Hydrology Training Series

Module 206 A - Time of Concentration

Study Guide

Module Description

Objectives

Upon completion of this module, the participant will be able to compute time of concentration (Tc) using the velocity approach concept (TR-55) and the simplified procedure used by ses. Upon completion of this module, the participant should be able to perform at ASK Level 3 (Perform with Supervision).

Prerequisites

Module 101 - Introduction to Hydrology, Module 102 -Precipitations

Length

Participant should take as long as necessary to complete module. Training time for this module is approximately two hours.

Who May Take the Module

This module is intended for all SCS personnel who calculate time of concentration for a drainage area.

Method of Completion

This module is self-study, but the state or NTe should select a resource person to answer any questions that the participant's supervisor cannot handle. "

Content

This module presents a step-by-step procedure for calculating the time of concentration using the velocity approach method from TR-55 and the simplified procedure used by ses.

Introduction

The time of concentration (T) is the time required for a particle of water to flow from the hydraulically most distant point on a watershed to the design point in question. This definition indicates that T is a function of length and velocity.

This module will cover two methods for computing time of concentration. They are the velocity approach method (TR-55) and the simplified procedure found in Chapter 2 (1988 Version or later), EFM.

Velocity Approach Method

In its simplest form, the velocity approach method states:

$T_c = T_{t1} + T_{t2} + T_{t3} + ... + T_{tm}$

where

Tc = time of concentration, which is the sum of various travel times

(T_t) = in each flow segment

T_t = time it takes water to move through a segment

m= number of flow segments

Also:

Tc = Tt sheet flow + Tt shallow cone. flow + Tt. channel flow

Using this approach allows the investigator to compute travel time for each . type of flow that is present. The velocity approach is explained in detail in Chapter 3, ofTR-55.

Sheet Flow

Travel time for the sheet flow component ofT. can be determined using the kinematic wave theory. SCS has made some simplifying assumptions to eliminate the trial and error problems of solving the kinematic wave equation. These assumptions are as follows:

1. Rainfall intensity duration curve versus duration curve for an SCS standard rainfall distribution is a straight line on log-log paper which gives a relationship between rainfall intensity and duration.
2. Rainfall excess intensity (runoff) equals rainfall intensity, which is reasonable for impervious areas during the most intense portion of the storm.
3. The problem of varying rainfall intensity with recurrence interval should not be overlooked for detailed studies. However, for simplicity, use the 2-yr, 24 hr precipitation.
4. The effect of infiltration on travel time is minimal and can be overlooked

5. Shallow steady uniform flow exists. Steady implies constant over time, while uniform implies constant over distance. It is assumed the depth does not exceed 0.1 ft.

6. The equation applies or can be used for all standard SCS rainfall distributions.

Therefore, the basic SCS equation for sheet flow is:

$$T_t = .\frac{0079(nl)^{.8}}{P_2{}^{.5}(s)^{.4}}$$

where

T_t = sheet flow travel time, hr

n = Manning's roughness coefficient for overland flow depths

L = flow length, ft

p_2= 2-yr, 24 hr precipitation, in

s = slope of the hydraulic grade line (slope of the land), ft/ft

The following apply when using the sheet flow equation:

1. In most watersheds the flow length is probably about 50 feet. Flow length should not exceed 300 feet. A visit to the watershed should be made to determine flow lengths.

2. The typical sheet flow Manning's un" values are shown in Appendix A (Table 3-1, TR-55). These values were developed from erosion data by Ted Engman of the Agricultural Research Service and are discussed in ASCE.Journal of Irrigation and Drainage, 112 (January, 1986):39-53.

Shallow Concentrated Flow

When the flow length exceeds 300 feet, flow tends to concentrate in small rills or channels, where Manning's open channel flow equation applies. However, these channels are not large enough to survey. The following equation is used to calculated travel time for both shallow concentrated and open channel flow:

$$T_t = \frac{L}{3600V}$$

where

Tt = travel time, hr

L = flow length, ft

v = velocity, ftls

3600 = conversion factor for seconds to hours

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SCS has developed the following relationships for velocity and slope for two cover conditions, using Manning's equation, for use in calculating Tt for shallow concentrated flow:

$$V = \frac{1.49r^{\left(\frac{2}{3}\right)}s^{\left(\frac{1}{2}\right)}}{n}$$

where

r = hydraulic radius and is equal to the depth of flow for shallow concentrated (wide rectangular) flow, ft

s = slope of the hydraulic grade line (slope of the land), ft/ft

n = Manning's roughness coefficient for open channel flow

For paved conditions: n = 0.025 r = d= 0.2 ft (depth of flow)

v = 20.32 $s^{\left(\frac{1}{2}\right)}$

For unpaved conditions: n = 0.05
r = d = 0.4 ft (depth of flow)

v = 16.13 $s^{\left(\frac{1}{2}\right)}$

These curves are shown in Appendix A (Figure 3-1, TR-55).

The following apply when computing the shallow concentrated flow component: '

1. This procedure should be used for that portion of flow between sheet or overland flow and defined channel flow. Defined channels are visible on aerial photo and are shown as blue lines on USGS quad sheets.

2. When the channel slope is less than 0.005 ft/ft, the equations, rather than Figure 3-1, should be used.

3. Wide rectangular channel flow theory applies (hydraulic radius equals depth of flow). This means that water is flowing over the ground and may be flowing in small channels also.

4. Flow may not always be directly down the watershed slope if tillage runs across the slope. This is particularly true if terraces are present in the watershed.

Channel Flow

When the flow is concentrated in defined channels, Manning's open channel flow equation can be used to estimate velocity:

$$T_t = \frac{L}{3600V}$$

and

$$V = \frac{1.49r^{\left(\frac{2}{3}\right)}s^{\left(\frac{1}{2}\right)}}{n}$$

where

V = velocity, in ft/s

r = hydraulic radius = $\frac{a}{p_w} = \frac{flow\ area}{wetted\ perimeter}, ft$

s = water surface slope, ft/ft

n = Manning's roughness coefficient for9pen channels flow

Manning's roughness coefficient values for open channel flow can be obtained from standard references.

The following assumptions should be considered when estimating the channel flow component:

1. Bank flow velocity and channel length are the representative values to use in computing channel travel time.

2. The slope of the water surface is equal] to channel slope.

3. In watersheds with storm sewers, carefully identify the appropriate flow path to estimate Tt. Storm sewers generally handle only a small portion of a large event. The rest of the flow may travel by streets, lawns etc. to the outlet.

Uses For The Velocity Approach Method

The velocity approach method for computing Te is the most theoretically correct. This procedure should be used in large watersheds where the impact of urbanization needs to be evaluated or where a major portion of the flow is channel flow.

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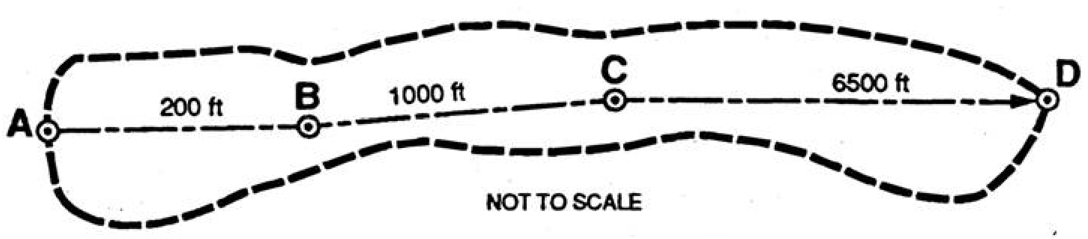
Velocity Approach Method Example

Worksheet 3 (TR-55) will be used as the guide for manual computation of Tc in either a rural or urban watershed. Using the information provided below, complete the blank worksheet on page 11 as you go from step to step.

Your problem is to estimate Tc for a small rural watershed near Dover, Delaware. The 2-yr, 24-hr rainfall is 3.45 inches. All three types of flow occur.



Segment AD - Sheet flow exists on dense grass where the land slope is 0.01 fl/ft. and the flow length is 200 feet.

Segment BC - Shallow concentrated flow exists on unpaved conditions where land) slope is 0.01 ft/ft, and the flow length is 1000 feet.

Segment CD - Channel flow exists where Manning's n value is 0.05. The flow area of the channel is 27 ft2, the wetted perimeter is 28.2 ft, the slope of the water surface is 0.004 ft/ft and the flow length is 6500 feet.

The manual calculations are as follows:

$$T_t, AB = .\frac{007(nL)^{.8}}{(P_2{}^{.5}s^{.4}})$$

n for dense grass is obtained from Table 3-1 in Appendix A

$$T_t, AB = .\frac{007\big((.24)(200ft)\big)^{.8}}{(3.45\ in)^{.5}(.01ft/ft)^{.4}}$$

$= 0.53\ hr$

V for unpaved conditions is obtained from Figure 3-1 in Appendix A

$T_{t,BC} = \frac{L}{3600(1.6\frac{ft}{s})}$ = .17 hr

$$T_t = \frac{L}{3600V}$$

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$$V = \frac{1.49r^{\left(\frac{2}{3}\right)}s^{\left(\frac{1}{2}\right)}}{n}$$ and

r=$\frac{a}{p_w}$=$\frac{27ft^2}{28.2ft} = .96\ ft$

$$V = \frac{1.49(.96ft)^{\left(\frac{2}{3}\right)}(.\frac{004ft}{ft})^{\left(\frac{1}{2}\right)}}{.05}$$ =1.83ft/s

$$T_{t,CD} = \frac{6500ft}{3600\left(1.83\frac{ft}{s}\right)}$$

Therefore,

compute $T_t = T_{t,AB} + T_{t,BC} + T_{t,CD}$

= .53 hr + .17 hr + .99 hr

=1.69 hr

Simplified Procedure

If the watershed is rural, less than 2000 acres in size, and the impact of urbanization will not be evaluated, a simplified method of estimating T. can be used.

This computed T. will be used in the design of on-farm conservation practices or in the computation of peak discharge in Chapter 2 (1988 Version or later), EFM:

$$T_c = \frac{\left[l^{.8}\left(\frac{1000}{CN}-9\right)^{.7}\right]}{1140Y^{.5}}$$

where

T_c= the time of concentration, hr

l = flow length, ft

CN = curve number

Y = average watershed slope, %.

The average watershed slope 00, which is the slope *of* the land and not the watercourse, is available at most field office locations from soil survey data or topographic maps. The individual land slope can be measured with a hand level in the direction *of* overland flow. The average watershed slope is a simple arithmetic average *of* individual land slopes.

Flow length *(l*) is the longest flow path in the watershed from the watershed divide to the outlet. It is the path water travels on the way to the outlet. The flow length can be determined either by using a map wheel or by marking along the edge *of* a paper, then comparing this with the map scale to get feet.

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This T_c equation has been incorporated into the graphs in Chapter 2, (1988 Version or later), EFM, as the suggested method for computing T_c where the chapter applies. The following limitations apply when using the simplified T_c equation:

1. The watershed must be rural and have less than 10% urban land use.
2. The drainage area of the watershed should be less than 2000 acres.
3. The weighted CN should be between 40 and 95. If it is outside these limits, use the velocity approach method to compute T_c
4. The average watershed slope should be between 0.5 and 64 percent. *If* outside these limits, use the velocity approach method to compute T_c
5. The hydraulic flow length should be greater than 100 ft and less than 15,000 ft/ft is outside these limits, use the velocity method to compute T_c
6. The watershed may have only one main stream

Example 1 For a 90 acre field on I. M. Hipp farm, compute T. using the equation from Chapter 2 (1988 Version or later), EFM. The curve number is 78, the flow length is 3400 ft, and the average watershed slope is 1%. The watershed is 90 ac and is in rural conditions. The rainfall distribution is Type II.

Solution 1 The given data is transferred to Worksheet 206A. Then, the formula provided was used to compute T.. Spend enough time reviewing Worksheet 206A-1 to be sure you fully understand the procedure.

Example

Worksheet 206A-1 Estimating Time of Concentration

(simplified procedure)

Project___I.M. Hipp____ By_DEW________________
Date____DEW___

Location___Field#2_____ Checked__MH___________
Date__MH______

Practice________________ Field Office____Dover DEW MH_____________

1. Data			
Rainfall distribution type	=	II	(I,IA,II,III)
Drainage area	A=	90	Ac
Runoff curve number	CN=	78	
Watershed slope	Y=	1	%
Flow length	l	3400	Ft
2. $T_c = \frac{\left[l^{.8}\left(\frac{1000}{CN}-9\right)^{.7}\right]}{1140Y^{.5}} = \frac{668.63*2.56}{1140(1)}$=1.5hr			

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Summary

The velocity approach method discussed in TR-55is the most flexible and theoretical procedure available for calculating the time of concentration. This procedure can be used for rural, urban and/or urbanizing, large or small watersheds. A majority of the flow paths can be channel flow.

SCS has developed a simplified Tc equation in that could be used in small rural watersheds where only a part of the flow path is channel flow. This procedure is the back bone of Chapter 2, EFM.

The use of the velocity approach method requires that the designer visit the watershed to determine flow lengths by type and cover. This is one advantage of the velocity method.

Retain the Study Guide as a reference until you are satisfied that have mastered all methods covered. It will provide an easy review at any time if you should encounter a problem.

If you have had problems understanding the module or if you would like to take additional, related modules, contact your supervisor.

When you are satisfied that you have completed this module, remove the Certification of Completion sheet (last page of the Study Guide), fill it out, and give it to your supervisor to submit, through channels, to your State or NTC Training Officer.

Appendix A Charts and Tables

Figure 3-1 *Average velocities for estimating travel time for shallow concentrated flow.*
SOURCE: Technical Release, 210-VI-TR-55. Second Ed., June 1986

Worksheet 3 - Time of Concentration (Tc) or travel time (Tt)

Worksheet 3- Time of Concentration (T_c) or Travel time (T_t)						
Project			By		Date	
Location			Checked		Date	
Circle one:	Present	Developed				
Circle one:	Tc	Tt through subarea				
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.						
Flow Sheet(Applicable to Tc only)	**Segment ID**					
1.Surface description (table 3-1)						
2.Manning's roughness cieff, n (table 3-1)						
3.flow length,(total L 300ft)	ft					
4.Two-yr 24-hr rainfall, P_2	in					
5.Land slope, s	ft/ft					
6. $T_t = .\frac{007(nL)^{.8}}{(P_2{}^{.5}s^{.4}})$ compute T_t	hr		+		=	
Shallow concentrated flow	**Segment ID**					
7.Shallow Description (paved or unpaved)						
8.Flow length, L	ft					
9. Watercourse slope, s	ft/ft					
10.Average velocity, V (figure 3-1)	ft/s					
11. $T_t = \frac{L}{3600V}$ compute T_t	hr		+		=	
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. $V = \frac{1.49r^{\left(\frac{2}{3}\right)}s^{\left(\frac{1}{2}\right)}}{n}$ 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 step 6,11 and 19)						

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Activity 1

At this time, complete Activity 1 in your Study Guide to review the material just covered. After finishing the Activity, compare your answers with the solution provided. When you are satisfied that you understand the material, continue with the Study Guide text.

1. Define time of concentration.
2. Name the three flow components that may exist in a watershed.
3. What is the basic SCS equation for sheet flow?
4. What are the two cover types used by SCS in computing the travel time for shallow concentrated flow?

Activity 2

Worksheet 3- Time of Concentration (T_c) or Travel time (T_t)				
Project I.M. Hipp			**By** DEW	**Date** 3/88
Location Dover, Delaware			**Checked** MH	**Date** 3/88
Cirlcle one:	Present (circled)	Developed		
Circle one:	Tc (circled)	Tt through subarea		

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.

Flow Sheet(Applicable to Tc only)	**Segment ID**	AB		
1.Surface description (table 3-1)		Dense grass		
2.Manning's roughness coeff, n (table 3-1)		.24		
3.flow length,(total L 300ft)	ft	200		
4.Two-yr 24-hr rainfall, P_2	in	3.45		
5.Land slope, s	ft/ft	.01		
6.T_t = $\frac{007(nL)^{.8}}{(P_2{}^{.5}s^{.4}}$) compute T_t	hr	.53 +		= .53
Shallow concentrated flow	**Segment ID**	BC		
7.Shallow Description (paved or unpaved)		unpaved		
8.Flow length, L	ft	1000		
9. Watercourse slope, s	ft/ft	.01		
10.Average velocity, V (figure 3-1)	ft/s	1.6		
11. T_t = L/3600V compute T_t =	hr	.17 +		= .17
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, $r=a/p_w$ compute r	ft	.96		
15. Channel slope, s	ft/ft	.004		
16.Manning's roughness coeff., n		.05		
17. V= $\frac{1.49r^{\left(\frac{2}{3}\right)}s^{\left(\frac{1}{2}\right)}}{n}$ compute V	ft/s	1.83		
18. Flow length, L	ft	6500		
19. T_t = L/3600V compute T_t =	hr	.99 +		= .99
20. Watershed or subarea T_c or T_t = (add T_t in step 6,11 and 19)				1.69

Given:

The watershed is near Dover, Delaware and is being urbanized. The urban condition Tc at the outlet is needed to determine the impact of urbanization on peak discharge, The flow path information is as follows:
Segment AB - Sheet flow exists on dense grass where the land slope is 0.01 ftlft and the flow length is 50 feet. The 2-yr, 24-hr precipitation is 3.45 inches.

Segment BC - Shallow concentrated flow exists on paved conditions where the watercourse land slope is 0.01 tV ft, and the flow length is 800 feet.

Segment CD - Channel flow exists in lined channel where Manning's n value is 0.035. The flow area is 30 ft2, the wetted perimeter is 30 ft, and the water .slopeis 0.0047 ftlft. Flow length is 6500 feet.

Find:

T c' using the velocity approach method. Complete Worksheet 3. Show your computations below-and on the following page.

Solution:

Worksheet 3- Time of Concentration (T_c) or Travel time (T_t)							
Project			**By**		**Date**		
Location			**Checked**		**Date**		
Cirlcle one:	Present	Developed					
Circle one:	Tc	Tt through subarea					
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.							
Flow Sheet(Applicable to Tc only)	**Segment ID**						
1.Surface description (table 3-1)							
2.Manning's roughness cieff, n (table 3-1)							
3.flow length,(total L 300ft)	ft						
4.Two-yr 24-hr rainfall, P_2	in						
5.Land slope, s	ft/ft						
6. $T_t = .\frac{007(nL)^{.8}}{(P_2{}^{.5}s^{.4}}$) compute T_t	hr		+		=		
Shallow concentrated flow	**Segment ID**						
7.Shallow Description (paved or unpaved)							
8.Flow length, L	ft						
9. Watercourse slope, s	ft/ft						
10.Average velocity, V (figure 3-1)	ft/s						
11. $T_t = \frac{L}{3600V}$ compute T_t	hr		+		=		
Channel flow	**Segment ID**						
12. Cross sectional flow area, a	ft²						
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. $V = \frac{1.49r^{\left(\frac{2}{3}\right)}s^{\left(\frac{1}{2}\right)}}{n}$ 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 step 6,11 and 19)							

Source: 210.VI.TR.55, Second edition, June 1986

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Activity 3

At this time, complete Activity 3 in your Study Guide to review the material just covered. After finishing the Activity, compare your answers with the solution provided. When you are satisfied that you understand the material, continue with the Study Guide text

Worksheet 206A-1 Estimating Time of Concentration

(simplified procedure)

Project________________ By____________________ Date__________

Location_______________ Checked_______________ Date__________

Practice________________ Field Office_______________________________

1. Data			
Rainfall distribution type	=		(I,IA,II,III)
Drainage area	A=		Ac
Runoff curve number	CN=		
Watershed slope	Y=		%
Flow length	ℓ		Ft
2. $T_c = \frac{\left[l^{.8}\left(\frac{1000}{CN}-9\right)^{.7}\right]}{1140Y^{.5}} = \frac{668.63*2.56}{1140(1)}$=1.5hr			

Given:

A waterway for a 100 acre drainage area is planned for the I. M. Rich farm. The average curve number is 75, flow length is 4,000 feet, and the average watershed slope is 0.5%. (Rainfall distribution type = II).

Find:

Tc" using the procedure in Chapter 2, EFM. Solution:

Show all work on Worksheet 20GA-1. When you are finished,compare your answer with the solution page.

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Example

Worksheet 206A-1 Estimating Time of Concentration

(simplified procedure)

Project____I.M Hipp______ By______DEW___________ Date_____8/87____

Location_________________ Checked_______MH_____ Date____8/88______

Practice___Waterway_______ Field Office_______Dover________________

3. Data			
Rainfall distribution type	=	II	(I,IA,II,III)
Drainage area	A=	100	Ac
Runoff curve number	CN=	75	
Watershed slope	Y=	.5	%
Flow length	ℓ	4000	Ft
$T_c = \frac{\left[l^{.8}\left(\frac{1000}{CN}-9\right)^{.7}\right]}{1140Y^{.5}} = \frac{761.46*7.79}{1140(.71)}$ =2.6hr			

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Activity 1 - Solution

1.Define time of concentration.

The time of concentration required for a particle of water to flow from the hydraulically most distant point on the watershed to the design point in question. Te is a function of length and velocity.

2.Name the three flow components that may exist in a watershed.

a. Sheet flow
b. Shallow concentrated flow
c. Channel flow

3.What is the basic SCS equation for sheet flow?

$$T_t = .\frac{.007(nl)^{.8}}{P_2{}^{.5}(s)^{.4}}$$

where:

T_t= sheet flow travel time
L = flow length, ft
n = Manning's roughness coefficient
s = slope of the hydraulic gradeline .
P_2= 2-yr, 24-hr precipitation

4. What are the two cover types used by SCS in computing the travel time for shallow concentraled flow? .

a. Paved
b. Unpaved

Activity 2 - Solution

Given:

The watershed is near Dover, Delaware and is being urbanized. The urban condnion Tc at the outlet is needed to deter
mne the impact of urbanization on peak discharge. The flow path information is as follows:

Segment AS - Sheet flow exists on dense grass where the land slope is 0.01 ftlft and the flow length is 50 feet. The 2-yr. 24-hr precpnation is 3.45 inches.

Segment BC. Shallow concentrated flow exists on paved conditions where the watercourse land slope is 0.01 ftl ft, and the flow length is 800 feet.

Segment CD - Channel flow exists in lined channel where Manning's n value is 0.035. The flow area is 30 ft2, the wetted perimeter is 30 ft. and the water slope is 0.0047 ftlft. Flow length is 6500 feet.

Find:

Tc. using the velocny approach method. Complete Worksheet 3. Show your computations below and on the following
page.

Solution:

Sheet flow. Segment AB

1. Surface descrption: dense grass
2. From Table 3-1, Appendix A: Manning's n. = 0.24
3. Flow length: l = 50 ft
4. 2-yr. 24-hr rainfall: P2 = 3.45 in
5. land slope: s = 0.01 ftlft
6. $T_t = .\frac{0079(nl)^{.8}}{P_2{}^{.5}(s)^{.4}} = T_t = .\frac{0079(.24*50ft)^{.8}}{3.45^{.5}(.01ft/ft)^{.4}} = \frac{.007(7.30)}{1.86(.16)} = .17$ hr

Activity 3 - **Solution.**

Given:

A waterway for a 100 acre drainage area is planned for the I. M. Rich farm. The average curve number is 75, flow length is 4,000 feet, and the average watershed slope is 0.5%. (Rainfall distribution type II).
Find:
Tc, Using the procedure in Chapter 2, EFM.

Solution:

7.Shallow Description :paved

8.Flow length, L=800ft

9. Watercourse slope, s=.0ft/ft

10.Average velocity, V =2.0 ft/s

11. $T_t = \frac{L}{3600V} = \frac{800ft}{3600(\frac{2.0ft}{s})} = .11hr$

12. Cross sectional flow area, a= $30ft^2$

13. Wetted perimeter, p_w=30ft

14.hydraulic radius, r=$\frac{a}{p_w}$ =$30ft^2$/30ft=1.0ft

15. Channel slope, s=.0047ft

16.Manning's roughness coeff., n=.035

17. $V = \frac{1.49r^{\left(\frac{2}{3}\right)}s^{\left(\frac{1}{2}\right)}}{n} = \frac{1.49(1.0ft)^{\left(\frac{2}{3}\right)}(.0047ft)^{\left(\frac{1}{2}\right)}}{.035} = 2.98\ ft/s$

18. Flow length, L=6500ft

19. $T_t = \frac{L}{3600V} = \frac{6500ft}{3600(\frac{2.98ft}{s})} = .61\ hr$

20. Watershed or subarea T_c or T_t (add T_t in step 6,11 and 19) $T_t = T_{t,AB} + T_{t,BC} + T_{t,CD}$

=.17hr + .11hr+ .61hr = .89hr

Worksheet 3- Time of Concentration (T_c) or Travel time (T_t)

Project I.M. Hipp		**By** DEW	**Date** 3/88
Location Dover, Delaware		**Checked** NPEG-1	**Date** 8/88
Cirlcle one:	Present	(Developed)	
Circle one:	(T_c)	T_t through subarea	

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.

Flow Sheet(Applicable to Tc only)	Segment ID	AB				
1.Surface description (table 3-1)		Dense grass				
2.Manning's roughness cieff, n (table 3-1)		.24				
3.flow length,(total L 300ft)	ft	50				
4.Two-yr 24-hr rainfall, P_2	in	3.45				
5.Land slope, s	ft/ft	.01				
6. $T_t = .\frac{007(nL)^{.8}}{(P_2{}^{.5}s^{.4}}$) compute T_t	hr	.17	+		=	.17

Shallow concentrated flow	Segment ID	BC				
7.Shallow Description (paved or unpaved)		paved				
8.Flow length, L	ft	800				
9. Watercourse slope, s	ft/ft	.01				
10.Average velocity, V (figure 3-1)	ft/s	2.0				
11. $T_t = \frac{L}{3600V}$ compute T_t	hr	.11	+		=	.11

Channel flow	Segment ID	CD				
12. Cross sectional flow area, a	ft²	30				
13. Wetted perimeter, p_w	ft	30				
14.hydraulic radius, r=$\frac{a}{p_w}$ compute r	ft	1				
15. Channel slope, s	ft/ft	.0047				
16.Manning's roughness coeff., n		.035				
17. $V = \frac{1.49r^{\left(\frac{2}{3}\right)}s^{\left(\frac{1}{2}\right)}}{n}$ compute V	ft/s	2.92				
18. Flow length, L	ft	6500				
19. $T_t = \frac{L}{3600V}$ compute T_t	hr	.61	+		=	.61
20. Watershed or subarea T_c or T_t (add T_t in step 6,11 and 19)						.89

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