TECHNIQUES FOR ESTIMATING FLOOD DEPTHS FOR OKLAHOMA STREAMS

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Cover photograph.--Spring Creek at Silver Lake in Oklahoma City, flood of Nov. 2, 1974. Photograph furnished by Jim Lucas, Oklahoma City, Oklahoma.

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CONVERSION FACTORS FOR ENGLISH UNITS AND METRIC UNITS

English units	Conversion factor	Metric units
inches (in)	25.4	millimetres (mm)
feet (ft)	.305	metres (m)
square miles (mi^2)	2.590	square kilometres (km^2)

Multiply English units by the conversion factor to obtain metric units.
Divide metric units by the conversion factor to obtain English units.

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ABSTRACT

Regional relations are defined for estimating the depths of floods having recurrence intervals ranging from 2 to 100 years for both natural and urban streams in Oklahoma. Contributing drainage area and the 2-year 24-hour rainfall are the only independent variables required for estimating flood depths for natural streams. For urban streams the percentage of the basin impervious and served by storm sewers is also required. The only limitations are that the stream be unregulated, that the main channels be unimproved, and that the contributing drainage area and the 2-year 24-hour rainfall be in the range of values used to derive the relations. The standard errors of estimate range from 24 percent for the 50- and 100-year floods to 33 percent for the 2-year flood for the natural streams. The estimation error for urban streams is not evaluated due to paucity of data. Although the flood depths estimated from techniques presented in this report are considered less reliable than those obtained from field surveys and hydraulic computations, the ease and simplicity of their determination are expected to make them useful for many purposes.

Data on flood depths for 132 gaging stations are given in table 1.

INTRODUCTION

Areas adjacent to streams and rivers that are subject to flooding are called flood-prone areas. The intelligent and discreet use of these flood-prone areas requires knowledge of flood discharges and flood depths. Two earlier reports by Sauer (1974a, 1974b) provide techniques for estimating flood discharges for Oklahoma streams, both natural and urbanized.

The purpose of this report is to present techniques for estimating flood depths for the 2-, 5-, 10-, 25-, 50-, and 100-year floods for both natural and urban streams in Oklahoma. These flood depths when added to streambed elevations provide estimates of flood elevations needed for land-use development, flood-plain zoning, and flood-insurance studies.

A study by Leopold and Maddock (1953) showed that for less than bankfull discharge a basin-wide relation exists between stream depth and discharge when discharge is of equal frequency of occurrence at all sites. They proposed a general equation of the form $D = cQ^f$, where D is the average cross-section depth, Q is the discharge of a given frequency at the section, and c and f are constants for a given frequency. Thomas (1964) found this type of relation applicable for greater than bankfull discharges in New Jersey, and for simplicity modified the equation to $h = C(Q_{2.33})^f$, where h is the height of the water surface above the average channel bottom determined at the time of median (50-percent duration) discharge, $Q_{2.33}$ is the mean annual flood discharge (recurrence interval of 2.33 years), and c and f are constants for a given frequency. Gann (1968) further modified Thomas' equation to $h = cA^f$, where A is the contributing drainage area, h is the height of the water surface above the elevation of the 50-percent duration discharge and c and f are constants for a given frequency. Gann found this equation adequate to describe the flood height - drainage area-frequency relation for the plains area in Missouri.

Flood depths, determined at 132 gaging stations throughout the State, were related to basin, climatic, and channel geometry characteristics by multiple regression techniques. This analysis indicated that contributing drainage area, A, and the 2-year 24-hour rainfall, I, are the two most useful variables for estimating flood depths in Oklahoma. Multiple regression equations are presented in graphical form in this report for ease in computing the appropriate flood depths. Techniques also are presented for estimating flood depths for urbanized streams by adjusting natural flood depths with a factor, R_D, determined from the percentage of the basin that is impervious and served by storm sewers. The urban adjustment factor R_D is computed mathematically and is not based on actual data. Data collection is presently underway to verify the mathematical computation of R_D. Within the limitations of use and accuracy described in the report, the techniques presented can be applied quickly and easily in estimating flood depths for solving many common engineering and land-use planning problems.

The flood depths, utilized in computing the multiple regression equations, were based on data collected and published by the U.S. Geological Survey for many years as part of cooperative programs with various State and Federal agencies, principally the U.S. Army Corps of Engineers, Oklahoma Water Resources Board, and Oklahoma Department of Highways. Much of the small-streams data used in this report was collected through a special project with the Oklahoma Department of Highways and Federal Highway Administration. The main-channel width and depth data for the large watersheds greater than 100 mi^2 (260 km^2) were obtained from the Agriculture Research Service, U.S. Department of Agriculture, Chickasha, Okla.

Computation of Flood Depths

Flood depths were computed for 132 gaging stations throughout Oklahoma (fig. 1); of these stations approximately two-thirds have drainage areas less than 100 mi^2 (260 km^2). Log-Pearson Type III flood-frequency curves were computed for the small-stream gaging stations, less than 100 mi^2 (260 km^2), using annual peak discharge through September 30, 1974, following guidelines given in U.S. Water Resources Council Bulletin 15 (1967). Flood-frequency curves for the large streams, greater than 100 mi^2 (260 km^2), were computed by Sauer (1974a) in preparing a statewide flood-frequency report. Using the flood-frequency curve and the stage-discharge relation at each station, the 2-, 5-, 10-, 25-, 50-, and 100-year flood stages or elevations were computed. Flood depth, D_x, for recurrence interval x was computed as the difference between the flood elevation for recurrence interval x and the minimum elevation of the streambed. Data for all gaging stations used in the analysis are given in table 1. For estimating depths at or near gaging stations these data should be used in preference to the equations given in the next section.

Relation of Flood Depths to Basin, Climatic, and Channel Geometry Parameters

Standard multiple linear regression techniques were used to determine the relation of flood depths for selected recurrence intervals to basin, climatic, and channel geometry parameters. The final regression equation has the following form,

$$D_x = aA^bI^c \qquad (1)$$

where D_x = peak flood depth in feet or metres for recurrence interval x;
A = contributing drainage area in square miles;
I = the 2-year 24-hour rainfall in inches adapted from U.S. Weather Bureau Tech. Paper 40 (1961), see figure 2;
a = regression constant;
b, c = regression coefficients.

The coefficients b and c are significant at the 1-percent level for all recurrence intervals indicating that A and I are extremely useful for estimating flood depths. Several other parameters were investigated and found to be less significant. They were: main-channel slope, gage slope, main-channel length, main-channel elevation, a soils index, percent of basin forested, mean annual precipitation, mean annual evaporation, main-channel width and main-channel depth. Main-channel slope, computed at points which are 10 and 85 percent of the channel length, was significant at the 5-percent level for some recurrence intervals but not all. Gage slope, computed using two contour intervals upstream and downstream from the gage, was even more significant than main-channel slope but did not significantly

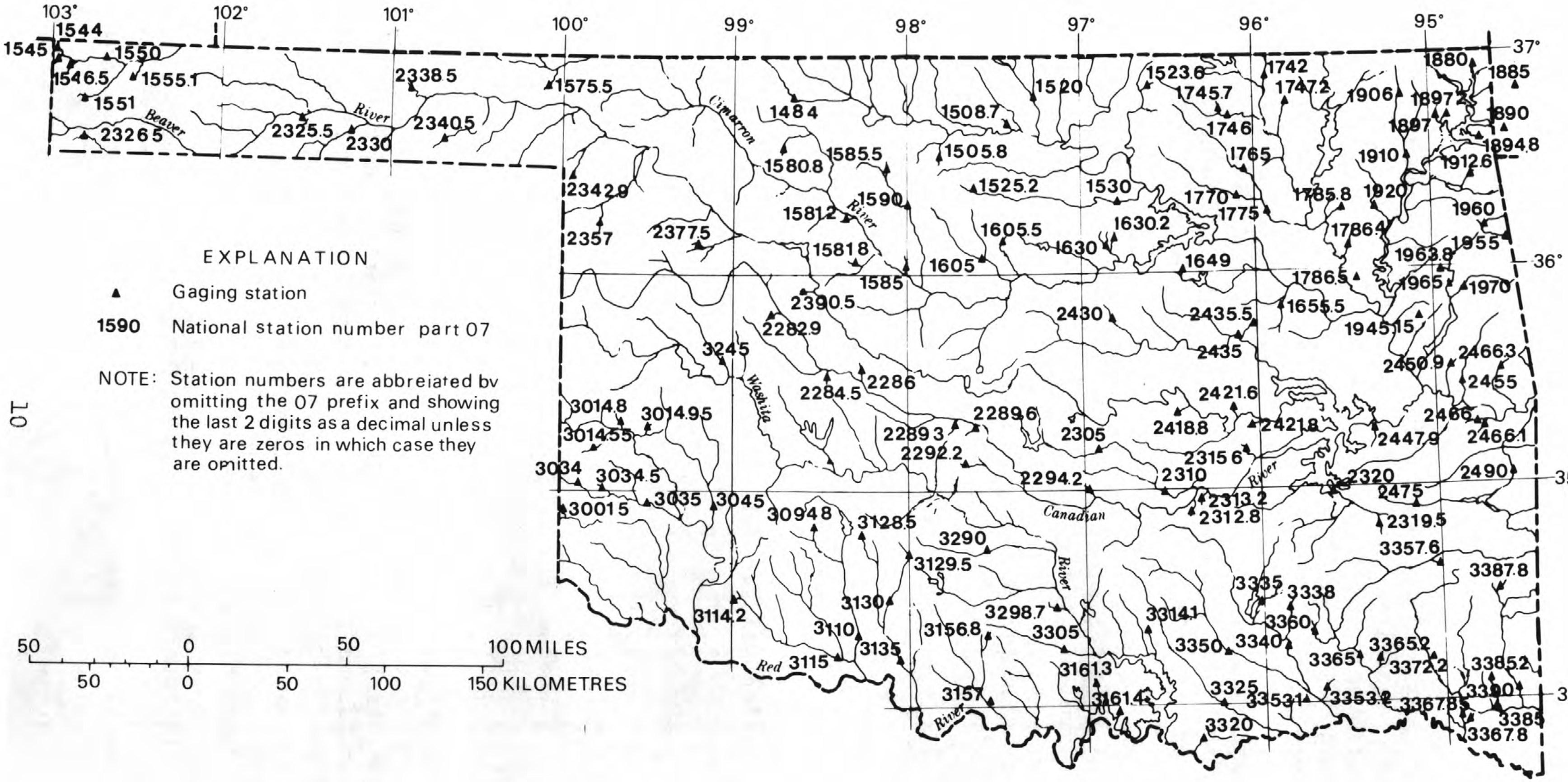

Figure 1.--Location of gaging stations for which flood depth data are listed in table 1.

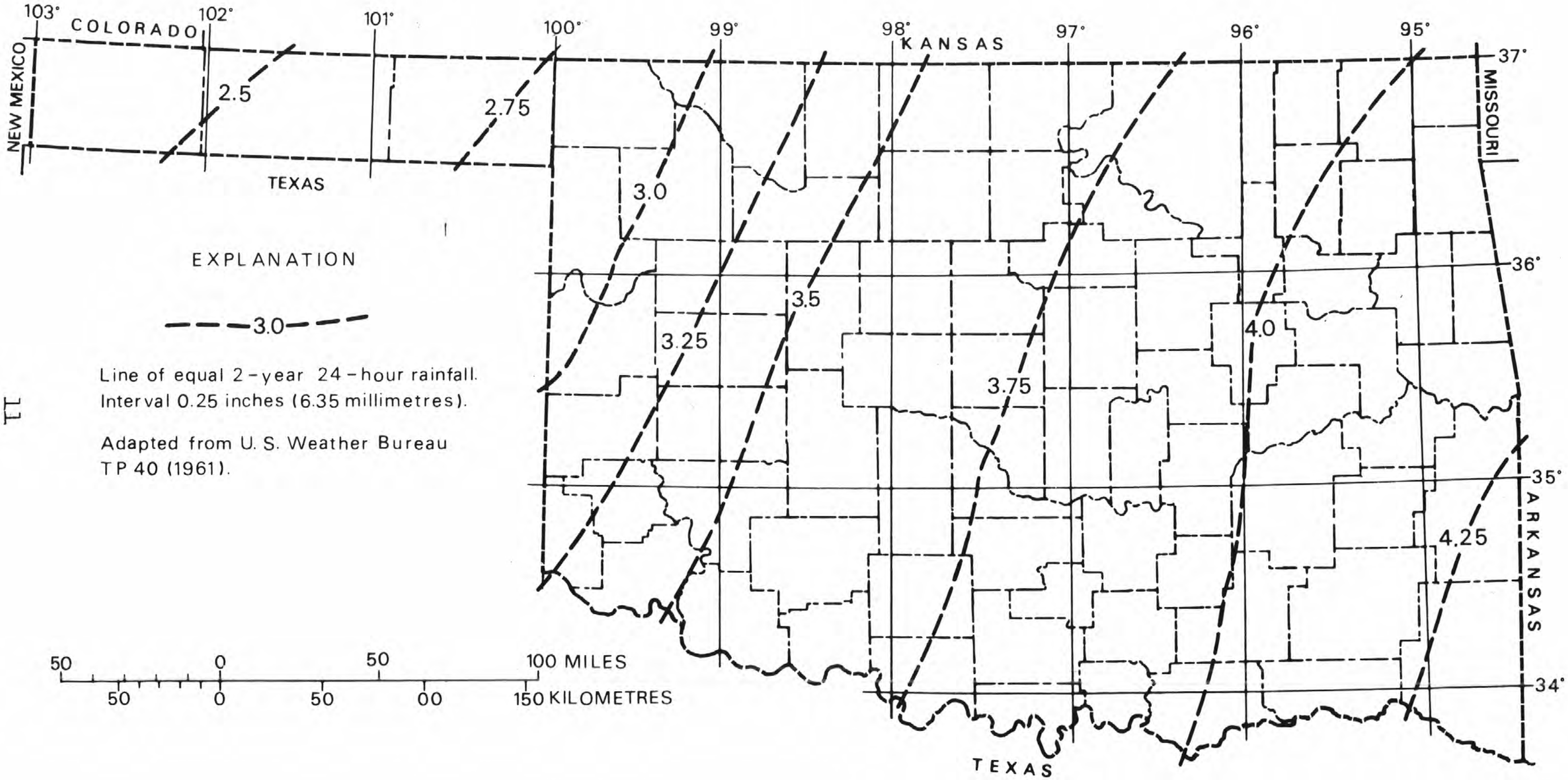

Figure 2-- The 2-year 24-hour rainfall for Oklahoma 1940-58.

reduce the standard error. The main-channel depth was significant at the 5-percent level for all recurrence intervals, but like the gage slope, it did not significantly reduce the standard error of estimate. Also main-channel depth cannot be determined from a map with suitable accuracy but requires a field survey. The added work could not be justified by the small reduction in standard error. The significance of main-channel depth in the regression analysis is discussed in a later section.

The following equations were defined in the regression analysis.

$$D_2 = 0.18\ A^{0.27}\ I^{2.00} \qquad (2)$$

$$D_5 = 0.53\ A^{0.24}\ I^{1.60} \qquad (3)$$

$$D_{10} = 0.85\ A^{0.22}\ I^{1.40} \qquad (4)$$

$$D_{25} = 1.20\ A^{0.21}\ I^{1.26} \qquad (5)$$

$$D_{50} = 1.58\ A^{0.20}\ I^{1.14} \qquad (6)$$

$$D_{100} = 1.95\ A^{0.19}\ I^{1.06} \qquad (7)$$

Equations 2-7 have been reduced to graphical form and are shown in figures 3, 4, 5, 6, 7, and 8, respectively.

Regional Analysis

Part of the variation in flood depths across the State is due to the variation in topography. Oklahoma does not have clearly defined topographic regions but there is a definite gradual change in topography from east to west. A regional analysis of the data indicated that the accuracy of the regression equations 2-7 could be improved by multiplying these equations by a regional factor. Figure 9 indicates the appropriate regional factors to use. The technical details of the regional analysis used to define figure 9 are discussed later in the section entitled "Analytical Technique."

To estimate flood depths for an ungaged site, use figures 3-8 and the appropriate contributing drainage area and 2-year 24-hour rainfall. Multiply these depths by the appropriate regional factor (RF) from figure 9. The final equations recommended for use for natural streams within the limitations described later in the report, have the following form:

$$D_2 = 0.18\ A^{0.27}\ I^{2.00}\ RF \qquad (8)$$

$$D_5 = 0.53\ A^{0.24}\ I^{1.60}\ RF \qquad (9)$$

$$D_{10} = 0.85\ A^{0.22}\ I^{1.40}\ RF \qquad (10)$$

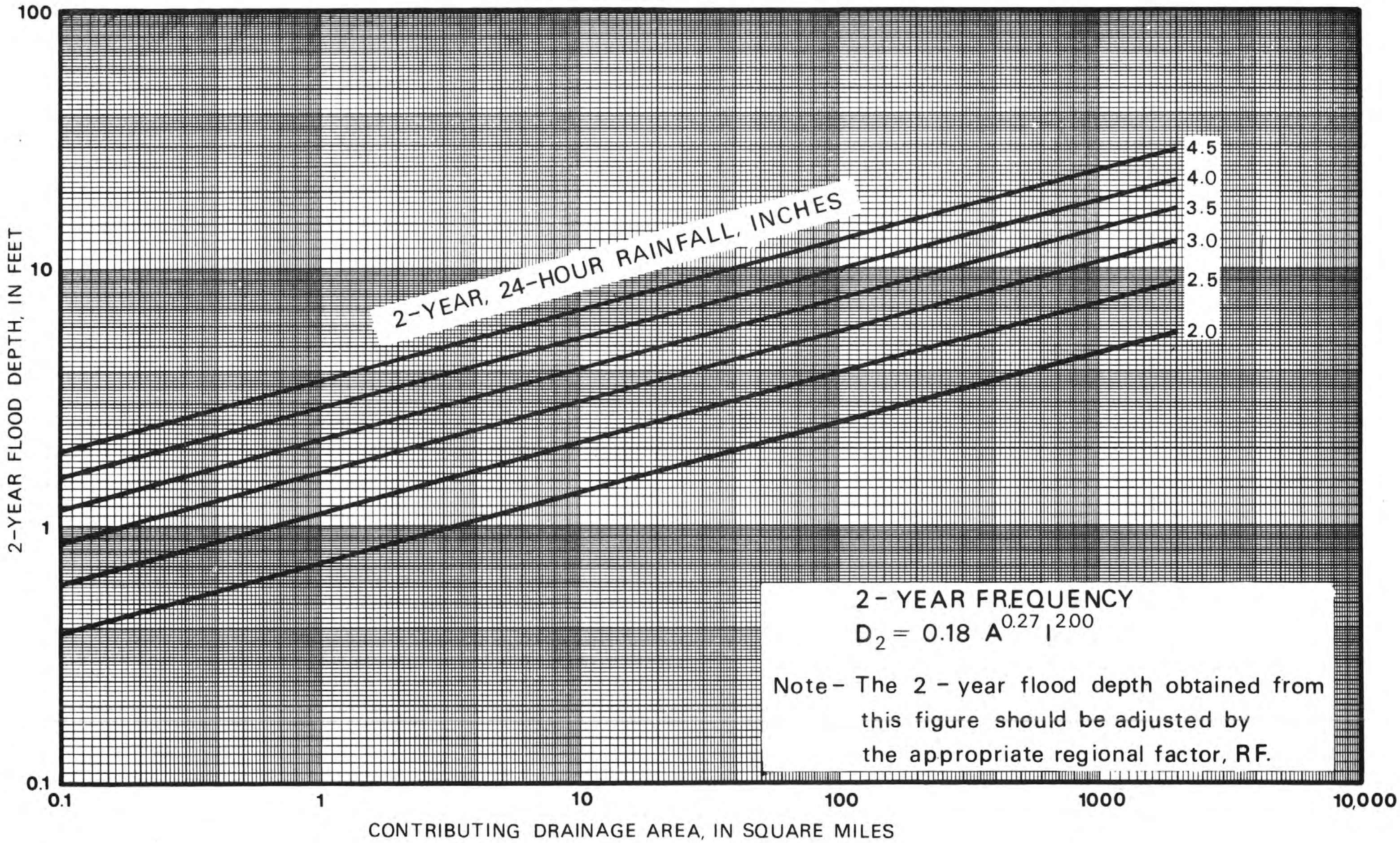

Figure 3.--Relation of 2-year flood depth to contributing drainage area and the 2-year 24-hour rainfall.

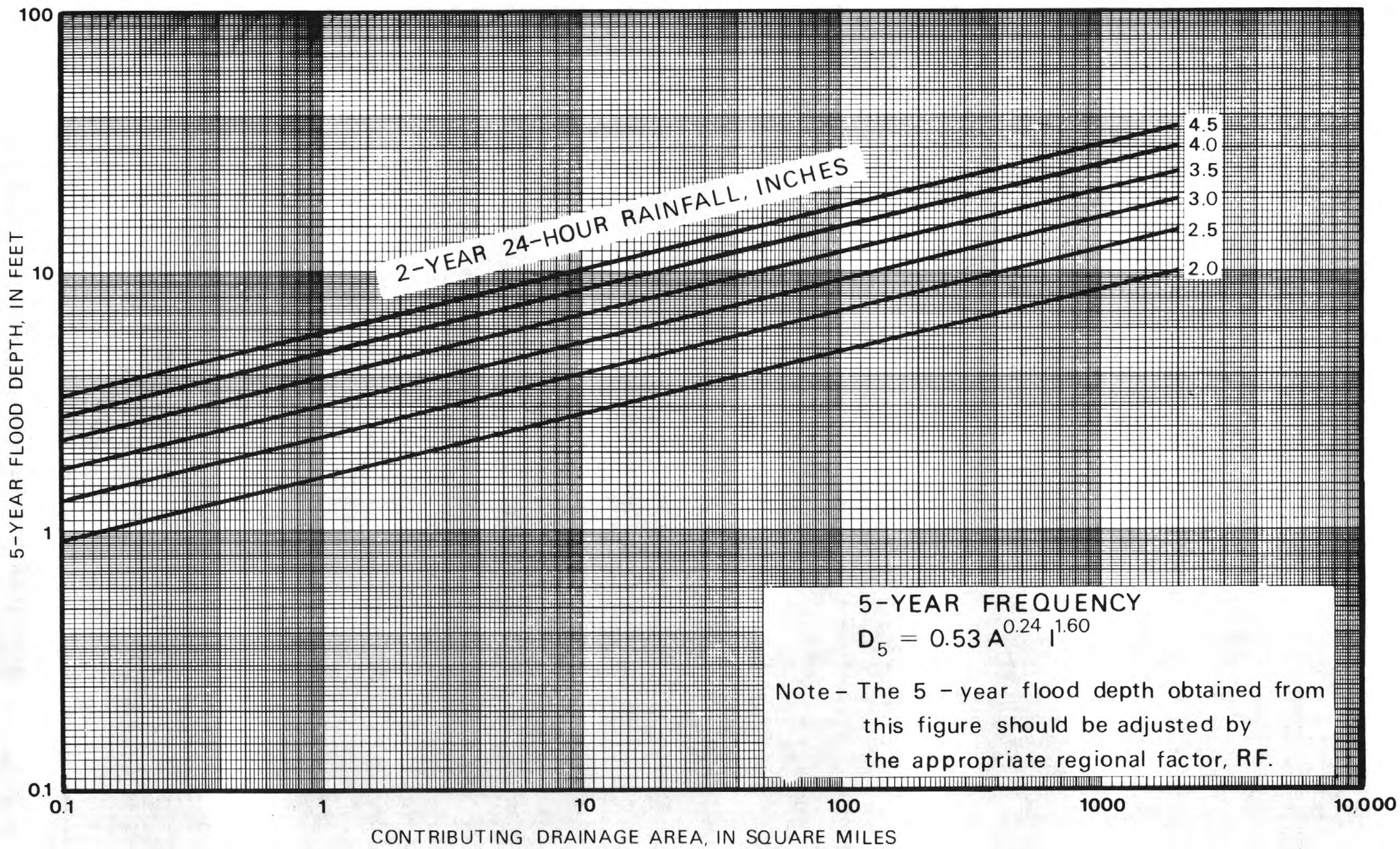

Figure 4--Relation of 5-year flood depth to contributing drainage area and the 2-year 24-hour rainfall.

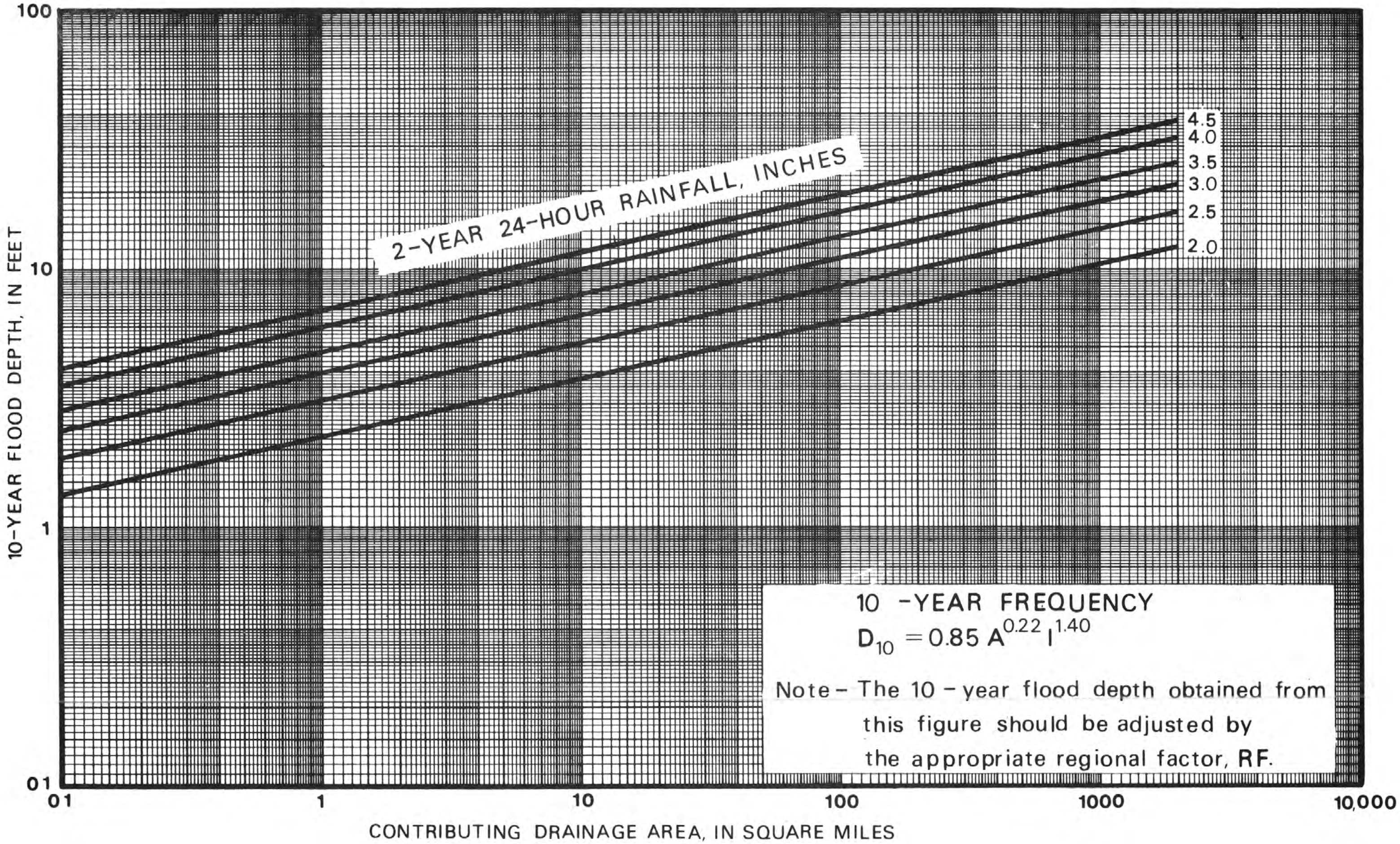

Figure 5.--Relation of 10-year flood depth to contributing drainage area and the 2-year 24-hour rainfall.

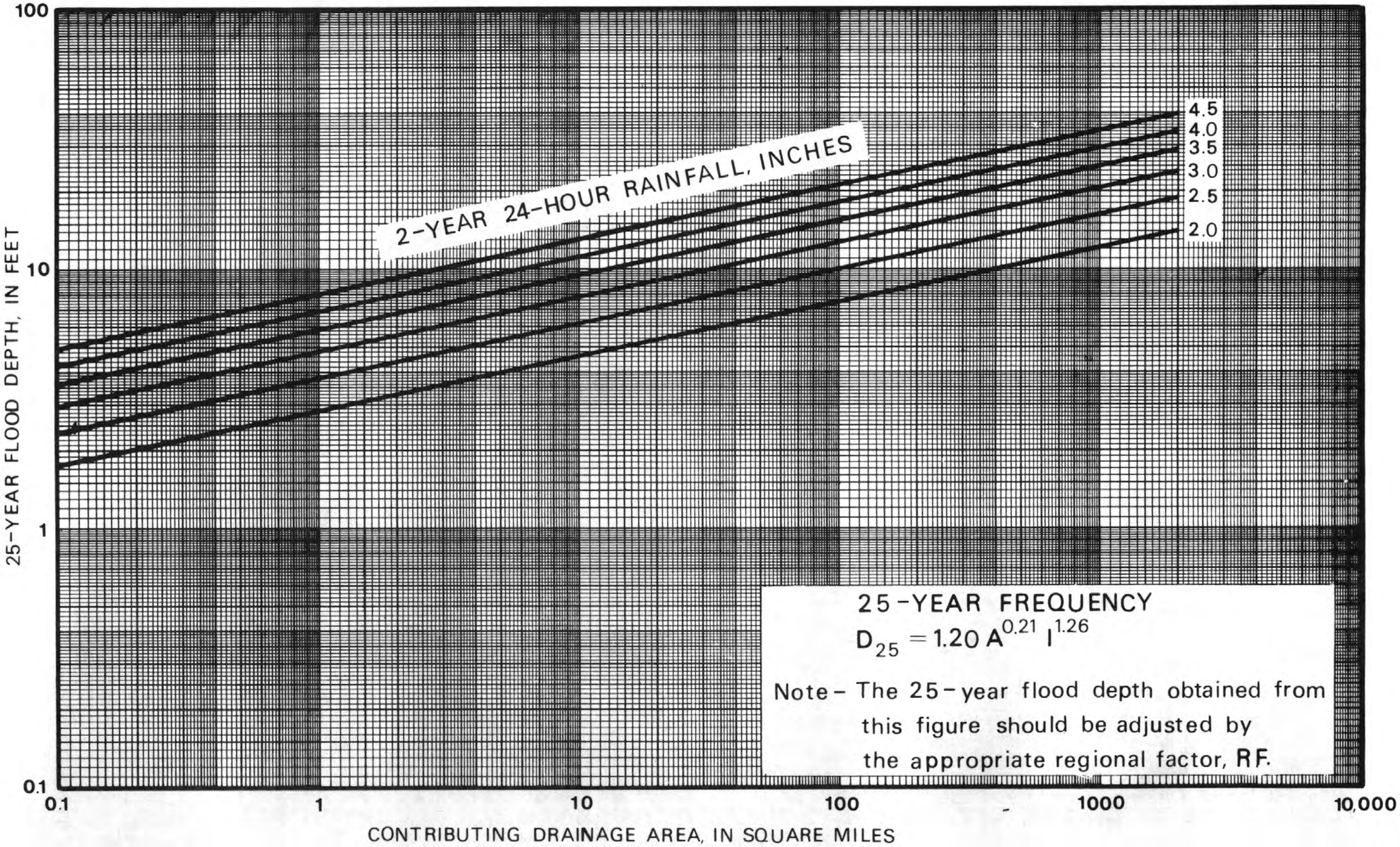

Figure 6.--Relation of 25-year flood depth to contributing drainage area and the 2-year 24-hour rainfall.

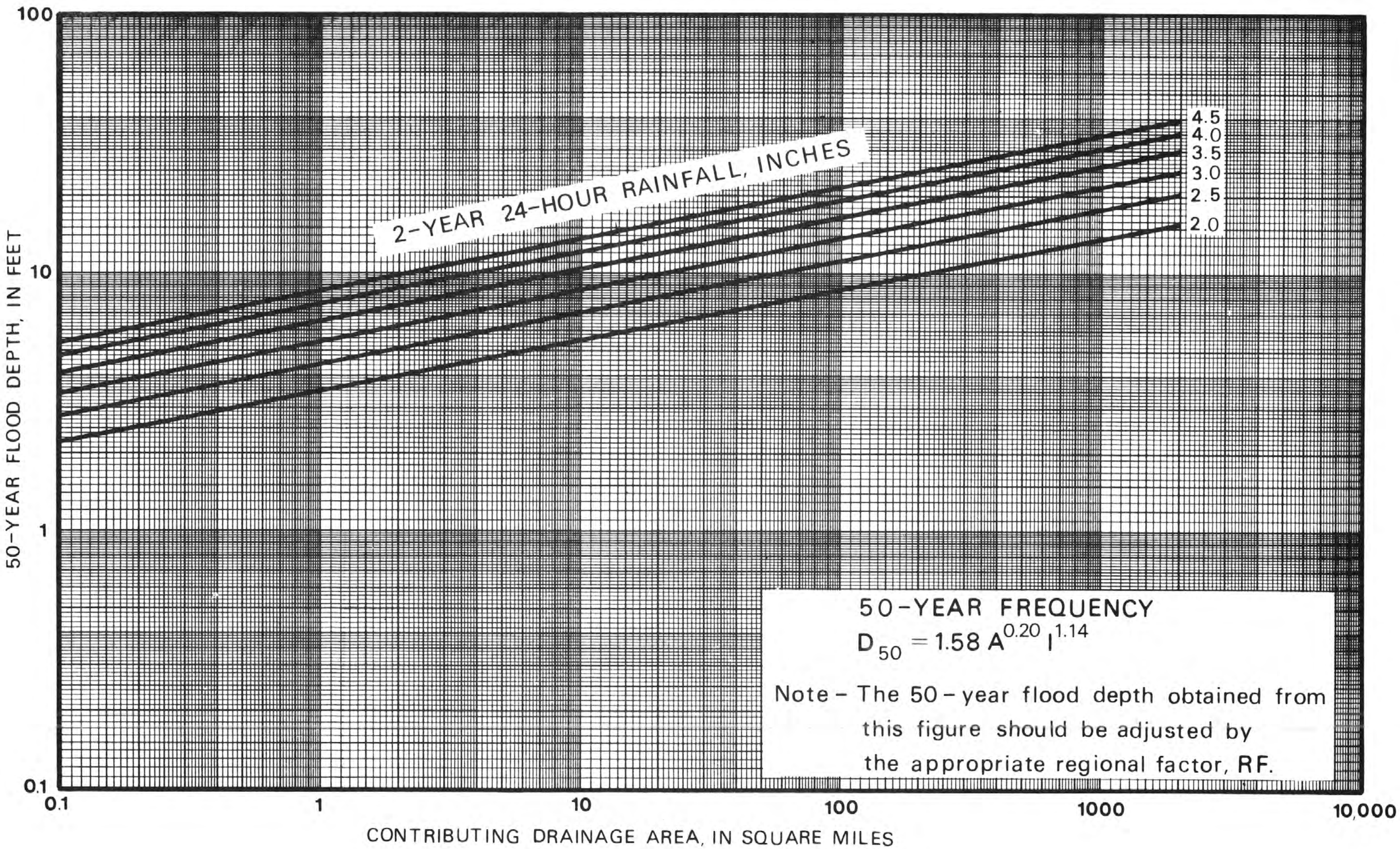

Figure 7.--Relation of 50-year flood depth to contributing drainage area and the 2-year 24-hour rainfall.

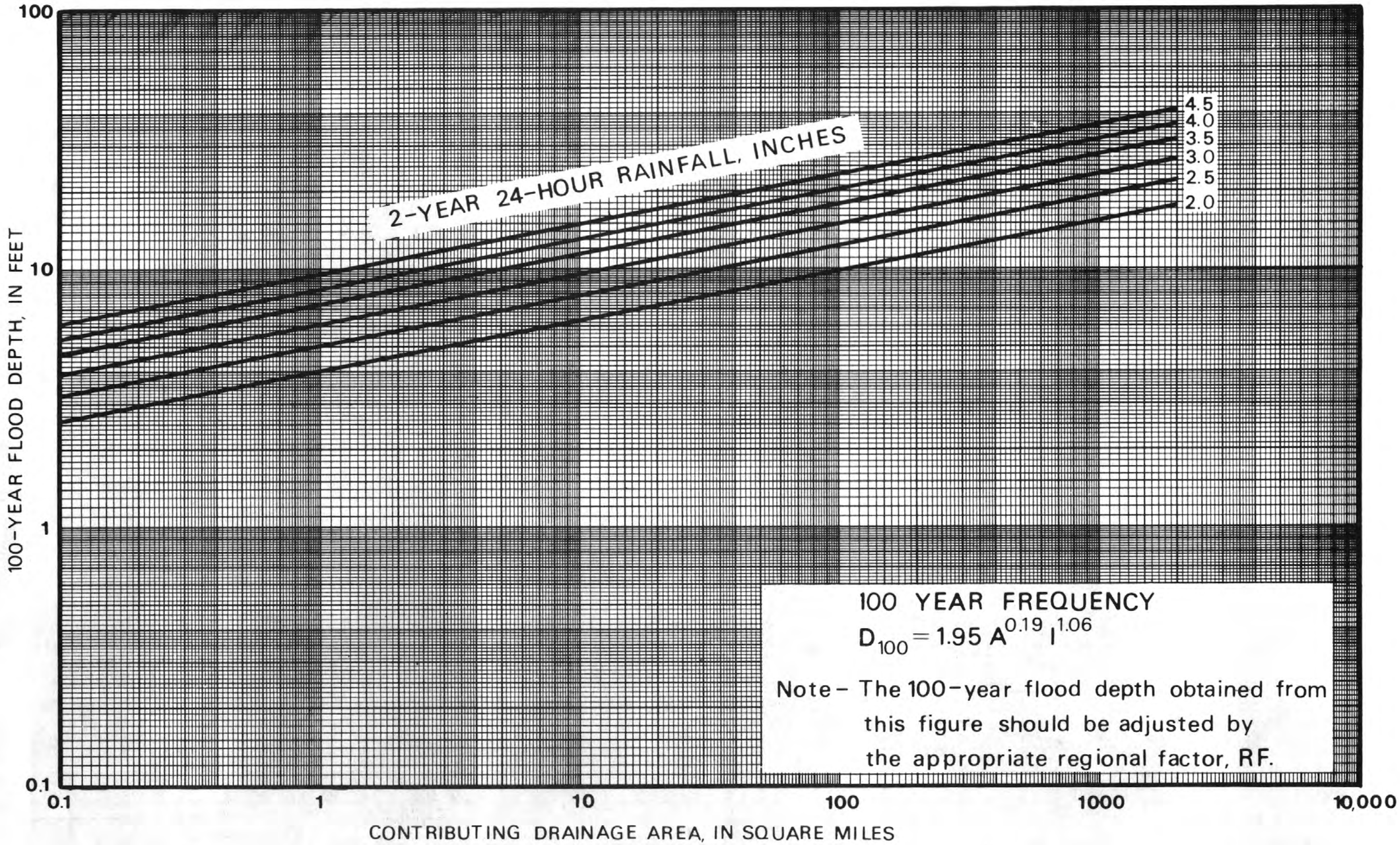

Figure 8.-- Relation of 100-year flood depth to contributing drainage area and the 2-year 24-hour rainfall.

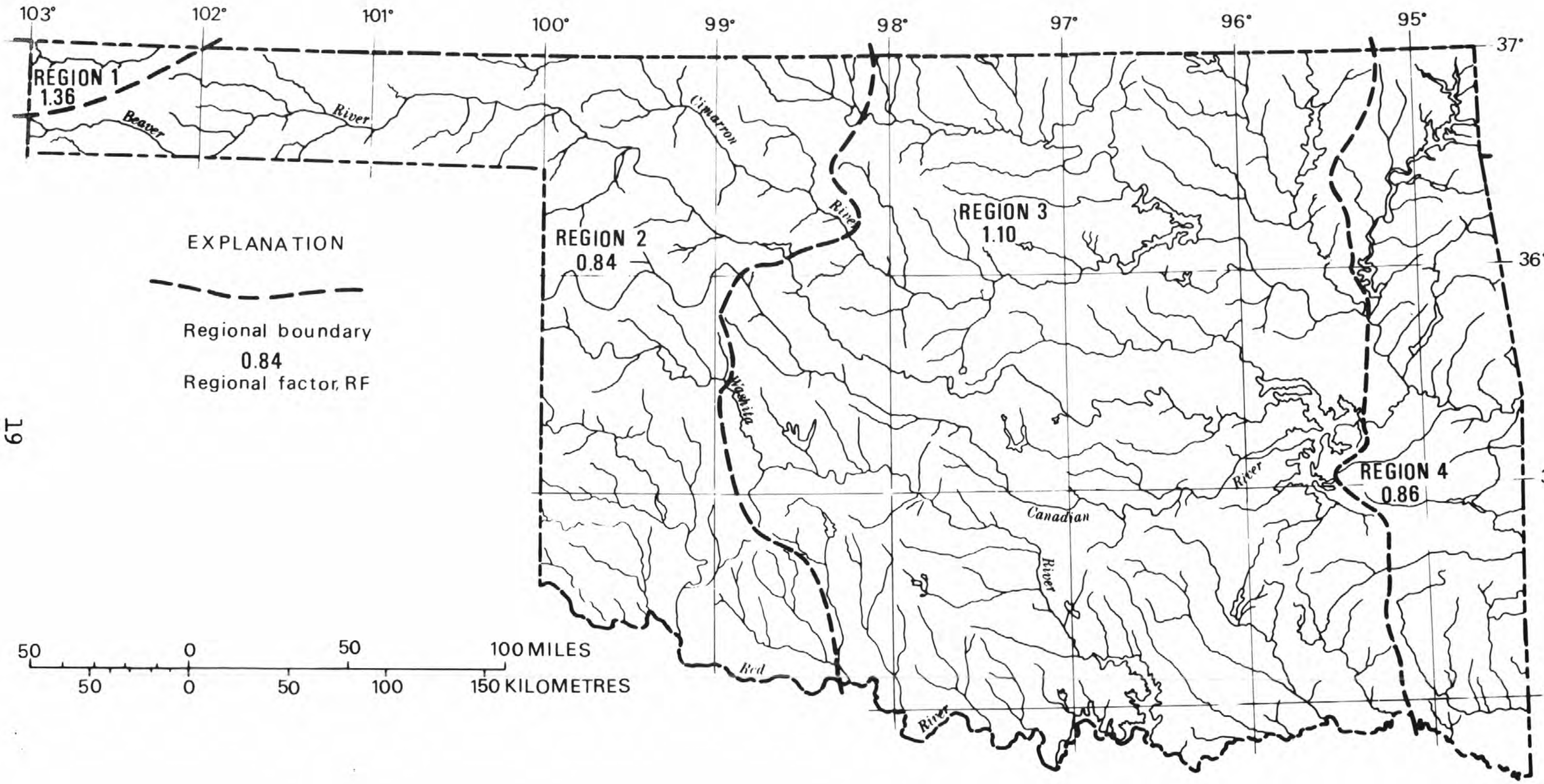

Figure 9.-- Map of Oklahoma showing boundaries of the regional factor, RF.

$$D_{25} = 1.20\ A^{0.21}\ I^{1.26}\ RF \qquad (11)$$

$$D_{50} = 1.58\ A^{0.20}\ I^{1.14}\ RF \qquad (12)$$

$$D_{100} = 1.95\ A^{0.19}\ I^{1.06}\ RF \qquad (13)$$

where RF is the regional factor from figure 9 and the remaining terms are the same as described for equations 2-7.

Computation of Urban Adjustment Factor

Planners and engineers often need to estimate flood depths in urban areas for land-use development and zoning purposes. An urban adjustment factor R_D was computed to adjust the flood depths obtained from equations 8-13. The mathematical derivation of R_D is given in the section entitled "Analytical Technique." The urban adjustment factor R_D is a function of an urban adjustment ratio R_L, determined by the percentage of the basin impervious and served by storm sewers. The relationship of R_L to the percentage of area impervious and served by storm sewers is given in figure 10 and was first defined by Leopold (1968). The urban adjustment ratio R_L as determined by Leopold indicates the increase in the 2-year flood discharge for given percentages of impervious area and areas served by storm sewers. Using results derived by Sauer (1974b) and equations given in table 2, the relationship between R_D and R_L was computed and is given in figures 11 and 12. Analysis of the equations given in table 2 indicated that the urban adjustment factor R_D was nearly identical for regions 1 and 2 (fig. 11) and also for regions 3 and 4 (fig. 12). The interested reader should consult the section entitled "Analytical Technique" for details of how figures 11 and 12 were developed.

The urban adjustment factor, R_D, equals 1.0 for rural basins having no significant urban development (less than 15 percent impervious areas and storm sewers). Also R_D decreases as the recurrence interval increases because for the higher floods the effects of impervious area and storm sewers become less significant. The final equations recommended for use for urban streams have the following form:

$$D_2\ (u) = 0.18\ A^{0.27}\ I^{2.00}\ RF\ R_D \qquad (14)$$

$$D_5\ (u) = 0.53\ A^{0.24}\ I^{1.60}\ RF\ R_D \qquad (15)$$

$$D_{10}\ (u) = 0.85\ A^{0.22}\ I^{1.40}\ RF\ R_D \qquad (16)$$

$$D_{25}\ (u) = 1.20\ A^{0.21}\ I^{1.26}\ RF\ R_D \qquad (17)$$

$$D_{50}\ (u) = 1.58\ A^{0.20}\ I^{1.14}\ RF\ R_D \qquad (18)$$

$$D_{100}\ (u) = 1.95\ A^{1.19}\ I^{1.06}\ RF\ R_D \qquad (19)$$

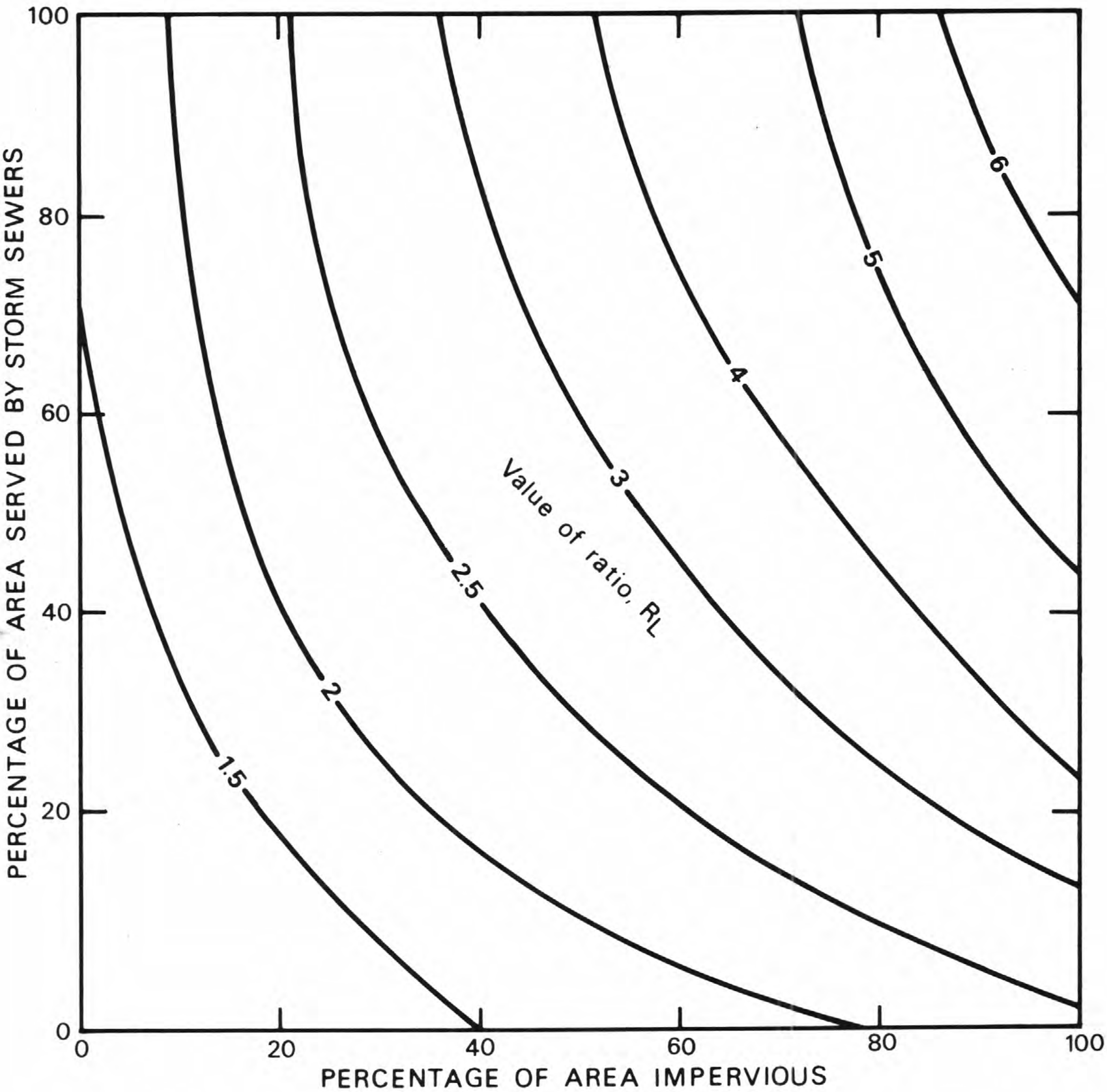

Figure 10.--Graph showing relation of urban adjustment ratio (R_L) to percentage of area impervious and served by storm sewers.

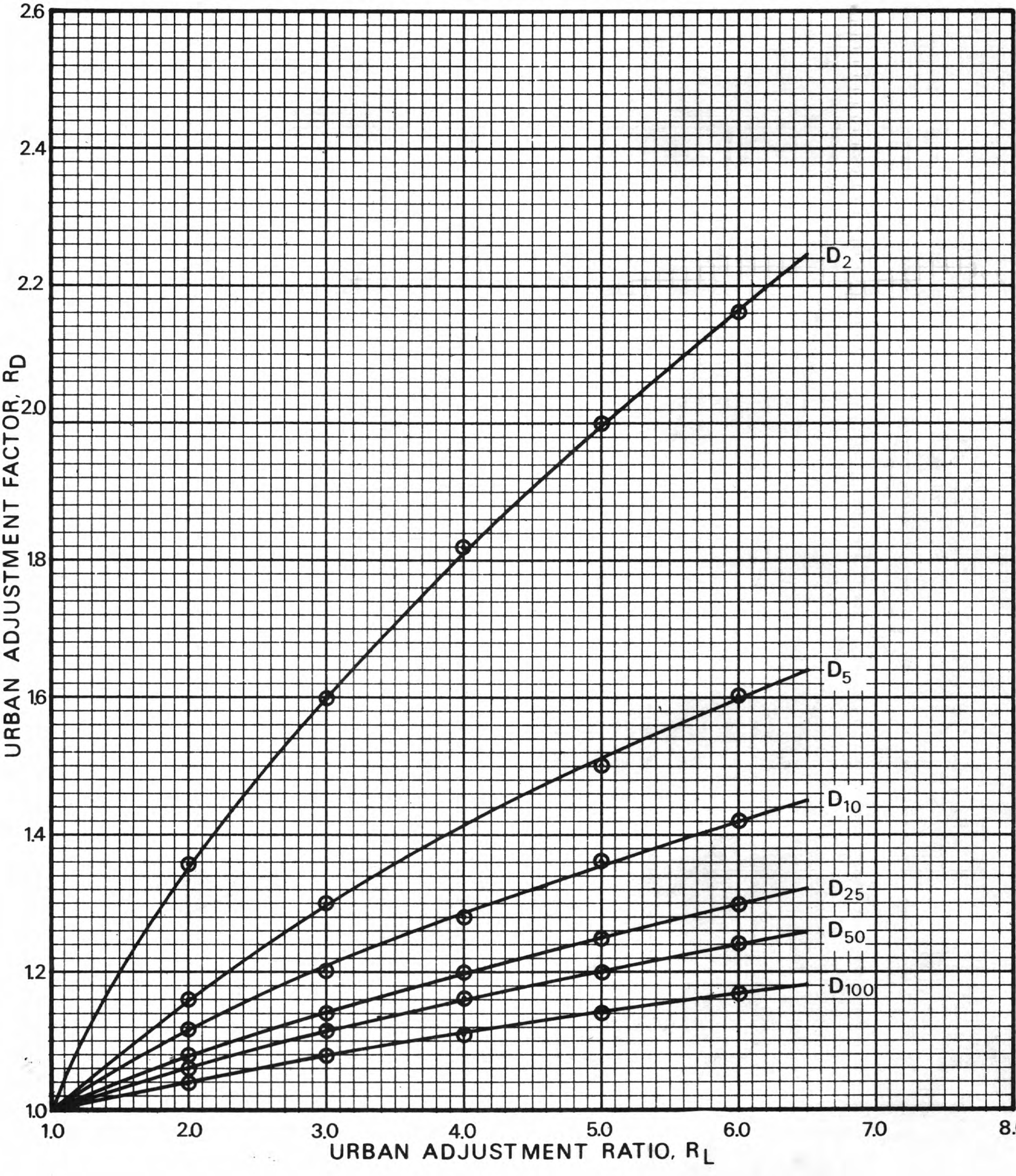

Figure 11.--Relation of urban adjustment factor (R_D) to urban adjustment ratio (R_L) for regions 1 and 2.

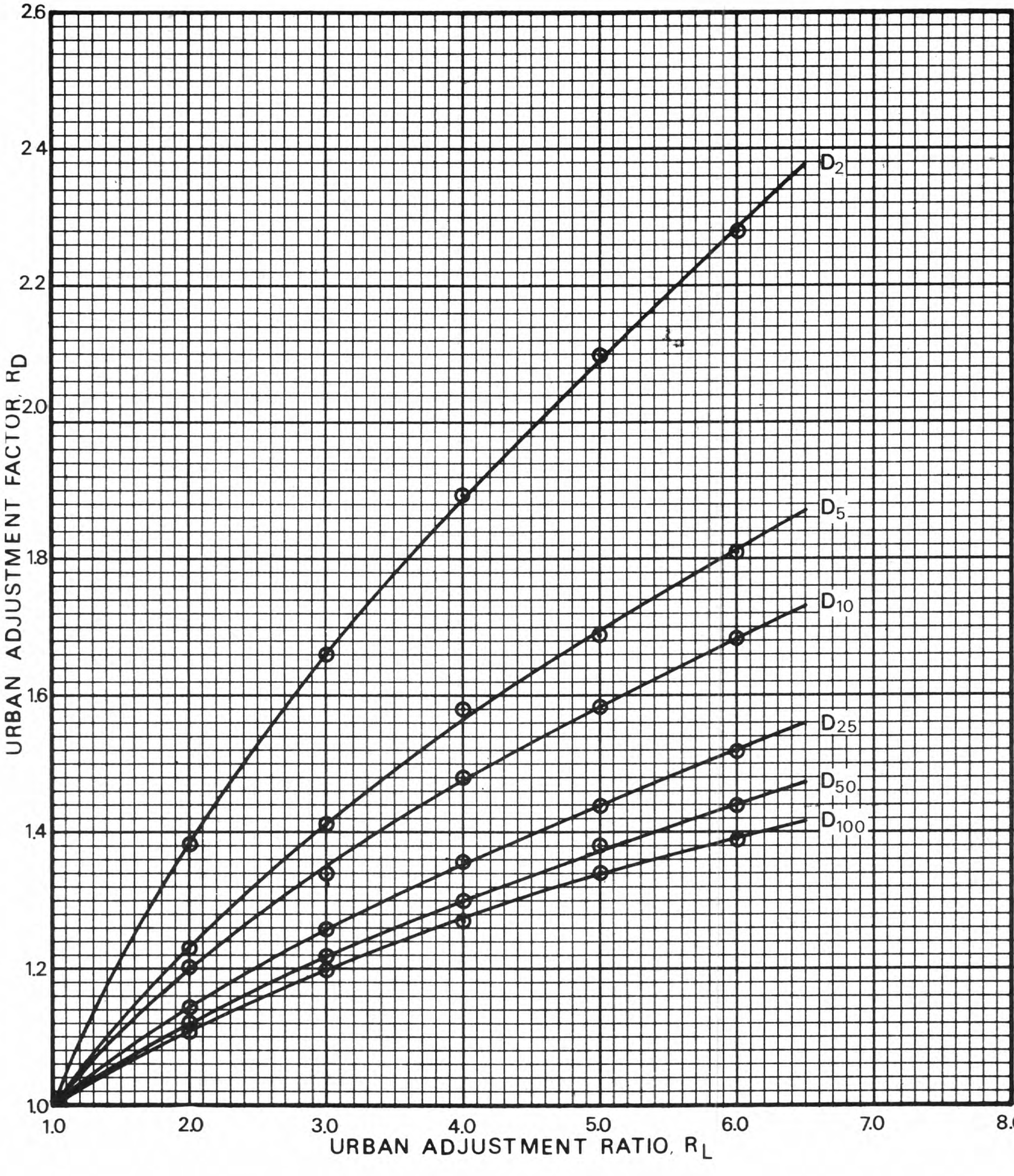

Figure 12.--Relation of urban adjustment factor (R_D) to urban adjustment ratio (R_L) for regions 3 and 4.

where eveything is the same as defined before for equations 9-13 except R_D which is the urban adjustment factor from figures 11 and 12. The use of equations 14-19 is facilitated by utilizing figures 3-12.

Application of Technique

The following hypothetical example is given to illustrate the techniques presented in earlier sections of this report. Assume a 100-year flood depth estimate is needed for a natural channel stream draining an urban area in Oklahoma City. The contributing drainage area and streambed elevation at the site can be computed from the latest U.S. Geological Survey topographic map. The 2-year 24-hour rainfall can be interpolated from figure 2. Assume the following basin and climatic characteristics have been determined:

$A = 10.0\ mi^2\ (25.9\ km^2)$
$I = 3.75$ in (95 mm)
Percentage of basin impervious = 50
Percentage of basin storm sewered = 55
Streambed elevation at site = 1,200 ft (366 m)

From figure 8 the D_{100} (unadjusted) depth is 12.3 ft (3.8 m). Since Oklahoma City is in region 3 the 12.3 ft (3.8 m) must be multiplied by 1.10 from figure 9 to give 13.5 ft (4.1 m). If the given stream did not drain an urban area, then 13.5 ft (4.1 m) would be the final estimate of the 100-year flood depth with a standard error of estimate of $\pm$ 3.2 ft (1.0 m). (For a discussion of accuracy of results see the section entitled "Accuracy and Limitations.") Because the basin is 50 percent impervious and 55 percent storm sewered, and R_L ratio of 2.9 is determined from figure 10. Entering figure 12 with $R_L = 2.9$ gives a value of 1.19 for R_D. Therefore the final estimate of the 100-year flood depth is 13.5 ft x 1.19 = 16.1 ft (4.9 m). The 16.1 ft (4.9 m) when added to 1,200 ft (366 m) gives a 100-year flood elevation of 1,216.1 ft (371 m). The estimate of accuracy of the urban flood depth cannot be determined but is greater than $\pm$ 3.2 ft (1.0 m) computed above.

ACCURACY AND LIMITATIONS

The evaluation of the accuracy of the regression equations is an important part of the total analysis. The accuracy evaluation provides a measure of confidence of each depth estimate. The accuracy in percent, referred to as the standard error of estimate, is the range of error to be expected about two-thirds of the time. The standard error of estimate is a measure of how well the observed data agree with the regression equation and is computed from the differences between observed data and the regression equation. The standard errors of estimate for equations 8-13 are summarized in the following table.

Recurrence interval, in years	Standard error of estimate, in percent
2	33
5	28
10	26
25	25
50	24
100	24

The standard error of estimate for the 100-year flood depth of ±24 percent means that an estimate of 15 ft (4.6 m) is accurate within ± 3.6 ft (1.1 m) two-thirds of the time.

The standard errors given in the table above are 4 to 7 percent lower than the standard errors of the statewide equations 2 to 7. The accuracy of equations 14-19 could not be determined because of the paucity of actual urban runoff data to compare with the computed values. Obviously, the standard error of estimate for equations 14-19 will be greater than the values given in the table above for natural streams. Even considering this fact equations 14-19 probably will give answers closer to the true values than by simply ignoring the effect of urbanization. Obtaining better answers is particularly true for the lower recurrence interval floods which are most affected by urbanization.

The regional regression equations 8-13 are applicable for the range in independent variables used to compute them. Contributing drainage area, A, ranged from 0.26 mi^2 (0.67 km^2) to 2,510 mi^2 (6,500 km^2) and the 2-year 24-hour rainfall, I, ranged from 2.20 in (55.9 mm) to 4.30 in (109.2 mm) for the 132 stations used in the analysis. Because of the linearity of the regression equations, some extrapolation is possible but the standard error of estimate may be greater than that shown in the table above.

Equations 8-13 should not be used where dams and flood-detention structures have a significant effect on flood discharge and depths. Equations 8-13 were defined using data from natural unimproved channels and should not be used for estimating depths in concrete-lined channels or channels significantly changed by man. For improved channels the depths should be computed using open-channel hydraulics formulas.

Equations 8-13 should not be used for urban areas where a significant percentage (greater than 15 percent) of the basin is impervious or served by storm sewers. When estimating flood depths for urban streams, equations 14-19 should be used.

The same limitations on contributing drainage area and 2-year 24-hour rainfall given for equations 8-13 apply to equations 14-19. Also equations 14-19 should not be used for regulated streams or streams with significantly improved channels. Equations 14-19 can be used for streams draining urban areas (impervious areas served by storm sewers) provided the main channels have not been significantly changed by man. Tributaries to the main channel may be storm sewers or improved channels.

ANALYTICAL TECHNIQUE

This section discusses some of the more technical points in the analysis that were omitted from earlier sections to increase their readability. This section discusses the multiple regression analysis in more detail, provides justification for the regional analysis, and discusses the computation of urban adjustment factor R_D shown in figures 11 and 12.

In addition to contributing drainage area and the 2-year 24-hour rainfall, several other parameters were investigated in the multiple regression analysis for estimating flood depths. Of those parameters mentioned in an earlier section, main-channel depth was the most significant. Main-channel depth as used in this analysis was computed as the difference in the minimum elevation of the streambed and the lower bank of the main channel. The main-channel depth for the watersheds greater than 100 mi^2 (260 km^2) was determined in the field by the Agriculture Research Service, Chickasha, Okla. The main-channel depth for the small watersheds less than 100 mi^2 (260 km^2) was determined from cross sections run for contracted opening measurements, slope-area measurements, culvert measurements, and step-backwater surveys. The inclusion of main-channel depth in the regression equation reduced the standard error of estimate 2 to 3 percent. This reduction in standard error of estimate was not significant enough to warrant the inclusion of main-channel depth in the regression equation. Main-channel depth cannot be determined from topographic maps, generally available, with suitable accuracy so a field determination is necessary. The added work of going to the site to compute main-channel depth did not seem warranted for such a small reduction in standard error.

The use of main-channel depth and other channel geometry parameters should be considered in future analyses. If the small watershed channel geometry data had been determined in the field, then main-channel depth might have been more useful in estimating flood depths.

A nonlinear equation of the form $D_x = aA^{bA^d}I^c$ also was investigated. For a value of d = 0, the nonlinear equation reduces to the same form as equations 2-19. Several runs were made using the above equation, each time changing the value of d. The minimum value of the standard error of estimate occurred at d = 0.02 but this standard error was not significantly lower than the linear equation of the form $D_x = aA^bI^c$.

The regional analysis consisted of plotting the residuals, the difference in log units between observed depth and computed depth, on a State map to investigate any regional trends. These residuals indicated a definite trend and defined the regional boundaries shown in figure 9. The regional boundaries were drawn primarily along river-basin divides on the basis of the residual data. Some justification for the regional boundaries is provided by observing the physical divisions of Fenneman (1930). Mathematically the regional factor is the geometric mean of the ratio, observed depth divided by computed depth, or the arithmetic mean of the residuals in log units.

Region 1 is the northwest corner of the Oklahoma Panhandle classified by Fenneman (1930) as the Raton section of the Great Plains province and characterized by lava-capped plateaus, buttes, and incised channels. This area differs considerably in topography from the rest of the Great Plains area in Oklahoma and includes the upper part of the Cimarron River basin. The regional factor (RF) for region 1 is 1.36.

Region 2 includes the rest of the Oklahoma Panhandle and the western part of the Osage Plains area (Fenneman, 1930). The regional factor (RF) for region 2 is 0.84.

Region 3 is composed primarily of the Osage Plains area (Fenneman, 1930) and characterized by old scarped plains with main streams intrenched. The regional factor (RF) for region 3 is 1.10.

Region 4 is composed of the Ozark Plateaus in the north and Ouachita province in the south (Fenneman, 1930). The northern part of the region is characterized by plateaus whereas the southern part of the region is fairly mountainous. The regional factor (RF) for region 4 is 0.86.

The urban adjustment factor R_D was introduced in an earlier section but the mathematical derivation was deferred until this section. Sauer (1974b) presented the following equation for adjusting flood discharges for Oklahoma streams:

$$Q_x\ (u) = \frac{7\ R_x Q_2 (R_L - 1)}{6} + \frac{Q_x\ (7 - R_L)}{6} \qquad (20)$$

where Q_x (u) and Q_x are the peak discharges for urban and rural conditions, respectively, for recurrence interval x; Q_2 is the natural 2-year flood discharge, R_L is an urban adjustment ratio determined by the percentage of the basin impervious and served by storm sewers and defined in figure 10, R_x is a rainfall-intensity ratio for recurrence interval x defined in the following table.

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

By substituting the appropriate values of R_x, R_L, and Q_x in equation 20 the x-year urban flood discharge can be computed.

Utilizing the results of Leopold and Maddock (1953) and Thomas (1964), equations of the following form were assumed to hold

$$D_x(u) = k(Q_x(u))^y \qquad (21)$$

and

$$D_x = kQ_x{}^y \qquad (22)$$

where $Q_x(u)$ and Q_x are peak discharges for urban and natural conditions, respectively; $D_x(u)$ and D_x are peak depths for urban and natural conditions, respectively, for recurrence interval x; and k and y are constants for a given frequency. The constants k and y were assumed to be the same for both equations 21 and 22 because these equations apply only to natural unimproved channels.

Dividing equation 21 by 22 yields the following results

$$\frac{D_x(u)}{D_x} = \left(\frac{Q_x(u)}{Q_x}\right)^y \qquad (23)$$

For a given increase in $Q_x(u)$ equation 23 gives the corresponding increase in $D_x(u)$. Equations of the form $D_x = kQ_x{}^y$ were computed for each region and recurrence interval to determine the value of y in equation 23. These equations are summarized in table 2. Substituting equation 20 into equation 23 and simplifying gives the following equation

$$D_x(u) = (1.166\ R_x\ (R_L - 1)\ {}^{Q_2}/Q_x + 1.166 - 0.167\ R_L)^y\ \ D_x \qquad (24)$$

The average value of ${}^{Q_2}/Q_x$ was computed for each region and recurrence interval.

Equation 24 can be simplified considerably by substituting for the appropriate values of R_x, y and Q_2/Q_x. Simplified equations for all regions are given in table 2.

The urban adjustment factor R_D is defined to be

$$R_D = (1.166\ R_x\ (R_L - 1)\ Q_2/Q_x + 1.166 - 0.167\ R_L)^y \qquad (25)$$

Substitution of R_L into the equations given in table 2 revealed that R_D for regions 1 and 2 and R_D for regions 3 and 4 were nearly identical. The relation of the urban adjustment factor R_D to the urban adjustment ratio R_L for regions 1 and 2 is shown in figure 11 and is shown for regions 3 and 4 in figure 12. Once the urban adjustment ratio R_L is determined from figure 10, R_D can be determined from figures 11 and 12.

It should be noted again that the computation of R_D is strictly mathematical and is not based on actual runoff data. Urban-runoff data collection is presently underway in Oklahoma at 15 sites in Oklahoma City. Hopefully, the collection of urban runoff data will be expanded in the future to include other cities in Oklahoma. When sufficient urban-runoff data are available, the increase in flood depths due to urbanization should be determined using actual data.

SUMMARY

Figures 2-12 can be used in conjunction with the latest Geological Survey topographic map to estimate the 2-, 5-, 10-, 25-, 50-, and 100-year flood depths for any ungaged stream in Oklahoma. The only limitations are that the stream be unregulated and have a natural main channel and that the contributing drainage area be less than 2,500 mi^2 (6,500 km^2). The standard error of estimate for natural streams is evaluated and shown to be low enough for the method to have practical use. The error of estimation for urban streams was not evaluated due to paucity of data. Data collection is underway in Oklahoma to verify the mathematical computation of R_D. However, the assumptions used in computing the urban adjustment factor R_D seem reasonable and the results appear logical. Although the flood depths estimated from techniques presented in this report are considered less reliable than those obtained from field surveys and hydraulic computations, the ease and simplicity of their determination are expected to make them useful for many purposes.

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Table 1.--Flood depth data at gaging stations.

The following table contains flood-depth data at the 132 gaging stations used in the analysis. The following information, if available, is given for each gaging station:

Station number, U.S. Geological Survey downstream order station number
Station name
A, the contributing drainage area, in square miles, determined from the latest U.S. Geological Survey topographic map.
I, the 2-year 24-hour rainfall, in inches, determined from figure 2 of this report.
The flood depths, in feet, for the 2-, 5-, 10-, 25-, 50- and 100-year floods determined as the difference between the 2-, 5-, 10-, 25-, 50- and 100-year flood elevations and the streambed elevation at the gage.
E, the elevation of the streambed at the gage, in feet above mean sea level.

Station number	Station name	A (mi^2)	I (in)	Flood depths, in feet D_2	D_5	D_{10}	D_{25}	D_{50}	D_{100}	E (ft)
07148400	Salt Fork Arkansas River nr Alva	1,009	3.00	6.0	7.0	7.7	9.5	11.0	12.0	1,298.5
07150580	Sand Creek tributary nr Kremlin	7.21	3.60	6.3	6.9	7.5	7.9	8.3	8.5	1,087
07150870	Salt Fork Arkansas River tributary nr Eddy	2.35	3.60	2.6	4.8	6.7	8.1	8.5	8.8	887
07152000	Chikaskia River nr Blackwell	1,859	3.40	30.3	32.6	33.6	34.7	35.1	35.8	967.6
07152360	Elm Creek nr Foraker	18.2	3.80	6.1	9.3	11.2	13.4	14.7	17.0	833
07152520	Black Bear Creek tributary nr Garber	.97	3.50	1.9	4.3	6.4	8.8	9.8	10.4	1,091
07153000	Black Bear Creek at Pawnee	576	3.70	12.5	20.4	25.2	28.2	30.0	31.2	804.5
07154500	Cimarron River nr Kenton	1,038	2.20	10.2	13.7	15.7	18.0	19.5	21.0	4,267.1
07154650	Tesequite Creek near Kenton	25.4	2.40	6.1	8.7	9.9	10.9	11.6	12.2	4,263
07155100	Cold Springs Creek nr Wheeless	11.0	2.40	1.2	4.0	6.6	11.5	16.0	21.0	4,446
07155510	Flagg Springs Creek tributary nr Boise City	5.15	2.40	2.5	3.8	5.0	6.5	7.8	9.5	3,955
07157550	West Fork Creek nr Knowles	4.22	2.70	4.4	7.2	8.0	8.2	8.3	8.5	2,253
07158080	Sand Creek tributary nr Waynoka	1.61	3.20	1.5	2.8	3.9	5.3	6.5	7.6	1,527
07158120	Cimarron River tributary nr Isabella	.62	3.50	2.4	3.3	2.9	4.5	5.0	5.4	1,184
07158180	Salt Creek tributary nr Okeene	8.23	3.45	4.4	6.0	7.0	7.6	7.9	8.2	.....
07158500	Preacher Creek nr Dover	14.5	3.50	4.9	7.7	9.5	11.7	13.2	14.7	1,068.3
07158550	Turkey Creek tributary near Goltry	5.08	3.50	3.1	6.3	7.2	7.7	8.2	8.5	1,284
07159000	Turkey Creek nr Drummond	248	3.50	8.1	14.3	16.2	18.8	20.7	22.4	1,148.8
07160500	Skeleton Creek nr Lovell	410	3.60	19.3	25.4	27.9	30.9	32.9	34.9	915.9
07160550	West Beaver Creek nr Orlando	13.9	3.70	6.0	7.4	8.9	10.9	12.0	13.5	1,001
07163000	Council Creek nr Stillwater	31.0	3.70	6.3	12.0	14.8	16.8	17.8	18.4	843.3
07163020	Corral Creek nr Yale	2.89	3.80	5.1	6.5	7.3	8.2	9.0	9.5	868
07164940	Deep Creek nr Olive	2.28	3.90	4.9	5.3	6.1	7.2	8.0	8.8	825
07165550	Snake Creek nr Bixby	50.0	3.95	16.3	18.3	19.3	20.6	21.4	27.2	626.8
07174200	Little Caney below Cotton Creek nr Copan	502.0	3.80	19.1	20.1	21.4	....	....	....	666.6

Table 1.--Flood depth data at gaging stations--continued.

Station number	Station name	A (mi^2)	I (in)	Flood depths, in feet D_2	D_5	D_{10}	D_{25}	D_{50}	D_{100}	E (ft)
07174570	Dry Hollow nr Pawhuska	1.67	3.80	2.4	3.3	3.9	4.8	5.4	6.1	785
07174600	Sand Creek nr Okesa	139.0	3.85	12.9	17.0	19.7	23.0	25.0	27.4	691.8
07174720	Hogshooter Creek tributary nr Bartlesville	.94	3.90	3.2	4.6	5.5	6.5	7.2	8.0	742
07176500	Bird Creek at Avant	364.0	3.80	16.5	23.5	28.1	29.2	30.0	30.7	653.6
07177000	Hominy Creek at Skiatook	340.0	3.80	27.2	32.0	34.0	....	....	....	621.7
07177500	Bird Creek at Sperry	905.0	3.80	26.1	28.6	29.1	30.5	31.2	31.9	580.3
07178580	Otter Creek nr Tiawah	15.2	4.00	10.2	11.2	11.6	12.1	12.5	12.8	557
07178640	Bull Creek nr Inola	10.7	4.00	4.5	6.3	7.3	8.3	9.0	9.5	592
07178650	Billy Creek tributary nr Wagoner	5.71	4.00	6.5	8.1	9.0	10.0	10.6	11.1	529
07188000	Spring River nr Quapaw	2,510.0	3.90	17.3	23.4	28.5	30.8	32.5	34.2	749.2
07188500	Lost Creek at Seneca, Mo.	42.0	4.05	4.2	7.2	8.9	10.7	12.1	13.3	839.5
07189000	Elk River nr Tiff City, Mo.	872.0	4.00	14.6	20.5	22.0	24.0	25.5	26.5	752.6
07189480	Wolf Creek nr Grove	7.21	4.10	6.5	7.2	7.6	8.0	8.2	8.5	785
07189700	Horse Creek at Afton	21.9	4.00	7.3	8.5	9.2	9.9	10.3	10.9	767
07189720	Horse Creek tributary near Afton	.81	4.00	3.0	3.5	3.9	4.4	4.8	5.2	767
07190600	Big Cabin Creek nr Pyramid Corners	71.1	3.95	13.4	17.2	18.9	20.9	21.9	22.9	720
07191000	Big Cabin Creek near Big Cabin	466.0	3.95	24.0	29.5	31.0	32.8	33.9	34.8	624.8
07191260	Brush Creek nr Jay	16.0	4.10	4.7	6.6	7.8	9.2	10.2	11.2	880
07192000	Pryor Creek nr Pryor	229.0	4.00	16.3	18.1	19.5	21.7	23.6	25.5	579.0
07194515	Mill Creek nr Park Hill	2.57	4.10	4.8	7.0	8.7	11.2	13.3	15.3	721
07195500	Illinois River nr Watts	635.0	4.10	16.5	21.7	22.9	25.5	27.1	28.5	894.9
07196000	Flint Creek near Kansas	110.0	4.10	4.3	6.7	8.2	11.0	13.0	14.4	859.9
07196380	Illinois River tributary nr Tahlequah	3.59	4.10	3.3	5.6	7.3	9.3	11.1	13.0	757
07196500	Illinois River nr Tahlequah	959.0	4.10	14.9	19.5	21.5	24.7	26.0	27.0	665.6
07197000	Baron Fork at Eldon	307.0	4.20	13.7	16.7	17.7	18.5	19.0	19.5	705.1
07228290	Rough Creek nr Thomas	10.4	3.50	5.9	9.6	12.0	14.8	16.8	18.2	1,617
07228450	Deer Creek tributary nr Hydro	2.31	3.60	4.2	6.5	8.3	11.0	13.4	15.9	1,452
07228600	Canyon View Creek nr Geary	11.8	3.60	2.4	4.8	6.6	8.7	10.3	12.3	1,392
07228930	Worley Creek nr Tuttle	11.2	3.70	9.7	11.4	12.4	13.4	14.2	15.0	1,219
07228960	Canadian River tributary nr Newcastle	3.32	3.70	3.3	4.7	5.6	6.9	7.9	9.0	1,273

Table 1.--Flood depth data at gaging stations.--continued.

Station number	Station name	A (mi^2)	I (in)	Flood depths, in feet D_2	D_5	D_{10}	D_{25}	D_{50}	D_{100}	E (ft)
07229220	Walnut Creek nr Blanchard	1.26	3.70	5.2	7.5	9.0	10.9	12.3	13.9	1,241
07229420	Julian Creek tributary nr Asher	2.28	3.85	3.5	5.2	6.3	7.8	9.0	10.2	960
07230500	Little River nr Tecumseh	456.0	3.80	10.6	15.8	22.0	...	...	....	904.1
07231000	Little River nr Sasakwa	865.0	3.80	24.5	29.5	31.8	33.8	35.0	35.8	749.4
07231280	Arbeca Creek nr Allen	2.26	3.90	4.8	7.9	10.0	12.5	14.4	16.0	806
07221320	Leader Creek nr Atwood	.72	3.90	5.5	8.4	9.6	10.0	10.2	10.6	768
07231560	Middle Creek nr Carson	7.40	3.95	7.2	10.6	12.4	14.2	15.2	16.0	683
07231950	Pine Creek nr Higgins	9.99	4.10	8.2	9.8	10.7	11.8	12.2	12.9	696
07232000	Gaines Creek nr Krebs	588	4.00	25.0	28.0	29.6	31.4	33.2	35.7	552.6
07232550	South Fork tributary near Guymon	.26	2.55	1.0	1.4	1.8	2.4	2.8	3.3	3,120
07232650	Aqua Frio Creek nr Felt	31.0	2.40	1.7	3.4	4.5	6.0	7.1	8.2	4,396
07233000	Coldwater Creek nr Hardesty	767.0	2.60	3.8	5.7	6.6	8.0	9.2	10.2	2,754.1
07233850	Sharp Creek tributary nr Turpin	1.0	2.60	1.1	1.9	2.5	3.4	4.1	4.8	2,753
07234050	North Fork Clear Creek tributary nr Balko	4.0	2.70	2.4	3.6	4.2	4.9	5.4	6.0	2,766
07234290	Clear Creek tributary nr Catesby	9.18	2.90	2.7	5.0	6.0	7.0	7.6	8.0	2,347
07235700	Little Wolf Creek tributary nr Gage	17.6	2.95	2.3	3.4	4.1	4.9	5.6	6.2	2,251
07237750	Cotton Creek nr Vici	11.5	3.20	3.5	4.6	5.3	6.2	6.8	7.3	1,902
07239050	North Canadian River tributary nr Eagle City	.52	3.45	1.9	3.6	5.2	7.7	10.4	13.7	1,602
07241880	Sand Creek near Cromwell	9.48	3.90	9.3	10.6	11.4	12.2	12.6	13.0	858
07242160	Alabama Creek nr Weleetka	16.5	3.90	6.8	9.2	10.6	12.5	13.6	15.0	695
07242180	Stidham Creek nr Dustin	2.56	3.95	4.5	5.9	6.7	7.6	8.2	9.0	678
07243000	Dry Creek nr Kendrick	69.0	3.80	11.5	13.3	14.2	15.3	16.1	16.8	832
07243500	Deep Fork nr Beggs	2,018.0	3.80	21.5	27.0	31.0	....	....	....	632.6
07243550	Adams Creek nr Beggs	5.90	3.95	6.4	8.4	11.0	12.5	13.5	14.5	709
07244790	Brooken Creek nr Enterprise	5.66	4.10	5.3	7.8	9.5	11.4	12.7	14.0	598
07245090	Vian Creek nr Vian	19.6	4.15	7.0	8.3	9.1	10.2	11.1	11.8	564
07245500	Sallisaw Creek nr Sallisaw	182.0	4.20	11.5	13.2	14.5	....	....	....	476.3
07246600	Cache Creek nr Cowlington	20.6	4.20	8.7	10.0	10.9	11.9	12.7	13.4	450
07246610	Pecan Creek nr Spiro	.90	4.20	3.1	4.3	5.1	6.0	6.7	7.4	478
07246630	Big Black Fox Creek nr Long	5.32	4.20	4.3	5.6	6.4	7.0	7.3	7.6	594

Table 1.--Flood depth data at gaging stations--continued.

Station number	Station name	A (mi^2)	I (in)	Flood depths, in feet D_2	D_5	D_{10}	D_{25}	D_{50}	D_{100}	E (ft)
07247500	Fourche Maline nr Red Oak	122.0	4.10	18.7	20.5	22.0	...	...	...	541.3
07249000	Poteau River at Poteau	1,240.0	4.20	31.9	36.9	40.9	...	...	...	410.9
07300150	Salt Fork Red River tributary nr Vinson	7.49	3.20	6.0	8.4	9.4	10.5	10.9	11.4	1,794
07301455	Turkey Creek nr Erick	19.8	3.10	3.1	4.8	5.8	6.8	7.6	8.2	1,937
07301480	Short Creek nr Sayre	9.12	3.20	3.1	4.4	5.5	7.0	8.3	9.5	1,822
07301485	Spring Creek nr Elk City	.93	3.20	4.8	6.7	7.9	9.5	10.5	11.6	2,042
07301495	Indian Creek nr Carter	24.9	3.20	7.4	10.0	11.6	13.6	15.3	16.7	1,820
07303400	Elm Fork of North Fork Red River nr Carl	416.0	3.00	5.0	6.8	7.9	9.6	10.6	11.7	1,717.1
07303450	Deer Creek nr Plainview	27.8	3.20	5.2	7.2	8.5	9.8	10.8	11.6	1,713
07303500	Elm Fork of North Fork Red River nr Mangum	838.0	3.10	11.6	14.2	15.4	...	...	...	1,531.0
07304500	Elk Creek nr Hobart	549.0	3.30	21.0	25.5	26.2	26.8	27.1	27.4	1,433.4
07390480	Canyon Creek nr Medicine Park	3.35	3.60	2.7	4.3	5.9	8.0	9.7	11.7	1,533
07311000	East Cache Creek nr Walters	675.0	3.60	24.6	25.6	25.8	26.1	26.3	26.6	940.9
07311420	Deadman Creek tributary at Manitou	2.57	3.55	3.2	4.2	4.8	5.6	6.3	6.9	1,227
07311500	Deep Red Run nr Randlett	617.0	3.60	7.4	13.4	17.1	19.4	20.0	20.8	927.1
07312850	Nine Mile Beaver Creek nr Elgin	6.29	3.65	5.6	9.2	10.8	12.0	12.4	12.8	1,238
07312950	Little Beaver Creek nr Marlow	35.4	3.65	2.3	4.0	5.3	6.9	8.0	9.2	....
07313000	Little Beaver Creek nr Duncan	158.0	3.70	16.3	17.7	18.8	19.8	20.5	21.3	1,003.4
07313500	Beaver Creek nr Waurika	563.0	3.70	19.5	21.0	22.0	23.0	24.0	25.1	879.1
07315680	Cottonwood Creek tributary nr Loco	1.74	3.75	2.8	5.2	7.4	10.7	13.0	15.3	....
07315700	Mud Creek nr Courtney	572.0	3.80	16.0	17.7	18.8	19.8	20.5	21.3	739.0
07316130	Wilson Creek tributary nr McMillan	2.97	3.90	5.1	6.5	7.4	8.3	9.0	9.7	730
07316140	Brier Creek nr Powell	12.0	3.90	9.0	11.2	12.7	14.1	15.1	16.2	702
07324500	Barnitz nr Arapaho	243.0	3.30	13.2	14.5	15.1	15.4	15.7	15.9	1,533.4
07329000	Rush Creek nr Purdy	145.0	3.70	9.9	14.5	18.0	22.5	25.5	28.5	993.2
07329870	Honey Creek nr Davis	18.7	3.80	6.3	7.9	9.1	9.6	10.0	10.5	982
07330500	Caddo Creek nr Ardmore	298.0	3.80	22.6	25.0	25.8	26.6	...	...	711.9
07331410	Buzzard Creek nr Reagan	4.30	3.90	4.4	5.6	6.3	7.3	8.1	8.9	826
07332070	Rock Creek nr Achille	.72	4.00	5.3	8.7	9.7	10.3	10.6	10.9	605
07332500	Blue River nr Blue	476.0	4.00	24.5	29.0	31.0	34.6	...	...	504.4

Table 1.--Flood depth data at gaging stations.--continued.

Station number	Station name	A (mi^2)	I (in)	Flood depths, in feet D_2	D_5	D_{10}	D_{25}	D_{50}	D_{100}	E (ft)
07333500	Chickasaw Creek nr Stringtown	32.7	4.00	14.5	16.9	17.8	18.4	18.8	19.3	543.5
07333800	McGee Creek nr Stringtown	86.6	4.02	12.4	15.4	17.2	19.0	20.2	21.4	623.8
07334000	Muddy Boggy nr Farris	1,087.0	4.00	37.5	40.5	41.5	43.5	44.5	46.0	445.9
07335000	Clear Boggy Creek nr Caney	720.0	3.90	20.9	22.2	23.1	24.1	24.6	25.1	487.4
07335310	Rock Creek nr Boswell	.94	4.05	4.2	5.8	6.8	7.8	8.5	9.1	538
07335320	Bokchito Creek nr Soper	16.6	4.10	6.1	7.7	8.5	9.4	10.1	10.6	462
07335760	Kiamichi River tributary nr Albion	1.43	4.15	2.3	3.5	4.3	5.8	7.7	10.1	825
07336000	Tenmile Creek nr Miller	68.0	4.10	16.1	16.6	18.3	18.8	19.2	19.5	578.1
07336500	Kiamichi River nr Belzoni	1,423.0	4.00	32.0	36.4	38.0	39.7	41.2	42.7	393.2
07336520	Frizier Creek nr Oleta	19.4	4.10	9.6	12.4	14.0	16.2	17.5	18.7	489
07336780	Perry Creek nr Idabel	7.53	4.30	7.5	8.3	8.7	9.1	9.3	9.6	390
07336785	Bokchito Creek nr Garvin	2.96	4.30	4.4	5.1	5.4	5.7	5.9	6.1	415
07337220	Big Branch nr Ringold	1.99	4.20	3.2	5.2	6.8	9.2	11.8	13.0	483
07338500	Little River below Lukfata	1,226.0	4.20	29.1	31.5	32.7	34.0	34.7	35.7	316.4
07338520	Yanubbe Creek nr Broken Bow	9.10	4.30	6.4	8.3	9.2	10.5	11.2	11.8	449
07338780	Mountain Fork tributary nr Smithville	.67	4.30	2.7	3.3	3.6	3.9	4.1	4.3	814
07339000	Mountain Fork nr Eagletown	787.0	4.20	18.0	22.7	24.5	26.0	27.0	27.5	334.9

Table 2.--Summary of equations used to compute the urban adjustment factor R_D.

Regional equations of the form $D_x = kQ_x^y$ used to compute equations 21-23. These equations were computed for each region by relating D_x to Q_x by linear regression techniques.

Region 1

$$D_2 = 0.12Q_2^{0.50}$$

$$D_5 = 0.22Q_5^{0.42}$$

$$D_{10} = 0.36Q_{10}^{0.37}$$

$$D_{25} = 0.42Q_{25}^{0.34}$$

$$D_{50} = 0.46Q_{50}^{0.34}$$

$$D_{100} = 0.73Q_{100}^{0.30}$$

Region 2

$$D_2 = 0.34Q_2^{0.36}$$

$$D_5 = 0.56Q_5^{0.32}$$

$$D_{10} = 0.70Q_{10}^{0.30}$$

$$D_{25} = 0.92Q_{25}^{0.27}$$

$$D_{50} = 1.08Q_{50}^{0.25}$$

$$D_{100} = 1.29Q_{100}^{0.23}$$

Region 3

$$D_2 = 0.18Q_2^{0.49}$$

$$D_5 = 0.35Q_5^{0.42}$$

$$D_{10} = 0.48Q_{10}^{0.38}$$

$$D_{25} = 0.71Q_{25}^{0.34}$$

$$D_{50} = 0.91Q_{50}^{0.31}$$

$$D_{100} = 1.12Q_{100}^{0.29}$$

Region 4

$$D_2 = 0.24Q_2^{0.42}$$

$$D_5 = 0.38Q_5^{0.39}$$

$$D_{10} = 0.45Q_{10}^{0.36}$$

$$D_{25} = 0.59Q_{25}^{0.33}$$

$$D_{50} = 0.69Q_{50}^{0.32}$$

$$D_{100} = 0.80Q_{100}^{0.30}$$

Simplifying equation 24 gives the following results:

Region 1

$$D_2(u) = R_L^{0.50} D_2$$

$$D_5(u) = (0.46R_L + 0.54)^{0.42} D_5$$

$$D_{10}(u) = (0.32R_L + 0.68)^{0.37} D_{10}$$

$$D_{25}(u) = (0.23R_L + 0.77)^{0.34} D_{25}$$

$$D_{50}(u) = (0.18R_L + 0.82)^{0.34} D_{50}$$

$$D_{100}(u) = (0.13R_L + 0.87)^{0.30} D_{100}$$

Region 2

$$D_2(u) = R_L^{0.36} D_2$$

$$D_5(u) = (0.57R_L + 0.43)^{0.32} D_5$$

$$D_{10}(u) = (0.43R_L + 0.57)^{0.30} D_{10}$$

$$D_{25}(u) = (0.32R_L + 0.68)^{0.27} D_{25}$$

$$D_{50}(u) = (0.28R_L + 0.72)^{0.25} D_{50}$$

$$D_{100}(u) = (0.21R_L + 0.79)^{0.23} D_{100}$$

Region 3

$$D_2(u) = R_L^{0.49} D_2$$

$$D_5(u) = (0.61R_L + 0.39)^{0.42} D_5$$

$$D_{10}(u) = (0.58R_L + 0.42)^{0.38} D_{10}$$

$$D_{25}(u) = (0.50R_L + 0.50)^{0.34} D_{25}$$

$$D_{50}(u) = (0.45R_L + 0.55)^{0.31} D_{50}$$

$$D_{100}(u) = (0.43R_L + 0.57)^{0.29} D_{100}$$

Region 4

$$D_2(u) = R_L^{0.42} D_2$$

$$D_5(u) = (0.73R_L + 0.27)^{0.39} D_5$$

$$D_{10}(u) = (0.66R_L + 0.34)^{0.36} D_{10}$$

$$D_{25}(u) = (0.50R_L + 0.50)^{0.33} D_{25}$$

$$D_{50}(u) = (0.42R_L + 0.58)^{0.32} D_{50}$$

$$D_{100}(u) = (0.40R_L + 0.60)^{0.30} D_{100}$$

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