United States
Department of
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Soil
Conservation
Service

NENTC
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TECHNICAL
NOTE

REVISED HYDROLOGY NO. N4

TIME OF CONCENTRATION

Introduction

The time of concentration (T_c) is used in most procedures to develop runoff hydrographs or estimate peak discharges. The peak rate of runoff is very sensitive to T_c, particularly for small watersheds. For example, the peak discharge of the standard SCS dimensionless unit hydrograph described in Chapter 16, NEH-4, is inversely related to 0.67 T_c.

The procedures used to estimate T_c depend upon several factors including watershed characteristics (especially drainage area), climatic conditions, required accuracy, available data, and available time. For example, to design a small conservation practice such as a grassed waterway, a shortcut procedure that assumes a certain generalized relationship between T_c and a few watershed characteristics but no relationship between T_c and rainfall intensity might be acceptable. However, for the development of a storm water management plan, an accurate estimate of the peak rate of runoff for a small watershed from at least two storm frequencies for the undeveloped, developing, and fully developed conditions would be needed. In this case, all available factors should be considered with particular attention given to the overland flow.

To accurately determine the T_c for a watershed, the hydraulics of each part of the flow path must be considered separately. This can be done by dividing the flow path into overland, channel (small), channel (large), and pipe flow segments. The travel time (T_c) can then be computed for each segment and totaled to obtain the T_c. Each of these will be discussed separately.

DIST: IM S, T, N (ENG)

Prepared by:
Paul I. Welle,.Hydraulic.Engineer
February 1983
Revised by:
Don Woodward, Hydraulic Engineer
June 1986
Revised by
Don Woodward, Hydraulic Engineer
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Overland Flow

This includes thin sheet flow over plane surfaces and flows over rilled and irregular surfaces. With such shallow flow over irregular surfaces, the friction factor (Manning's value) is an effective roughness coefficient that includes the effects of raindrop impact; channelization of flow into rills; obstacles such as litter crop ridges, and rocks; frictional drag over the surface; and erosion and transport of sediment. Although only limited data exist for these factors, enough are available to relate the surface conditions to a single friction factors value. It is important to note that, particularly for unpaved surfaces, these friction factors are significantly different than those traditionally used for channel flow.

The Manning-kinematic solution is sound, defensible, and easy to use. Therefore, it is recommended that this equation be used to compute T_t for the overland flow segment. A maximum flow length of 100' should be used in overland flow computations for unpaved areas. Paved areas may have longer lengths of sheet flow until flow becomes channelized in gutters or low areas of parking lots. The depth is 0.002'and varies up to 0.02'.

This method uses Manning's equation so that the Manning-kinematic solution becomes:

$$T_t = \frac{0.93\ (nL)^{0.6}}{i^{0.4}\ \ s^{0.3}} \qquad (1)$$

Where n = friction factor (Manning's n)
L = slope length (ft.)
i = average rainfall excess intensity for a storm duration = Tc (in./hr.)
s = slope (ft./ft.)
T_t = travel time (min.)

The assumptions include those for Manning's equation (steady uniform flow); a flat, wide plane surface; constant rainfall excess intensity; and duration of rainfall equals T_t. Overton (1972) found that the Manning-kinematic solution for the rising overland flow hydrograph produced a 15% standard error in fitting the observed data. Use of this equation requires an estimate of the rainfall excess intensity and trial and error calculations until T_t equals rainfall duration.

Since it is not readily available, it was eliminated from the equation as follows:

The rainfall intensity-duration curve for the Type II rainfall distribution was plotted on logarithmic paper. A best fit straight line for the entire curve was drawn:

$$\frac{i}{P_{24}} = 5.7\ T_t^{-0.62}$$

Where P_{24} = 24 hr. precipitation (in.)

A similar equation was developed for the Type III rainfall distribution. The best fit straight line portion of curve was:

$$\frac{i}{P_{24}} = 4.76\ T_t^{-0.63}$$

Solving for i and substituting into equation (1), the Manning-kinematic solution can then be expressed in terms of n, L, P_{24}, and S.

The weighted equation for Types II and III rainfall distribution is:

$$T_t = \frac{0.007\ (nL)^{0.8}}{P_{24}^{0.5}\ S^{0.4}} \qquad (2)$$

This also eliminates the need for trial and error calculations until T_t equals storm duration. The best fit straight line for the entire curve introduces little error for the most likely range of T_t's (1-100 min.).

The additional assumption is that rainfall excess intensity equals rainfall intensity. This is obviously a reasonable assumption for concrete and other impermeable surfaces. For short permeable planes the error introduced by this assumption is partially counterbalanced by the lack of a perfectly flat plane. A lower i would increase T_t while channelization on an irregular surface would decrease T_t.

For detailed analyses, the effect of recurrence interval should not be overlooked; however, for a shortcut procedure, the 2-year P_{24} can be used.

The estimation of the overland flow n using Table 1 requires careful consideration due to the sensitivity of T_t to the estimated n value. Table 1 relates friction factors for overland flow to surface conditions and land use using existing data from small watersheds and plots, analyzed in a uniform way (Engman, 1985). Included were data from two other studies (Woolhiser, 1975), and (Palmer, 1946). These n values are consistent with values published elsewhere (Hathaway, 1945; Ree, 1963; Jens & McPherson, 1964; Emmett, 1970; Ragan and Duru, 1972; FHWA, 1979). Using these data, the computed mean depths of overland flow are consistent with those reported by Ree(1963) of 0.002 to 0.02 ft.

Shallow Concentrated Flow (Small)

After a maximum of 100 feet, sheet flow usually becomes shallow concentrated flow. The average velocity for this flow can be determined using Manning's equation or Figure 1, in which average velocity is a function of watercourse slope and type of channel. 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, you can estimate travel time for the shallow concentrated flow segment.

$$T_t = \frac{L}{3,600v}$$

Where v = velocity (fps)

Channel Flow (Large)

This includes channelized flow where surveyed cross sections usually are available. Either Manning's equation may be used or water surface profiles may be used.

$$T_t = \frac{L}{3,600v}$$

Pipe Flow

This includes storm drain flow. By using average conduit sizes and an average slope (excluding any vertical drops in the system), the average velocity can be estimated using Manning's equation.

$$T_t = \frac{L}{3,600v}$$

The time of concentration (Tc) is the sum of the individual Tt for the various consecutive flow segments:

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

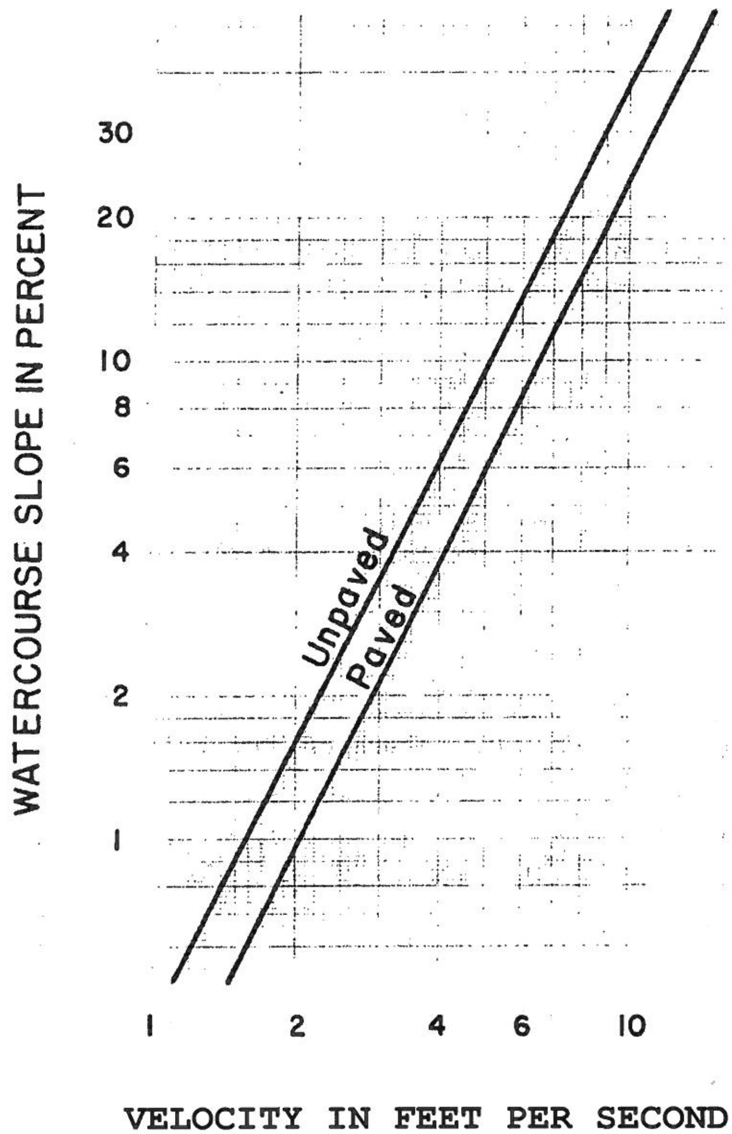

Figure 1. Average Velocities for Estimating Travel Time for Shallow Concentrated Flow.

TABLE 1

Recommended Manning's Roughness Coefficients for Overland Flow

Cover or treatment (1)	Residue rate (ton/acre) (2)	Value recommended (3)	Range (4)
Concrete or asphalt[a]		0.011	0.01 -0.013
Bare sand[a]		0.01	0.010-0.016
Graveled surface[a]		0.02	0.012-0.03
Bare clay-loam (eroded)[a]		0.02	0.012-0.033
Fallow--no residue		0.05	0.006-0.16
Chisel plow	1/4	0.07	0.006-0.17
	1/4-1	0.18	0.07 -0.34
	1-3	0.30	0.19 -0.47
	3	0.40	0.34 -0.46
Disk/harrow	1/4	0.08	0.008-0.41
	1/4-1	0.16	0.10 -0.41
	1-3	0.25	0.14 -0.53
	3	0.30	-
No-till	1/4	0.04	0.03 -0.07
	1/4-1	0.07	0.01 -0.13
	1-3	0.30	0.16 -0.47
Moldboard Plow (Fall)		0.06	0.02 -0.10
Coulter		0.10	0.05 -0.13
Range (natural)		0.13	0.01 -0.32
Range (clipped)		0.10	0.02 -0.24
Grass (bluegrass sod)		0.45	0.39 -0.63
Short grass prairie[a]		0.15	0.10 -0.20
Dense grass[b]		0.24	0.17 -0.30
Bermuda grass[b]		0.41	0.30 -0.48
Woods-Light underbrush		0.40	
Woods-Dense underbrush		0.80	

[a]From Woolhiser, Ref. 12

[b]Weeping lovegrass, bluegrass, buffalo grass, blue gamma grass, native grass mix (OK), alfalfa, lespedeza (from Palmer, Ref. 8).

Example

An urbanizing watershed is shown in Figure 2. The flow conditions shown are for the anticipated urbanized state. Four types of flow exist in the flow path from the hydraulically most distant point of the watershed to the outlet. Compute the travel times (T_t) for each segment and the T_c for both the present and urbanized conditions based on the following data:

Present Condition

Segment	Description of Flow Path	Slope	Length
A to B	Overland (chisel plow - 1/4-1 ton/acre)	.02	100
B to C	Waterway (unpaved)	.05	600
C to D	Small channel, triangular tall bluegrass (T = 5, d = 1, n = 0.04)	.015	1,500
D to E	Large channel, brushy, trapezoidal (b = 4, d = 3, z = 1:1, n = 0.05)	.005	3,000

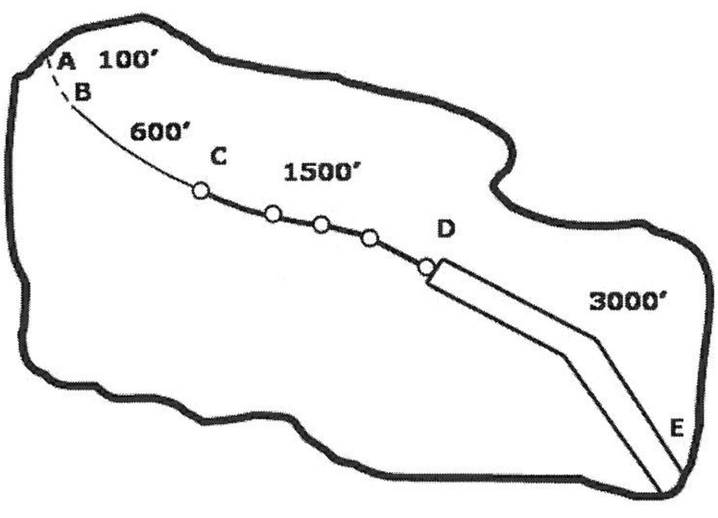

Figure 2a - Watershed Schematic for Present Conditions

Urbanized Condition

Segment	Description Of Flow Path	Slope	Length
A to B	Overland (concrete parking lot)	.02	100
B to C	Shallow gutter	.06	500
C to D	Storm drain with manhole covers, inlets, etc. (n = 0.015, diameter 3 ft.)	.018	1,250
D to E	Open channel, gunite, trapezoidal (b = 5, d = 3, z = 1:1, n = 0.019)	.0053	2,800

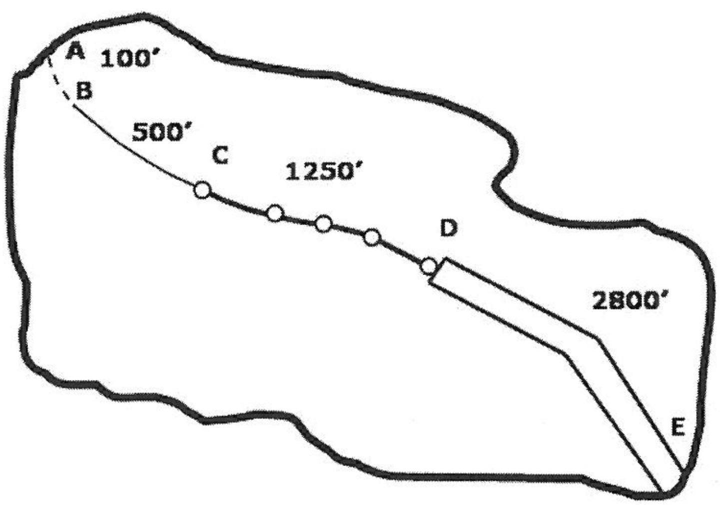

Figure 2b - Watershed Schematic for Urbanized Conditions

Computations

Present Conditions

1. Compute the overland flow travel time for segment A to B. From Table 1, n = 0.018. From Equation (2), T_t = 0.03 hrs. (assuming P_{24} = 3.0").

$$T_t = \frac{(.007)(nL)^{.8}}{(P)^{.5}\ (S)^{.4}} = \frac{(.007)[(.018)(100)]^{.8}}{(3)^{.5}\ (.02)^{.4}} = 0.03$$

2. Compute the waterway travel time for segment B to C. From Figure 1 V = 3.6 fps.

$$T_t = \frac{L}{v} = \frac{600\text{ ft.}}{(3.6\text{ fps})\ (3,600\text{ sec/hr})} = 0.05\text{ hr.}$$

3. Compute the small channel flow travel time for segment C to D. Using Manning's equation:

$$v = \frac{1.49}{n} r^{2/3}\ s^{1/2}$$

$$r = \frac{A}{P} = \frac{2.5}{5.4} = 0.46\text{ ft.}$$

$$= \frac{1.49}{0.04}(0.46)^{2/3}\ (.015)^{1/2}$$

$$= 2.7\text{ fps}$$

$$T_t = \frac{1,500\text{ ft.}}{2.7\text{ fps}\ (3,600\text{ sec/hr})} = .15\text{ hr.}$$

4. Compute the large channel flow travel time for segment D to E. Using Manning's equation:

$$r = \frac{A}{P} = \frac{21}{12.5} = 1.7\text{ ft.}$$

$$v = \frac{1.49}{0.05}(1.7)^{2/3}\ (0.005)^{1/2} = 3.0\text{ fps}$$

$$T_t = \frac{3,000\text{ ft.}}{3.0\text{ fps}\ (3,600\text{ sec/hr})} = .28\text{ hr.}$$

Urbanized Conditions.

1. Compute the overland flow travel time for segment A to B. From Table 1, n = 0.011. From Equation (2), T_t = 0.02 hr. (assuming P_{24} = 3.0").

$$T_t = \frac{.007(nL)^{.8}}{(P)^{.5}\ (S)^{.4}} = \frac{(.007)[(100)\ (.011)]^{.8}}{(3)^{.5}\ \ (.02)^{.4}} = .02hr$$

2. Compute the shallow gutter flow travel time for segment B to C.

$$r = \frac{A}{P} = \frac{1}{4.5} = 0.22 \text{ ft.}$$

$$v = \frac{1.49}{0.011}\ (0.22)^{2/3}(0.06)^{1/2} = 12.1 \text{ fps}$$

$$T_t = \frac{500 \text{ ft.}}{12.1 \text{ fps } (3,600 \text{ sec/hr})} = 0.01 \text{ hr.}$$

3. Compute the storm drain flow travel time for segment C to D.

$$v = \frac{1.49}{n}(D/4)^{2/3}\ s^{1/2}$$

$$= \left(\frac{1.49}{0.015}\right)\ (3/4)^{2/3}\ (0.015)^{1/2} = 10 \text{ fps}$$

$$T_t = \frac{1,250 \text{ ft.}}{10 \text{ fps } (3,600 \text{ sec/hr})} = 0.03 \text{ hr.}$$

4. Compute the open channel flow travel time for segment D to E.

$$r = \frac{A}{P} = \frac{24}{13.6} = 1.76$$

$$v = \frac{1.49}{(0.019)}\ (1.76)^{2/3}(0.0053)^{1/2} = 8.3 \text{ fps}$$

$$T_t = \frac{2,800 \text{ ft.}}{8.3 \text{ fps } (3,600 \text{ sec/hr})} = 0.09 \text{ hr.}$$

Summary of T_c.(hours).

Segment	Condition: Present	Condition: Urbanized
A to B	0.03	0.02
B to C	0.05	0.01
C to D	0.15	0.03
D to E	0.28	0.09
	0.51 hr.	0.15 hr.

References

1. Emmett, W. W., 1970. The Hydraulics of Overland Flow on Hill Slopes. U.S. Geological Survey Professional Paper 662-A.

2. Engman, E. T. Roughness Coefficients for Routing Surface Runoff. Proceedings of Journal of Irrigation and Drainage, Vol. 112, No. 1, February 1986, ASCE, New York, NY.

3. Federal Highway Administration, 1979. Design of Urban Highway Drainage - The State-of-the-Art. 3-10.

4. Hathaway, G. A., 1946. Military Airfields - Design of Drainage Facilities. Proceedings, American Society of Civil Engineers, Transactions Number 1945, Volume 72, No. 2, Part 3.

5. Henderson, F. M., 1966. Open Channel Flow. Macmillan Co., New York, 366.

6. Jens, S. W. and McPherson, M. B., 1964. Hydrology of Urban Areas, p. 20-39. In: V.T. Chow (ed.), Handbook of Applied Hydrology. McGraw-Hill Book Co., New York.

7. Overton, D. E., 1972. Kinematic Flow on Long Impermeable Planes. Water Resources Bulletin 8, No. 6, p. 1198-1204.

8. Palmer , V. J., 1946. Retardance Coefficients for Low Flow in Channels Lined with Vegetation. Transactions, American Geophysical Union, Volume 27, Number II, p. 187-197.

9. Rallison, R. E., 1977. Letter to Dr. G. O. Schwab.

10. Ragan, R. M. and J. O. Duru, 1972. Kinematic Wave Nomograph for Times of Concentration. Hydraulics Division, ASCE, 98 (HY 10): p. 1765-1771.

11. Ree, W. O., 1963. A Progress Report on Overland Flow Studies. Presented at SCS Hydraulic Engineers Meeting, August 12-16, 1963, New York, NY.

12. Woolhiser, D. A., 1975. Simulation of Unsteady Overland Flow. Chapter 12, Institute on Unsteady Flow, Colorado State University, Fort Collins, Colorado, June 1974, Water Resources Pub., Fort Collins, CO.