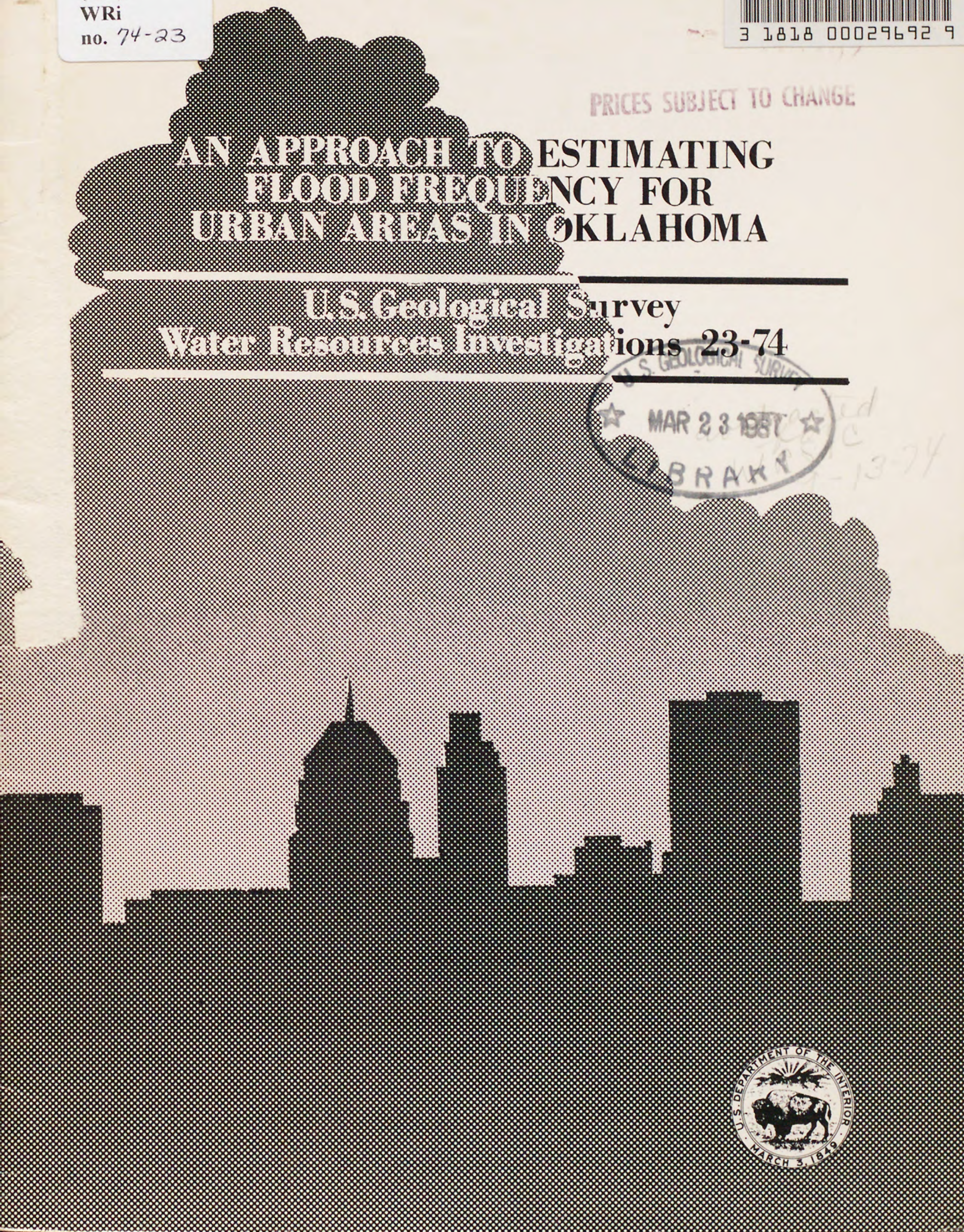
AN APPROACH TO ESTIMATING FLOOD FREQUENCY FOR URBAN AREAS IN OKLAHOMA

U.S. Geological Survey Water Resources Investigations 23-74



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$$Q_{x(u)} = \frac{7R_xQ_2(R_L-1)}{6} + \frac{Q_x(7-R_L)}{6}$$

where $Q_{x(u)}$ is the urban peak discharge for recurrence interval, x; R_L is an adjustment factor to account for the effect of urban development; Q_x is the natural peak discharge for recurrence interval, x; Q_2 is the mean annual flood discharge for natural conditions; and R_x is the rainfall-intensity ratio for recurrence interval, x. The above equation could be used in an area outside Oklahoma where the several assumptions can be accepted, by substituting local values of Q_2, Q_x, and R_x.

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FACTORS FOR CONVERTING ENGLISH UNITS
TO INTERNATIONAL SYSTEM (SI) UNITS

Multiply English units	by	To obtain metric (SI) units
Length		
inches (in)	25.4	millimetres (mm)
feet (ft)	0.3048	metres (m)
Area		
square miles (mi^2)	2.590	square kilometres (km^2)
Slope		
feet per mile (ft/mi)	0.189	metres per kilometre (m/km)
Flow		
cubic feet per second (ft^3/s)	0.0283	cubic metres per second (m^3/s)

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ABSTRACT

Flood-frequency studies for urban areas in several parts of the United States and flood-frequency relations for natural streams of Oklahoma were used to develop a set of flood-frequency equations for urban areas of Oklahoma. Equations are presented for estimating the 2-, 5-, 10-, 25-, 50-, and 100-year flood-peak discharges for basins of 0.5 to 100 mi^2 (1.3 to 260 km^2). The general form of the equations is

$$Q_{x(u)} = \frac{7R_xQ_2(R_L-1)}{6} + \frac{Q_x(7-R_L)}{6}$$

where $Q_{x(u)}$ is the urban peak discharge for recurrence interval, x; R_L is an adjustment factor to account for the effect of urban development; Q_x is the natural peak discharge for recurrence interval, x; Q_2 is the mean annual flood discharge for natural conditions; and R_x is the rainfall-intensity ratio for recurrence interval, x. Flood-frequency data for urban areas in Oklahoma are virtually non-existent; therefore, the accuracy of the urban equations cannot be determined.

The general form of the equations could be used in an area outside Oklahoma where the several assumptions can be accepted. Such usage would require local values of Q_2, Q_x, and R_x.

INTRODUCTION AND PURPOSE

There is an ever-increasing need for defining the magnitude and frequency of floods for streams in urban areas of Oklahoma. Delineating areas subject to flooding is required for insurance purposes, zoning, and building codes. The construction of embankments, bridges, culverts, improved stream channels, and storm sewers requires a knowledge of the magnitude of flood peaks. At the present time (1974), there are no data available for urban areas of Oklahoma which could be used to define urban flood frequency. The purpose of this report is to describe a method of estimating magnitude and frequency of floods for urban areas in Oklahoma on the basis of previous studies in other parts of the United States and the natural flood-frequency and rainfall characteristics of the local area.

Methods of estimating magnitude and frequency of floods in urban areas have been the subject of several reports by various investigators during recent years. The usual approach is to relate selected flood magnitudes, such as the mean annual flood or 50-year flood, to basin and climatic characteristics, and a measure of urban development. Urban development, from a hydraulic viewpoint, is usually measured by the amount of impervious areas in the basin and the percentage of the basin served by storm sewers and channel improvements. Examples of such reports are by Anderson (1970), Carter (1961), Martens (1968), James (1965), Espey and others (1966), Espey and Winslow (1974), and Wilson (1966). This report combines a summary of data and methods from these reports with the local rainfall-intensity data and natural-flow flood-frequency data to define urban flood-frequency equations for Oklahoma. A similar study for Missouri is described by Gann (1971).

FLOOD MAGNITUDE AND FREQUENCY OF NATURAL BASINS

The magnitude and frequency of floods for natural basins of 0.5 to 2,500 mi^2 (1.3 to 6,500 km^2) in Oklahoma can be estimated from the following regression equations developed by Sauer (1974):

$$Q_2=0.0568\ A^{0.67}\ S^{0.37}\ P^{2.00} \tag{1}$$

$$Q_5=0.498\ A^{0.66}\ S^{0.40}\ P^{1.58} \tag{2}$$

$$Q_{10}=1.081\ A^{0.67}\ S^{0.42}\ P^{1.44} \tag{3}$$

$$Q_{25}=2.56\ A^{0.68}\ S^{0.44}\ P^{1.27} \tag{4}$$

$$Q_{50}=5.40\ A^{0.69}\ S^{0.47}\ P^{1.12} \tag{5}$$

$$Q_{100}=9.14\ A^{0.70}\ S^{0.48}\ P^{1.01} \tag{6}$$

where Q_2, Q_5, Q_{10}, Q_{25}, Q_{50}, and Q_{100} are peak discharges, in cubic feet per second, of the 2-, 5-, 10-, 25-, 50-, and 100-year recurrence interval floods, respectively; A is the contributing drainage area of the basin, in square miles; S is the main channel slope, in feet per mile, between points 10 percent and 85 percent of the main channel length upstream from the site; and P is the mean annual precipitation, in inches, near the center of the basin (see fig. 1). The standard error of prediction for these equations is on the order of $\pm$40 percent for basins larger than 100 mi^2

(260 km^2). For basins smaller than 100 mi^2 (260 km^2), the standard error of prediction for equations (1), (2), and (3) is on the order of ± 60 percent; the standard error of prediction for equations (4), (5), and (6) could not be determined because of insufficient data. See Sauer (1974) for a more detailed description.

Equations (1) through (6) were developed for English units of measurements. To convert the peak discharges from cubic feet per second to the metric equivalent of cubic metres per second, multiply by 0.0283.

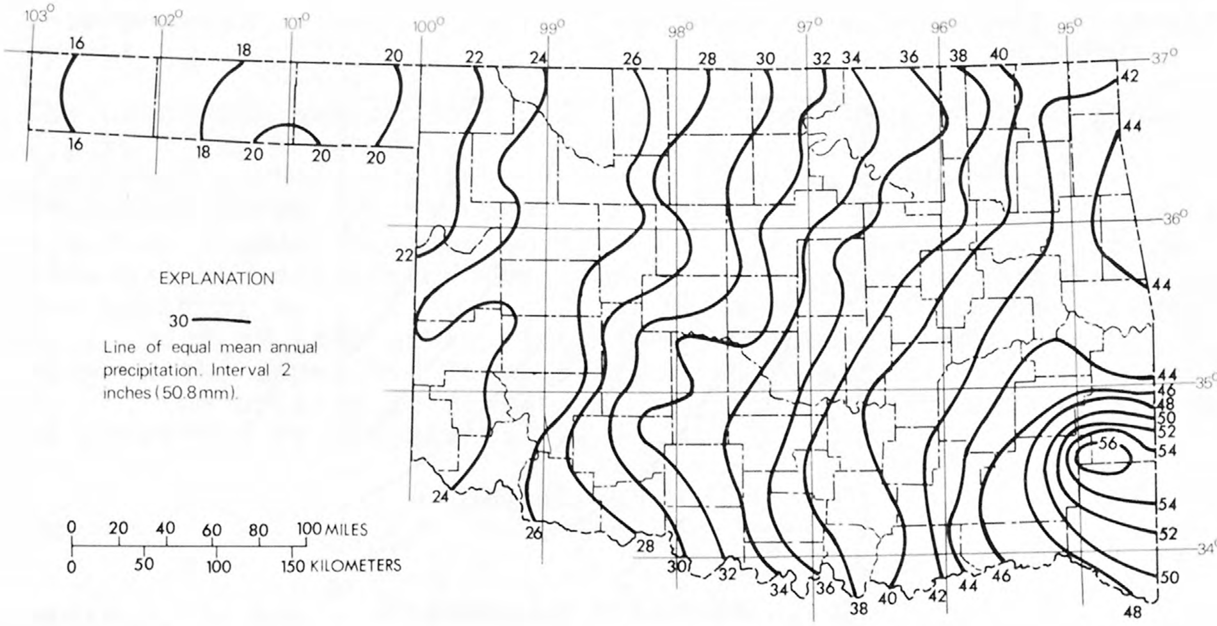

Figure 1.--Map showing mean annual rainfall for Oklahoma for the base period 1931-60

MEAN ANNUAL FLOOD FOR URBAN AREAS

Leopold (1968) summarized the results of several flood-frequency investigations for urban areas and developed the family of curves shown in figure 2. These curves are based on data from several different areas of the United States and define a ratio, R_L, which is equal to the mean annual urban flood, $Q_{2(u)}$, divided by the mean annual natural flood, Q_2. The percentage of impervious area, I, in the basin and the percentage of the basin served by storm sewers (including improved channels) are the parameters needed to estimate R_L. The curves of figure 2 were developed on the basis of a unit area of 1 mi^2 (2.59 km^2), from data for basins of 1 to 40 mi^2 (2.59 to 104 km^2). For this study, it has been assumed that the curves of figure 2 are applicable to basins of from 0.5 to 100 mi^2 (1.3 to 260 km^2). This assumption is supported within a small percentage by Anderson (1970) where the ratios for an average basin differed by approximately 10 percent from the ratios for small steep basins and large flat basins. By further assuming that the curves of figure 2 are applicable to urban areas of Oklahoma, the mean annual flood, $Q_{2(u)}$, for an urban area can be estimated from the equation,

$$Q_{2(u)} = R_L Q_2 \qquad (7)$$

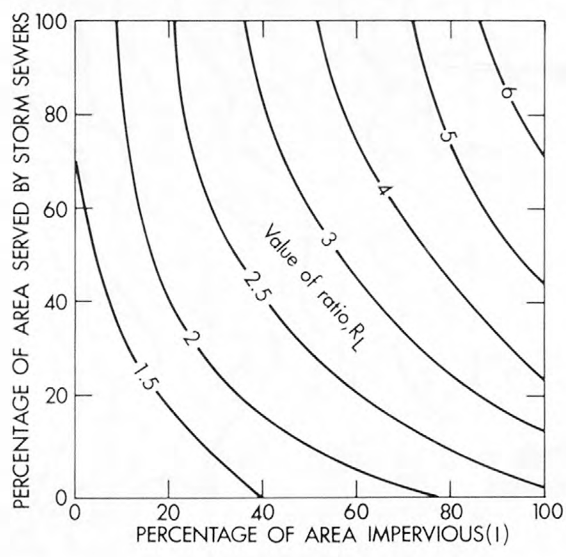

Figure 2.--Graph showing urban adjustment ratio, R_L, for mean annual flood

URBAN FLOODS GREATER THAN THE MEAN ANNUAL

Anderson (1970) suggested that the ratios of various recurrence interval floods to the mean annual flood for a 100-percent impervious area approached the respective ratios of the rainfall-intensity-frequency curve. For Oklahoma, U.S. Weather Bureau Technical Paper No. 25 (1955) was used to define average rainfall-intensity ratios, R_x, for selected recurrence intervals, x, as follows:

Recurrence interval, x, in years	Rainfall-intensity ratio, R_x
2	1.00
5	1.37
10	1.60
25	1.89
50	2.11
100	2.33

It is assumed for this report that the flood-frequency curve for a basin that is fully developed, 100-percent impervious and 100-percent storm-sewered, would have the same ratios, R_x, as the rainfall-intensity-frequency curve. It is highly unlikely that an urban basin would ever reach this degree of development, but the assumption serves to set an upper limit for purposes of interpolating flood frequency for intermediate degrees of development.

The preceding assumptions and the maximum value of $R_L=7$ from figure 2 can be used to compute the upper limiting flood-frequency curve for a fully developed basin. The flood-frequency curve for natural conditions ($R_L=1$) defines the lower limiting flood-frequency curve. Flood-frequency curves for intermediate degrees of development can then be interpolated on the basis of R_L. For example, if $R_L=4$ which is halfway between $R_L=1$ and $R_L=7$, the urban flood-frequency curve would lie halfway between the upper and lower limiting curves. Interpolation of $Q_{x(u)}$, the urban peak discharge for recurrence interval, x, can be expressed by the general equation,

$$Q_{x(u)} = \frac{7R_xQ_2(R_L-1)}{6} + \frac{Q_x(7-R_L)}{6} \qquad (8)$$

where Q_x is the peak discharge for natural conditions for recurrence interval, x, and other terms are as previously defined. Inserting numerical values of R_x in equation (8) results in the following flood-frequency equations for urban areas in Oklahoma:

$$Q_{5(u)}=1.60(R_L-1)Q_2 + 0.167(7-R_L)Q_5 \tag{9}$$

$$Q_{10(u)}=1.87(R_L-1)Q_2 + 0.167(7-R_L)Q_{10} \tag{10}$$

$$Q_{25(u)}=2.21(R_L-1)Q_2 + 0.167(7-R_L)Q_{25} \tag{11}$$

$$Q_{50(u)}=2.46(R_L-1)Q_2 + 0.167(7-R_L)Q_{50} \tag{12}$$

$$Q_{100(u)}=2.72(R_L-1)Q_2 + 0.167(7-R_L)Q_{100} \tag{13}$$

All equations are based on English units of measurement. To convert peak discharges to the metric equivalent of cubic metres per second, multiply by the factor 0.0283.

Equation (8) can be applied to another area (for instance, in another state) by inserting local values of R_x, Q_2, and Q_x. The user should, of course, satisfy himself that all assumptions are reasonable for the area in question.

EXAMPLE COMPUTATION

The following hypothetical example is given to illustrate the use of the equations for estimating flood frequency for an urban area. All discharges are rounded to two significant figures.

<u>Basin characteristics</u>:

$A = 10\ mi^2$

$S = 30$ ft/mi

$P = 32$ in

Percentage of basin impervious = 40

Percentage of basin storm sewered = 60

$R_L = 2.8$ (from fig. 2)

<u>Natural flood discharges</u>:

From equation (1),

$Q_2=0.0568(10)^{0.67}(30)^{0.37}(32)^{2.00}=960\ ft^3/s\ (27\ m^3/s)$

From equation (2),

$Q_5=0.498(10)^{0.66}(30)^{0.40}(32)^{1.58}=2,100$ ft^3/s(59 m^3/s)

From equation (3),

$Q_{10}=1.081(10)^{0.67}(30)^{0.42}(32)^{1.44}=3,100$ ft^3/s(88 m^3/s)

From equation (4),

$Q_{25}=2.56(10)^{0.68}(30)^{0.44}(32)^{1.27}=4,500$ ft^3/s(130 m^3/s)

From equation (5),

$Q_{50}=5.40(10)^{0.69}(30)^{0.47}(32)^{1.12}=6,300$ ft^3/s(180 m^3/s)

From equation (6),

$Q_{100}=9.14(10)^{0.70}(30)^{0.48}(32)^{1.01}=7,800$ ft^3/s(220 m^3/s)

Urban flood discharges:

From equation (7),

$Q_{2(u)}=2.8(960)=2,700$ ft^3/s(76 m^3/s)

From equation (9),

$Q_{5(u)}=1.60(2.8-1)(960)+0.167(7-2.8)(2,100)=$

4,200 ft^3/s(120 m^3/s)

From equation (10),

$Q_{10(u)}=1.87(2.8-1)(960)+0.167(7-2.8)(3,100)=$

5,400 ft^3/s(150 m^3/s)

From equation (11),

$Q_{25(u)}=2.21(2.8-1)(960)+0.167(7-2.8)(4,500)=$

7,000 ft^3/s(200 m^3/s)

From equation (12),

$Q_{50(u)}=2.46(2.8-1)(960)+0.167(7-2.8)(6,300)=$

8,700 ft^3/s(250 m^3/s)

From equation (13),

$$Q_{100(u)} = 2.72(2.8-1)(960) + 0.167(7-2.8)(7,800) = 10,000 \text{ ft}^3/\text{s} \ (280 \text{ m}^3/\text{s})$$

The natural and urban flood-frequency curves for this hypothetical example have been plotted in figure 3 for comparative purposes. Note that the curves are converging at the higher recurrence intervals. This is generally to be expected because the effects of urbanization are reduced as flood magnitude increases. In this instance, the mean annual flood, Q_2, is increased by a factor of 2.8, whereas the 100-year flood, Q_{100}, is increased by a factor of only 1.3.

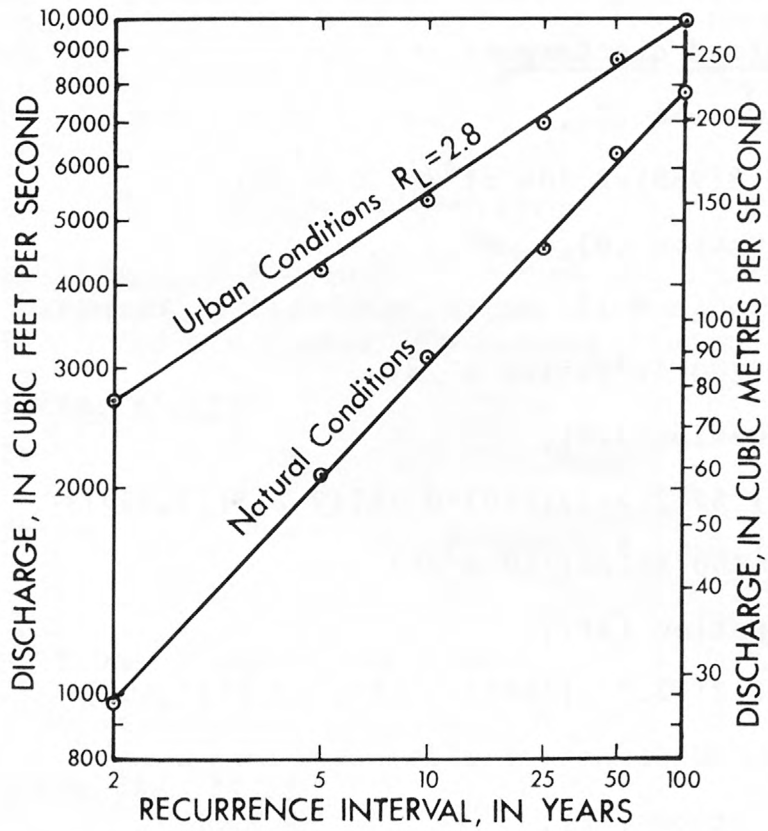

Figure 3.--Graph showing comparison of natural and urban flood-frequency curves for a hypothetical basin

SUMMARY

Equation (7) and equations (9) through (13) can be used in conjunction with equations (1) through (6) to estimate flood magnitude and frequency of streams in urban areas of Oklahoma. At the present time, there are no urban flood data for Oklahoma to verify this method and consequently the accuracy is questionable. The method does, however, take into account the natural flood-frequency characteristics of the stream in question, and then adjusts the natural data according to methods defined by other investigators using data for several different parts of the United States. The assumptions seem reasonable and the results appear logical. By making the same assumptions used for Oklahoma, equation (8) could be used in areas outside Oklahoma by inserting local values of R_x, Q_2, and Q_x.

This study emphasizes the need to obtain peak runoff data for urbanized areas in Oklahoma.

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