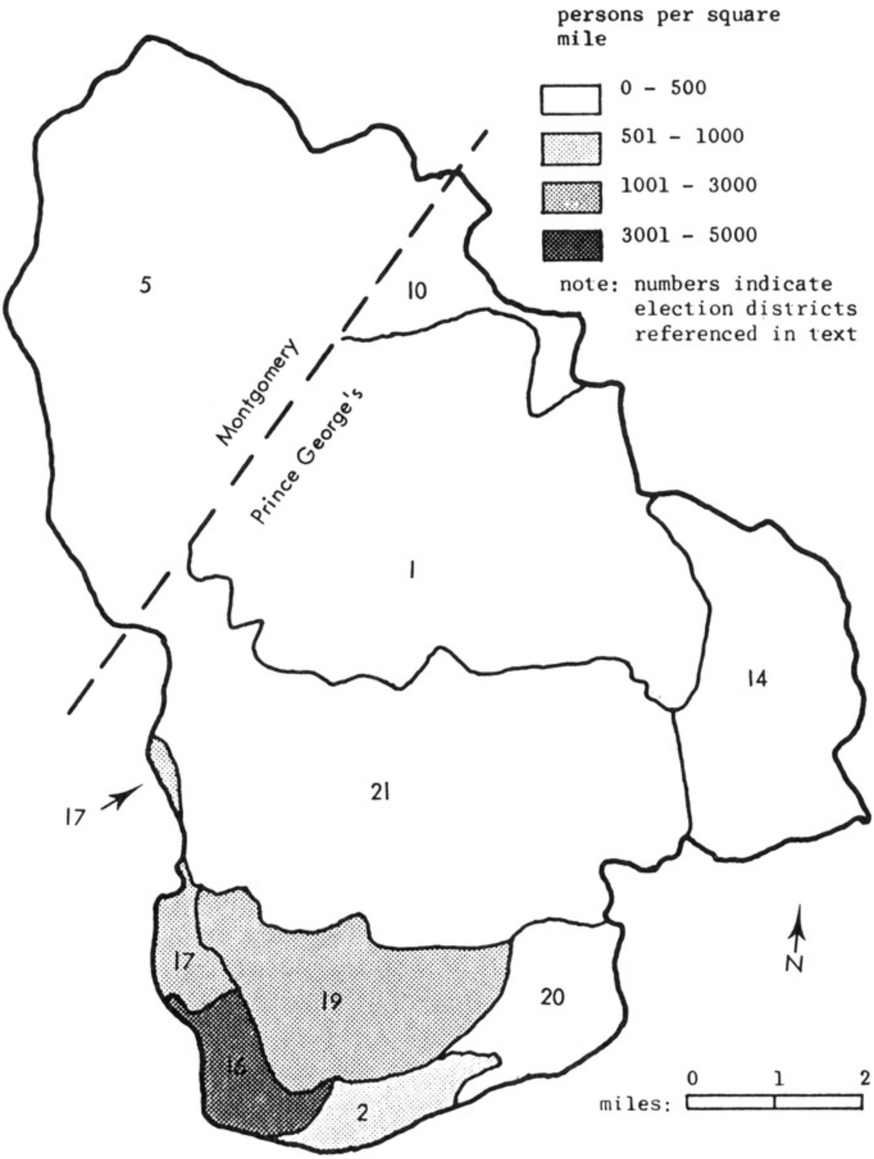

Figure 2. Northeast branch basin population density by election district: 1940 [1, p. 11].

1940. For accuracy in enumeration of population over this thirty-year period, election districts were selected as the smallest census units in comparison to population for towns, which were not available over the entire study period. Figure 2 delineates the location of the election districts in the study region. Prince Georges

Table 1. Comparison of Population Data for the Northeast Branch Basin 1940 and 1970 [1]

Election District No.	*Election District*	*Population* *1940*	*1970*
1	Vansville	1,923	20,914
2	Bladensburg	6,103	41,885
10	Laurel	3,691	31,579
14	Bowie	3,600	29,161
16	Hyattsville	7,923	15,491
17	Chillum	10,864	75,728
19	Riverdale	6,187	21,909
20	Lanham	1,758	37,739
21	Berwyn	7,741	61,688
5	Colesville	4,045	49,605
Totals		53,835	385,699

County has nine election districts within the basin, while Montgomery County has one. The study area does not totally contain all of these election districts; however, this method offers the closest estimate of population.

In 1940, the average population density for the ten election districts was 339 people per square mile (ppsm). As is indicated in Figure 2, election district 16 (Hyattsville) had the highest density in 1940. Hyattsville acted as a core with election districts 17, 19, and 2 acting as fringe areas with correspondingly lower densities. The majority of the remaining area to the northwest and northeast is rural, with densities of less than 500 ppsm. Six election districts had less than 500 ppsm (Figure 2).

The average population density for the ten election districts in 1970 was 2,429 ppsm. Figure 3 illustrates that the election district population densities have increased dramatically. The white area, which indicated 0-500 persons per square mile in Figure 2, is absent. The highest density in 1940 was located in election district 16; in 1970 this area became denser and expanded to include election districts 17, 19 and 2. Election district 17, Chillum, was the most highly populated area of the basin with 8,605 inhabitants per square mile; district 16 ranks second highest with 8,153. The fringe of this core is now the gray areas or election districts 20 and

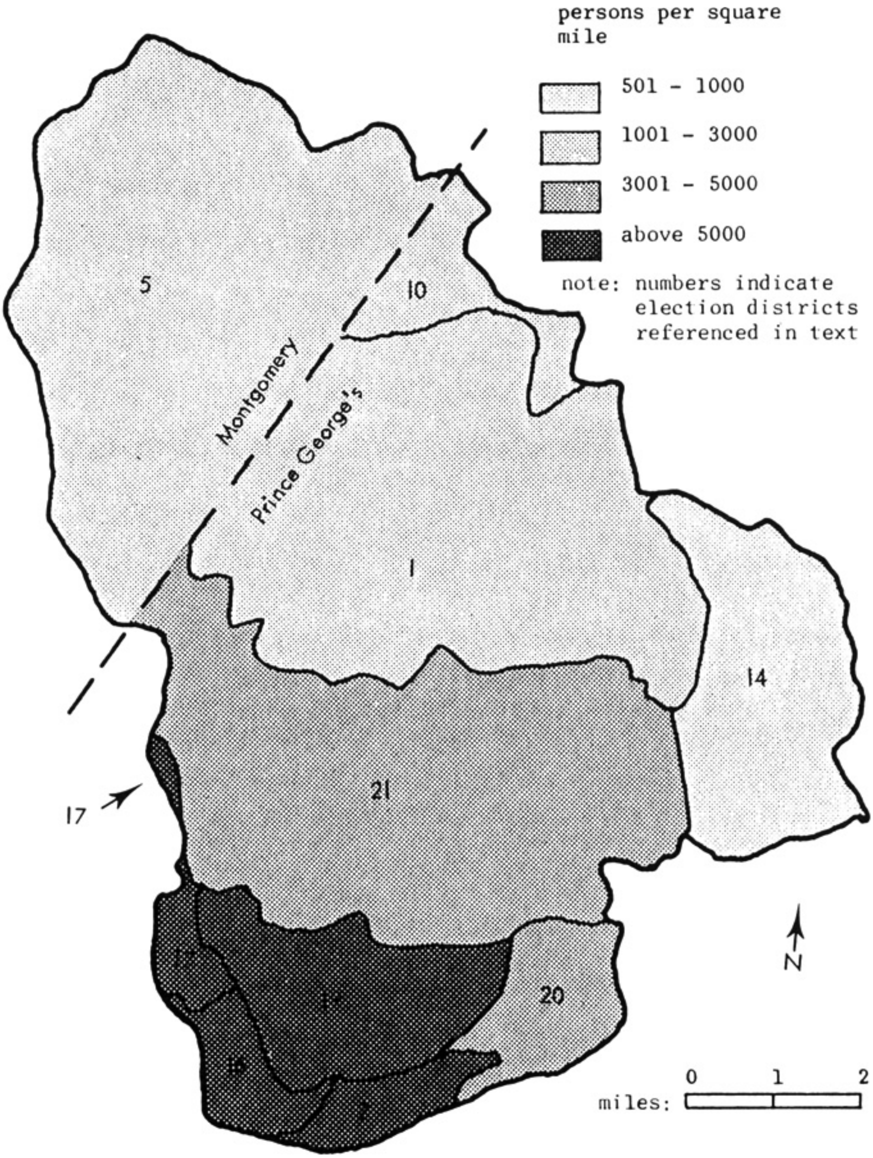

Figure 3. Northeast branch basin population density by election district: 1970 [1, p. 15].

21. In essence, the 1940 density core of election district 16 has increased in density and shifted outward from Washington to encompass a much larger area. A basic urban density ring pattern is

Table 2. Comparison of Housing Unit Data for the Northeast Branch Basin 1940 and 1970 [1]

		Housing units	
Election District No.	*Election District*	*1940*	*1970*
1	Vansville	1,250	6,100
2	Bladensburg	2,663	13,037
10	Laurel	1,684	10,756
14	Bowie	683	7,751
16	Hyattsville	3,804	5,306
17	Chillum	5,128	28,253
19	Riverdale	2,336	7,110
20	Lanham	474	10,413
21	Berwyn	3,005	17,329
5	Colesville	944	14,586
Totals		21,971	120,641

observed with the election districts closest to Washington having the highest population densities. Density decreases with distance away from Washington. For the entire watershed, the average population density increased by 616 per cent over the thirty-year study period.

Quantifying Land Use Changes

A housing boom accompanied the tremendous increase in population. Table 2 shows that within the ten election districts in 1940 there were 21,971 housing units; in 1970 the number of units increased by approximately 500 per cent to 120,641.

Remote sensing was used to quantify the actual surface structural change. Two sets of aerial photographs were examined, corresponding as closely as possible to the two census dates already compared. One set was taken in October, 1936 and the other in April, 1968. The Northeast Branch Basin was delineated on the photography and the entire area planimetered for three different land uses:

1. forest,
2. grass and crop land, and
3. residential and urban (defined as asphalt, sidewalk and roof).

The data collected are compared in Figure 4. In 1936, forest

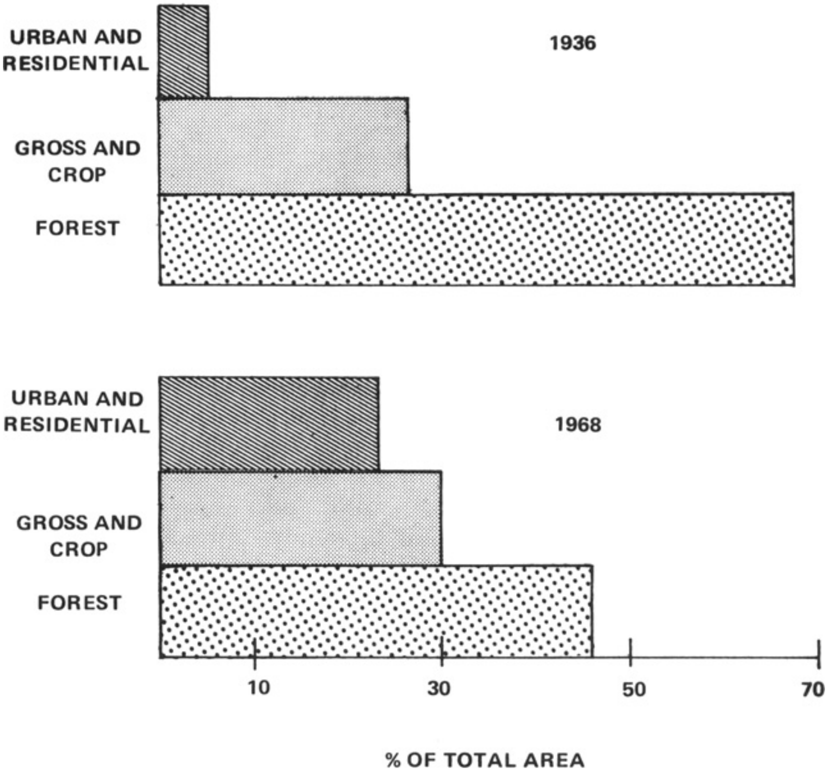

Figure 4. Distribution by percentage of land use within the Northeast branch basin [1, p. 19].

occupied 49.8 square miles; grass and crop, 19.1 square miles (26.3%); and residential/urban 3.9 square miles (5.3%).

In 1968, forest covering was still the major land use with 33.4 square miles or 45.9 per cent, and grass and crop became 21.8 square miles or 29.9 per cent. In the thirty-two years between the aerial photographs, residential/urban land use increased by 331 per cent and occupied 16.8 square miles (23.1%).

Hydrologic Response Analysis

Large population increases within the Northeast Branch Basin are reflected in the changes in land use. Hydrologists have been concerned with the influence of these surface modifications on stream regimen. Waananen observed that:

> Urban development creates changes in land use, in cover, and even in the configuration of the land surface. These changes significantly affect the hydrologic environment. The impact on peak flows in streams and storm drains is the most dramatic . . . [2].

In order to examine the peak handling response of the Northeast Branch over the study period, a simplistic, practical nonparametric statistical technique was applied along with conventional hydrologic methods.

The paired watershed method, a technique proposed by Snyder entails the comparison of certain hydrologic data in a basin which has not undergone urbanization (rural) with a basin which has experienced urbanization (urbanized) [3]. Maximum annual peaks, found in U.S.G.S. Water Supply Papers which are published annually, were the compared data. Having experienced structural changes, the Northeast Branch (the urbanized basin) watershed should have progressively larger peaks over the urbanizing period. As McCuen and James reported, a change in peak central tendency of the annual series should be expected [4]. The Wilcoxon Matched-Pairs Signed-Ranks Test was utilized to detect a shift in the magnitude and in the direction of annual peak central tendency, and is shown in Table 3

Table 3. Application of Wilcoxon Matched-Pairs Signed-Ranks Test To the Northeast Branch Annual Peak (Qp) Series

1939-1953 (Qp)	*1954-1969 (Qp)*	*Diff.*	*+ Rank*	*- Rank*
3680	5660	1980	15	
3660	5060	1400	14	
3000	4080	1080	13	
2980	3400	420	1	
2770	3300	530	2	
2350	3240	890	11	
2280	3120	840	9	
2060	2870	810	8	
1980	2830	850	10	
1820	2510	690	5.5	
1780	2470	690	5.5	
1660	2340	680	4	
1350	2310	960	12	
1280	1940	660	3	
889	1670	781	7	
		SUM =		0
		T =		0

Table 4. Application of Wilcoxon Matched-Pairs Signed-Ranks Test to the Patuxent River Above Unity, Maryland, Annual Peak (Qp) Series

1944-1956 (Qp)	*1957-1969 (Qp)*	*Diff.*	*+ Rank*	*- Rank*
10700	2920	7780		13
8060	2290	5770		12
3490	1800	1690		11
2220	1590	630		8
2200	1490	710		9
1920	1340	580		7
1830	1090	740		10
1300	934	366		6
1240	920	320		5
1100	828	272		3
1080	788	292		4
494	716	222	2	
240	446	206	1	
		SUM =	3	
		T =	3	

for the Northeast Branch and Table 4 for the Patuxent Watershed. The latter is a rural basin in close proximity to the study area which experienced a much smaller, almost insignificant density increase from 125 ppsm in 1940 to 250 ppsm in 1970 (see Figure 1 for location). The Patuxent Basin has essentially the same climatology as the Northeast Branch and the underlying geology is similar. However, the surface structure has not undergone the vast urbanization-related changes experienced within the Northeast Branch Basin.

The following null hypothesis was tested by use of the Wilcoxon Matched-Pairs Signed-Ranks method [5].

^{H}null: There is no difference in the proportion of positive to negative rankings in the two halves of the annual peak series.

An examination of Tables 3 and 4 reveals T = 0 for the Northeast Branch and T = 3 for the Patuxent. Therefore, the null hypothesis can be rejected for both series [6]. A change in central tendency has occurred; however, the change in the Patuxent Basin data is in the negative direction, whereas the change in the Northeast Branch Basin data is in the positive direction.

The change in direction of peak central tendency in annual series data from both watersheds may be accounted for by either a change in (1) the quantities of incoming precipitation and/or (2) the hydrologic processes within the watersheds. The vegetative surface configuration has remained intact throughout the study period within the Patuxent and therefore, a change in hydrologic process is not considered to have occurred. Hence, the decreasing trend in peak central tendency is assumed to be closely correlated to smaller rainstorms.

Nonparametric analysis of the Northeast Branch annual peak data suggests a positive change in peak central tendency. If rainstorms are getting smaller, but maximum annual peaks produced are getting larger, then the impact of urbanization on the basin hydrologic processes is clearly illustrated.

Before/After Treatment Method

In the before treatment/after treatment method (pre-urbanization/after urbanization) data from a basin are examined through time; the urbanized period is compared to the pre-urbanized period to see if there has been a change in certain hydrologic phenomena [3]. Between 1950 and 1960 the Northeast Branch Basin population density increased from 792 ppsm to 1395 ppsm respectively. The U.S. Bureau of Census (1971) defined an urbanized area as having an average density of 1000 ppsm outside of a city of at least 50,000 persons. Hence, by this definition, the Northeast Branch Basin became urbanized in this decade [7].

Rainfall data for the Northeast Branch were examined. The thirty-year study period was divided in half and the Wilcoxon Matched-Pairs Signed-Ranks test was applied to the data (Table 5). The following null hypothesis was tested:

> ^{H}null: There is no difference in the proportion of positive to negative rankings in the two halves of the annual rainstorm series.

A negative change in central tendency is observed, significant at the .01 level. These data evidence the fact that rainstorms did get smaller; however, peaks are larger.

The two nonparametric applications show that the Northeast Branch watershed has progressively had its hydrologic processes altered and that at the end of the study period significantly larger peak flows were produced by significantly smaller rainstorms. A flood is caused by a peak exceeding a certain magnitude and overflowing the banks of a river. When this phenomenon occurs, inhabitants may be subjected to a severe hazard, and there is the

Table 5. Wilcoxon Matched-Pairs Signed-Ranks Test Applied to Rainstorms Producing Maximum Annual Peak Discharges on the Northeast Branch

1940-1955	*1956-1971*	*Diff.*	*+ Rank*	*- Rank*
7.7	5.4	-2.3		
7.0	4.6	-2.4		
6.1	4.3	-1.8		
5.2	4.3	-0.9		7.5
5.0	4.1	-0.9		7.5
4.5	3.5	-1.0		9.5
4.3	2.8	-1.5		
3.8	2.6	-1.2		
2.9	2.5	-0.4		5
2.6	2.4	-0.2		2.5
2.3	2.1	-0.2		2.5
2.2	2.1	-0.1		1.5
2.1	2.0	-0.1		1.5
2.0	1.3	-0.7		6
2.0	1.0	-1.0		9.5
			SUM = 0	
			T = 0	

T = 15 at a level of .01

possibility of loss of property and lives. Therefore, a change in the stream hydrological character has a direct bearing on safety. With this concern in mind, flood return periods will be investigated.

Flood Return Period Analysis

After Dalrymple the California Method was applied to the annual maximum peak discharge data (annual flood series) [8]. The formula used to determine the flood return period was:

$$Tr = \frac{n}{m}$$

where

Tr = return period
n = number of years of record
m = rank starting with the highest as 1

For example, the largest Qp value in Table 3 is 5660 cfs. This is the

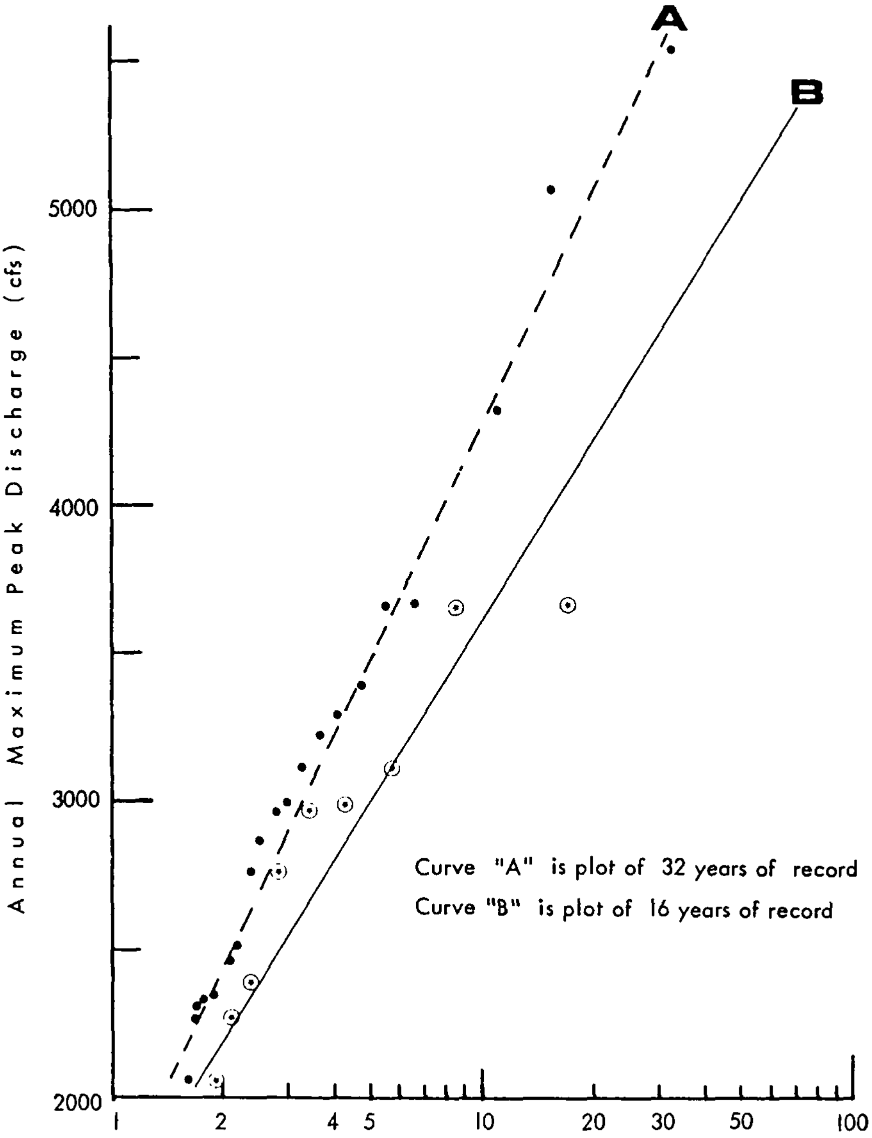

Figure 5. Annual flood return period of the northeast branch [1, p. 37].

first ranked event; thirty-two is the number of years of record, and by use of the formula, the return period becomes thirty-two years. Figure 5 shows the plot of the thirty-two return periods. Curve A in Figure 5 is an approximated best fit line for the entire period of record, while curve B represents a projection of the first sixteen years of record (hypothesizing that if the basin had not been structurally modified, curve B would be the predicted flood return period). A 3000 cfs peak can be expected to occur once in every three years, on curve A, whereas on curve B it would be predicted to happen once in five years. The flood potential has increased dramatically for people living on the Northeast Branch flood plain and is not only illustrated by the decreased return period, but also by the higher peaks now possible. Increased peaks enlarge the flood-prone area and affect inhabitants who would not normally be flooded, and decrease the amount of developable land. This is a factor which must be considered by planners.

The shift in curve A is the most pronounced indication of the physical impact experienced in the watershed.

Concluding Comments

Today there exists a wealth of literature in planning journals dealing with the economic and political strategy used by urban planners, but on the other hand there is a paucity of literature dealing with the analysis of the physical impact accompanying urban land use changes. Urban man is influenced by the physical changes as well as by economic and political ones. This paper serves as a demonstration of methods which it is hoped will be used as planning aids to develop an understanding of the physical impact of urbanization.

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