AN ALTERNATIVE BASIN CHARACTERISTIC FOR ESTIMATING IMPERVIOUS AREA AND URBAN FLOOD FREQUENCY AND ITS POTENTIAL APPLICATION IN MISSISSIPPI

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INTRODUCTION

Information on the magnitude and frequency of floods is essential in the planning and design of bridges, culverts, dams, levees, and buildings in or near floodplains, and in establishing flood-insurance rates. This information commonly is developed using a statistical analysis of streamflow data for sites where streamflow records are available. Flood-frequency information commonly is needed for areas where streamflow records are unavailable. In ungaged basins, flood magnitudes of given frequencies commonly are estimated from regional relations based on gaged-site data and are a function of drainage area and other physical features or basin characteristics.

In rural basins, flood peaks for a given frequency of occurrence are related to natural features of a basin such as drainage area, channel slope, and channel length. However, in urban basins, the existence of increased impervious area (for example, streets, parking lots, and driveways) can result in increased volumes and rates of runoff to the streams. Channel modifications, storm drains, curb and gutter street drainage, and other drainage features can also increase the magnitude of floods in urban areas. To account for the higher rates of runoff in urban areas, several basin characteristics have been developed for use in flood-estimating relations.

This paper will briefly discuss methods of computing the urban basin characteristic, percentage of impervious area. An alternative basin characteristic termed percentage of developed area, which can be used to compute percentage of impervious area, is described and applied to basins in Mississippi. Statistical analyses indicate that percentage of developed area is applicable for use in estimating impervious area and is potentially useful in estimating the magnitude and frequency of floods in urban areas in Mississippi.

URBAN BASIN CHARACTERISTICS

Previous investigations have led to the development of urban basin characteristics that partially account for the increase in runoff volumes and rates from urban basins. The following are brief descriptions of four such basin characteristics:

1. An urban basin characteristic termed the urbanization factor developed by Espey and Winslow (1974) is based on drainage improvements in urban basins. The urbanization factor accounted for channelization and storm-drainage development, and was a measure of the extent of development of the storm-sewer system and the quantity of vegetation in the channel.
2. Similar to the urbanization factor is the basin development factor (BDF) presented by Sauer and others (1983). The basin development factor is an index of urbanization that provides a measure of the efficiency of the drainage system in a basin.
3. An urban basin characteristic based on area is the percentage of impervious area, which is the percentage of a basin covered by impervious surfaces, such as houses, buildings, streets, and parking lots. Percentage of impervious area was found to be an important basin characteristic in Missouri in a flood-frequency analysis by Spencer and Alexander (1978).
4. Another basin characteristic based on area is the percentage of developed area (Southard, 1986). It is the percentage of a drainage basin that is shown as the urbanized area on 7.5-minute topographic quadrangle maps. Unlike percentage of impervious area, the area considered urbanized will contain both pervious and impervious surfaces.

ESTIMATING PERCENTAGE OF IMPERVIOUS AREA

Different methods can be used to compute the percentage of impervious area. One method is field reconnaissance. A typical urbanized subarea of the basin being studied is selected and the areas of impervious surfaces are measured and summed. The percentage of impervious area for this subarea is multiplied by the total urbanized area to obtain the estimated percentage of impervious area for the basin. This method is very labor intensive and time consuming.

A second and faster method uses photographs of the basin. Low-altitude aerial photographs are used to measure impervious surfaces by placing a grid over the photographs and summing the squares that lie on indicated impervious surfaces.

A third and even faster method can be used to estimate the percentage of impervious area from 7.5- minute topographic quadrangle maps. The drainage area is divided into open area and developed (urban) area. Open area consists of all undeveloped land, which may have scattered farm houses and buildings, scattered single-family housing, and paved roads, if there is no significant development along the roads. Developed areas include single- or multifamily housing structures, large business and office buildings, shopping centers, extensively industrialized areas, and schools. When delineating developed areas, it is important to include those areas devoted to paved parking lots around buildings. Once the developed area has been determined, it can be converted into a percentage of developed area (PDA) by dividing by the total drainage area. This percentage of developed area is used in a regression equation to compute percentage of impervious area (Southard, 1986).

PERCENTAGE OF DEVELOPED AREA

The relation developed by Southard (1986) between estimated percentage of impervious area (IA) and the percentage of developed area (PDA) was based on data from 23 streamflow-gaging stations

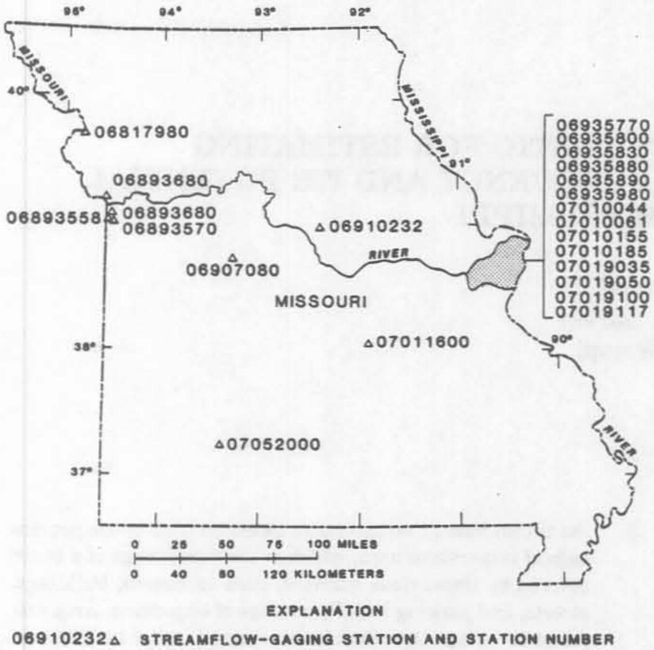

Figure 1. Location of the U.S. Geological Survey streamflow-gaging stations in Missouri.

in Missouri (fig. 1). The resulting regression equation that relates these two variables is:

$$IA = 2.03(PDA)^{0.618} \quad (1)$$

where:

IA = estimated percentage of impervious area

PDA = percentage of developed area.

The percentage of developed area was statistically significant at the 1-percent probability level. The average standard error of estimate for the relation is 12.1 percent. For clarity, IA is used to denote the estimated value of percentage of impervious area, and I is used to denote the measured value of percentage of impervious area.

From field reconnaissance, the percentage of commercial area that makes up the percentage of developed area value was estimated for the 23 gaged basins to develop the range and limitations of equation 1 for different types of land use. Commercial area ranged from 0 to 50 percent of the developed areas; the remaining percentage of developed area was single- and multifamily residence. Equation 1 is applicable for Missouri basins with:

1) a drainage area between 0.80 and 23 square miles,
2) 1 to 35 percent impervious area,
3) developed area that has 50 percent or less commercial area.

The estimated percentage of impervious area (IA) for the 23 gaged basins (table 1) was then computed using equation 1. The difference between the measured and estimated impervious area values, expressed as a percentage, was also calculated (table 1).

Percentage of developed area, percentage of impervious area, and basin development factor were used separately in developing regional flood-frequency relations from the 23 gaged basins in Missouri. The average standard errors of estimate for each relation were then compared. The results indicated there were no significant differences in the accuracy of estimates based on the various basin characteristics. Therefore, the percentage of developed area is an important urban basin characteristic in Missouri (Southard, 1986).

POTENTIAL APPLICATION IN MISSISSIPPI

Estimating Impervious Area

To determine if the percentage of developed area can be used to estimate percentage of impervious area on basins in Mississippi, three regression analyses were completed. Only six stations in Mississippi are available with known percentage of impervious area values. The data for these sites are listed in table 1. The first regression analysis used only the six stations in Mississippi (fig. 2) resulting in the following equation:

$$IA = 1.82(PDA)^{0.463} \quad (2)$$

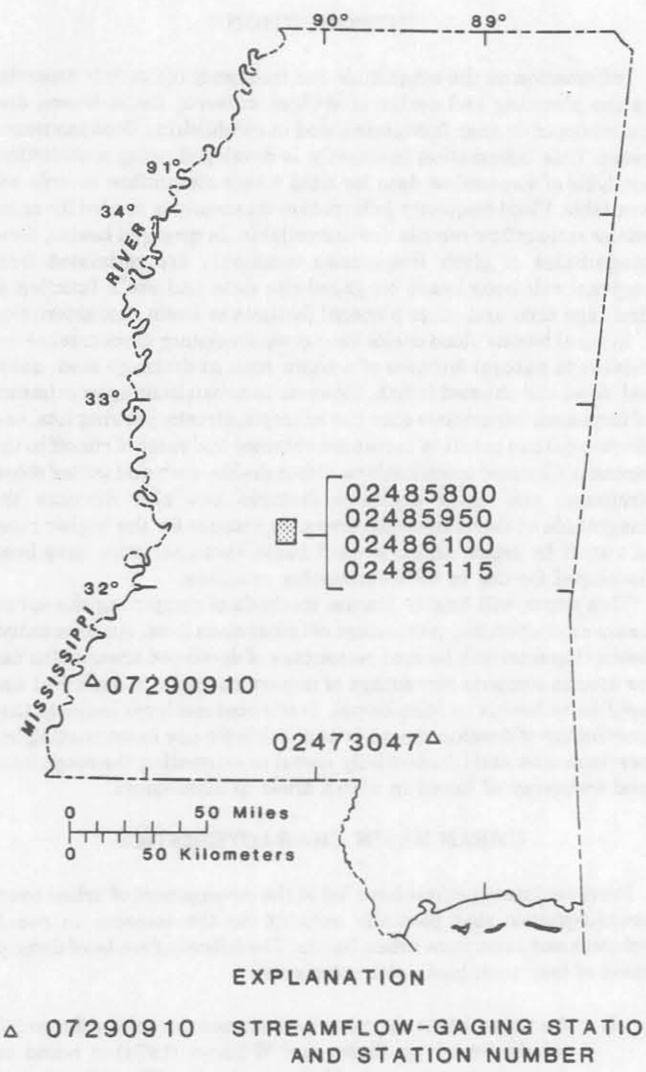

Figure 2. Location of the U.S. Geological Survey streamflow-gaging stations used in this study, in Mississippi.

Equation 2 has an average standard error of estimate of 9.2 percent. The slope and intercept of equation 2 are considerably different compared to equation 1 because of the small range of percentage of

Table 1.Basin characteristics and flood discharges for selected U.S. Geological Survey streamflow-gaging stations [mi², square miles; ft³/s, cubic feet per second]

Streamflow-gaging station number (figs. 1,3)	Drainage area (A, mi²)	Percentage of developed area (PDA, (percent)	Percentage of impervious area (I, percent measured)	Percentage of imprevious area (IA, percent from equation 1)	Difference between measured and estimated impervions area (percent)	Flood Discharge (ft³/s) Q_2	Q_5	Q_{10}	Q_{25}	Q_{50}	Q_{100}
Missouri Stations											
06817980	4.32	15.9	13	11.2	-13.8	1,130	2,220	3,100	4,330	5,340	6,400
06893558	14.4	94.1	30	33.7	12.3	4,650	7,740	10,200	13,800	16,900	20,300
06893570	5.62	66.8	26	27.2	4.6	1,440	2,370	3,120	4,210	5,130	6,160
06893600	5.72	84.6	30	31.5	5.0	1,500	2,580	3,450	4,730	5,820	7,030
06893680	1.23	88.2	34	32.3	-5.0	415	702	933	1,270	1,560	1,870
06907080	.93	51.6	25	23.2	-7.2	493	803	1,010	1,290	1,490	1,690
06910232	3.01	86.4	30	31.9	6.3	1,340	2,080	2,600	3,280	3,800	4,330
06935770	11.6	2.50	3	3.58	19.3	2,010	3,320	4,380	5,960	7,310	8,820
06935800	.81	9.4	22	19.7	-10.5	560	830	1,100	1,460	1,670	1,870
06935830	17.1	5.60	5	5.89	17.8	3,060	5,170	6,910	9,510	11,800	14,300
06935880	4.44	25.0	18	14.8	-17.8	1,240	1,950	2,510	3,310	3,980	4,720
06935890	22.0	23.8	15	14.4	-4.0	2,340	3,900	5,200	7,170	8,900	10,900
06935980	3.70	35.5	20	8.4	-8.0	1,240	1,950	2,520	3,370	4,110	4,930
07010044	8.59	62.4	25	26.1	4.4	2,690	4,310	5,670	7,730	9,570	11,700
07010061	6.42	64.4	25	26.6	6.4	2,280	3,650	4,760	6,420	7,860	9,480
07010155	12.1	80.0	32	30.5	-4.7	3,160	5,020	6,600	9,100	11,400	14,000
07010185	22.3	75.0	32	29.3	-8.4	3,230	5,070	6,640	9,120	11,400	14,000
07401160	1.40	64.3	26	26.6	2.3	451	691	866	1,110	1,300	1,510
07019035	3.14	1.20	2	2.27	13.5	820	1,390	1,850	2,530	3,110	3,760
07019050	9.85	.26	1	.88	-12.0	1,600	2,590	3,380	4,500	5,540	6,650
07019100	2.40	69.7	27	28.0	3.7	1,000	1,510	1,800	2,400	2,810	3,250
07019117	2.40	23.6	17	14.3	15.9	1,160	1,700	2,080	2,640	3,070	3,520
07052000	19.3	70.1	22	28.1	27.7	2,900	4,800	6,350	8,660	10,600	12,900
Mississippi Stations											
02473047	8.83	47.2	21	22.0	4.8	2,210	2,890	3,290	3,740	4,040	4,320
02485800	3.91	87.8	33	32.3	-2.1	2,180	2,610	2,850	3,110	3,280	3,430
02485950	11.4	72.5	29	28.7	-1.0	2,800	3,430	3,780	4,170	4,420	4,650
02486100	12.0	67.2	27	27.3	1.1	3,670	5,050	5,880	6,850	7,520	8,140
02486115	1.12	91.3	29	33.0	13.8	1,230	1,510	1,660	1,840	1,950	2,050
07290910	5.46	51.5	27	23.2	-14.1	1,140	1,560	1,830	2,150	2,380	2,600

developed area, from 47 to 91 percent. To explain the differences between equations 1 and 2, six stations in Missouri were randomly selected and added to the six stations in Mississippi to develop a wider range of data. The resulting regression equation is:

$$IA = 1.82(PDA)^{0.644} \quad (3)$$

The average standard error of estimate for equation 3 is 11.3 percent. The constant and exponent of equation 3 are different than those of equation 1, with a lower y-intercept and greater slope in equation 3. Another regression analysis was completed with all 29 stations to determine a combined regression equation and the result is:

$$IA = 2.04(PDA)^{0.617} \quad (4)$$

The average standard error of estimate was 11.4 percent. Equation 4 is essentially the same as equation 1. Equations 2, 3, and 4 are shown in figure 3 which illustrates that equations 3 and 4 provide very similar results. Analysis of the residuals of equation 4 indicates no apparent geographical bias between Mississippi and Missouri stations. Equation 1 is to be used to estimate percentage of impervious area because its limitations have been documented and equation 4 would not provide a significant improvement in accuracy.

Flood-Frequency Relations

The application of percentage of developed area as a potential basin characteristic in future urban Mississippi flood-frequency investigations was determined using statistical analyses based on the six stations in Mississippi. The first multiple-regression analysis was based on the variables discharge (Q), drainage area (A), and percentage of developed area (PDA) and resulted in the following relations:

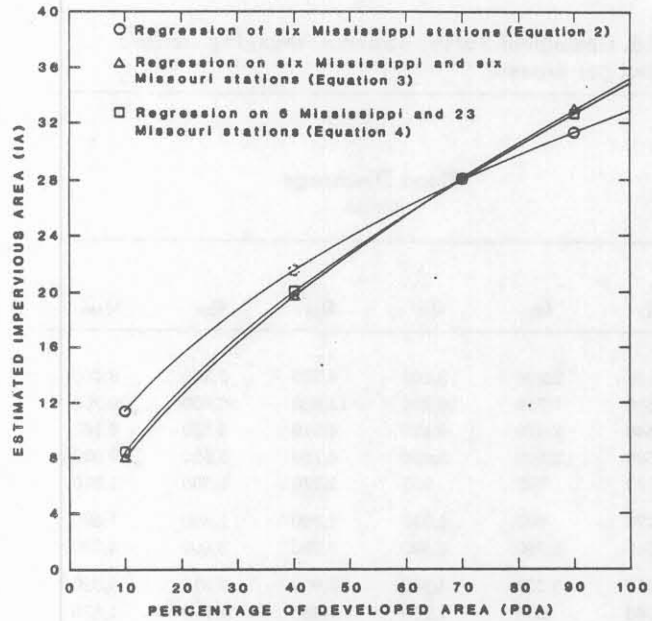

Figure 3.–Comparisons of estimated impervious area equations.

Equations		Average standard Errors of Estimate	
Q_2	$= 51.4A^{0.502}\ PDA^{0.684}$	13	(5)
Q_2	$= 132A^{0.501}\ PDA^{0.519}$	17	(6)
Q_{10}	$= 220A^{0.499}\ PDA^{0.428}$	19	(7)
Q_{25}	$= 361A^{0.494}\ PDA^{0.341}$	21	(8)
Q_{50}	$= 499A^{0.492}\ PDA^{0.282}$	23	(9)
Q_{100}	$= 668A^{0.489}\ PDA^{0.229}$	24	(10)

The second multiple regression analysis is based on the variables discharge (Q), drainage area (A), and percentage of Impervious area (I) and resulted in the following relations:

Equations		Average Standard Errors of Estimate	
Q_2	$= 61.4A^{0.475}\ I^{0.830}$	21	(11)
Q_5	$= 158A^{0.480}\ I^{0.616}$	21	(12)
Q_{10}	$= 253A^{0.481}\ I^{0.510}$	22	(13)
Q_{25}	$= 406A^{0.480}\ I^{0.404}$	23	(14)
Q_{50}	$= 541A^{0.480}\ I^{0.340}$	24	(15)
Q_{100}	$= 701A^{0.480}\ I^{0.281}$	25	(16)

Equations 5 to 16 are not to be used for flood-frequency estimates because of the very limited data base and an exhaustive flood-frequency analysis was not involved. Although only six stations were used in the analysis, comparing both sets of equations (5-10, 11- 16) indicates no loss of accuracy, and even some improvement in accuracy for lower-order floods, using percentage of developed area instead of percentage of impervious area. Therefore, based on this small sample of stations, percentage of developed area has potential for use in developing urban flood-frequency relations for Mississippi.

CONCLUSIONS

During this study, the urban basin characteristic called percentage of developed area (PDA) was applied to six Mississippi streamflow-gaging stations. Using statistical analyses, percentage of developed area was shown to estimate impervious area without apparent geographical bias. Flood-frequency relations also indicated that percentage of developed area is a potentially important basin characteristic. The percentage of developed area proved to be as statistically significant as percentage of impervious area in Mississippi. Therefore, the alternative urban basin characteristic of percentage of developed area (PDA) is considered to be an accurate indicator of urbanization in a basin and has potential application to streams in Mississippi.

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