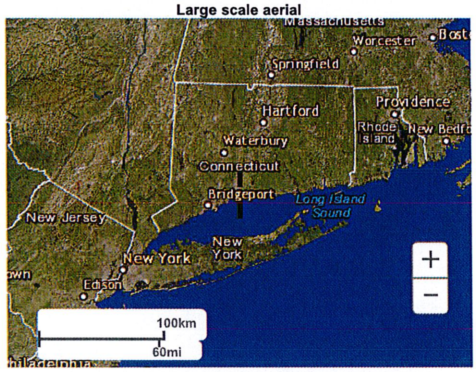
Large scale aerial



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6.9 Rational Method

6.9.1 Introduction

The rational method is recommended for estimating the design storm peak runoff for areas as large as 81 ha (200 ac). This method, while first introduced in 1889, is still used in many engineering offices in the United States. Even though it has frequently come under criticism for its simplistic approach, no other drainage design method has received such widespread use.

6.9.2 Application

Some precautions should be considered when applying the rational method.

- The first step in applying the rational method is to obtain a good topographic map and define the boundaries of the drainage area in question. A field inspection of the area should also be made to determine if the natural drainage divides have been altered.
- In determining the runoff coefficient C value for the drainage area, thought should be given to future changes in land use that might occur during the service life of the proposed facility that could result in an inadequate drainage system.
- The charts, graphs and tables included in this section are not intended to replace reasonable and prudent engineering judgment which should permeate each step in the design process.

6.9.3 Characteristics

Characteristics of the rational method which limit its use to 81 ha (200 ac) include:

(1) The rate of runoff resulting from any rainfall intensity is a maximum when the rainfall intensity lasts as long or longer than the time of concentration. That is, the entire drainage area does not contribute to the peak discharge until the time of concentration has elapsed.

This assumption limits the size of the drainage basin that can be evaluated by the rational method. For large drainage areas, the time of concentration can be so large that constant rainfall intensities for such long periods do not occur and shorter more intense rainfalls can produce larger peak flows. For this reason, the rational method is inappropriate for watersheds greater than about 81 ha (200 ac).

(2) The frequency of peak discharges is the same as that of the rainfall intensity for the given time of concentration.

Frequencies of peak discharges depend on rainfall frequencies, antecedent moisture conditions in the watershed, and the response characteristics of the drainage system. For small and largely impervious areas, rainfall frequency is the dominant factor. For larger drainage basins, the response characteristics control. For drainage areas with few impervious surfaces (less urban development), antecedent moisture conditions usually govern, especially for rainfall events with a return period of 10 years or less.

(3) The fraction of rainfall that becomes runoff (C) is independent of rainfall intensity or volume.

The assumption is reasonable for impervious areas, such as streets, rooftops and parking lots. For pervious areas, the fraction of runoff varies with rainfall intensity and the accumulated volume of rainfall. Thus, the art necessary for application of the rational method involves the selection of a coefficient that is appropriate for the storm, soil and land use conditions. Many guidelines and tables have been established, but seldom, if ever, have they been supported with empirical evidence.

(4) The peak rate of runoff is sufficient information for the design.

Modern drainage practice often includes detention of urban storm runoff to reduce the peak rate of runoff downstream. With only the peak rate of runoff, the rational method severely limits the evaluation of design alternatives available in urban and in some instances, rural drainage design.

6.9.4 Equation

The rational formula estimates the peak rate of runoff at any location in a watershed as a function of the drainage area, runoff coefficient and mean rainfall intensity for a duration equal to the time of concentration (the time required for water to flow from the most remote point of the basin to the location being analyzed). The rational formula is expressed as follows:

$$Q = 0.00278\ CIA \qquad (Q = CIA) \qquad (6.1)$$

where: Q = maximum rate of runoff, m^3/s (ft^3/s)
C = runoff coefficient representing a ratio of runoff to rainfall
I = average rainfall intensity for a duration equal to the time of concentration, for a selected return period, mm/h (in/h)
A = drainage area tributary to the design location, ha (acres)

6.9.5 Infrequent Storm

The runoff coefficients given in Tables 6-3 through 6-5 are applicable for storms of 2-year to 10-year frequencies. Less frequent, higher intensity storms will require modification of the runoff coefficient because infiltration and other losses have a proportionally smaller effect on runoff (Wright-McLaughlin 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 C_f. The rational formula now becomes:

$$Q = 0.00278\ CC_fIA \qquad (Q = CC_fIA) \qquad (6.2)$$

C_f values are listed in Table 6-2. The product of C_f times C shall not exceed 1.0.

Table 6-2 Frequency Factors For Rational Formula

Recurrence Interval (years)	C_f
25	1.1
50	1.2
100	1.25

6.9.6 Procedures

The results of using the rational formula to estimate peak discharges are very sensitive to the parameters that are used. The designer must use good engineering judgment in estimating values that are used in the method. Following is a discussion of the different variables used in the rational method.

Time Of Concentration

The time of concentration is the time required for water to flow from the hydraulically most remote point of the drainage area to the point under investigation. Use of the rational formula requires 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).

Appendix C (Travel Time Estimation) at the end of this chapter describes the method based on the NRCS Technical Release No. 55 (2nd Edition). This method shall be used for the rational method. Note: under certain circumstances, where tributary areas are very small or completely paved, the computed time of concentration would be very short. For design purposes the minimum time of concentration for paved areas shall be 5 minutes and 10 minutes for grassed areas.

Common Errors

Two common errors should be avoided when calculating t_c. First, in some cases runoff from a portion of the drainage area which is highly impervious may result in a greater peak discharge than would occur if the entire area were considered. In these cases, adjustments can be made to the drainage area by disregarding those areas where flow time is too slow to add to the peak discharge. Sometimes it is necessary to estimate several different times of concentration to determine the design flow that is critical for a particular application.

Second, when designing a drainage system, the overland flow path is not necessarily perpendicular to the contours shown on available mapping. Often the land will be graded and swales will intercept the natural contour and conduct the water to the streets which reduces the time of concentration.

Rainfall Intensity

The rainfall intensity (I) is the average rainfall rate mm/h (in/h) for a duration equal to the time of concentration for a selected return period. Once a particular return period has been selected for design and a time of concentration calculated for the drainage area, the rainfall intensity can be determined from Rainfall-Intensity-Duration curves. The rainfall intensity can be determined from rainfall-intensity-duration Table B-2 which can be found in Appendix B.

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 designer. While engineering judgment will always be required in the selection of runoff coefficients, a typical coefficient represents the integrated effects of many drainage basin parameters, the following discussion considers only the effects of soil groups, land use and average land slope.

Methods for determining the runoff coefficient are presented based on hydrologic soil groups and land slope (Table 6-3), land use (Table 6-4) and a composite coefficient for complex watersheds (Table 6-5).

Table 6-3 gives the recommended coefficient C of runoff for pervious surfaces by selected hydrologic soil groupings and slope ranges. From this table the C values for non-urban areas such as forest land, agricultural land, and open space can be determined. Soil properties influence the relationship between runoff and rainfall since soils have differing rates of infiltration. Infiltration is the movement of water through the soil surface into the soil. Based on infiltration rates, the NRCS has divided soils into four hydrologic soil groups as follows:

Group A Soils having a low runoff potential due to high infiltration rates. These soils consist primarily of deep, well drained sands and gravels.

Group B Soils having a moderately low runoff potential due to moderate infiltration rates. These soils consist primarily of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures.

Group C Soils having a moderately high runoff potential due to slow infiltration rates. These soils consist primarily of soils in which a layer exists near the surface that impedes the downward movement of water or soils with moderately fine to fine texture.

Group D Soils having a high runoff potential due to very slow infiltration rates. These soils consist primarily of clays with high swelling potential, soils with permanently high water tables, soils with a claypan or clay layer at or near the surface and shallow soils over nearly impervious parent material.

The NRCS has developed detailed soil surveys for all counties within Connecticut. From these documents, the designer can determine the nature and relative percentages of the soils within a given watershed. It is important to note that the level of effort required in the determination of soil types is commensurate with the size of the watershed and the design objectives. Normally, in the computation of discharge quantities for gutter flow analysis and related storm drainage design, a detailed evaluation of soil types is not necessary, as contributing areas adjoining highways are usually relatively small. However, in the design of cross culverts, channels or interceptor ditches the determination of soil types will provide valuable assistance to the design engineer in the evaluation of the runoff potential from a particular watershed.

The second factor for consideration in the determination of a runoff coefficient is land use. As unimproved areas are developed, the potential for increased runoff becomes greater due to the loss of vegetative cover, the reduction in retention by surface depressions and the increase in impervious surface area. Table 6-4 lists recommended ranges for the runoff coefficient value classified with respect to the general character of the tributary area. **The potential for future watershed development should be considered by the designer**.

The final element to be factored into the determination of runoff coefficients is the land slope. As the slope of the drainage basin increases, the selected C value should also increase. This is caused by the fact that as the slope of the drainage area increases, the velocity of overland and channel flow will increase allowing less opportunity for water to infiltrate the ground surface. Thus, more of the rainfall will become runoff from the drainage area.

In summary, it should be reiterated that in assigning a value to the runoff coefficient for use in the rational method, the engineer must rely heavily on experience and judgement.

Table 6-3 Recommended Coefficient Of Runoff For Pervious Surfaces By Selected Hydrologic Soil Groupings And Slope Ranges

Slope	A	B	C	D
Flat (0 - 1%)	0.04-0.09	0.07-0.12	0.11-0.16	0.15-0.20
Average (2 - 6%)	0.09-0.14	0.12-0.17	0.16-0.21	0.20-0.25
Steep (Over 6%)	0.13-0.18	0.18-0.24	0.23-0.31	0.28-0.38

Source: Storm Drainage Design Manual, Erie and Niagara Counties Regional Planning Board.

Table 6-4 Recommended Coefficient Of Runoff Values For Various Selected Land Uses

Description of Area		Runoff Coefficients
Business: Downtown areas		0.70-0.95
Neighborhood areas		0.50-0.70
Residential:	Single-family areas	0.30-0.50
	Multi units, detached	0.40-0.60
	Multi units, attached	0.60-0.75
	Suburban	0.25-0.40
Residential (0.5 ha (1.2 ac) lots or more)		0.30-0.45
Apartment dwelling areas		0.50-0.70
Industrial:	Light areas	0.50-0.80
	Heavy areas	0.60-0.90
Parks, cemeteries		0.10-0.25
Playgrounds		0.20-0.40
Railroad yard areas		0.20-0.40
Unimproved areas		0.10-0.30

Table 6-5 Coefficients For Composite Runoff Analysis

Surface		Runoff Coefficients
Street:	Asphalt	0.70-0.95
	Concrete	0.80-0.95
Drives and walks		0.75-0.85
Roofs		0.75-0.95

Appendix C - Time Of Concentration

6.C.1 Introduction

Travel time (T_t) is the time it takes runoff to travel from one location to another in a watershed (subreach) and is a component of time of concentration (T_c), which is the time for runoff to travel from the hydraulically most distant point of the watershed to a point of interest within the watershed. **T_c is computed by summing all the travel times for consecutive components of the drainage conveyance system**.

Following is a discussion of procedures and equations for calculating time of concentration and travel time.

6.C.2 Time Of Concentration

The time of concentration, which is denoted as T_c ,is defined as the time required for a particle of runoff to flow from the hydraulically most distant point in the watershed to the outlet or design point. Factors that affect the time of concentration are the length of flow, the slope of the flow path, and the roughness of the flow path. For flow at the upper reaches of a watershed, rainfall characteristics, most notably the intensity, may also influence the velocity of the runoff.

The time of concentration equals the sum of the travel times on each segment of the principal flow path, accordingly, it is useful to describe the segments of flow paths. Sheet flow occurs in the upper reaches of a watershed. Such flow occurs over short distances and at shallow depths prior to the point where topography and surface characteristics cause the flow to concentrate in rills and swales. The depth of such flow is usually 20 to 30mm (3/4 in to 1 in) or less. Concentrated flow is runoff that occurs in rills and swales and has depths on the order to 40 to 100 mm (1.5 in to 4 in). Part of the principal flow path may include pipes or small streams. The travel time through these segments would be computed separately. Velocities in open channels are usually determined assuming bank-full depths.

The following equation represents the time of concentration which is the sum of the travel times (T_t) values for the various consecutive flow segments:

$$T_c = T_{t1} + T_{t2} + \ldots T_{tm} \qquad \textbf{(6.C.1)}$$

Where T_c = time of concentration, h
m = number of flow segments
T_{tm} = travel time segment, h

6.C.3 Travel Time, T_t

Water moves through a watershed as sheet flow, shallow concentrated flow, open channel flow, or some combination of these. The type that occurs is a function of the conveyance system and is best determined by field inspection.

6.C.4 Sheet-Flow Travel Time, T_t

Sheet flow is a shallow mass of runoff on a plane surface with the depth uniform across the sloping surface. **Typically flow depths will not exceed 30mm (1 in). Such flow occurs over relatively short distances, rarely more than about 91.4m (300 ft), but most likely less than 46m (150 ft)**. Sheet flow rates are commonly estimated using the NRCS TR-55 (1986) variation of the kinematic wave equation:

$$T_t = \frac{0.091(nL)^{0.8}}{P_2^{0.5} S^{0.4}} \qquad \left(T_t = \frac{0.007(nL)^{0.8}}{P_2^{0.5} S^{0.4}} \right) \qquad \textbf{(6.C.2)}$$

Where T_t = travel time, h
n = Manning's roughness coefficient (values of n can be obtained from Table C.1)
L = flow length, m (ft)
S = slope of the hydraulic grade line (land slope), m/m (ft/ft)
P_2 = 2 year, 24 hour rainfall depth, mm (in) (See Table B-1.)

TR-55 recommends an upper limit of L=91.4m (300 ft) for using Equation 6.C.2, although others have suggested that 91.4m (300 ft) is too long of a flow length for Connecticut so **engineering judgement should be used when selecting the flow length.**

Travel time is the ratio of flow length to flow velocity:

$$\mathbf{T_t = L/(3600V)} \qquad \textbf{(6.C.3)}$$

Where: T_t = travel time, h
L = flow length, m (ft)
V = average velocity, m/s (ft/s)
3600 = conversion factor from seconds to hours.

n	**Surface Description**
0.011	Smooth asphalt
0.012	Smooth concrete
0.05	Fallow (no residue)
	Cultivated soils
0.06	Residue cover = 20%
0.17	Residue cover >20%
0.13	Range (natural)
	Grass
0.15	Short grass prairie
0.24	Dense grasses
0.41	Bermuda grass
	Woods**
0.40	Light underbrush
0.80	Dense underbrush

Table C-1 Mannings's Roughness Coefficient (n) for Overland Sheet Flow*

* Values obtained from NRCS TR-55 (1986) and McCuen (1989).

** When selecting n for woody underbrush, consider cover to a height of about 25mm (1in). This is the only part of the plant cover that will obstruct sheet flow.

6.C.5 Shallow Concentrated Flow Travel Time

After a maximum of 91.4 m (300 ft), sheet flow usually becomes shallow concentrated flow. The average velocity for this flow can be determined from equations 6.C.4 and 6.C.5, in which average velocity is a function of watercourse slope and type of channel.

Unpaved $V = 4.9178(s)^{0.5} \quad (V = 16.1345(s)^{0.5})$ **(6.C.4)**

Paved $V = 6.1961(s)^{0.5} \quad (V = 20.3284(s)^{0.5})$ **(6.C.5)**

Where: V = average velocity, m/s (ft/s)
s = slope of hydraulic grade line (watercourse slope), m/m (ft/ft)

These two equations are based on the solution of Manning's equation with different assumptions for n (Manning's roughness coefficient) and r (hydraulic radius, m (ft)). For unpaved areas, n is 0.05 and r is 0.12 m (0.4 ft); for paved areas, n is 0.025 and r is 0.06 m (0.2 ft).

After determining average velocity, use equation 6.C.3 to estimate travel time, T_t for the shallow concentrated flow segment.