3.1.3 Rational Method

A popular approach for determining the peak runoff rate is the Rational Formula. The Rational Method considers the entire drainage area as a single unit and estimates the peak discharge at the most downstream point of that area.

The Rational Formula follows the assumptions that:

- the rainfall is uniformly distributed of the entire drainage area and is constant over time;
- the predicted peak discharge has the same probability of occurrence (return period) as the used rainfall intensity (I);
- peak runoff rate can be represented by the rainfall intensity averaged over the same time period as the drainage area's time of concentration (tc); and
- the runoff coefficient (C) is constant during the storm event.

When using the Rational Method some precautions should be considered:

- in determining the C value (runoff coefficient based on land use) for the drainage area, hydrologic analysis should take into account any future changes in land use that might occur during the service life of the proposed facility;
- if the distribution of land uses within the drainage basin will affect the results of hydrologic analysis (e.g., if the impervious areas are segregated from the pervious areas), the basin should be divided into sub-drainage basins. The single equation used for the Rational Method uses one composite C and one t_c value for the entire drainage area; and,
- the charts, graphs, and tables included in this section are given to assist the engineer in applying the Rational Method. The engineer shall use sound engineering judgment in applying these design aids and shall make appropriate adjustments when specific site characteristics dictate that these adjustments are appropriate.

3.1.3.1 Application

The Rational Method can be used to estimate stormwater runoff peak flows for the design of gutter flows, drainage inlets, storm drain pipe, culverts and small ditches. It is most applicable to small, highly impervious areas. Knox County policies regarding the use of the Rational Method are as follows:

- In Knox County, the Rational Method shall not be utilized for drainage areas less than five (5) acres.
- The Rational Method shall not be used for storage design or any other application where a more detailed routing procedure is required.
- The Rational Method shall not be used for calculating peak flows downstream of bridges, culverts or storm sewers that may act as restrictions and impact the peak rate of discharge.

3.1.3.2 Equations

The Rational Method estimates the peak rate of runoff at a specific watershed location as a function of the drainage area, runoff coefficient, and mean rainfall intensity for a duration equal to the time of concentration, t_c. The t_c is the time required for water to flow from the most remote point of the basin to the location being analyzed.

The Rational Method is expressed in Equation 3-1. Further explanation of each variable in the Rational Method equation is presented in Sections 3.1.3.3 and 3.1.3.4.

Equation 3-1

$$Q = CIA$$

where:

- Q = maximum rate of runoff (cfs)
- C = runoff coefficient representing a ratio of runoff to rainfall
- I = average rainfall intensity for a duration equal to the t_c (in/hr)
- A = drainage area contributing to the design location (acres)

3.1.3.3 Runoff Coefficient

The runoff coefficient (C) is the variable of the Rational Method least susceptible to precise determination and requires judgment and understanding on the part of the design engineer. While engineering judgment will always be required in the selection of runoff coefficients, typical coefficients represent the integrated effects of many drainage basin parameters. Table 3-6 gives the recommended runoff coefficients for the Rational Method.

It is often desirable to develop a composite runoff coefficient based on the percentage of different types of surfaces in the drainage areas. Composites can be made with the values from Table 3-6 by using percentages of different land uses. In addition, more detailed composites can be made with coefficients for different surface types such as rooftops, asphalt, and concrete. The composite procedure can be applied to an entire drainage area or to typical “sample" blocks as a guide to the selection of reasonable values of the coefficient for an entire area.

It should be remembered that the Rational Method assumes that all land uses within a drainage area are uniformly distributed throughout the area. If it is important to locate a specific land use within the drainage area, then another hydrologic method should be used where hydrographs can be generated and routed through the drainage system.

Using only the impervious area from a highly impervious site (and the corresponding high C factor and shorter time of concentration) can in some cases yield a higher peak runoff value than by using the whole site. Peak flow calculations can be underestimated due to areas where the overland portion of flow is grassy (yielding a longer t_c).

Note that the coefficients given in Table 3-6 are applicable for storms of 5 to 10-year frequencies. Less frequent, higher intensity storms may require modification of the coefficient because infiltration and other losses have a proportionally smaller effect on runoff (Wright - McLaughlin Engineers, 1969). The adjustment of the Rational Method for use with major storms can be made by multiplying the right side of the Rational Formula by a frequency factor Cf. The Rational Formula for major storm events now becomes:

Equation 3-2

$$Q = C_f CIA$$

C_f values are listed in Table 3-7. The product of C_f times C shall not exceed 1.0.

3.1.3.4 Rainfall Intensity (I)

The rainfall intensity (I) is the average rainfall rate in in/hr for a selected return period that is based on a duration equal to the time of concentration (t_c). Once a particular return period has been selected for design and a time of concentration has been calculated for the drainage area, the rainfall intensity can be determined from rainfall-intensity-duration data given in Table 3-4 or Figure 3-1. Calculation of t_c is discussed in detail in the next section.

Table 3-6. Recommended Runoff Coefficient Values for Rational Method

Land Use	Runoff Coefficient (C) by Hydrologic Soil Group and Ground Slope											
	A			B			C			D		
	<2%	2 - 6%	>6%	<2%	2 - 6%	>6%	<2%	2 - 6%	>6%	<2%	2 - 6%	>6%
Forest	0.08	0.11	0.14	0.10	0.14	0.18	0.12	0.16	0.20	0.15	0.20	0.25
Meadow	0.14	0.22	0.30	0.20	0.28	0.37	0.26	0.35	0.44	0.30	0.40	0.50
Pasture	0.15	0.25	0.37	0.23	0.34	0.45	0.30	0.42	0.52	0.37	0.50	0.62
Farmland	0.14	0.18	0.22	0.16	0.21	0.28	0.20	0.25	0.34	0.24	0.29	0.41
Res. 1 acre	0.22	0.26	0.29	0.24	0.28	0.34	0.28	0.32	0.40	0.31	0.35	0.46
Res. 1/2 acre	0.25	0.29	0.32	0.28	0.32	0.36	0.31	0.35	0.42	0.34	0.38	0.46
Res. 1/3 acre	0.28	0.32	0.35	0.30	0.35	0.39	0.33	0.38	0.45	0.36	0.40	0.50
Res. 1/4 acre	0.30	0.34	0.37	0.33	0.37	0.42	0.36	0.40	0.47	0.38	0.42	0.52
Res. 1/8 acre	0.33	0.37	0.40	0.35	0.39	0.44	0.38	0.42	0.49	0.41	0.45	0.54
Industrial	0.85	0.85	0.86	0.85	0.86	0.86	0.86	0.86	0.87	0.86	0.86	0.88
Commercial	0.88	0.88	0.89	0.89	0.89	0.89	0.89	0.89	0.90	0.89	0.89	0.90
Streets: ROW	0.76	0.77	0.79	0.80	0.82	0.84	0.84	0.85	0.89	0.89	0.91	**0.95**
Parking	0.95	0.96	0.97	0.95	0.96	0.97	0.95	0.96	0.97	0.95	0.96	**0.97**
Disturbed Area	0.65	0.67	0.69	0.66	0.68	0.70	0.68	0.70	0.72	0.69	0.72	0.75

Table 3-7. Frequency Factors for Rational Formula

Recurrence Interval (years)	C_f
10 or less	1.0
25	1.1
50	1.2
100	1.25

3.1.3.5 Time of Concentration

Use of the Rational Method requires calculating the time of concentration (t_c) for each design point within the drainage basin. The duration of rainfall is then set equal to the time of concentration and is used to estimate the design average rainfall intensity (I). The basin time of concentration is defined as the time required for water to flow from the most remote part of the drainage area to the point of interest for discharge calculations. The time of concentration is computed as a summation of travel times within each flow path as follows:

Equation 3-3

$$t_c = t_{t1} + t_{t2} + t_{tm}$$

where:

t_c = time of concentration (hours)
t_t = travel time of segment (hours)
m = number of flow segments

Knox County policies regarding the calculation of t_c are as follows:

- The t_c shall be the longest sub-basin travel time when all flow paths are considered.
- The minimum t_c for all computations shall be five (5) minutes.

Time of concentration calculations are subject to the following limitations:

1. the equations presented in this section should not be used for sheet flow on impervious land uses where the flow length is longer than 50 feet; and
2. in watersheds with storm sewers, use care to identify the appropriate hydraulic flow path to estimate t_c.

Two common errors should be avoided when calculating time of concentration. First, in some cases runoff from a highly impervious portion of a drainage area may result in a greater peak discharge than the calculated peak discharge for the entire area. Second, the designer should consider that the overland flow path does not necessarily remain the same when comparing pre-development and post-development areas. Grading operations and development can alter the overland flow path and length. Selecting overland flow paths for impervious areas that are greater than 50 feet should be done only after careful consideration. For typical urban areas, the time of concentration consists of multiple flow paths including overland flow, shallow concentrated flow and the travel time in the storm drain, paved gutter, roadside ditch, or drainage channel.

Overland Flow:
Overland flow in urbanized basins occurs from the backs of lots to the street, across and within parking lots and grass belts, and within park areas, and is characterized as shallow, steady and uniform flow with minor infiltration effects. The travel time (T_t) for overland flow over plane surfaces for distances of less than 300 lineal feet (100 feet for paved surfaces) can be calculated using Manning's kinematic solution (Overton and Meadows, 1976), shown in Equation 3-4. Following the equation, Table 3-8 presents Manning's "n" roughness coefficients for use in Equation 3-4.

Equation 3-4

$$T_t = \frac{0.007(nL)^{0.8}}{(P_2)^{0.5} S^{0.4}}$$

where:

T_t = travel time (hours)
n = Manning's roughness coefficient (see Table 3-8)
L = flow length (ft)
P_2 = 2-year 24-hour rainfall (inches)
S = ground slope, (ft/ft)

Table 3-8. Roughness coefficients (Manning's "n")[1]

(Soil Conservation Service, 1986)

Surface Description	n
Smooth surfaces (concrete, asphalt, gravel or bare soil)	0.011
Fallow (no residue)	0.05
Cultivated soils:	
Residue cover ≤ 20%	0.06
Residue cover > 20%	0.17
Grass:	
Short grass prairie	0.15
Dense grasses[2]	0.24
Bermuda grass	0.41
Range (natural)	0.13
Woods[3]:	
Light underbrush	0.40
Dense underbrush	0.80

[1] The n values are a composite of information by Engman (1986).
[2] Includes species such as weeping lovegrass, bluegrass, buffalo grass, blue grama grass, and native grass mixtures.
[3] When selecting n, consider cover to a height of about 0.1 ft. This is the only part of the plant cover that will obstruct sheet flow.

Additionally, the SCS lag equation is an acceptable method for calculating the time of concentration for overland flow (T_c) based on watershed lag time (T_L). T_L is defined as the time between the center of mass of excess rainfall to the time of peak runoff (similar to an average flow time for a small homogeneous area). The following equations can be used to determine T_c:

Equation 3-5

$$T_c = 1.67 T_L$$

where:

T_C = time of concentration of overland flow portion of flow path (hours)
T_L = NRCS lag time (hours)

Equation 3-6

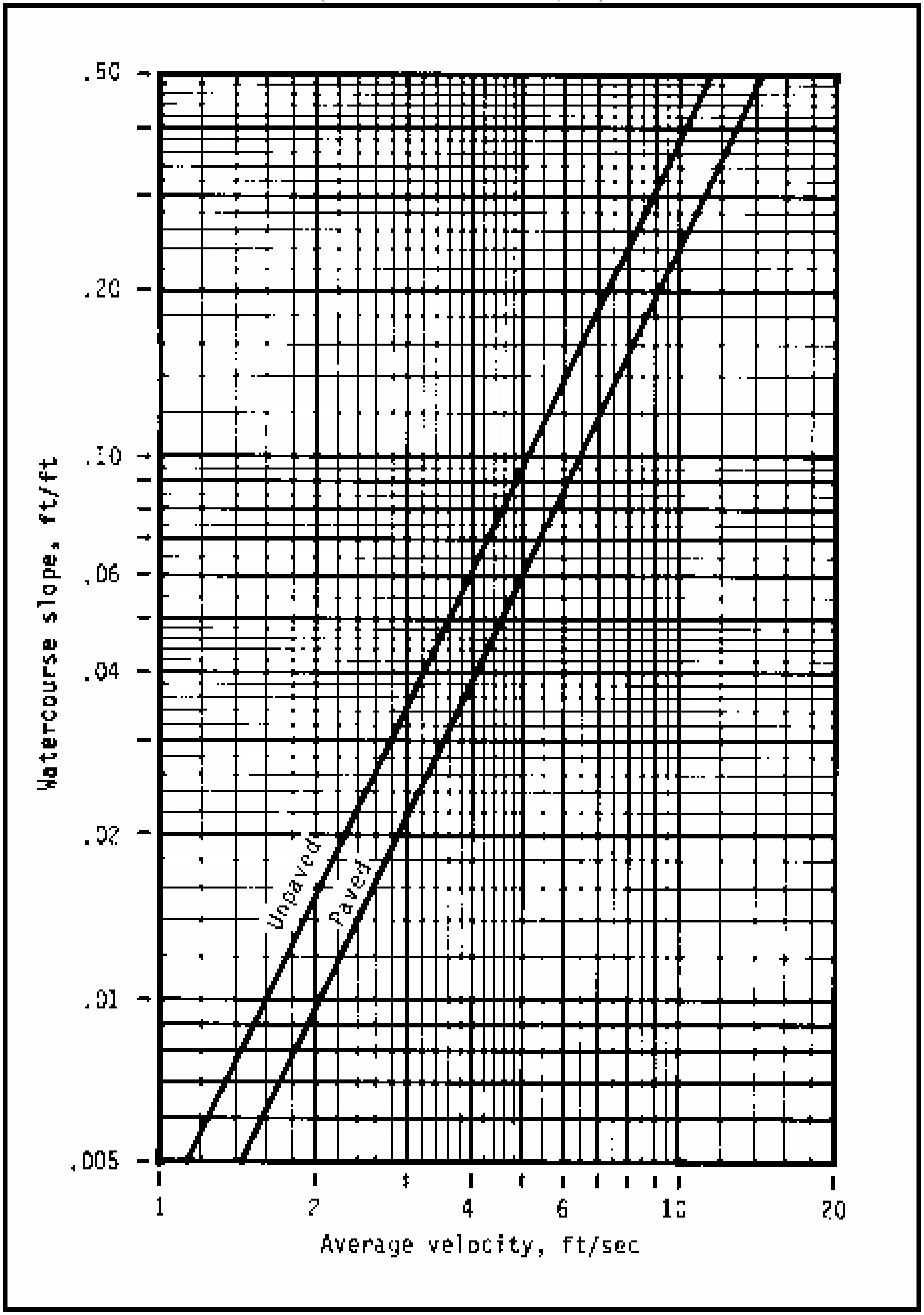
$$T_L = \frac{L^{0.8}(S+1)^{0.7}}{1900 W_s^{0.5}}$$

where:

T_L = SCS lag time (hours)
L = flow length for sheet flow over the surface (feet)
S = potential maximum soil retention (inches) = 1000/CN-10
W_s = average ground surface slope as a percentage (%)

Figure 3-2. Average Velocities - Shallow Concentrated Flow

(Source: Soil Conservation Service, 1986)



Shallow Concentrated Flow:

After a maximum of 300 feet (100 feet for paved areas), overland flow will normally become shallow concentrated flow. The average velocity of this flow can be determined from Figure 3-2, in which average velocity is a function of watercourse slope and type of channel. Equations 3-7 and 3-8 can be used to determine the average flow velocity on paved and unpaved surfaces for slopes less than the minimum slope in Figure 3-2 (0.005 ft/ft):

Equation 3-7 Unpaved $V = 16.13(S)^{0.5}$

Equation 3-8 Paved $V = 20.33(S)^{0.5}$

where:

V = average velocity (ft/s), and
S = slope of hydraulic grade line (watercourse slope, ft/ft)

After determining average velocity, use Equation 3-9 to estimate travel time for the shallow concentrated flow segment.

Equation 3-9

$$T_t = \frac{L}{60V}$$

where:

T_t = travel time (min)
L = reach length (ft)
V = velocity in reach (ft/sec) = Q/A

Paved Gutter and Open Channel Flow:

The travel time within the storm drain, gutter, swale, ditch, or other drainage way can be determined through an analysis of the hydraulic properties of these conveyance systems using Manning's equation (Equation 3-10).

Equation 3-10

$$V = \frac{1.49(R)^{2/3}(S)^{1/2}}{n}$$

where:

V = average velocity (ft/s)
R = hydraulic radius (feet) and equals A/P_w
A = cross sectional flow area (sq.ft.)
P_w = wetted perimeter (feet)
S = slope of energy grade line (channel slope, ft/ft), and
n = Manning's roughness coefficient for open channel flow

Open channels are assumed to begin where surveyed cross section information has been obtained, where channels are visible on aerial photographs, where channels have been identified by TDEC or Knox County, or where blue lines (indicating streams) appear on USGS quadrangle sheets. Equation 3-10 or water surface profile information can be used to estimate average flow velocity. Average flow velocity for travel time calculations is usually determined for bankfull elevation assuming low vegetation winter conditions.

Values of Manning's "n" for use in Equation 3-10 may be obtained from standard design textbooks such as Chow (1959) and Linsley et al. (1949). These values are also included as a part of discussion of Manning's equation within Chapter 7 of this Manual, *Stormwater Drainage System Design*.

After the average velocity is computed using Equation 3-10, T_t for the channel segment can be estimated using Equation 3-9 shown previously.

Example 3-1. Calculation of Peak Discharge Using Rational Method

Estimates of the maximum rate of runoff are needed at the inlet to a proposed culvert for a 25-year return period.

Site Data
From an example topographic map and a field survey, the area of the drainage basin upstream from the point in question is found to be 23 acres. In addition the following data were measured:

- Average overland slope = 2.0% = 0.02 ft/ft
- Length of overland flow = 50 ft
- Length of main basin channel = 2,250 ft
- Hydraulic Radius R taken from channel dimensions = 1.62
- Slope of channel = 0.018 ft/ft = 1.8%
- Roughness coefficient (n) of channel was estimated to be 0.040
- Roughness coefficient (n) of overland flow area was estimated to be 0.090
- From existing land use maps, land use for the drainage basin was estimated to be:
  - Residential ($^1/_2$ acre) - 80%
  - Pasture - sandy soil, 3% slope - 20%
- From existing land use maps, the land use for the overland flow area at the head of the basin was estimated to be: lawn – silty clay soil, 2% slope

Step 1: The overland flow time can be calculated using Equation 3-4:

$$T_t = 0.007[(0.090)(50)]^{0.8}/(3.30)^{0.5}(0.02)^{0.4}$$
$$= 0.061 \text{ hrs} = 3.7 \text{ minutes}$$

Step 2: Calculate the channel flow time by first calculating the main channel velocity using Equation 3-10:

$$V = 1.49(1.62)^{2/3}(0.018)^{1/2}/(0.040)$$
$$= 6.9 \text{ ft/s}$$

The flow time is calculated using Equation 3-9:

$$T_t = 2250/[(6.9)(60)]$$
$$= 5.4 \text{ minutes}$$

Step 3: Calculate t_c.

$$t_c = 3.7 + 5.4 = 9.1 \text{ min (use 9 min)}$$

Step 4: From Table 3-4, use interpolation to calculate the intensity for a duration equal to 8 minutes,

$$I_{25} = 6.42 \text{ in/hr}$$

Step 5: A weighted runoff coefficient (C) for the total drainage area is determined below by utilizing the C values from Table 3-6. Assume the silty clay soil specified is classified in hydrologic soil group C.

1	2	3	4
Land Use	Percent of Total Land Area	Runoff Coefficient	Weighted Runoff Coefficient[1]
Residential ($^1/_2$ acre)	80	0.35	0.280
Pasture	20	0.42	0.084
Total Weighted Runoff Coefficient = 0.364			

[1] - Column 4 equals Column 2 multiplied by Column 3.

Step 6: The Rational Method estimate of peak runoff for a 25-yr design storm for the given basin is:

$Q_{25} = C_f CIA = (1.10)(0.364)(6.42)(23)$

$= 59.1$ cfs