2C-3 Time of Concentration

A. Introduction

The time of concentration (T_c) is used in numerous equations to calculate discharge, particularly with the Rational method, WINTR-55, and WINTR-20. In most watersheds, it is necessary to add the many different time of concentrations resulting from different field conditions that runoff flows through to reach the point of investigation. Water moves through a watershed as sheet flow, shallow concentrated flow, swales, open channels, street gutters, storm sewers, or some combination of these. This section describes the many conditions and corresponding solutions that need to be considered when estimating the total time of concentration (T_c) (sum of runoff travel time).

There are also many methods utilized to estimate the time of concentration. Examples are the Kinematic Wave Method, Kirpich formula, Kerby formula, and the NRCS Velocity Method. The NRCS Velocity Method is one of the most common, is easily understood, has continuity with many computer programs, and is considered as accurate as other methods. It is for these reasons the NRCS Velocity Method is used in this manual. If there is a desire to use a different method in determining the time of concentration, the Engineer needs to be contacted for approval.

B. Definition

The time of concentration is defined as the time required for water falling on the most remote point of a drainage basin to reach the outlet where remoteness relates to time of travel rather than distance. Probably a better definition is that it is the time after the beginning of rainfall excess when all portions of the drainage basin are contributing simultaneously to flow at the outlet.

Using an appropriate value for time of concentration is very important, although it is hard sometimes to judge what the correct value is.

The time of concentration is often assumed to be the sum of two travel times (T_t). The first is the initial time required for the overland flow, and the second is the travel time in the conveyance elements (open channels, street gutters, storm sewers, etc).

C. Factors affecting time of concentration

1. **Surface roughness.** One of the most significant effects of urban development on flow velocity is a decrease in 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.

2. **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.

3. **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.

D. Estimating time of concentration (NRCS velocity method)

1. **Travel time.** Travel time (T_t) is the time it takes water to travel from one location to another in a watershed. T_t is a component of time of concentration (T_c), which is 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:
   - Ponding behind small or inadequate drainage systems, including storm drain inlets and road culverts
   - Reduction of land slope through grading
   - Lengthening the flow path
   - Decreasing the impervious area and/or reducing the directly connected impervious area in the catchment

   Travel time (T_t) is the ratio of flow length to flow velocity:

   $$T_t = \frac{L}{3600V}$$ **Equation 1**

   where
   T_t = travel time (hours)
   L = flow length (ft)
   V = average velocity (ft/s)
   3600 = conversion factor from seconds to hours

   Time of concentration (T_c) is the sum of T_t values for the various consecutive flow segments:

   $$T_c = T_{t1} + T_{t2} + T_{t3} \ldots\ldots\ldots T_{tm}$$ **Equation 2**

   where
   T_c = time of concentration (hr)
   T_t = travel time for a flow component
   m = number of flow segments

2. **Sheet flow.** Sheet flow is flow over plane surfaces (parking lots, farm fields, lawns). 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 rain drop impact; drag over the plane surface; obstacles such as litter, vegetation, crop ridges, and rocks; and erosion and transportation of sediment. These n values are for very shallow flow depths of about 0.1 foot. Table 1 gives Manning's n values for sheet flow for various surface conditions.

   For sheet flow of less than 100 feet, use Manning's kinematic solution (Overton and Meadows, 1976) to compute T_t;

$$T_t = \frac{0.007[(n)(L)]^{0.8}}{\sqrt{P_2}S^{0.4}}$$ **Equation 3**

where
T_t = travel time (hours)
n = Manning's roughness coefficient (Table 2)
L = flow length (ft)
P_2 = the 2-year, 24-hour rainfall (inches)
S = slope of hydraulic grade line (land slope, ft/ft)

This simplified form of Manning's kinematic solution is based on the following:
- Shallow steady uniform flow
- Constant intensity of rainfall excess (that part of a rain available for runoff)
- Rainfall duration of 24 hours
- Minor effect of infiltration on travel time

Table 1: Roughness coefficients (Manning's *n*) for sheet flow

Surface Description	*n*[1]
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 compiled 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.

3. **Shallow concentrated flow (urban/suburban areas).** After a maximum of 100 feet, sheet flow (gutter, swales, etc.) usually becomes shallow concentrated flow. The average velocity (V) for this flow can be determined from Figure 1, in which average velocity is a function of watercourse slope and type of channel surface. For slopes less than 0.005 ft/ft, use equations given below for Figure 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 1, use Equation 4 to estimate travel time for the shallow concentrated flow segment.

Figure 1 (average velocities for estimating travel time for shallow concentrated flow):

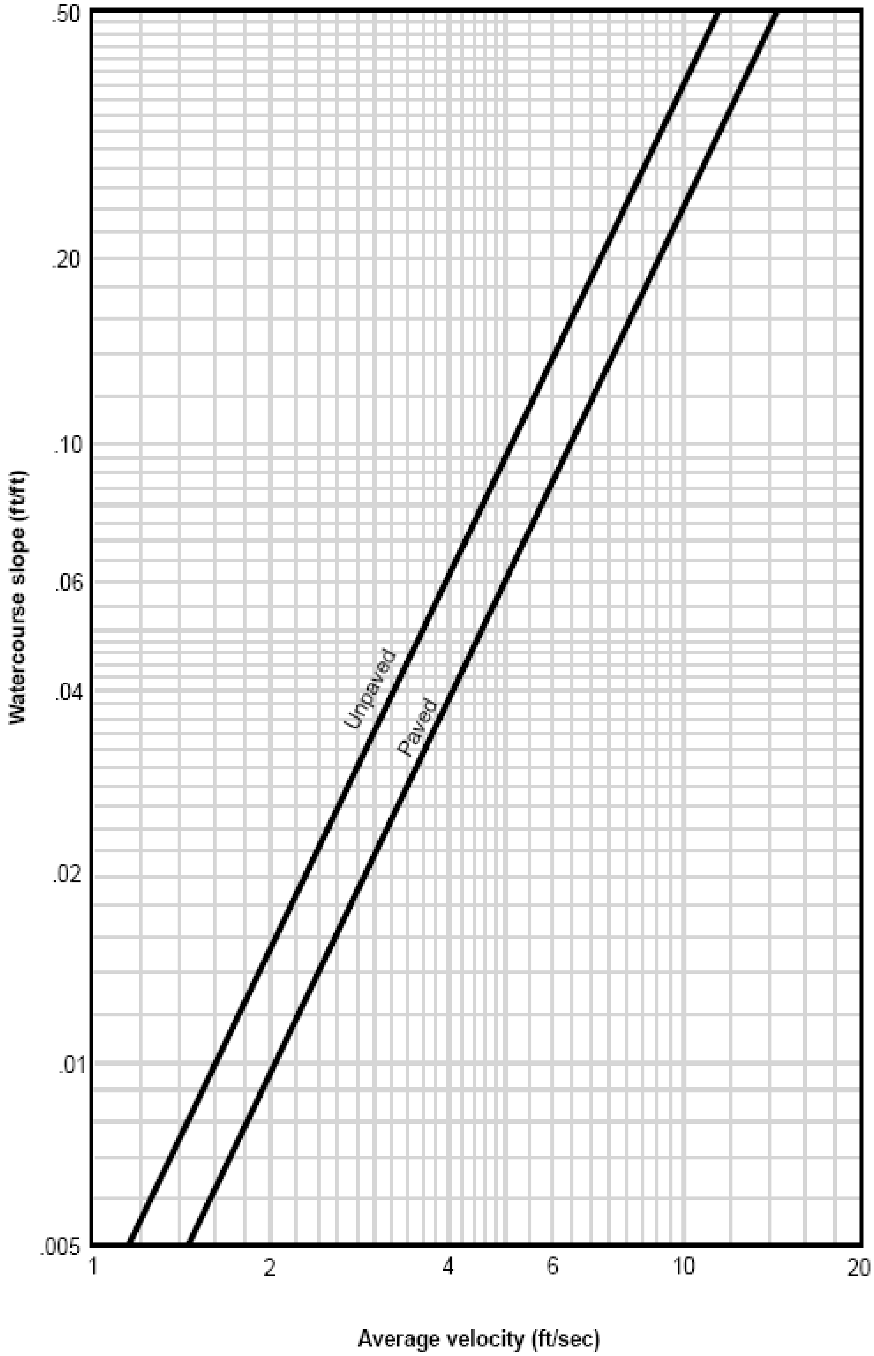
Unpaved V = 16.1345 (s) 0.5
Paved V = 20.3282 (s) 0.5

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

These two equations are based on the solution of Manning's equation (Equation 4) with different assumptions for *n* (Manning's roughness coefficient) and *r* (hydraulic radius, ft). For unpaved areas, *n* is 0.05 and r is 0.4; for paved areas, *n* is 0.025 and r is 0.2.

Tillage and vegetation surfaces 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 (V) in Figure 1, use Equation 1 to estimate travel time for the shallow concentration flow segment.

Figure 1: Shallow concentrated flow



Source: NRCS Urban Hydrology for Small Watersheds, v 2.1, 1986

4. **Open channels (open swales, ditches, and storm sewer piping under gravity flow).** 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 bankfull elevation.

Manning's equation is:

$$V = \frac{1.49\ R^{2/3}\ S^{1/2}}{N}$$ **Equation 4**

where:
V = average velocity (ft/s)
R = hydraulic radius (ft) and is equal to A/WP
A = cross sectional flow area (ft^2)
WP = wetted perimeter (ft)
s = slope of the hydraulic grade line (channel slope, ft/ft)
n = Manning's roughness coefficient for open channel flow (See Table 2)

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 Equations 3-4, T_t for the channel segment can be estimated using Equation 1.

5. **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.

6. **Limitations:**

   a. Manning's kinematic solution should not be used for sheet flow longer than 100 feet. Equation 3 was developed for use with the four standard rainfall intensity-duration relationships.

   b. In watersheds with storm sewers, carefully identify the appropriate hydraulic flow path to estimate T_c. 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 non-pressure flow.

   c. The minimum T_c used in WINTR-55 is 0.1 hour.

E. Estimating time of concentration (NRCS lag method)

1. In rural/suburban area drainage basins where a large segment of the area is rural in character and has long hydraulic length, the potential for retention of rainfall on the watershed increases along with travel time. Under these conditions, the NRCS watershed lag equation is used since it includes most of the factors to estimate travel time, and thus, time of concentration. The lag time (T_l) is really a weighted time of concentration for each segment of the watershed. It is related to the physical properties of a watershed such as area, length, and slope. The NRCS developed an empirical relationship between lag and time of concentration:

$$t_c = \frac{L}{0.6}$$ **Equation 5**

The NRCS equation to estimate lag is:

$$L = \frac{l^{0.8}(S+1)^{0.7}}{1900Y^{0.5}}$$ **Equation 6**

where:

t_c = time of concentration (hr)
l = hydraulic length of watershed (ft)
L = basin lag (hr)
S = (1000/CN)-10 where CN = NRCS curve number (See Table 2)
Y = average watershed land slope (percent)

2. **Hydraulic length of watershed.** Watershed lag is a function of the hydraulic length of the watershed, the potential maximum retention of rainfall on the watershed and the average land slope of the watershed. The potential retention, S, is a function of the runoff curve number.

   The hydraulic length of the watershed, L, is the length from the point of design along the main channel to the ridgeline at the upper end of the watershed. At one or more points along its length moving upstream, the main channel may appear to divide into two channels. The main channel is then defined as that channel which drains the greater tributary drainage area. This same definition is used for all further upstream channel divisions until the watershed ridgeline is reached.

   Since many channels meander through their floodplains, and since most designs are based on floods which exceed channel capacity, the proper channel length to use is actually the length along the valley; i.e., the channel meanders should be ignored.

   The average watershed land slope, Y, is just that and is estimated using one of the two methods described on the following two pages. These pages were excerpted from a user's guide to TR-55 prepared by the state office of NRCS in Iowa.

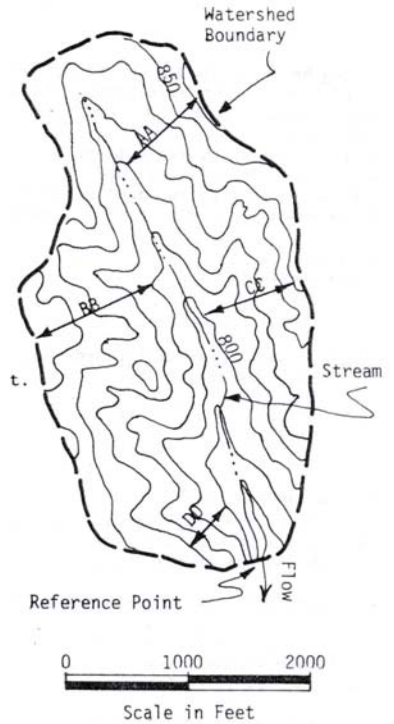
   a. **Computing average watershed slope.** Average watershed slope is a variable, which is usually not readily apparent. Therefore, a systematic procedure for finding slope is desirable. Several observations or map measurements are commonly needed. Reasonable care should be taken in determining this parameter as peak discharge and hydrograph shape are sensitive to the value used for watershed slope. Best hydrologic results are obtained when the slope value represents a weighted average for the area. Two methods for computing slope are demonstrated in example exercises below. Remember, watershed slope is not the same as stream gradient.

   b. **Watershed lag.** The lag equation was developed for rural areas and thus overestimates lag and T_c in urban areas for two reasons. First, the increased amount of impervious area permits water from overland flow sources and side channels to reach the main channel at a much faster rate than under natural conditions. Second is the extent to which a stream (usually the major watercourse in the watershed) has been changed over natural conditions to allow higher flow velocities. The lag time can be corrected for the effects of urbanization by using Figures 3 and 4. The amount of modification to the hydraulic flow length must usually be determined from topographic maps or aerial photographs following a filed inspection of the drainage area.

   c. **Estimating lag and time of concentration.** Figure 2 may be used to estimate lag, and Equation 3 to estimate time of concentration. The NRCS EFH-2 Computer program is a Windows program which computed runoff and peak discharge. Peak discharges are determined using the lag equation. The program will compute the time of concentration, and the nomograph in Figure 2 is not used. The NRCS EFH-2 program can be downloaded at http://www.wcc.nrcs.usda.gov/hydro/hydro-tools-models-efh2.html. The limitations of the lag method for determining time of concentration, runoff volume, and peak rate are listed below.

d. **Limitations for using the NRCS lag method for T_c and runoff determination:**

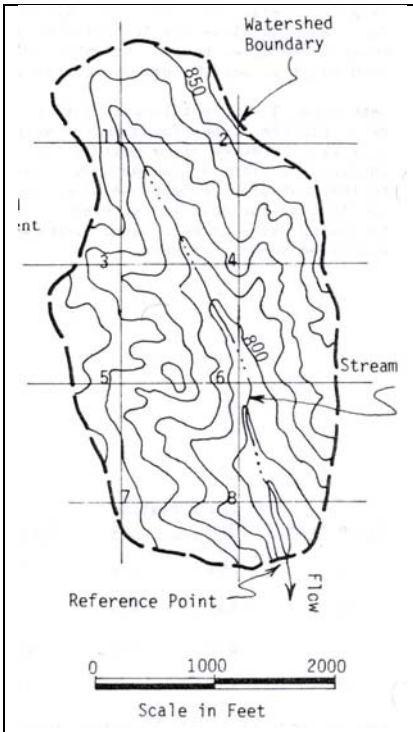
1) The watershed drainage area must be greater than 1 acre, and less than 2,000 acres. If the drainage area is outside these limits, another procedure such as WINTR-55 or WINTR-20, Project Formulation-Hydrology, should be used to estimate peak discharge.
2) The watershed should have only one main stream. If more than one exists, the branches must have nearly equal T_c's.
3) The watershed must be hydrologically similar; i.e., able to be represented by a weighted CN. Land use, soils, and cover are distributed uniformly throughout the watershed. The land use must be primarily rural. If urban conditions are present and not uniformly distributed throughout the watershed, or if they represent more than 10 percent of the watershed, then WINTR-55 or other procedures must be used.
4) If the computed T_c is less than 0.1 hour, use 0.1 hour. If the computed T_c is greater than 10 hours, peak discharge should be estimated by using the NRCS National Engineering Handbook (NEH) Part 630 procedures, which are automated in the WINTR-20 computer program.
5) When the flow length is less than 200 feet or greater than 26,000 feet, use another procedure to estimate T_c. WINTR-55 provides an alternative procedure for estimating T_c and peak discharge.
6) Runoff and peak discharge from snowmelt or rain on frozen ground cannot be estimated using these procedures. The NEH Part 630 provides a procedure for estimating peak discharge in these situations.
7) If potholes constitute more than one-third of the total drainage area, or if they intercept the drainage, the procedures in NEH Part 630 should be used.
8) When the average watershed slope is less than 0.5 percent, a different unit hydrograph shape can be used.
9) When the weighted CN is less than 40, or more than 98, use another procedure to estimate peak discharge.
10) When the average watershed slope is greater than 64 percent, or less than 0.5 percent, use another procedure to estimate T_c. An alternative procedure is shown in WINTR-55 for estimating T_c and peak discharge.



Method One

Select locations that represent the slopes found in the watershed. Near each selected place measure the inclination along a line perpendicular to the contours. Weight the slope for each location by the area it represents. The following data has been taken from the watershed shown below.

	End Elevation			Slope	Prop. Of Watershed	Product
Slope Line	High	Low	Distance	(Pct)	(Pct)	(Pct x Pct)
AA	860	820	780	5	25	1.25
BB	845	810	1070	3	35	1.05
CC	840	800	800	5	25	1.25
DD	820	790	460	7	15	1.05
Sum of Products = Weighted Average Watershed Slope						4.60 Use 5%



Method Two

In this method, each sample location represents the same proportion of the watershed. Select the locations by overlaying the map with a grid system. The watershed slop perpendicular to contours through each intersection of grid lines is determined as in Method One and the average for all intersections is considered to be watershed slope. The watershed used as an example for this method is the same watershed as above. A grid system with numbered intersections is shown in the figure. Tabulations below demonstrate use of this procedure.

Location	1	2	3	4	5	6	7	8	Sum
Slope (Percent)	6	8	6	7	5	10	3	6	51

The Weighted Average Watershed Slop is the arithmetic average, 6.4%. Use 6%.

The two answers are not identical. Due to the greater number of sample locations used in Method Two, perhaps the answer of 6% watershed slope is more accurate.

When sub-areas of a watershed have widely varying slopes, this may justify separate analyses by sub-areas and use of the hydrograph method for hydrologic data at the watershed outlet. With other parameters held constant, a slope variation of 10% affects peak discharge approximately 3-4%. A 20% change in slope is reflected by a 6-8% change in the peak rate.

Figure 2: NRCS curve number method for estimating lag (L)

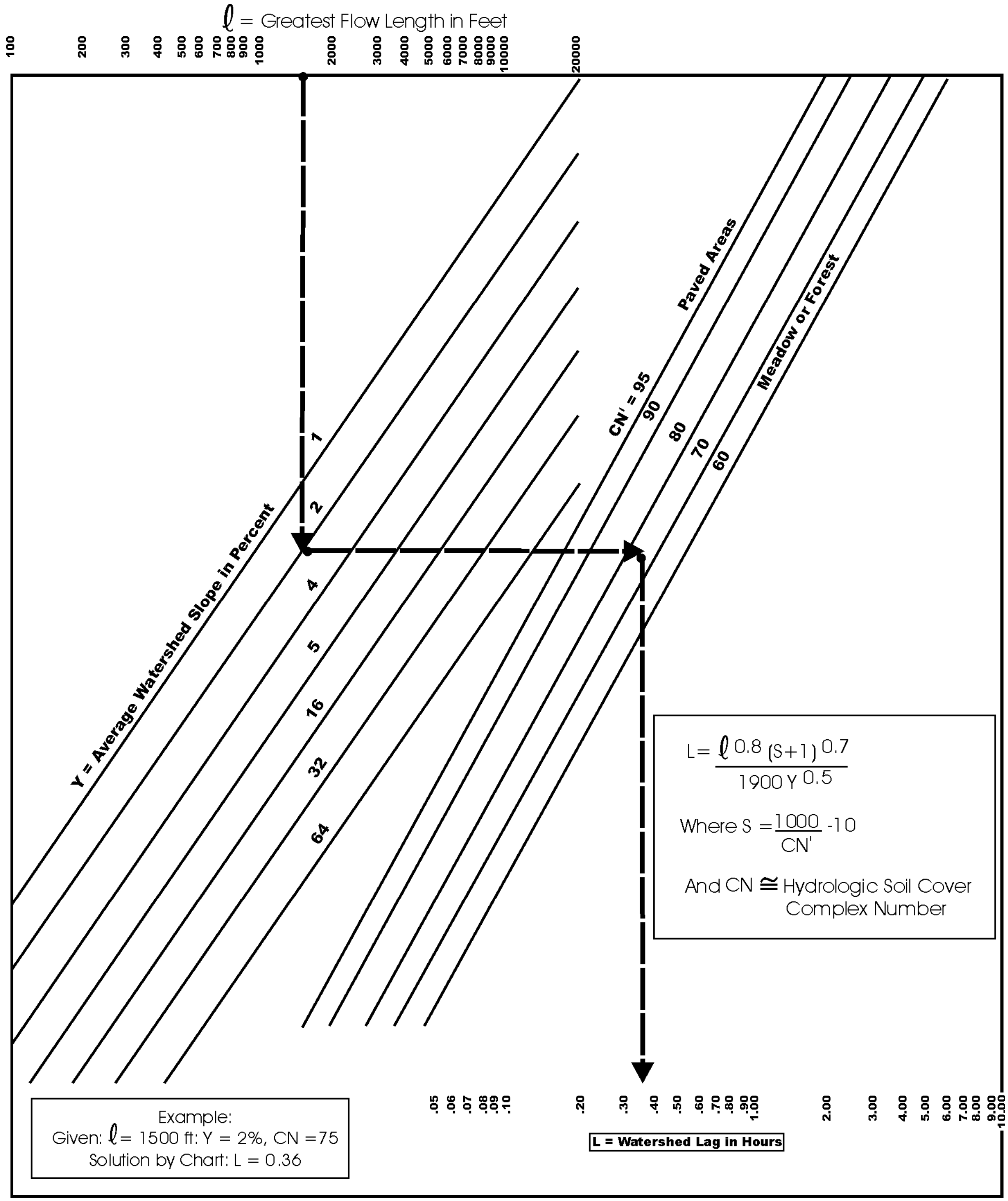


Figure 3: Factors for adjusting lag from Equation 6 when the main channel has been hydraulically improved

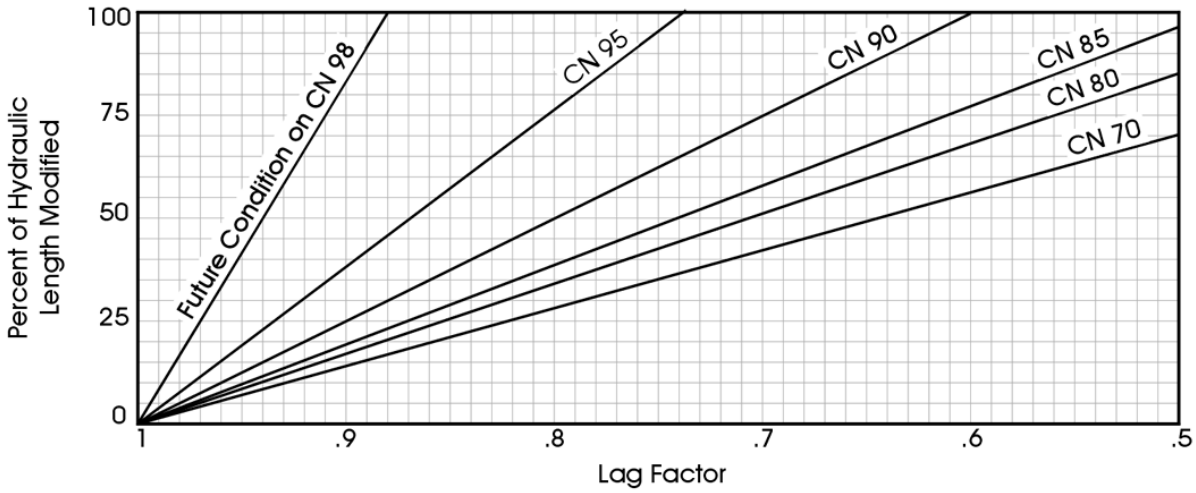


Figure 4: Factors for adjusting lag from Equation 6 when impervious areas occur in the watershed

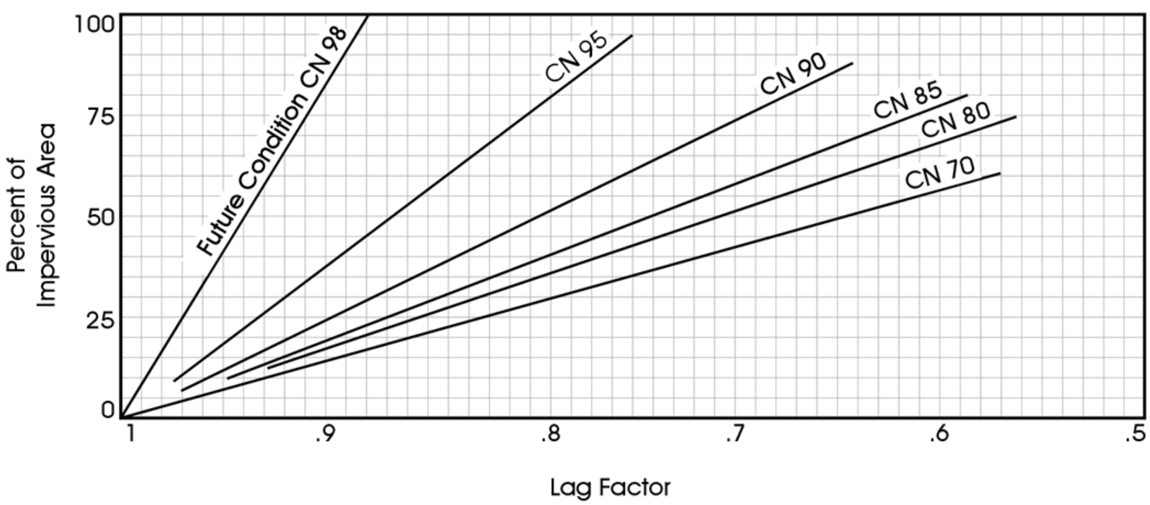


Table 2: Manning roughness coefficients, *n*

	Manning's *n* range
I. Closed conduits:	
A. Concrete pipe	0.011-0.013
B. Corrugated-metal pipe or pipe-arch:	
1. 2 by ½-in. corrugation (riveted pipe):	
a. Plain or fully coated	0.024
b. Paved invert (range values are for 25 and 50 % of circumference paved):	
(1)Flow full depth	0.021-0.018
(2)Flow 0.8 depth	0.021-0.016
(3)Flow 0.6 depth	0.019-0.013
2. 6 by 2-in. corrugation (field bolted)	0.03
C. Vitrified clay pipe	0.012-0.014
D. Cast-iron pipe, uncoated	0.013
E. Steel pipe	0.009-0.011
F. Brick	0.014-0.017
G. Monolithic concrete:	
1. Wood forms, rough	0.015-0.017
2. Wood forms, smooth	0.012-0.014
3. Steel forms	0.012-0.013
H. Cemented rubble masonry walls:	
1. Concrete floor and top	0.017-0.022
2. Natural floor	0.019-0.025
I. Laminated treated wood	0.015-0.017
J. Vitrified clay liner plates	0.015
II. Open channels, lined (straight alignment):	
A. Concrete with surfaces as indicated:	
1. Formed, no finish	0.013-0.017
2. Trowel finish	0.012-0.014
3. Float finish	0.013-0.015
4. Float finish, some gravel on bottom	0.015-0.017
5. Gunite, good section	0.016-0.019
6. Gunite, wavy section	0.018-0.022
B. Concrete, bottom float finish, sides as indicated:	
1. Dressed stone in mortar	0.015-0.017
2. Random stone in mortar	0.017-0.020
3. Cement rubble masonry	0.020-0.025
4. Cement rubble masonry, plastered	0.016-0.020
5. Dry rubble (riprap)	0.020-0.030
C. Gravel bottom, sides as indicated:	
1. Formed concrete	0.017-0.020
2. Random stone in mortar	0.020-0.023
3. Dry rubble (riprap)	0.023-0.033
D. Brick	0.014-0.017
E. Asphalt:	
1. Smooth	0.013
2. Rough	0.016
F. Wood, planed, clean	0.011-0.013
G. Concrete-lined excavated rock:	
1. Good section	0.017-0.020
2. Irregular section	0.022-0.027
III. Open channels, excavated (straight alignment, natural lining):	
A. Earth, uniform section:	
1. Clean, recently completed	0.016-0.018
2. Clean, after weathering	0.018-0.020
3. With short grass, few weeds	0.022-0.027
4. In gravely soil, uniform section, clean	0.022-0.025
B. Earth, fairly uniform section:	
1. No vegetation	0.022-0.025
2. Grass, some weeds	0.025-0.030
3. Dense weeds or aquatic plants in deep channels	0.030-0.035
4. Sides clean, gravel bottom	0.025-0.030
5. Sides clean, cobble bottom	0.030-0.040
C. Dragline excavated or dredged:	
1. No vegetation	0.028-0.033
2. Light brush on banks	0.035-0.050
D. Rock:	
1. Based on design section	0.035
2. Based on actual mean section:	
a. Smooth and uniform	0.035-0.040
b. Jagged and irregular	0.040-0.045
E. Channels not maintained, weeds and brush uncut:	
1. Dense weeds, high as flow depth	0.08-0.12
2. Clean bottom, brush on sides	0.05-0.08
3. Clean bottom, brush on sides, highest stage of flow	0.07-0.11
4. Dense brush, high stage	0.10-0.14
IV. Highway channels and swales with maintained vegetation (values shown are for velocities of 2 and 6 fps):	
A. Depth of flow up to 0.7 foot:	
1. Bermudagrass, Kentucky bluegrass, Buffalograss:	
a. Mowed to 2 inches	0.07-0.045
b. Length 4-6 inches	0.09-0.05
2. Good stand, any grass:	
a. Length about 12 inches	0.18-0.09
b. Length about 24 inches	0.30-0.15
3. Fair stand, any grass:	
a. Length about 12 inches	0.14-0.08
b. length about 24 inches	0.25-0.13
B. Depth of flow 0.7-1.5 feet:	
1. Bermudagrass, Kentucky bluegrass, Buffalograss:	
a. Mowed to 2 inches	0.05-0.035
b. Length 4 to 6 inches	0.06-0.04
2. Good stand, any grass:	
a. Length about 12 inches	0.12-0.07
b. Length about 24 inches	0.20-0.10
3. Fair stand, any grass:	
a. Length about 12 inches	0.10-0.06
b. Length about 24 inches	0.17-0.09
V. Street and expressway gutters:	
A. Concrete gutter, trowelled finish	0.012
B. Asphalt pavement:	
1. Smooth texture	0.013
2. Rough texture	0.016
C. Concrete gutter with asphalt pavement:	
1. Smooth	0.013
2. Rough	0.015
D. Concrete pavement:	
1. Float finish	0.014
2. Broom finish	0.016
E. For gutters with small slope, where sediment may accumulate, increase Above values of *n* by	*0.002*
VI. Natural stream channels:	
A. Minor streams (surface width at flood stage less than 100 ft.):	
1. Fairly regular section:	
a. Some grass and weeds, little or no brush	0.030-0.035
b. Dense growth of weeds, depth of flow materially greater than weed height	0.035-0.05
c. Some weeds, light brush on banks	0.035-0.05
d. Some weeds, heavy brush on banks	0.05-0.07
e. Some weeds, dense willows on banks	0.06-0.08
f. For trees within channel, with branches submerged at high stage, increase all above values by	*0.01-0.02*
2. Irregular sections, with pools, slight channel meander; increase values giver in la-e about	*0.01-0.02*
3. Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stage:	
a. Bottom of gravel, cobbles, and few boulders	0.04-0.05
b. Bottom of cobbles, with large boulders	0.05-0.07
B. Flood plains (adjacent to natural streams):	
1. Pasture, no brush:	
a. Short grass	0.030-0.035
b. High grass	0.035-0.05
2. Cultivated areas:	
a. No crop	0.03-0.04
b. Mature row crops	0.035-0.045
c. Mature field crops	0.04-0.05
3. Heavy weeds, scattered brush	0.05-0.07
4. Light brush and trees:	
a. Winter	0.05-0.06
b. Summer	0.06-0.08
5. Medium to dense brush:	
a. Winter	0.07-0.11
b. Summer	0.10-0.16
6. Dense willows, summer, not bent over by current	0.15-0.20
7. Cleared land with tree stumps, 100-150 per acre:	
a. No sprouts	0.04-0.05
b. With heavy growth of sprouts	0.06-0.08
8. Heavy stand of timber, a few down trees, little undergrowth:	
a. Flood depth below branches	0.10-0.12
b. Flood depth reaches branches	0.12-0.16
C. Major streams (surface width at flood stage more than 100 ft.): Roughness coefficient is usually less than for minor streams of similar description on account of less effective resistance offered by irregular banks of vegetation on banks. Values of *n* may be somewhat reduced. Follow recommendation in publication cited, if possible. The value of *n* for larger streams of most regular section, with no boulders or brush, may be in the range of 0.028-0.033/	

F. Design example

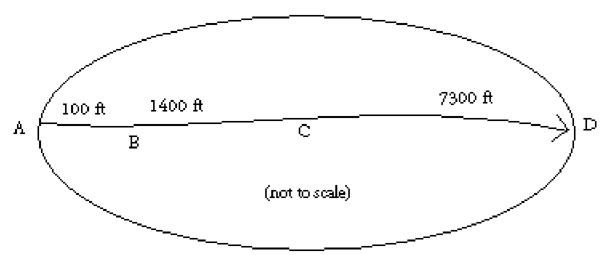
Time of concentration

Example: The sketch below shows a watershed. The problem is to compute T_c at the outlet of the watershed (point D). The 2-year 24-hour rainfall depth is 3.6 inches. All three types of flow occur from the hydraulically most distant point (A) to the point of interest (D). To compute T_c, first determine T_t for each segment from the following information:

Segment AB: Sheet flow
Dense grass
Slope (s) = 0.01 ft/ft
Length (L) = 100 ft

Segment BC: Shallow concentrated flow
Unpaved
s = 0.01 ft/ft
L = 1400 ft

Segment CD: Channel flow
Manning's n = .05
Flow area (a) = 27 ft^2
Wetted perimeter (p_w) = 28.2 ft
s = 0.005 ft/ft
L = 7300 ft



Worksheet 1: Time of Concentration (T_c) or Travel Time (T_t)

Project ______________________________ By ____________ Date _______

Location ______________________________ Checked _________ Date _______

Circle one: Present Developed

Circle one: T_c T_t through sub area

Notes: Space for as many as two segments per flow type can be used for each worksheet.

Include a map, schematic, or description of flow segments.

Sheet flow (Applicable to T_c only)

Segment ID

1. Surface description (Table 2)………………………….
2. Manning's roughness coeff., n (Table 2)……………..
3. Flow Length, L (Total L less than or equal to 300')… ft
4. Two-year 24-hour rainfall, P_2……………………………. in
5. Land slope, s………………………………………………. ft / ft
6. $T_t = \frac{0.007(nL)^{0.8}}{(\sqrt{P_2})(s^{0.4})}$ Compute T_t…………….. hr + =

Shallow concentrated flow

Segment ID

7. Surface description (paved or unpaved)………………..
8. Flow length, L……………………………………………… ft
9. Watercourse slope, s…………………………………... ft / ft
10. Average velocity, V (Figure 1)………………………… ft / s
11. $T_t = \frac{L}{3600V}$ Compute T_t…………….. hr + =

Open channel flow

Segment ID

12. Cross sectional flow area, a……………………………... ft^2
13. Wetted perimeter, P_w…………………………………….. ft
14. Hydraulic radius, $r = \frac{a}{P_w}$ Compute r……………… ft
15. Channel slope, s………………………………………….. ft / ft
16. Manning's roughness coeff., n…………………………...
17. $V = \frac{1.49r^{2/3}s^{1/2}}{n}$ Compute V……………... ft / s
18. Flow length, L……………………………………………… ft
19. $T_t = \frac{L}{3600V}$ Compute T_t…………….. hr + =
20. Watershed or subarea T_c or T_t (add T_t in steps 6, 11 and 19)………………………………………… hr

Worksheet 2: Time of Concentration (T_c) or Travel Time (T_t)

Project *Example* By ____________ Date _______

Location ____________________________________ Checked _________ Date _______

Circle one: Present (Developed)

Circle one: (T_c) T_t through subarea

Notes: Space for as many as two segments per flow type can be used for each worksheet. Include a map, schematic, or description of flow segments.

		Unit	Segment 1	Segment 2	Total
	Sheet flow (Applicable to T_c only)	Segment ID	AB		
1.	Surface description (Table 2)…………………………		Dense Grass		
2.	Manning's roughness coeff., n (Table 2)……………..		0.24		
3.	Flow Length, L (Total L less than or equal to 300')…	ft	100		
4.	Two-year 24-hour rainfall, P_2…………………………….	in	3.6		
5.	Land slope, s……………………………………………….	ft / ft	0.01		
6.	$T_t = \frac{0.007(nL)^{0.8}}{(\sqrt{P_2})(s^{0.4})}$ Compute T_t……………..	hr	0.30	+	= 0.30
	Shallow concentrated flow	Segment ID	BC		
7.	Surface description (paved or unpaved)………………..		Unpaved		
8.	Flow length, L………………………………………………	ft	1400		
9.	Watercourse slope, s……………………………………...	ft / ft	0.01		
10.	Average velocity, V (Figure 1)…………………………	ft / s	1.6		
11.	$T_t = \frac{L}{3600V}$ Compute T_t……………..	hr	0.24	+	= 0.24
	Open channel flow	Segment ID	CD		
12.	Cross sectional flow area, a……………………………...	ft^2	27		
13.	Wetted perimeter, P_w……………………………………..	ft	28.2		
14.	Hydraulic radius, $r = \frac{a}{P_w}$ Compute r………………	ft	0.957		
15.	Channel slope, s…………………………………………..	ft / ft	0.005		
16.	Manning's roughness coeff., n…………………………...		0.05		
17.	$V = \frac{1.49 r^{2/3} s^{1/2}}{n}$ Compute V……………...	ft / s	2.05		
18.	Flow length, L………………………………………………	ft	7300		
19.	$T_t = \frac{L}{3600V}$ Compute T_t……………..	hr	0.99	+	= 0.99
20.	Watershed or subarea T_c or T_t (add T_t in steps 6, 11 and 19)…………………………………………	hr			1.53