

# TR-55 Chapter 3

## Time of Concentration and Travel Time

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Travel time ( $T_t$ ) is the time it takes water to travel from one location to another in a watershed.  $T_c$  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.

$T_c$  influences the shape and peak of the runoff hydrograph. Urbanization usually decreases  $T_c$ , thereby increasing the peak discharge. But  $T_c$  can be increased as a result of (a) ponding behind small or inadequate drainage systems, including storm drain inlets and road culverts, or (b) reduction of land slope through grading.

### Factors affecting time of concentration and travel time

#### Surface roughness

One of the most significant effects of urban development on flow velocity is less retardance to flow. That is, undeveloped areas with very slow and shallow overland flow through vegetation become modified by urban development: the flow is then (delivered to streets, gutters, and storm sewers that transport runoff downstream more rapidly. Travel time through the watershed is generally decreased.

#### Channel shape and flow patterns

In small non-urban watersheds, much of the travel time results from overland flow in upstream areas. Typically, urbanization reduces overland flow lengths by conveying storm runoff into a channel as soon as possible. Since channel designs have efficient hydraulic characteristics, runoff flow velocity increases and travel time decreases.

#### Slope

Slopes may be increased or decreased by urbanization, depending on the extent of site grading or the extent to which storm sewers and street ditches are used in the design of the water management system. Slope will tend to increase when channels are straightened and decrease when overland flow is directed through storm sewers, street gutters and diversions.

## Computation of travel time and time of concentration

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.

Travel time ( $T_t$ ) is the ratio of flow length to flow velocity (eqn 3-1):

$$T_t = L / (3600 V)$$

- $T_t$  = travel time (hr),
- $L$  = flow length (ft).
- $V$  = average velocity (ft/s), and
- 3600 = conversion factor from seconds to hours.
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Time of concentration ( $T_c$ ) is the sum of  $T_t$  values for the various consecutive flow segments (eqn 3-2):

$$T_c = T_{t1} + T_{t2} + \dots + T_{tm}$$

- $T_c$  - time of concentration (hr) and
- $m$  = number of flow segments.

### Sheet flow

Sheet flow is flow over plane surfaces. It usually occurs in the headwater of streams. With sheet flow, the friction value (Manning's  $n$ ) is an effective roughness coefficient that includes the effect of raindrop impact; drag over the plane surface; obstacles such as litter, crop ridges, and rocks; and erosion and transportation of sediment. These  $n$  values are for very shallow flow depths of about 0.1 foot or so. Table 3.1 gives Manning's  $n$  values for sheet flow for various surface conditions.

For sheet flow of less than 300 feet, use Manning's kinematic solution (Overton and Meadows 1976) to compute  $T_t$  (eqn 3-3).

$$T_t = 0.007 (nL)^{.8} / (P_2^{.5} s^{.4})$$

where

- $n$  = Manning's roughness Coefficient (table 3-1),
- $L$  = flow length (ft),
- $P_2$  = 2-year, 24 hour rainfall (in), and
- $s$  = slope of hydraulic grade line land slope.(ft/ft).

Table 3-1.- Roughness coefficients (Manning's n) for sheet flow

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	0.24
Bermuda grass	0.41
Range (natural)	0.13
Woods	
Light underbrush	0.40
Dense underbrush	0.80

This simplified form of the Manning's kinematic solution is based on the following: (1) shallow steady uniform flow, (2) constant intensity of rainfall excess (that part of a rainfall available for runoff), (3) rainfall duration of 24 hours, and (4) minor effect of infiltration on travel time. Rainfall depth can be obtained from Appendix B.

### Shallow concentrated flow

After a maximum of 300 feet, sheet flow usually becomes shallow concentrated flow. The average velocity for this flow can be determined from figure 3-1, in which average velocity is a function of watercourse slope and type of channel. For slopes less than 0.005 ft/ft. use equations given in appendix F for figure 3-1. Tillage can affect the direction of shallow concentrated flow. Flow may not always be directly down the watershed slope if tillage runs across the slope.

After determining average velocity in [figure 3-1](#), use equation 3-1 to estimate travel time for the shallow concentrated flow segment.

### Open channels

Open channels are assumed to begin where surveyed cross section information has been obtained, where channels are visible on aerial photographs, or where blue lines (indicating streams) appear on United States Geological Survey (USGS) quadrangle sheets. Manning's equation or water surface profile information can be used to estimate average flow velocity. Average flow velocity is usually determined for bank-full elevation.

Manning's equation is (eqn 3-4)

$$V = 1.49/n * r^{(2/3)}s^{(1/2)}$$

where

- V = average velocity (ft/s),
- r = hydraulic radius (ft) and is equal to a/Pw,
- a = cross sectional flow area (ft<sup>2</sup>),
- Pw = wetted perimeter (ft)
- s = slope of the hydraulic grade line (channel slope, ft/ft), and
- n = Manning's roughness coefficient for open channel flow.

Manning's n values for open channel flow can be obtained from standard textbooks such as Chow (1959) or Linsley et al. (1982). After average velocity is computed using equation 3-4, Tt for the channel segment can be estimated using equation 3-1.

### **Reservoirs or lakes**

Sometimes it is necessary to estimate the velocity of flow through a reservoir or lake at the outlet of a watershed. This travel time is normally very small and can be assumed as zero.

### **Limitations**

- Manning's kinematic solution should not be used for sheet flow longer than 300 feet. Equation 3-3 was developed for use with the four standard rainfall intensity-duration relationships.
- In watersheds with storm sewers, carefully identify the appropriate hydraulic flow path to estimate Tc. Storm sewers generally handle only a small portion of a large event. The rest of the peak flow travels by streets, lawns, and so on, to the outlet. Consult a standard hydraulics textbook to determine average velocity in pipes for either pressure or nonpressure flow.
- The minimum Tc used in TR-55 is 0.1 hour.
- A culvert or bridge can act as a reservoir outlet if there is significant storage behind it. The procedures in TR-55 can be used to determine the peak flow upstream of the culvert. Detailed storage routing procedures should be used to determine the outflow through the culvert.

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