AN ALTERNATIVE BASIN CHARACTERISTIC FOR USE IN ESTIMATING IMPERVIOUS AREA IN URBAN MISSOURI BASINS

By Rodney E. Southard

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CONVERSION FACTORS

For readers who prefer to use metric (International System) units, conversion factors for inch-pound units used in this report are listed below.

Multiply inch-pound unit	By	To obtain metric unit
mile	1.609	kilometer
square mile	2.590	square kilometer
cubic foot per second	0.02832	cubic meter per second

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ABSTRACT

A previous regression analysis of flood peaks on urban basins in St. Louis County, Missouri, indicated that the basin characteristics of percentage of impervious area and drainage area were statistically significant for estimating the 2-, 5-, 10-, 25-, 50-, and 100-year peak discharges at ungaged urban basins. In this statewide regression analysis of urban basins for Missouri, an alternative basin characteristic called the percentage of developed area was developed. A regression analysis of the percentage of developed area (independent variable) and percentage of impervious area (dependent variable), resulted in a simple equation for computing percentage of impervious area. The percentage of developed area also was evaluated using flood-frequency data for 23 streamflow-gaging stations, and the use of this variable was determined to be valid.

Using nationwide data, Sauer and others (1983) determined that an urban basin characteristic known as the basin development factor was valid for inclusion in urban regression equations for estimating floodflows. The basin development factor and the percentage of developed area were compared for use in regression equations to estimate peak flows of streams in Missouri. The equations with the basin development factor produced peak flow estimates with slightly smaller average standard errors of estimate than the equation with the percentage of developed area; however, this study indicates that there was not enough statistical or numerical difference to warrant using the basin development factor instead of the percentage of developed area in Missouri. The selection of a basin characteristic to describe the physical conditions of a drainage basin will depend not only on its contribution to accuracy of regression equations, but also on the ease of determining the characteristic; the percentage of developed area has this advantage.

A correlation analysis was made by correlating drainage area to percentage of impervious area, the percentage of developed area, and the basin development factor. The results of the analysis indicate that the three basin characteristics are independent of drainage area and appropriate to use in multiple-regression analysis.

INTRODUCTION

Flood discharges are measured by streamflow-gaging stations at only a few of the many sites where design data are needed. Streamflow-gaging stations are expensive to operate; therefore, more generalized methods are used to estimate discharges at ungaged sites. Estimating techniques, which use known variables such as basin characteristics, are used to determine discharges for most planning and design purposes. Flood-frequency relations are used to estimate peak floodflows for selected recurrence intervals to aid in the design of bridges, culverts, dams, levees, and in establishing flood insurance rates in flood plains.

A basin characteristic describes a certain type of feature that is unique to a drainage basin, such as drainage area, slope, stream length, or amount of impervious area. Characteristics that are used to describe the physical changes made by man on a drainage basin are referred to as urban basin characteristics. Alternative urban basin characteristics are needed that can be used to evaluate the effects on flood discharges of the physical changes (because of urbanization) taking place in rural basins of Missouri. These characteristics can be used in flood-estimating equations to partially account for the increase in flood-peak magnitude that generally occurs when the basin undergoes urbanization.

Regression equations can be used for determining the relation between basin characteristics (independent variables) and stream discharges (dependent variables). However, the estimate of a peak floodflow for an ungaged drainage basin by use of a regression equation is only an approximation based on certain statistically significant basin characteristics. If a drainage basin has unique features, such as detention storage or land use that make it dissimilar to the basins that the equation was based on, then the estimate may be in error. The user must determine if the regression equation is applicable to a particular basin.

For major projects, such as bridges or dams, more detailed hydrologic techniques, such as installation and operation of streamflow-gaging stations may be used for final designs. However, regression equations can be used to provide preliminary reconnaissance information. Therefore, basin characteristics used in regression equations need to adequately describe the conditions that exist within the basin.

Purpose and Scope

The purpose of this report is to describe the use of an alternative urban basin characteristic, called the percentage of developed area, to simplify the computation process of evaluating the percentage of impervious area within a basin. The urban basin characteristics of percentage of impervious area, percentage of developed area, and the basin development factor were compared for use in regression equations for estimating peak flows at selected recurrence intervals. The analysis used data from 14 selected streamflow-gaging stations located in St. Louis County (Spencer and Alexander, 1978) and 9 stations located in other counties of Missouri (L.D. Becker, in press).

Approach

Basin and climatic characteristics applicable to Missouri were selected from a list compiled by Benson and Carter (1973, p. 19) as a starting point for evaluating the suitability of variables for estimating peak flows. The selected characteristics included drainage area, channel slope, stream length, area of lakes, forested area, and mean annual precipitation. A step-backward multiple-regression analysis was used to measure the contribution of each of the selected independent variables (Riggs, 1968) for estimating the dependent variable. In the use of the step-backward technique, all the independent variables are entered at the beginning of the analysis and the contribution of each variable can be compared as it is statistically rejected (McCuen, 1985). See "Supplemental Information" section at the back of the report.

Spencer and Alexander (1978) reported that the percentage of impervious area was a significant urban basin characteristic for the St. Louis County area in Missouri. Percentage of impervious area is the percentage of the basin occupied by impervious surfaces such as buildings, streets, and parking lots. Because of the results of this study, the percentage of impervious area was tested for its significance for use in regression analyses for estimating peakflows in urban streams on a statewide basis. The analysis used data for 14 selected streamflow-gaging stations in St. Louis County (Spencer and Alexander 1978) and 9 additional urban streamflow-gaging stations (fig. 1) operated as part of a statewide small-streams project (L.D. Becker, in press). In addition to evaluating percentage of impervious area, the percentage of developed area and basin development factor also were tested for use in regression equations for estimating peak flows on a statewide basis. The basin development factor is a measure of the extent of development of the drainage system in a basin. Field reconnaissance was made on the nine streamflow-gaging stations (L.D. Becker, in press) to determine how easily the basin development factor could be determined from field reconnaissance for use in a statewide multiple-regression analysis for urban areas.

The procedure used by Spencer and Alexander (1978) to compute percentage of impervious area consisted of measuring the impervious areas from low-altitude aerial photograph maps. Disadvantages with this procedure are that it is time consuming and dependent on low-altitude aerial photograph maps not normally available for drainage basins. A simplified procedure was developed in this study to compute percentage of impervious area. An alternative basin characteristic called percentage of developed area was determined from 7.5-minute topographic quadrangle maps. Percentage of developed area is the percentage of a drainage basin that is shown as being urbanized on 7.5-minute topographic quadrangle maps. The area considered urbainzed will contain both pervious and impervious surfaces. The developed areas were measured and divided by the total drainage-area size. The resultant percentage of developed area was used in a simple-regression analysis as the independent variable with percentage of impervious area as the dependent variable. Finally, the three basin characteristics, percentage of impervious area, percentage of developed area, and the basin development factor, were analyzed for their ease of use and for their contribution to accuracy in estimating flood discharges.

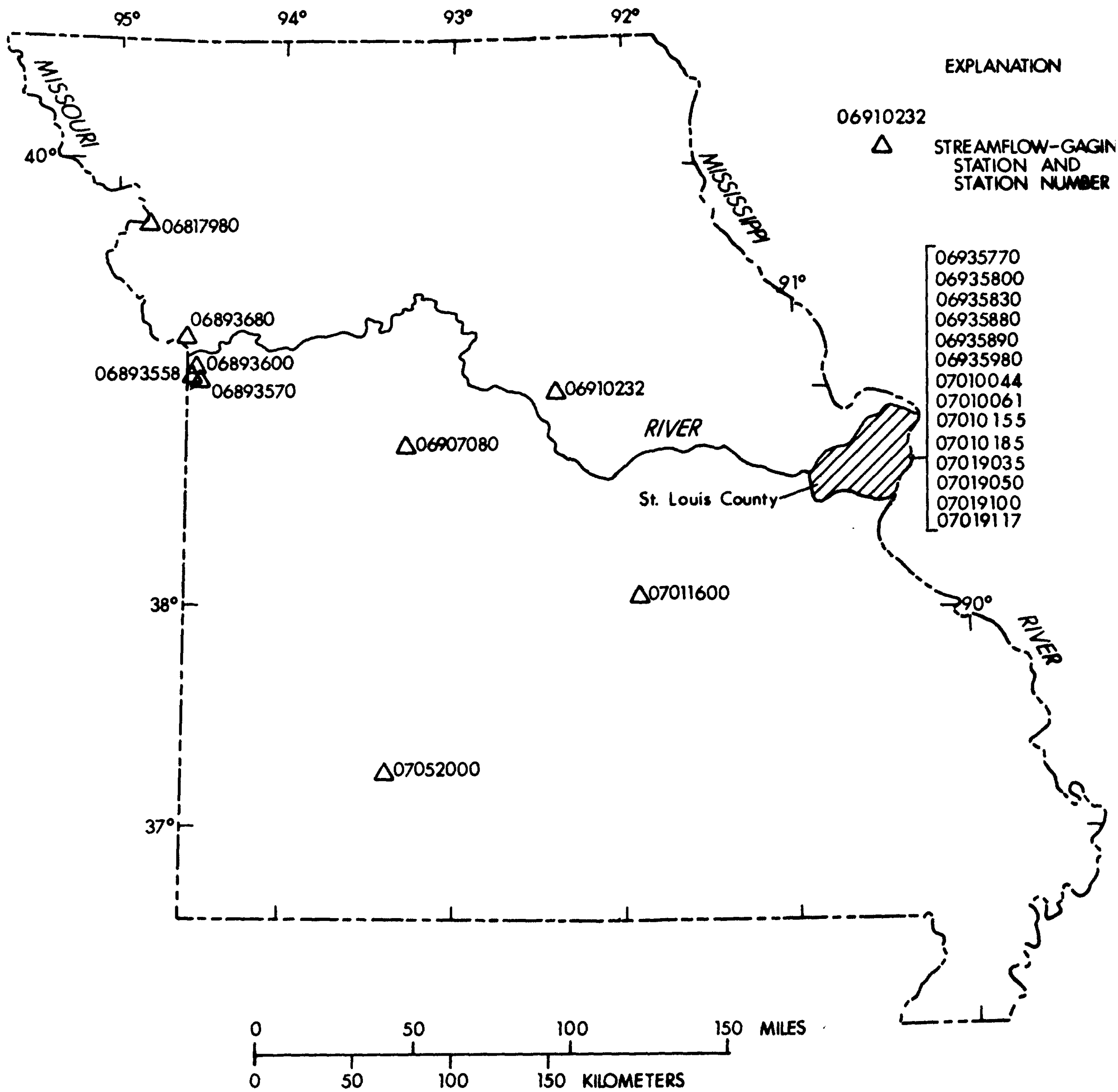

Figure 1.--Location of the U.S. Geological Survey streamflow-gaging stations used in this study.

Several commonly-used streamflow routing models such as HEC-1 (U.S. Army Corps of Engineers, written commun., 1985) require the data value of percentage of impervious area as input. The relation between percentage of developed area and percentage of impervious area allows percentage of developed area to be used to estimate percentage of impervious area for use in streamflow routing procedures.

PREVIOUS INVESTIGATIONS

Previous regression analysis of rural basins floodflow-frequency data has led to the identification of many basin characteristics for use in estimating magnitude and frequency of floods. In one of the earliest in-depth regression analysis of rural streams, Benson (1959, p. 2) evaluated 6 basin characteristics for 170 streamflow-gaging stations in New England. The characteristics are: area; slope; mean annual runoff; mean annual precipitation; 10-year, 60-minute maximum precipitation; and length/area. The results of Benson's study indicated that drainage area and channel slope were the most significant basin characteristics. Benson (1959) described how channel slope could be computed for use in the regression equations. This method of slope computation is widely accepted and used by Federal agencies.

In 1968, Sandhaus and Skelton collected data from 208 streamflow-gaging stations in Missouri as part of a statewide flood-frequency study. Six rural basin characteristics--area, slope, mean annual precipitation, elevation, forest cover, and length of main channel--for estimating flood peaks at selected recurrence intervals were selected as the independent variables. A multiple-regression analysis of the data indicated that only two of the variables--drainage area and channel slope--were statistically significant at the 1-percent level (Sandhaus and Skelton, 1968, p. 7-10). The same independent variables were derived from rural streams located in the Washington, D.C., area by Armentrout and Bissell (1970) with the resulting flood-estimating equations based solely on the easily measured basin characteristics of drainage area and channel slope.

With increased need for estimates of flood-frequency information for urban areas, studies were begun to evaluate the larger discharges that generally occur in surface runoff that result from the increased impervious areas and channelization. In 1961, the effects of the decrease in time between center of mass of runoff and of rainfall, increase in impervious area, and increase in runoff peaks caused by urbanization were studied. A ratio of peak flows between urbanized basins and unurbanized basins of 1.8 was determined to be the maximum effect of complete suburban development on flood peaks for any recurrence interval on basins 4 square miles or larger in the Washington, D.C., area (Carter, 1961, p. B9-B11). Carter's (1961) work was continued by Anderson (1970), with these results indicating that the magnitude of floods with an average recurrence interval of 2.33 years may double or triple as a result of urbanization. Urban basin characteristics described by Espey and Winslow (1974) were channel slope and a variable they termed the urbanization factor. 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.

A regression study for estimating the magnitude and frequency of urban floods in St. Louis County, Missouri, was made by Spencer and Alexander (1978). Their study used 30 streamflow-gaging stations that ranged in development from rural to moderately urban. The resulting flood-frequency relation from the multiple-regression analysis indicated that the independent variables--drainage area and percentage of impervious area--were statistically significant at the 5-percent probability level.

An urban watershed study by Sauer and others (1983) introduced the urban basin characteristic called the basin development factor. The basin development factor is an index of urbanization that provides a measure of the efficiency of the drainage system in a drainage basin. In the procedure, four criteria are applied to one-third of the drainage system at a time. A value of 1 is assigned to each criteria that is met. The basin development factor is the sum of all values for each criteria met for the entire drainage basin. See "Analysis of Basin Development Factor" section later in this report for further details. The study by Sauer and others (1983) had a nationwide data base consisting of 269 streamflow-gaging stations (including the St. Louis County streamflow-gaging network) and included basins that ranged from 15 percent urbanized to extensively urbanized. The final three-variable regression equations for that study indicate that drainage area, basin development factor, and the rural peak discharge to be most significant for estimating urban flood discharges.

COMPUTATION AND ANALYSIS OF URBAN BASIN CHARACTERISTICS

Percentage of Developed Area, an Alternative

The procedure developed for computing the urban basin characteristic, percentage of developed area, requires a planimeter and 7.5-minute topographic quadrangle maps. It is essential to use topographic quadrangle maps that accurately reflect the urban conditions of the drainage area at the time the peak-flow data were collected. The first step in computing percentage of developed area is to outline the drainage divide for each watershed. The drainage area is then divided into two subareas, open area and developed (urban) area. Open area consists of all undeveloped land, which may have scattered farmhouses 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 (fig. 2). On 7.5-minute topographic quadrangle maps, areas within the drainage basin that are purple or red should be considered developed areas, except for parks, cemeteries, golf courses, areas along and including the stream channel that are not developed, and all other areas the user can identify as not developed. Commercial areas, subdivisions, and apartment complexes characterized by one or more large buildings close to each other are to be designated developed whether indicated or not. When delineating developed areas, it it 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 drainage-area size. Depending on the areal distribution of the developed areas and the drainage-basin size (22 square miles or less), the topographic map work generally can be done in 2 hours or less.

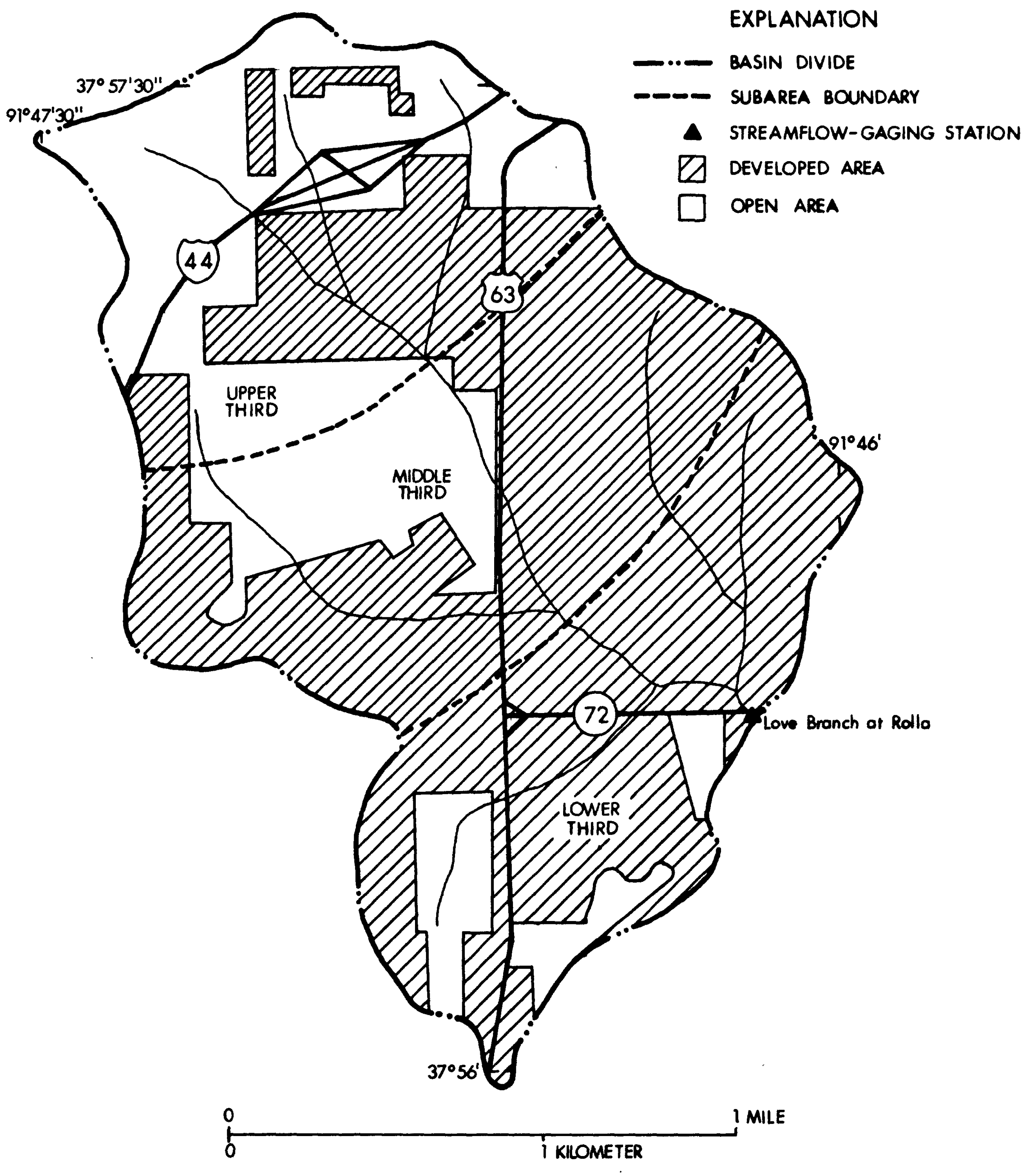

Figure 2.--Drainage basin upstream from streamflow-gaging station 07011600, Love Branch at Rolla.

Relation between Impervious and Developed Areas

To develop the relationship between percentage of impervious area (I) and the percentage of developed area (PDA), 23 streamflow-gaging stations were selected in the State where the percentage of impervious area (I) in the basins had been previously measured. A simple-regression analysis was made using percentage of impervious area (I) as the dependent variable and the percentage of developed (PDA) as the independent variable. The regression equation that relates these two variables is:

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

The percentage of developed area (PDA) was statistically significant at the 1-percent probability level. The correlation coefficient of the relation is 0.985 and the average standard error of estimate for the relation is 12.1 percent. For equation 1 the percentage of impervious area will range plus or minus one standard error of estimate in about two-thirds of the estimates or, expressed as a percentage, the estimate will be within plus or minus 12.1 percent of the actual percentage of impervious area value in about two-thirds of the estimates. Figure 3 is a graphical representation of the relation between percentage of developed area and percentage of impervious area (see table 1 for data.) The figure also shows the regression relation between the two variables. In the delineation of developed areas, the decision to include areas on a topographic map not purple or red or located in main commercial areas may require personal judgment; differences in judgment will be reflected in percentage of developed area values. However, the area encompassed by these outlying developed areas represents a small percentage of the total developed area of the basin. Therefore, the effect of these differences will be negligible on the percentage of developed area values computed. For percentage of developed area values below 6 percent, the percentage of impervious area becomes greater than the percentage of developed area. For undeveloped basins the effect of impervious surfaces such as lakes and rock outcroppings become the major contributor to impervious area. Since percentage of developed area does not take into account these natural surfaces as measured from a map, the value of percentage of developed area will be less than that of percentage of impervious area. However, since observed impervious area values for each basin do take into account these surfaces, then equation 1 will be valid for basins that have a low percentage of developed area. There is a limited number of data points of percentage of developed area below 10 percent but further analysis revealed no bias from these points in equation 1. From field reconnaissance, the percentage of commercial area that makes up the percentage of developed area value was estimated for all 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 multi-family residence. Therefore, equation 1 is applicable for basins with: 1) A drainage area between 0.80 and 23 square miles, 2) 1 to 35 percent impervious area, and 3) developed area which has 50 percent or less commercial area. The percentage of impervious area (I) for the 23 gaged basins was then computed using equation 1 and listed in table 1. The difference or error between the measured and estimated impervious area values, expressed as a percentage, also is given for each station in table 1.

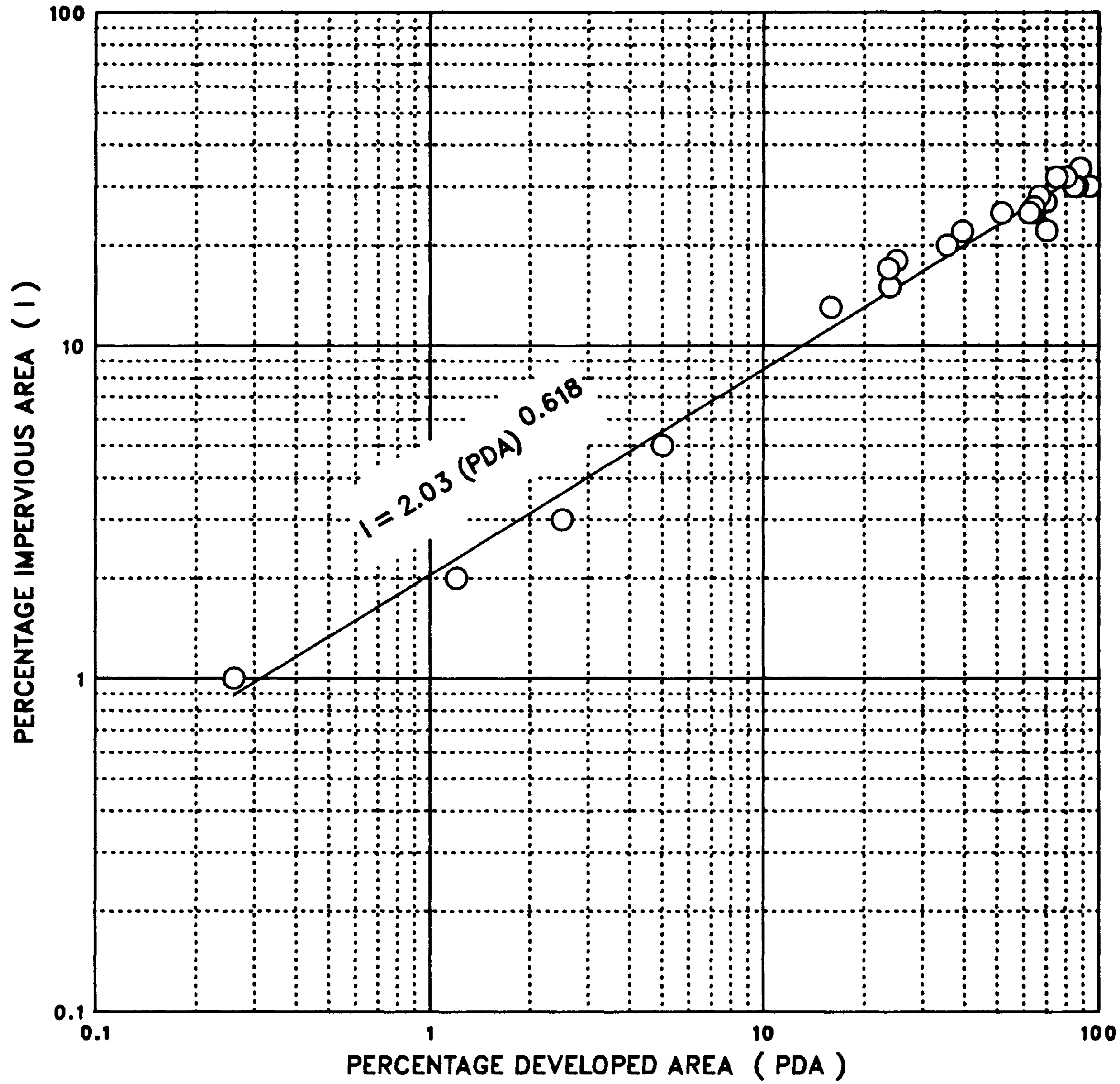

Figure 3. -- Relation of percentage of developed area to percentage of impervious area.

Table 1.--Basin characteristics and flood discharges for selected streamflow-gaging stations.

[mi^2, square miles; ft^3/s, cubic feet per second; Q_x, flood discharge with subscript x designating the recurrence interval, in years]

Streamflow-gaging station number (fig. 1)	Drainage area (A, mi^2)	Basin development factor (BDF)	Percentage of developed area (PDA, percent)	Percentage of impervious area (I, percent measured	Percentage of impervious area (I percent From equation 1	Difference between measured and estimated impervious area (percent)	Flood discharge (ft^3/s)					
							Q_2	Q_5	Q_{10}	Q_{25}	Q_{50}	Q_{100}
06817980	4.32	0	15.9	13	11.2	-13.8	1,130	2,220	3,100	4,330	5,340	6,400
06893558	14.4	11	94.1	30	33.7	12.3	4,650	7,740	10,200	13,800	16,900	20,300
06893570	5.62	4	66.8	26	27.2	4.6	1,440	2,370	3,120	4,210	5,130	6,160
06893600	5.27	5	84.6	30	31.5	5.0	1,500	2,580	3,450	4,730	5,820	7,030
06893680	1.23	4	88.2	34	32.3	-5.0	415	702	933	1,270	1,560	1,870
06907080	.93	3	51.6	25	23.2	-7.2	493	803	1,010	1,290	1,490	1,690
06910232	3.01	6	86.4	30	31.9	6.3	1,340	2,080	2,600	3,280	3,800	4,330
06935770	11.6	0	2.50	3	3.58	19.3	2,010	3,320	4,380	5,960	7,310	8,820
06935800	.81	5	39.4	22	19.7	-10.5	560	830	1,100	1,460	1,670	1,870
06935830	17.1	3	5.60	5	5.89	17.8	3,060	5,170	6,910	9,510	11,800	14,300
06935880	4.44	4	25.0	18	14.8	-17.8	1,240	1,950	2,510	3,310	3,980	4,720
06935890	22.0	5	23.8	15	14.4	-4.0	2,340	3,900	5,200	7,170	8,900	10,900
06935980	3.70	9	35.5	20	18.4	-8.0	1,240	1,950	2,520	3,370	4,110	4,930
07010044	8.59	9	62.4	25	26.1	4.4	2,690	4,310	5,670	7,730	9,570	11,700
07010061	6.42	9	64.4	25	26.6	6.4	2,280	3,650	4,760	6,420	7,860	9,480
07010155	12.1	9	80.0	32	30.5	-4.7	3,160	5,020	6,600	9,100	11,400	14,000
07010185	22.3	9	75.0	32	29.3	-8.4	3,230	5,070	6,640	9,120	11,400	14,000
07011600	1.40	7	64.3	26	26.6	2.3	451	691	866	1,110	1,300	1,510
07019035	3.14	0	1.20	2	2.27	13.5	820	1,390	1,850	2,530	3,110	3,760
07019050	9.85	0	.26	1	.88	-12.0	1,600	2,590	3,380	4,500	5,540	6,650
07019100	2.40	7	69.7	27	28.0	3.7	1,000	1,510	1,880	2,400	2,810	3,250
07019117	2.40	6	23.6	17	14.3	-15.9	1,160	1,700	2,080	2,640	3,070	3,520
07052000	19.3	6	70.1	22	28.1	27.7	2,900	4,800	6,350	8,660	10,600	12,900

Verification of the percentage of developed area was made by comparing regression estimates for the 2-, 5-, 10-, 25-, 50-, and 100-year discharges with station records for the 23 streamflow-gaging stations listed in table 1. The regression analysis of discharge (Q), drainage area (A), and percentage of impervious area (I) values from Spencer and Alexander (1978) resulted in the following flood-frequency relation:

Estimating equations	Average standard errors of estimate	
$Q_2=364A^{0.647}I^{0.114}$	24.2	(2)
$Q_5=594A^{0.661}I^{0.103}$	23.1	(3)
$Q_{10}=770A^{0.672}I^{0.099}$	23.2	(4)
$Q_{25}=1{,}010A^{0.690}I^{0.097}$	23.4	(5)
$Q_{50}=1{,}190A^{0.711}I^{0.095}$	23.4	(6)
$Q_{100}=1{,}370A^{0.733}I^{0.094}$	23.2	(7)

Where Q_x is a peak discharge having an average recurrence interval of x years.

For this study, a second multiple-regression analysis using discharge (Q), drainage area (A), and percentage of developed area (PDA) was made and resulted in the following flood-frequency relation:

Estimating equations	Average standard errors of estimate	
$Q_2=396A^{0.642}PDA^{0.072}$	23.9	(8)
$Q_5=640A^{0.657}PDA^{0.065}$	23.1	(9)
$Q_{10}=827A^{0.668}PDA^{0.062}$	23.1	(10)
$Q_{25}=1{,}080A^{0.687}PDA^{0.061}$	23.2	(11)
$Q_{50}=1{,}270A^{0.708}PDA^{0.060}$	23.2	(12)
$Q_{100}=1{,}460A^{0.729}PDA^{0.060}$	23.2	(13)

All independent variables in equations 2 to 13 were statistically significant at the 10-percent probability level. The intercepts, exponents of the independent variables (A,I;A,PDA), and the average standard errors of estimate are virtually the same for both sets of equations (2-7,8-13). This indicates no loss of accuracy in estimating peakflows by using the equations with percentage of developed area instead of percentage of impervious area. Therefore, the percentage of developed area can be used in developing urban flood-frequency relationships for Missouri. This study did not include an exhaustive flood-frequency analysis and the data base was limited; equations 2-13 should not be used for flood-frequency estimates. A study by Becker (in press) gives flood-frequency analysis and a more comprehensive data base.

Analysis of Basin Development Factor

To determine if the basin development factor (BDF) used by Sauer and others (1983) is applicable statewide in Missouri, values of basin development factor for the nine streamflow-gaging stations (L.D. Becker, in press) were computed from field reconnaissance (fig.1). Basin development factor values for streamflow-gaging stations 06935770, 07019035, and 07019050 (table 1) in St. Louis County also were determined for a statewide multiple-regression analysis because they were not determined in the study of Sauer and others (1983). Another reason for determining the basin development factor for these three streamflow-gaging stations was to keep the data base the same for all independent variables so that comparisons of their contributions to the accuracy of regression equations could be made.

The criteria used in computing the basin development factor (BDF) are explained using Love Branch at Rolla (07011600) as an example. The first step is to locate the Love Branch streamflow-gaging station (fig. 2) on a 7.5-minute topographic quadrangle map and outline the drainage divide. The possible effects of drainage-area boundary distortion due to development (urbanization) of the area was checked during the field reconnaissance and none were detected. The Love Branch basin was divided into three subareas having about equal drainage area and traveltimes with the four criteria from Sauer and others (1983, p. 8) then applied to each one-third of the basin (fig. 2). The four criteria are based on whether each subarea has undergone development of 50 percent or more for the following: (1) channel improvements, (2) channel linings, (3) storm drains or storm sewers, and (4) curbs and gutters on streets. One point is given for each criteria in each subarea for a maximum of 12 points indicating complete urbanization. If any of these criteria were met within the subarea, a value of 1 was then assigned. After evaluating each subarea, the total value represents the basin development factor (BDF) for the area upstream from that streamflow-gaging station. The results of the field reconnaissance and evaluation of the Love Branch at Rolla (07011600) streamflow-gaging station indicated the basin development factor to be 7, as shown in table 2.

Table 2.--Summary of computations for basin development factor (BDF) for Love Branch upstream from streamflow-gaging station 07011600

Subarea (fig. 2)	Criteria number category[a] 1	2	3	4
	BDF values [BDF value of 1 indicates criteria were met]			
Lower one-third	1	1		
Middle one-third	1	1	1	1
Upper one-third	1			

[a]Sauer and others (1983): (1) Channel improvements, (2) channel linings, (3) storm drains or storm sewers, (4) street curbs and gutters.

To analyze the basin development factor's applicability within Missouri, the data from the 23 streamflow-gaging stations (table 1) were then used in a multiple-regression analysis at significance level of 0.10 resulting in the following flood-frequency relation:

Estimating equations	Average standard errors of estimate	
$Q_2=1{,}120A^{0.583}(13\text{-BDF})^{-0.359}$	19.7	(14)
$Q_5=1{,}560A^{0.606}(13\text{-BDF})^{-0.304}$	20.2	(15)
$Q_{10}=1{,}920A^{0.620}(13\text{-BDF})^{-0.285}$	20.7	(16)
$Q_{25}=2{,}440A^{0.640}(13\text{-BDF})^{-0.274}$	21.1	(17)
$Q_{50}=2{,}820A^{0.661}(13\text{-BDF})^{-0.269}$	21.4	(18)
$Q_{100}=3{,}230A^{0.683}(13\text{-BDF})^{-0.268}$	21.4	(19)

Equations 14 to 19 have slightly smaller average standard errors of estimate than equations 8 to 13 indicating little difference in accuracy. To illustrate the similarity of the two sets of equations, the 100-year computed flood discharges for each streamflow-gaging station were plotted against the station data (table 1) for comparison (fig. 4).

The regression lines plotted in figure 4 are about identical, indicating that the equations will provide essentially the same results. As stated previously, these equations should not be used for flood-frequency estimates.

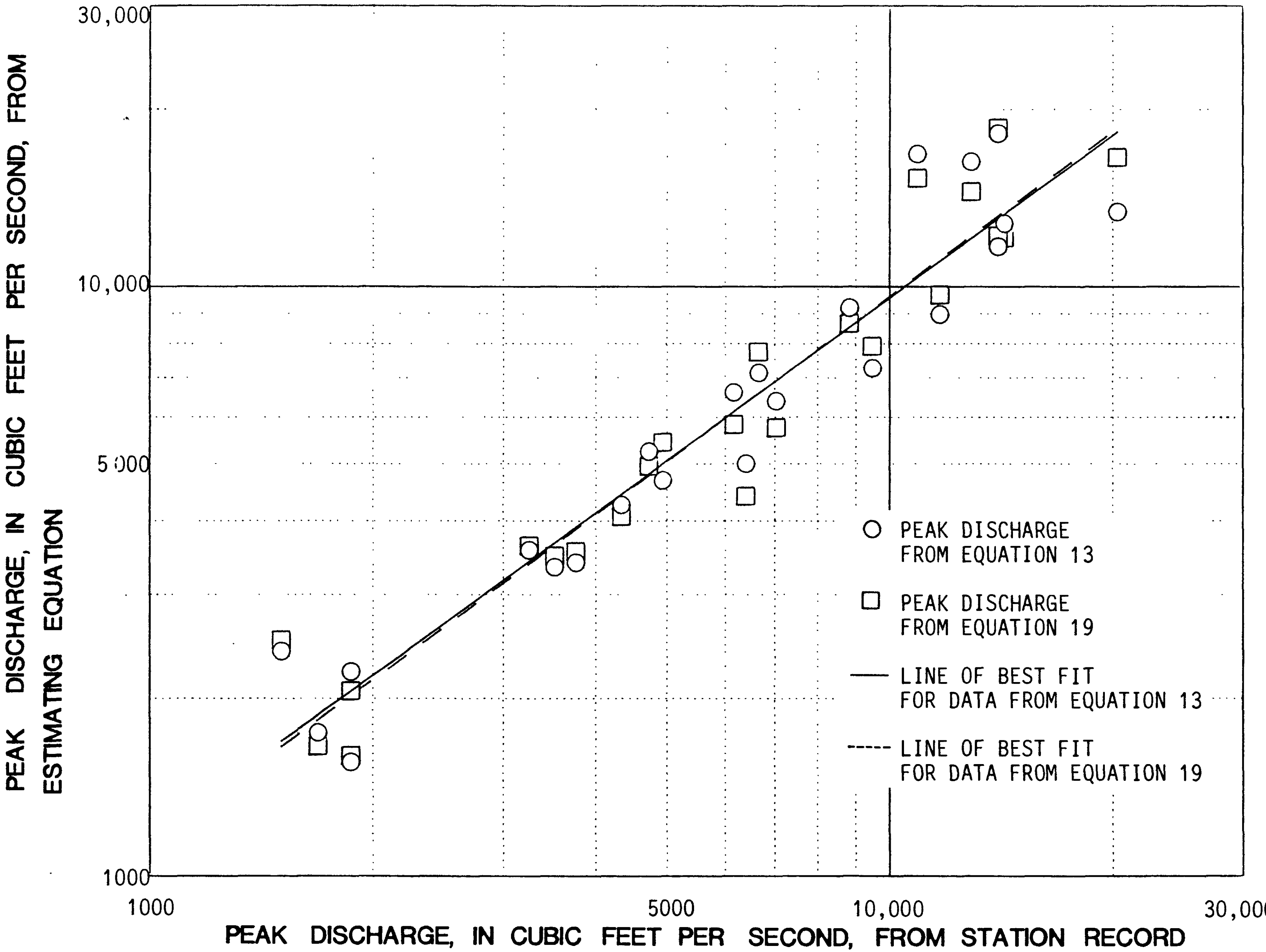

Figure 4.--Comparison of 100-year peak discharges computed from station record and estimating equations.

The decision to use the percentage of developed area or the basin development factor should not be based solely upon the small differences in accuracy from the two sets of flood-frequency relation (eq. 8-13; eq. 14-19). Instead, the choice also should be based on which of the basin characteristics (PDA or BDF) is easier to obtain. The evaluation of the basin development factor (BDF) using 7.5-minute topographic quadrangle maps is difficult because of the lack of channel details necessary to accurately evaluate the four criteria from Sauer and others (1983). As noted by Sauer and others (1983, p. 8), field reconnaissance would be preferred to obtain the best estimates of the basin development factor (BDF). If the user is located near the study area, then the basin development factor (BDF) can be easily evaluated; for this study field reconnaissance took 1 to 6 hours for basins up to 20 square miles, disregarding traveltime. In comparison, the percentage of developed area can be computed in 2 hours or less for basins with drainage areas of 22 square miles or less. Field reconnaissance necessary to determine a basin development factor (BDF) may be impractical if the user is located a considerable distance from the basin. Therefore, the percentage of developed area generally would be much faster and more efficient for the user to obtain than the basin development factor. However, field visits are desirable in either case because field visits may disclose obvious changes in a basin that have not been reflected in updated mapping.

CORRELATION ANALYSIS

An underlying assumption of a regression analysis is that the independent variables (basin characteristics) are completely independent. If two independent variables are significantly intercorrelated, the tests for significance of each variable in the regression analysis may not be accurate. When two independent variables are intercorrelated, the standard errors of estimate of their regression coefficients are increased. This increase in the standard errors of estimate decreases the significance of each variable, thus making it more difficult to determine if the regression coefficients are significantly different from zero.

A correlation analysis was selected using drainage area (A) to test for interdependence of the three statistically significant variables used in this study, and results are presented in table 3. A negative coefficient indicates an inverse correlation. A correlation coefficient of zero indicates complete independence of the variables, whereas a value of ±1 indicates total dependence. A correlation coefficient of -0.02 indicates the percentage of developed area is the most independent variable with respect to drainage area. A correlation coefficient of 0.73 (table 3) for the basin development factor with respect to the percentage of impervious area shows these two basin characteristics to be significantly correlated and dependent. The correlation coefficients for the three basin characteristics indicate they are slightly correlated with drainage area; however, for this study the slight intercorrelation was ignored, and these basin characteristics were assumed to be independent of drainage area.

Table 3.--Results of correlation analysis for the basin characteristics used in this study

	Correlation Percentage of impervious area	Coefficient Percentage of developed area	Basin development factor
Drainage area	-0.11	-0.02	0.18
Percentage of impervious area		0.95	0.73
Percentage of developed area			0.70

CONCLUSIONS

During this study, an urban basin characteristic called percentage of developed area (PDA) was evaluated. Percentage of developed area was shown to be statistically significant at the 1-percent probability level on a statewide basis in Missouri for computing percentage of impervious area. The principal advantages in using the percentage of developed area relation as an independent basin characteristic in determining the percentage of impervious area within a basin are its accuracy and ease of use.

Flood-frequency relation also indicated that percentage of developed area was an important basin characteristic on a statewide basis. 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 applicable to streams throughout Missouri.

The basin characteristic, basin development factor, was tested for application in flood-frequency analyses and proven to be statistically significant at the 10-percent probability level on a statewide basis. The basin development factor was then compared to the percentage of developed area. The results indicate that the percentage of developed area is almost as descriptive as the basin development factor, but percentage of developed area has the advantage of being easier to use. This study did not include an exhaustive flood-frequency analysis, and the data base was limited. Equations 2-19 should not be used for flood-frequency estimates pending further study.

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(page 19 follows)

SUPPLEMENTAL INFORMATION

Multiple-Regression Technique

Statistical multiple-regression analyses were used in this study to develop the relation between (1) percentage of impervious area and percentage of developed area, and (2) discharge, area, and other selected urban basin characteristics. Multiple-regression provides a mathematical relationship between a single dependent variable and the independent variables. It also provides the standard error of estimate, a measure of the accuracy of the relation. Each independent variable in the relation is tested for statistical significance and improvement in the standard error of estimate. The standard error of estimate is the range of error that is to be expected in about two-thirds of the estimates. In previous hydrologic studies, it has been shown that streamflow discharges are linearly related to basin characteristics if the logarithms of each are used, and this also applies for the relation of percentage of impervious area and percentage of developed area.

Before using a mathematical regression model versus a graphical relation, the advantages and disadvantages need to be assessed. The advantages in using a mathematical relation compared to a graphical relation are:

1. The line of best fit is obtained.
2. The standard error and correlation coefficient can be computed.
3. The significance of each independent variable can be determined.
4. The equation usually is easier and quicker to use than a graphical relation.

Disadvantages are:

1. If the appropriate model is not used, the results may not be as good as results obtained by a graphical correlation.
2. If curvilinear relations are present, the equations may be difficult to solve.

For this study, a stepwise regression was used because statistical measures determine what independent variables will be used in the final regression equation. The statistical analysis usually eliminates independent variables with significant intercorrelations, thereby producing equations with rational regression coefficients. The type of stepwise regression used was a step-backward regression. Step-backward regression begins with an equation that includes all independent variables. The significance of each variable is determined and tested against a predetermined level of significance. If all independent variables are significant, then the regression is completed; however, if one or more variables are insignificant the least significant variable is dropped in sequence until only the remaining independent variables are left, if any.

In a stepwise regression analysis, two basic tests exist that determine the statistical significance of the equation and each independent variable. The test that determines whether the dependent variable is significantly related to the independent variables is the total F test. The null hypothesis is that all the population regression coefficients equal zero, and the alternative hypothesis is that at least one regression coefficient is significantly different from zero. The equation for computing the total F test is:

$$F = \frac{R_q^2 / q}{(1-R_q^2)/(n-q-1)}$$

where F is the test statistic;
R_q is the multiple correlation coefficient;
q is number of independent variables; and
n is number of observations.

The total F is compared to the critical F value that is based on the level of significance chosen and the degrees of freedom (q,n-q-1) for the numerator and denominator, respectively. If F is less than or equal to the critical F value, the null hypothesis is accepted and the dependent variable is not related to any of the independent variables. If the null hypothesis is rejected, one or more of the independent variables are statistically related to the dependent variables, but not necessarily all are related. The other basic test used in a stepwise regression to determine if each independent variable is significant is the partial F test. The equation for the partial F test is (used to select the independent variable under consideration):

$$F = \frac{(R_q^2 - R_{q-1}^2)}{(1-R_q^2)/(n-q-1)}$$

where F is the test statistic;
R_{q-1} is the correlation coefficient for the regression excluding the independent variable being tested;
R_q is the correlation coefficient for the regression including the independent variable;
q is the number of independent variables including the tested variable; and
n is the number of observations.

The partial F is compared to the critical F value with the null hypothesis of the regression coefficient of the independent variable equal to zero, and the alternative hypothesis that it is not equal to zero. If the partial F is less than the critical F value, adding the X_q independent variable to the equation does not result in a significant increase in the explained variation of the dependent variable. Therefore, the independent variable should not be added to the regression equation or should be deleted from the equation if it is already in it. In a stepwise regression, the partial F statistics are computed for every independent variable in each step of the regression. The mathematical algorithms used in the multiple-regression analysis are documented in the Statistical Analysis System User's Guide: Statistics (1982).