16.10.5 Time of Concentration, t_c

With regard to storm duration to be considered for runoff assessment, *time of concentration*, t_c, is relevant. It is defined as the time required for runoff from the hydraulically most remote part of the drainage area to reach the point of reference. There is another definition of this term as well, as stated in Section 9.8.1. For various routes of flow, t_c is taken as the longest time of travel to the point of reference. There are many ways to estimate t_c. Some of these methods are designed primarily for overland flow, some primarily for channel flow, and a few for both overland and channel flows. Many formulas are summarized in Table 16.6, which can be used when overland flow conditions dominate. The specific condition for which a formula applies is indicated in the table. To apply the Izzard formula, rainfall intensity must be known. A suitable procedure is to assume a time of concentration, determine the intensity from eq. (2.15), and calculate the time of concentration from the Izzard formula. If the initially assumed value was inconsistent, the process above is repeated.

Table 16.6 Empirical Relations for Time of Overland Flow, t_i

Name	Formula for t_i	Remarks	Eq. Number
1. Kirpich	$0.0078\dfrac{L^{0.77}}{S^{0.385}}$		(16.4)
2. Kerby	$0.828\left(\dfrac{rL}{S^{0.5}}\right)^{0.467}$	Applicable to $L < 1300$ ft $r = 0.02$ smooth pavement 0.1 bare packed soil 0.3 rough bare or poor grass 0.4 average grass 0.8 dense grass, timber	(16.5)
3. Izzard	$\dfrac{41.025(0.007i + K)L^{0.33}}{S^{0.333}i^{0.667}}$	Applicable to $iL < 500$ $K = 0.007$ smooth asphalt 0.012 concrete pavement 0.017 tar and gravel pavement 0.046 closely clipped sod 0.060 dense bluegrass turf	(16.6)
4. Bransby-Williams	$\dfrac{0.00765L}{S^{0.2}A^{0.1}}$		
5. Federal Aviation Agency	$\dfrac{0.388(1.1 - C)L^{0.5}}{S^{0.333}}$	C = Rational coefficient	(16.7)
6. Kinematic Wave	$\dfrac{0.94L^{0.6}n^{0.6}}{i^{0.4}S^{0.3}}$	n = Manning's coefficient for overland flow	(16.8)
7. NRCS (SCS)	see eqs. (16.9) and (16.10) and open channel travel time		

where: i = rainfall intensity, in./hr; L = Length of flow path, ft; S = slope of flow path, ft/ft; A = drainage area, acres; and t_i = overland flow time, min.

Since rainfall intensity reduces with increase in storm duration, the duration should be as short as possible. However, if the rainfall duration is less than t_c, then only a part of the drainage area will be contributing to the runoff. For an entire area to contribute, the shortest storm duration should equal t_c. Thus the time of concentration is used as a unit duration for which the rainfall intensity is determined.

In storm sewer design, in addition to the time required for the rain falling on the most remote point of the tributary area to flow across the ground surface, along streets and gutters, to the point of entry to a sewer, the time of flow through the sewer line is also important. Either the surface and sewer flow times are added together (rational method) or they are considered separately [NRCS (SCS) TR-55 method].

According to the Natural Resources Conservation Service (1986), water moves through a watershed as (1) sheet flow, (2) shallow concentrated flow, (3) open channel flow, or some combination of these before it enters the sewer line. The types that occur depend on the drainage area and can best be determined by field inspection. Time of concentration is the sum of sheet flow, shallow concentrated flow, and channel flow, whichever occur.

Sheet flow in the form of a thin layer can occur for a maximum length of 300 ft. The travel time is given by Manning's kinematic solution (Overton and Meadows, 1976) as follows:

$$t_{t1} = \frac{0.42(nL)^{0.8}}{(P_2)^{0.5} S^{0.4}} \quad \text{[unbalanced]} \tag{16.9}$$

where

t_{t1} = sheet flow travel time, min
n = Manning's roughness coefficient (Table 16.7)
L = Flow length, ft
P_2 = 2-yr 24-hr rainfall, in.
S = land slope

The Manning roughness coefficient n, as presented in Table 16.7, is taken to be a constant value for a particular surface. This holds for a large Reynolds number and a fully developed turbulent condition that exists in an open channel flow. Comparison of the Darcy-Weisbach equation and the Manning equation has revealed that the value of n actually increases for low Reynolds numbers. Engman (1986) and others have assessed the values of n utilizing data from controlled experiments and observations on small experimental watersheds. The value tends to be higher for overland flow than for channel flow for rough surfaces.

Table 16.7 Overland Flow Roughness Coefficient

Surface	Manning's n
Concrete, asphalt, bare soil	0.01– 0.016
Gravel, clay-loam eroded	0.012– 0.03
Sparse vegetation, cultivated soil	0.053– 0.13
Short grass	0.1– 0.2
Dense grass, bluegrass, Bermuda grass	0.17– 0.48
Woods	0.4– 0.8

After a maximum of 300 ft, sheet flow usually becomes shallow concentrated flow. The average velocity for this flow can be determined from Figure 16.7 using the land slope and the type of soil cover. The travel time for shallow concentrated flow is the length divided by the average velocity.

$$t_{t2} = \frac{L}{V} \times \frac{1}{60} \quad [\mathrm{T}^{-1}] \tag{16.10}$$

where

t_{t2} = shallow concentrated flow travel time, min
L = concentrated flow length, ft
V = flow velocity, ft/s (Figure 16.7)

Open channel is assumed to begin where a channel form is visible from field investigations or on aerial photographs. Manning's equation of open channel flow is used to determine the average velocity, and the travel time is ascertained by dividing the channel length by the velocity. The coefficient n for channel flow is obtained from Table 14.4.

Whenever a drainage area consists of several types of surfaces, the time of concentration is determined by adding the times for different surfaces.

Example 16.8

An urbanized watershed in Providence, Rhode Island, is shown in Figure 16.8. Determine the time of concentration to point C by the various methods. The average velocity of flow in the storm drain = 3 ft/s.

Solution

(a) Time of overland flow:

1. Kirpich method

$$t_i = \frac{0.0078(1000)^{0.77}}{(0.02)^{0.385}} = 7.18 \text{ min}$$

2. Kerby method

$$r = 0.02$$

$$t_i = 0.828\left[\frac{(0.02)(1000)}{(0.02)^{0.5}}\right]^{0.467} = 8.36 \text{ min}$$

3. Izzard method. Assume that the time of concentration = 10 min. For Providence, RI (area 3 in Fig. 2.7) and 5-year frequency

$$i = \frac{131.1}{t+19} = \frac{131.1}{10+19} = 4.52 \text{ in./hr}$$

$iL = (4.52)(1000) = 4520 > 500$; thus the formula is not applicable

4. Bransby-Williams method

$$t_i = \frac{0.00765(1000)}{(0.02)^{0.2}(375)^{0.1}} = 9.25 \text{ min}$$

5. Federal Aviation Agency method

$$C = 0.9 \text{ for asphalt paving}$$

$$t_i = \frac{0.388(1.1-0.9)(1000)^{0.5}}{(0.02)^{0.333}} = 9.03 \text{ min}$$

6. Kinematic wave method

$$n = 0.011 \text{ (Table 16.7)}$$

$$i = 4.52 \text{ in./hr (method 3 above)}$$

$$t_i = \frac{0.94(1000)^{0.6}(0.011)^{0.6}}{(4.52)^{0.4}(0.02)^{0.3}} = 7.00 \text{ min}$$

7. NRCS (SCS) method. Sheet flow for first 300 ft

$$P_2 = 3.5 \text{ in./hr (from Fig. B-3 in the TR-55, U.S. NRCS, 1986)}$$

$$t_{t1} = \frac{0.42[(0.011)(300)]^{0.8}}{(3.5)^{0.5}(0.02)^{0.4}} = 2.79 \text{ min}$$

Shallow concentrated flow for remaining length of 700 ft

$$V = 2.8 \text{ ft/s from Fig. 16.7}$$

$$t_{t2} = \frac{700}{2.8\,(60)} = 4.17 \text{ min}$$

$$t_i = 2.79 + 4.17 = 6.96 \text{ min}$$

(b) Sewer flow time:

$$t_f = \frac{\text{sewer length}}{\text{velocity}} = \frac{1500}{3} = 500 \text{ sec or } 8.3 \text{ min}$$

Adding time to inlet and sewer flow time, t_c varies from 15.26 min to 17.55 min, depending on the method of computation.

16.11 APPLICATION OF THE RATIONAL METHOD

The drainage area usually consists of more than one type of surface. Equation (16.2) is then applied in the following form:

$$Q = iC_f \sum_{j=1}^{n} C_j a_j \quad [\mathrm{L^3T^{-1}}] \tag{16.11}$$

Figure 16.7 Average velocity of overland flow (from U.S. SCS 1975b).

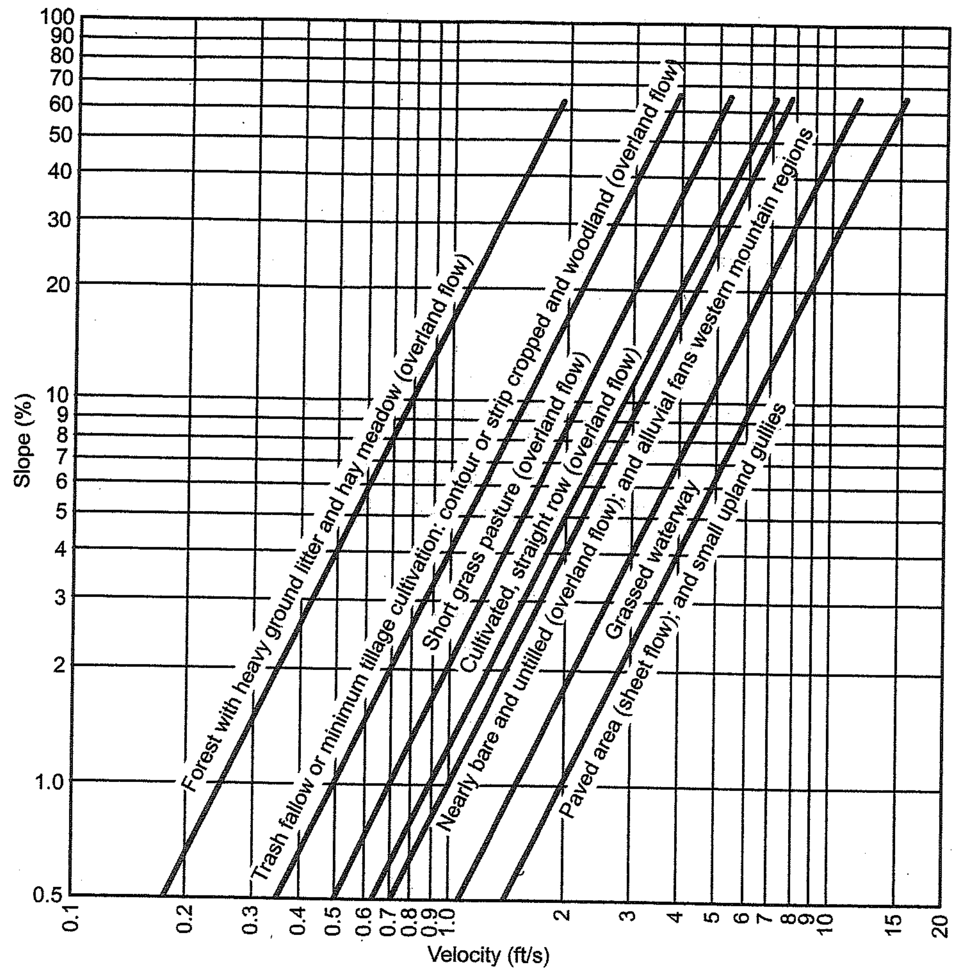

Figure 16.8 Urbanized watershed for Example 16.8.