3

Rational Method

3.1 General

The Rational Method was originally developed to estimate runoff from small areas and its use should be generally limited to those conditions. For the purposes of this manual, its use should be limited to areas of up to 160 acres. In such cases, the peak discharge and the volume of runoff from rainfall events up to and including the 100-year, 2-hour duration storm falling within the boundaries of the proposed development are to be retained. If the development involves channel routing, the procedures given in Chapters 4 through 6 should be used, since the peak generated by the Rational Method cannot be directly routed.

3.2 Rational Equation

The Rational Equation relates rainfall intensity, a runoff coefficient and the watershed size to the generated peak discharge. The following shows this relationship:

$$Q = CiA \tag{3.1}$$

where

Q	=	the peak discharge (cfs) from a given area.
C	=	a coefficient relating the runoff to rainfall.
i	=	average rainfall intensity (inches/hour), lasting for a Tc.
Tc	=	the time of concentration (hours).
A	=	drainage area (acres).

The Rational Equation is based on the concept that the application of a steady, uniform rainfall intensity will produce a peak discharge at such a time when all points of the watershed are contributing to the outflow at the point of design. Such a condition is met when the elapsed time is equal to the time of concentration, Tc, which is defined to be the floodwave travel time from the most remote part of the watershed to the point of design. The time of concentration should be computed by applying the following equation developed by Papadakis and Kazan (1987):

$$Tc = 11.4\, L^{0.5} Kb^{0.52} S^{-0.31} i^{-0.38} \quad (3.2)$$

where

Tc	=	time of concentration in hours
L	=	length of the longest flow path in miles
K_b	=	watershed resistance coefficient (see Figure 3.1, or Table 3.1)
S	=	watercourse slope in feet/mile
i	=	rainfall intensity in inches/hour*

*It should be noted that i is the "rainfall excess intensity" as originally developed. However, when used in the Rational Equation, rainfall intensity and rainfall excess intensity provide similar values because of the hydrologic characteristics of small, urban watersheds which result in minimal rainfall loss. This is because of the extent of imperviousness associated with urban watersheds and the fact that the time of concentration is usually very short.

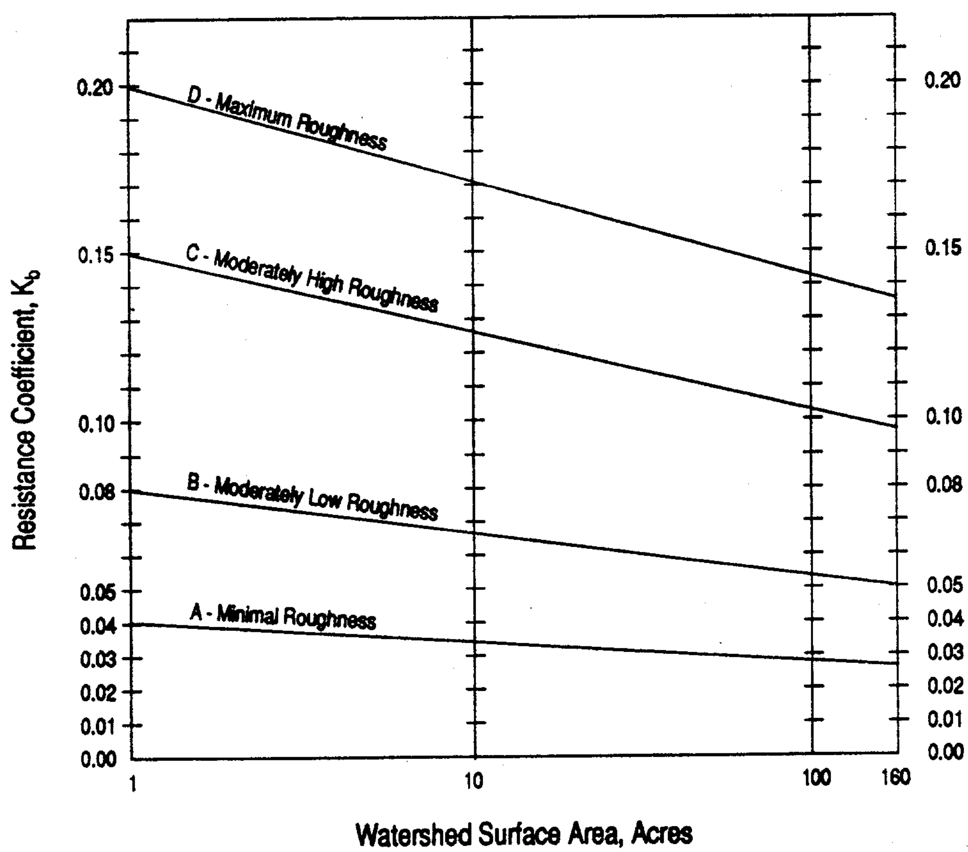


Figure 3.1
Resistance Coefficient Kb as a Function of Watershed Size

Table 3.1
Equation for Estimating K_b in the Tc Equation

$K_b = m \log A + b$ Where A is drainage area, in acres				
Type	**Description**	**Typical Applications**	**Equation Parameters**	
			m	**b**
A	Minimal roughness: Relatively smooth and/or well graded and uniform land surfaces. Surface runoff is sheet flow.	Commercial/ industrial areas Residential area Parks and golf courses	–0.00625	0.04
B	Moderately low roughness: Land surfaces have irregularly spaced roughness elements that protrude from the surface but the overall character of the surface is relatively uniform. Surface runoff is predominately sheet flow around the roughness elements.	Agricultural fields Pastures Desert rangelands Undeveloped urban lands	–0.01375	0.08
C	Moderately high roughness: Land surfaces that have significant large- to medium-sized roughness elements and/or poorly graded land surfaces that cause the flow to be diverted around the roughness elements. Surface runoff is sheet flow for short distances draining into meandering drainage paths.	Hillslopes Brushy alluvial fans Hilly rangeland Disturbed land, mining, etc. Forests with underbrush	–0.025	0.15
D	Maximum roughness: Rough land surfaces with torturous flow paths. Surface runoff is concentrated in numerous short flow paths that are often oblique to the main flow direction.	Mountains Some wetlands	–0.030	0.20

3.3 Assumptions

Application of the Rational Equation requires consideration of the following:

1. The peak discharge rate corresponding to a given intensity would occur only if the rainfall duration is at least equal to the time of concentration.

2. The calculated runoff is directly proportional to the rainfall intensity.

3. The frequency of occurrence for the peak discharge is the same as the frequency for the rainfall producing that event.

4. The runoff coefficient increases as storm frequency decreases.

3.4 Limitations

Application of the Rational Method is appropriate for watersheds less than 160 acres in size. This is based on the assumption that the rainfall intensity is to be uniformly distributed over the drainage area at a uniform rate lasting for the duration of the storm. The Maricopa County Unit Hydrograph Procedure described in Chapter 5 may also be used for areas less than 160 acres where hydrograph routing is desired, or, in cases where the Rational Method assumptions do not apply.

3.5 Application

The Rational Method can be used to calculate the generated peak discharge and runoff volume from drainage areas less than 160 acres.

3.5.1 Peak Discharge Calculation

1. Determine the area within the development boundaries.

2. Select the runoff coefficient, C from Table 3.2

3. Calculate time of concentration (see Example 4). This is to be done by an iterative process. Select a duration from the I-D-F curves, Figure 3.2. This value should not be longer than two hours and normally it will be less than an hour. Determine the maximum rainfall intensity indicated on the I-D-F curve for a frequency that includes the 100-year. The intensity value of the corresponding Tc in the above is for the Phoenix Metro area. Use i_p in the following equation for estimating i for other areas:

$$i = i_p \frac{(P^6{}_{10})}{2.07} \qquad (3.3)$$

where

i	=	the desired intensity for a given duration and frequency.
i_p	=	the intensity for the Phoenix Metro area.
$P^6{}_{10}$	=	the 10-year, 6-hour precipitation depth at the point of interest. (Can be read from Figure 2.4.)

4. Use the adjusted intensity in Equation 3.2 to calculate time of concentration. Repeat this process until the selected and computed Tc values are reasonably close. For more details see Example 1.

5. Determine peak discharge (Q) by using the above value of i in Equation 3.1.

6. As an alternative to the above procedure, the computer program RATIONAL.EXE may be used to calculate peak discharges.

Table 3.2
C Coefficients for Use with the Rational Method

Land Use	Return Period			
	2-10 Year	25 Year	50 Year	100 Year
Streets and Roads				
Paved Roads	0.75 – 0.85	0.83 – 0.94	0.90 – 0.95	0.94 – 0.95
Gravel Roadways & Shoulders	0.60 – 0.70	0.66 – 0.77	0.72 – 0.84	0.75 – 0.88
Industrial Areas				
Heavy	0.70 – 0.80	0.77 – 0.88	0.84 – 0.95	0.88 – 0.95
Light	0.60 – 0.70	0.66 – 0.77	0.72 – 0.84	0.75 – 0.88
Business Areas				
Downtown	0.75 – 0.85	0.83 – 0.94	0.90 – 0.95	0.94 – 0.95
Neighborhood	0.55 – 0.65	0.61 – 0.72	0.66 – 0.78	0.69 – 0.81
Residential Areas				
Lawns – Flat	0.10 – 0.25	0.11 – 0.28	0.12 – 0.30	0.13 – 0.31
– Steep	0.25 – 0.40	0.28 – 0.44	0.30 – 0.48	0.31 – 0.50
Suburban	0.30 – 0.40	0.33 – 0.44	0.36 – 0.48	0.38 – 0.50
Single Family	0.45 – 0.55	0.50 – 0.61	0.54 – 0.66	0.56 – 0.69
Multi-Unit	0.50 – 0.60	0.55 – 0.66	0.60 – 0.72	0.63 – 0.75
Apartments	0.60 – 0.70	0.66 – 0.77	0.72 – 0.84	0.75 – 0.88
Parks/Cemetaries	0.10 – 0.25	0.11 – 0.28	0.12 – 0.30	0.13 – 0.31
Playgrounds	0.40 – 0.50	0.44 – 0.55	0.48 – 0.60	0.50 – 0.63
Agricultural Areas	0.10 – 0.20	0.11 – 0.22	0.12 – 0.24	0.13 – 0.25
Bare Ground	0.20 – 0.30	0.22 – 0.33	0.24 – 0.36	0.25 – 0.38
Undeveloped Desert	0.30 – 0.40	0.33 – 0.44	0.36 – 0.48	0.38 – 0.50
Mountain Terrain (Slopes > 10%)	0.60 – 0.80	0.66 – 0.88	0.72 – 0.95	0.75 – 0.95

Note: Values of C for 25, 50 and 100 Year were derived using frequency adjustment factors of 1.10, 1.20, and 1.25, respectively, with an upper limit of 0.95 for C for the 2-10 Year values.

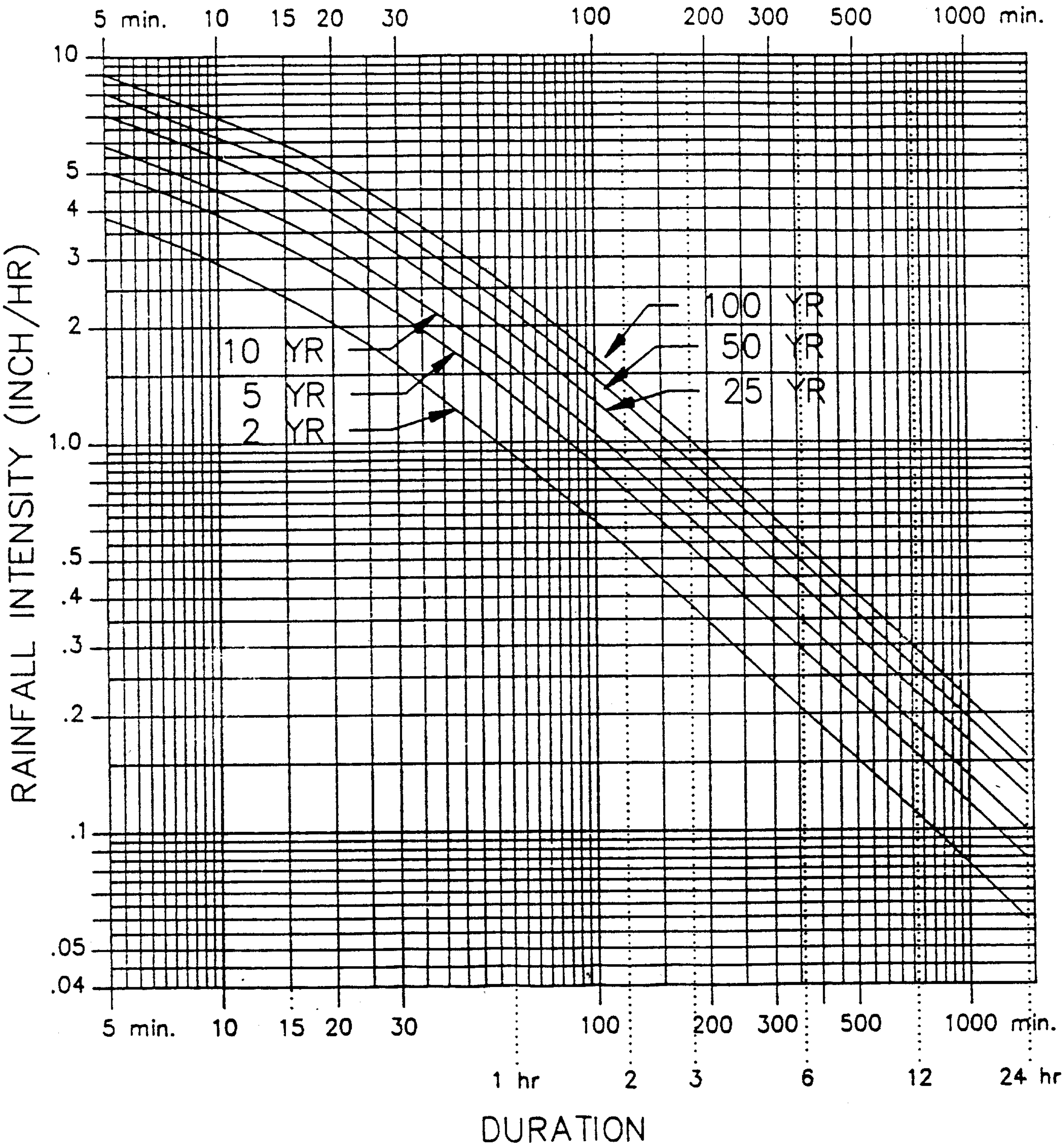


Figure 3.2
Rainfall Intensity-Duration-Frequency Relation
(Phoenix Metro Area)

3.5.2 Volume Calculations

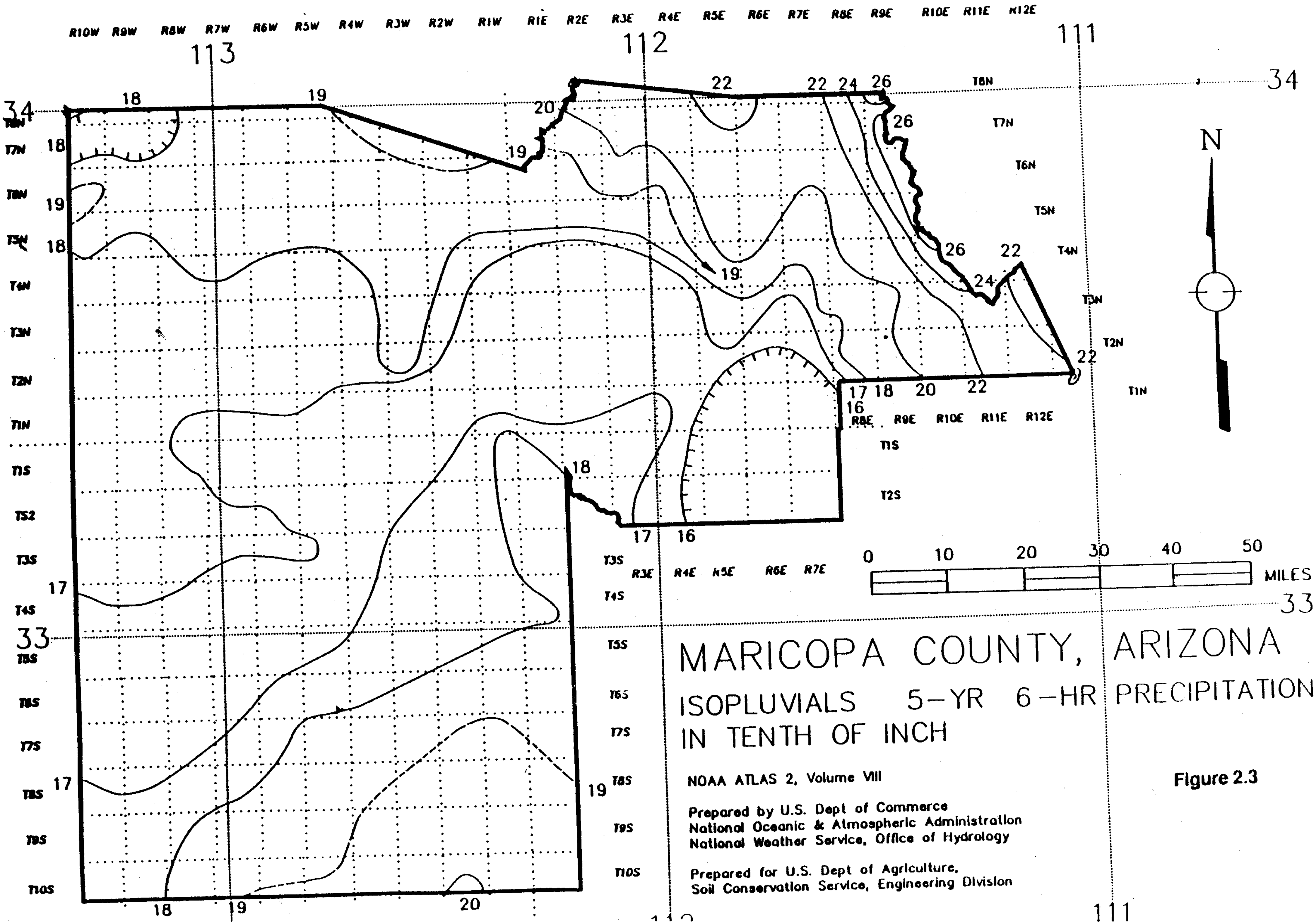
Volume calculation should be done by applying the following equation:

$$V = C\left(\frac{P}{12}\right)A \qquad (3.4)$$

where

V	=	Calculated volume in acre-feet
C	=	Runoff coefficient from Table 3.2
P	=	Rainfall depth in inches
A	=	Drainage area in acres

In the case of volume calculations for retention/detention design, P equals the 100-year, 2-hour depth, in inches, from Section 2.2 or Figure 3.3.



MARICOPA COUNTY, ARIZONA

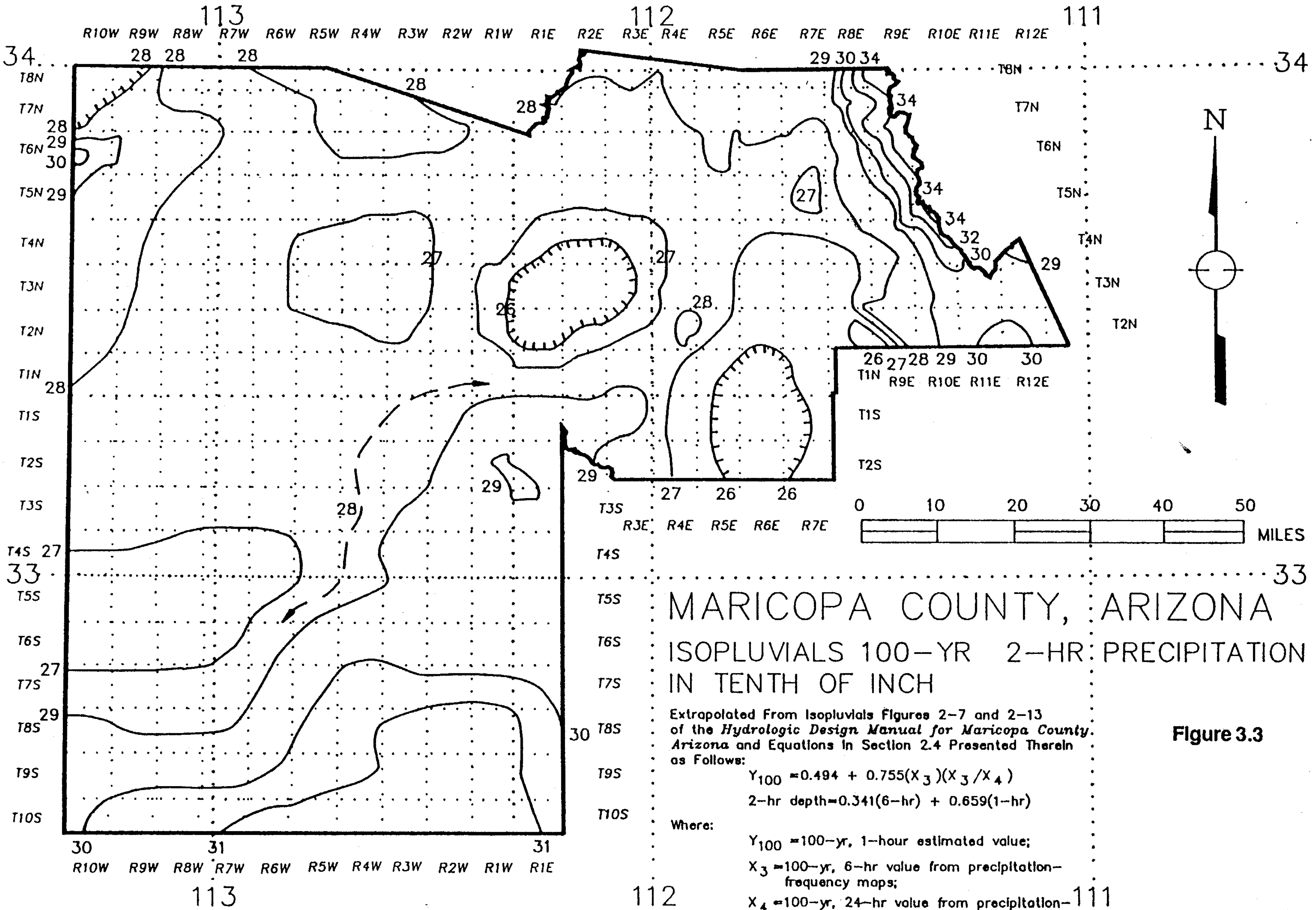
ISOPLUVIALS 5–YR 6–HR PRECIPITATION IN TENTH OF INCH

NOAA ATLAS 2, Volume VIII

Prepared by U.S. Dept of Commerce
National Oceanic & Atmospheric Administration
National Weather Service, Office of Hydrology

Prepared for U.S. Dept of Agriculture,
Soil Conservation Service, Engineering Division

Figure 2.3



MARICOPA COUNTY, ARIZONA

ISOPLUVIALS 100-YR 2-HR PRECIPITATION IN TENTH OF INCH

Extrapolated From Isopluvials Figures 2-7 and 2-13 of the *Hydrologic Design Manual for Maricopa County Arizona* and Equations in Section 2.4 Presented Therein as Follows:

$Y_{100} = 0.494 + 0.755(X_3)(X_3/X_4)$

2-hr depth = 0.341(6-hr) + 0.659(1-hr)

Where:

Y_{100} = 100-yr, 1-hour estimated value;

X_3 = 100-yr, 6-hr value from precipitation-frequency maps;

X_4 = 100-yr, 24-hr value from precipitation-frequency maps;

6-hr = isopluvial values from figure 2.7;
1-hr = Y_{100} value as computed above.

Figure 3.3