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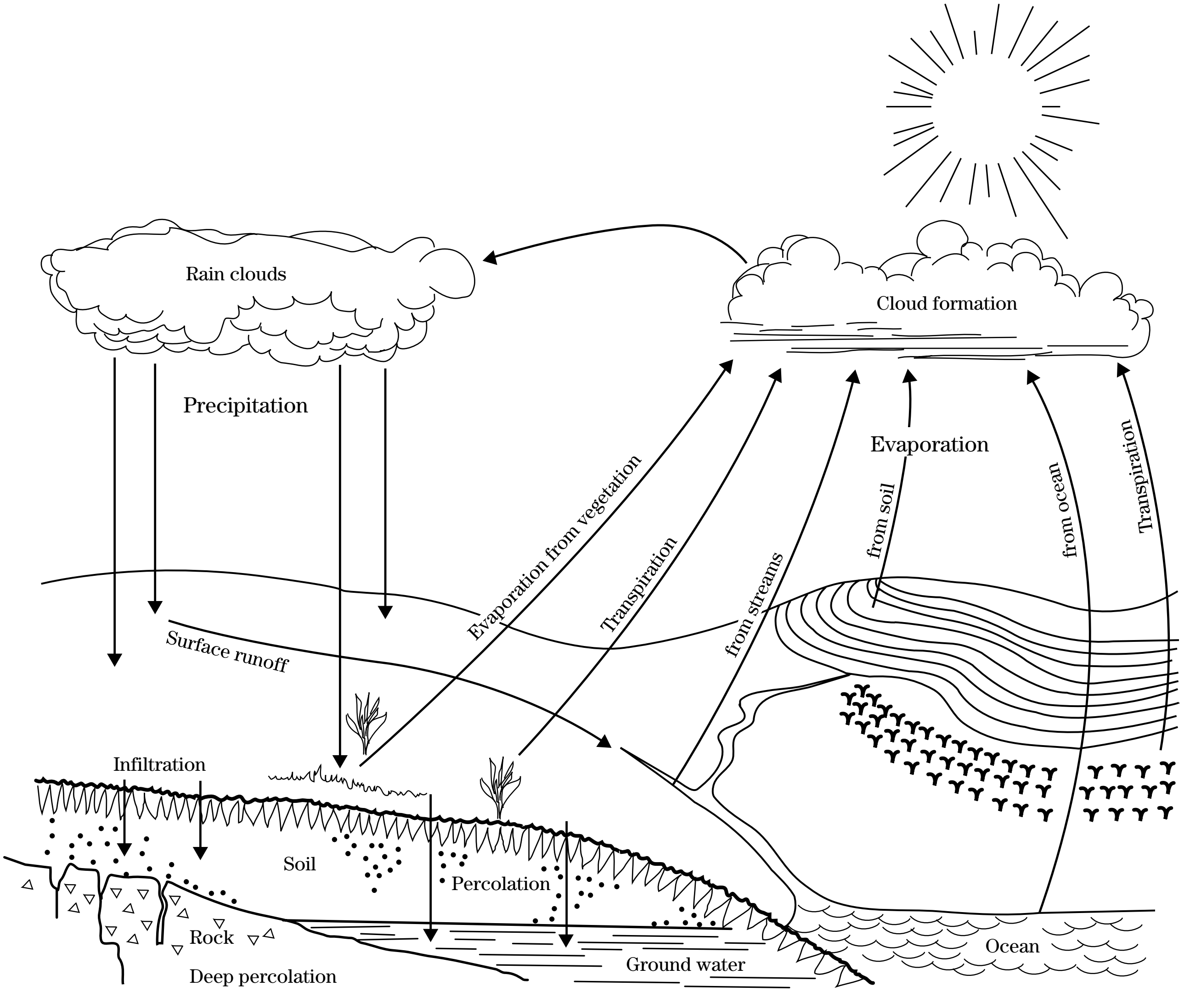
**Natural
Resources
Conservation
Service**

Part 630 Hydrology
National Engineering Handbook

Chapter 15 Time of Concentration



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Chapter 15 was originally prepared in 1971 by **Kenneth M. Kent** (retired). This version was prepared by **Donald E. Woodward** (retired), under the guidance of **Claudia C. Hoeft**, national hydraulic engineer, Washington, D.C. **Annette Humpal**, hydraulic engineer, Wisconsin, and **Geoffrey Cerrelli**, hydraulic engineer, Pennsylvania, provided the information in appendix 15B.

Chapter 15 Time of Concentration

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630.1500 Introduction

This chapter contains information on the watershed characteristics called travel time, lag, and time of concentration, which influence the shape and peak of the runoff hydrograph.

630.1501 Definitions and basic relations

(a) Lag

There is a delay between the time a rainfall event begins over a watershed until runoff reaches its maximum peak. The delay is called lag (L). The lag of a watershed may be thought of as a weighted time of concentration. If for a given storm, the watershed is divided into equal time bands and the travel times from the centroids of the increments to the main watershed outlet are determined, the lag is:

$$L = \frac{\sum\left(a_x Q_x T_{tx}\right)}{\sum\left(a_x Q_x\right)} \qquad \text{(eq 15–1a)}$$

$$L = \frac{\sum\left(a_x Q_x T_{tx}\right)}{AQ_a} \qquad \text{(eq. 15–1b)}$$

where:
L = lag, hr
a_x = increment of watershed area, mi^2
Q_x = runoff in inches from area a_x
T_{tx} = travel time (h) from the centroid of a_x to the point of reference
A = total area of the watershed above the point of reference, mi^2
Q_a = total runoff (in) from the watershed

The approach in general practice is to develop a hydrograph for each of the subareas (a_x) and route the hydrographs downstream to the point of reference. The subareas are usually a subdivision of a hydrologic unit as described in NEH630.06. A lag time (L) or time of concentration (T_c) is usually estimated for each hydrologic unit by one of the methods in this chapter. Hydrographs are then developed for each subarea by the method described in NEH630.16 of routed to point of reference by the method described in NEH630.17.

In hydrograph analysis, lag is the time interval between the center of mass of the excess rainfall and the peak runoff rate (fig. 15–1).

(b) Time of concentration

Time of concentration (T_c) is the time required for runoff to travel from the hydraulically most remote point of the watershed to the outlet. Time of concentration will vary, depending on the slope and character of the surface. When the drainage area consists of several different types of surfaces, time of concentration is calculated by adding the time for each type of flow along the flow path from the watershed divide to the watershed outlet. Time of concentration is generally applied only to surface runoff.

In hydrograph analysis, time of concentration is the time from the end of excess rainfall to the point on the falling limb of the hydrograph (point of inflection) where the recession curve begins (fig. 15–1).

(c) Relation between lag and time of concentration

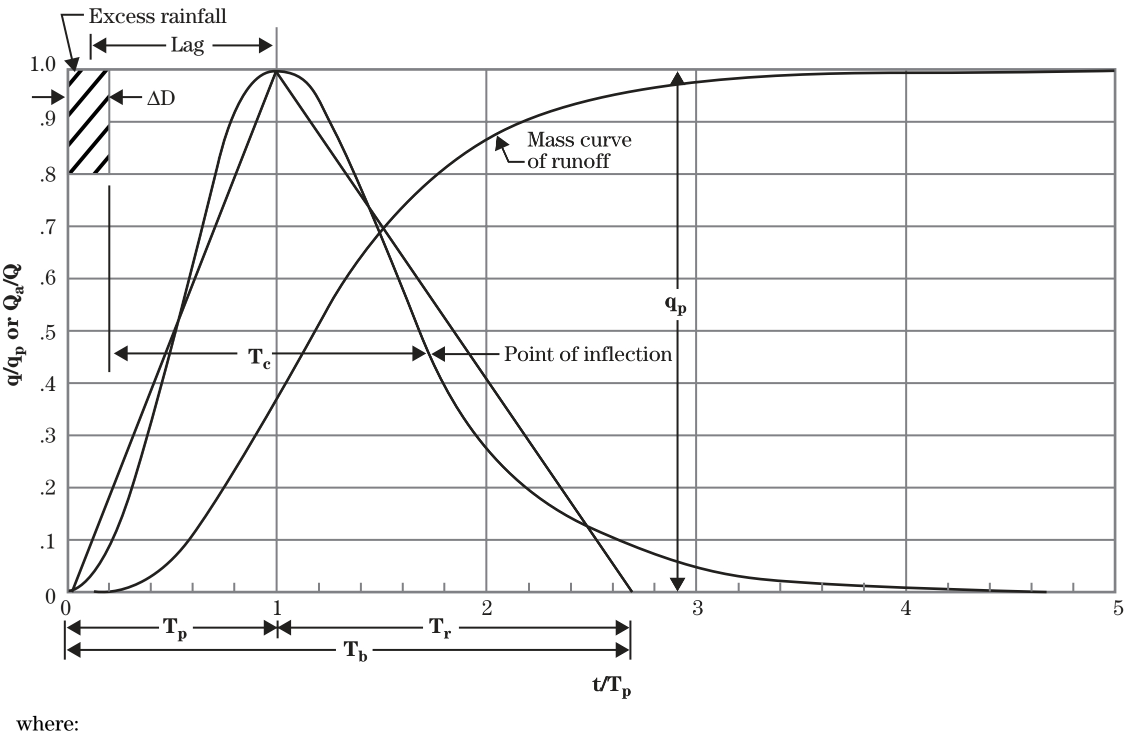
Various researchers (Mockus 1957; Simas 1996) found that for average natural watershed conditions and approximately uniform distribution of runoff:

$$L = 0.6T_c \qquad \text{(eq. 15–2)}$$

where:
L = lag, h
T_c = time of concentration, h

When runoff is not uniformly distributed, the watershed can be subdivided into areas with nearly uniform flow so that equation 15–2 can be applied to each of the subareas.

Figure 15–1 The relation of time of concentration (T_c) and lag (L) to the hydrograph



where:
T_c = time of concentration, in hours
T_p = time to peak, in hours
T_r = recession time or the time from the peak to the end of the hydrograph, in hours. The time parameters are shown for the equivalent triangular hydrograph, but the same relations are true for the curvilinear hydrograph
T_b = base time or the total time of the hydrograph, in hours
D = duration of excess rainfall, in hours
t/T_p = dimensionless ratio of any time to time to peak

630.1502 Methods for estimating time of concentration

Two primary methods of computing time of concentration were developed by the Soil Conservation Service (SCS), now the Natural Resources Conservation Service (NRCS).

(a) Watershed lag method

The SCS method for watershed lag was developed by Mockus in 1961. It spans a broad set of conditions ranging from heavily forested watersheds with steep channels and a high percent of the runoff resulting from subsurface flow, to meadows providing a high retardance to surface runoff, to smooth land surfaces and large paved areas.

$$L = \frac{\ell^{0.8}\left(S+\ell\right)^{0.7}}{1900Y^{0.5}} \qquad \text{(eq. 15–3a)}$$

Applying equation 15–2 yields:

$$T_c = \ell^{0.8}\frac{\left(S+1\right)^{0.7}}{1140Y^{0.5}} \qquad \text{(eq. 15–3b)}$$

where:
L = lag, h
T_c = time of concentration, h
ℓ = flow length, ft
Y = average watershed land slope, percent
S = maximum potential retention, in
$= \frac{1,000}{cn'} - 10$
where:
cn' = the retardance factor

Flow length (ℓ)—Flow length is defined as the path along which water flows from the watershed divide to the outlet. Flow length can be measured using aerial photographs, quadrangle sheets, or GIS techniques. Mockus (1973) developed a relationship between flow length and drainage area characteristics using data from Agricultural Research Service (ARS) watersheds. This relationship is:

$$\ell = 209A^{0.6} \qquad \text{(eq. 15–4)}$$

where:
ℓ = flow length, ft
A = drainage area, acres

Land slope (Y), in percent—The average land slope of the watershed, not to be confused with the slope of the flow path. The average land slope for small watersheds can be determined several different ways:

- by assuming land slope is equal to the soil map unit slope, from the soil survey
- by using a clinometer, as measured in the field
- by drawing three to four lines on a topographic map perpendicular to the contour lines and determining the average slope of these lines
- by determining the average of the land slope from grid points using a dot counter
- by using the following equation (Chow 1964):

$$Y = \frac{100\left(MN\right)}{A} \qquad \text{(eq. 15–5)}$$

where:
Y = average land slope, in percent
M = summation of the length of the contour lines that pass through the watershed drainage area on the quad sheet, ft
N = contour interval used, ft
A = drainage area, ft^2 (1 acre = 43,560 ft^2)

Retardance factor—The retardance factor, cn′, is a measure of surface conditions relating to the rate at which runoff concentrates at some point of interest. The retardance factor is approximately the same as the curve number (CN) as defined in NEH630.09.

Thick mulches in forests are associated with low retardance factors and reflect high degrees of retardance, as well as high infiltration rates. Hay meadows have relatively low retardance factors. Like thick mulches in forests, stem densities in meadows provide a high degree of retardance to overland flow in small watersheds. Conversely, bare surfaces with very little retardance to overland flows are represented by high retardance factors.

In practical usage, the runoff curve number (CN) is used as a surrogate for cn′, and the CN tables in NEH630.09 can be used to approximate the retardance factor, S, in equations 15–3a and 15–3b. A CN of less than 50 or greater than 95 should not be used in the solution of equation 15–3a and 15–3b.

Applications and limitations—The watershed lag equation was developed from data from 24 watersheds ranging in size from 1.3 acres to 9.2 square miles, with the majority less than 2,000 acres in size (Mockus 1961). Folmar and Miller (2000) revisited the development of this equation using additional watershed data and found that 5 to 19 square miles may be a more realistic upper limit.

(b) Velocity method

Another method for determining time of concentration normally used within NRCS is called the velocity method. The velocity method assumes that time of concentration is the sum of travel times for segments along the hydraulically most remote flow path.

$$T_c = T_{t1} + T_{t2} + T_{t3} + \ldots T_{tn} \qquad \text{(eq. 15–6)}$$

where:
T_c = time of concentration, h
T_t = travel time of a segment, h
n = number of segments comprising the total hydraulic length

The segments used in the velocity method may be of three types: sheet flow, shallow concentrated flow, and open channel flow.

The travel time for any given segment is equal to:

$$T_t = \frac{\ell}{3600V} \qquad \text{(eq. 15–7)}$$

where:
T_t = travel time, h
ℓ = flow length, ft
V = average velocity, ft/s
3600 = a conversion factor (seconds to hours)

Sheet flow—Sheet flow is flow over plane surfaces. It usually occurs in the headwaters of a stream.

A simplified version of the Manning's kinematic solution may be used to compute travel time for sheet flow. This simplification of the kinematic equation was developed by Welle and Woodward (1986) after studying the impact of various parameters on the estimates.

$$T_t = \frac{0.007\left(n\ell\right)^{0.8}}{\left[\left(P_2\right)^{0.5} S^{0.4}\right]} \qquad \text{(eq. 15–8)}$$

where:
T_t = travel time, h
n = roughness coefficient (table 15–1)
ℓ = flow length, ft
P_2 = 2-year, 24-hour rainfall, in
S = slope of hydraulic grade line, ft/ft

Table 15–1 Roughness coefficients for sheet flow (flow depth generally ≤ 0.1 feet)

Surface description	n[1]
Smooth surface (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 priarie	0.15
Dense grasses[2]	0.24
Bermudagrass	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, buffalograss, blue gramma 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.

This simplified form of Manning's kinematic solution is based on the following assumptions:

- shallow steady uniform flow
- constant rainfall excess intensity (that part of a rain available for runoff) both temporal and spatial
- rainfall duration of 24 hours
- minor effect of infiltration on travel time

For sheet flow, the roughness coefficient is an effective roughness coefficient that includes the effects of roughness and the effects of raindrop impact including drag over the surface; obstacles such as litter, crop ridges, and rocks; and erosion and transport of sediment. These n values are only applicable for flow depths of approximately 0.1 foot or less, where sheet flow is said to occur. Table 15–1 gives roughness coefficient values for sheet flow for various surface conditions.

Shallow concentrated flow—After approximately 100 feet, sheet flow usually becomes shallow concentrated flow collecting in swales, small rills, and gullies. Shallow concentrated flow is not assumed to have a well-defined channel. Velocities are developed using wide, rectangular channel flow concepts. Average velocity for shallow concentrated flow can be determined using figure 15–2, in which average velocity is a function of watercourse slope and type of channel (Kent 1964). For slopes less than 0.005 foot per foot, the equations in table 15–2 may be used.

After estimating average velocity using figure 15–2, use equation 15–7 or the equations in table 15–2 to estimate travel time for the shallow concentrated flow segment.

It is assumed that shallow concentrated flow can be represented by one of seven flow types. The curves in figure 15–2 were used to develop the information in table 15–2.

Open channel flow—Open channels are assumed to begin where surveyed cross-sectional information has been obtained, where channels are visible on aerial photographs, or where blue lines (indicating streams) appear on U.S. 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 the bankfull elevation.

Manning's equation is:

$$V = \frac{1.49 r^{\frac{2}{3}} s^{\frac{1}{2}}}{n} \qquad \text{(eq. 15–9)}$$

where:
V = average velocity, ft/s
r = hydraulic radius, ft, and equal to a/P_w
a = cross-sectional flow area, ft^2
P_w = wetted perimeter, ft
s = slope of the hydraulic grade line (channel slope), ft/ft
n = Manning's n value for open channel flow

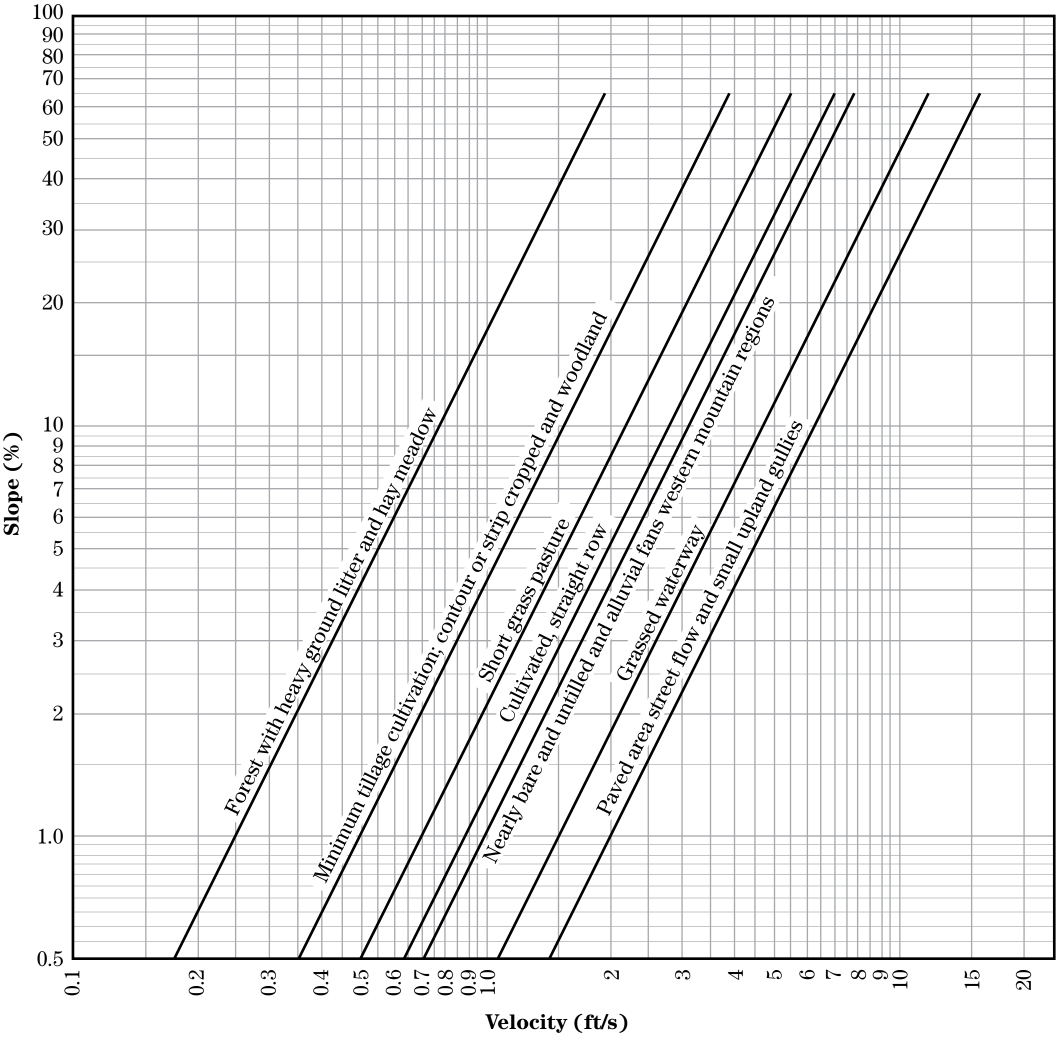
Manning's *n* values for open channel flow can be obtained from standard textbooks such as Chow (1959); Linsley, Kohler, and Paulhus (1982); Barnes (1967); Arcement and Schneider (1989); Phillips and Ingersoll (1998); and Cowen (1956).

Applications and limitations—The velocity method of computing time of concentration is hydraulically sound and provides the opportunity to incorporate changes in individual segments if needed. The velocity method is the best method for calculating time of concentration if a watershed is being urbanized or if channel improvement is being considered.

Table 15–2 Equations and assumptions developed from figure 15–2

Flow type	**Depth (ft)**	**Manning's *n***	**Equation (ft/s)**
Pavement	.2	.025	$V = 20.328(S)^{0.5}$
Grass waterway	.4	.05	$V=16.1345(S)^{0.5}$
Nearly bare alluvial fans	.2	.051	$V=10.277(S)^{0.5}$
Cultivated straight row	.2	.056	$V=9.0125(S)^{0.5}$
Short-grass pasture	.2	.07	$V=6.957(S)^{0.5}$
Trash fallow	.2	.101	$V=5.06(S)^{0.5}$
Forest	.2	.175	$V=2.53(S)^{0.5}$

Figure 15–2 Velocity versus slope for shallow concentrated flow



The channel length can be considered to represented by the blue line length on a 15- or 30-minute quad sheet. This length represents an average flow length for a wide range of storms.

Use the average velocity and the valley length of the reach to compute the travel time through the reach by equation 15–7. If the stream is quite sinuous, the channel length and valley length may be significantly different. Use whichever is more appropriate for the flow depth of the event being evaluated.

Manning's kinematic solution should not be used for sheet flow lengths greater than 100 feet. Equation 15–8 was developed for use with the standard NRCS rainfall intensity-duration relationships and will work with the new NOAA atlases dated 2002 and forward. It was also developed assuming the 2-year, 24-hour precipitation value would be used.

Time of concentration calculations are based on the 2-year frequency discharge or bankfull discharge. Considering the variation in all the variables that impact time of concentration in a watershed, it is normally assumed that the time of concentration computed using 2-year characteristics is representative of the travel time conditions for a wide range of frequencies.

When combinations of flow occur together, a compound hydrograph with more than one peak and lag time may result. Ideally, the various types of flow should be separated for lag analysis and combined at the end of the study. In practice, lag is usually determined only for the direct runoff portion of flow.

The role of channel and valley storage is inportant in the development and translation of a flow wave and the estimation of lag. Both the hydraulics and storage may change from storm to storm with velocity distribution varying greatly both horizontally and vertically. As a result, an average lag may have a large variation.

For multiple subarea watersheds, the time of concentration must be computed for each subarea individually and consideration must be given to the travel time through downstream subareas from upstream subareas.

630.1503 Other considerations

(a) Field observations

For an accurate estimate of the time of concentration, field observations of significant factors should be made. These include:

- the type of material in the banks and bottom of the channel
- an estimate of Manning's *n* value
- condition of vegetation in the channel and its flood plain
- slope of the channel bed
- presence of any significant obstructions

When the time of concentration is needed as part of calculations for a specific design, sufficient surveys and observations should be made to ascertain that the values used for calculations are realistic. When the time of concentration is needed for preliminary conclusions, the time of concentration may be estimated by taking travel distances from maps or aerial photographs. This may involve velocity estimates based on general knowledge of approximate sizes and characteristics for channels in the geographic area.

(b) Surface flow

Both of the standard methods, as well as most other methods, assume that flow reaching the channel as surface flow or quick return flow adds directly to the peak of the subarea hydrograph. Locally derived procedures might be developed from data where a major portion of the contributing flow is other than surface flow. This is normally determined by making a site visit to the watershed.

Kibler and Aron (1982) and others indicated the maximum sheet flow length is less than 100 feet. McCuen and Spiess (1995) indicated that use of flow length as the limiting variable in the equation 15–8 could lead to less accurate designs. They indicated that the limitation should instead be based on:

$$\ell = \frac{100\sqrt{S}}{n} \qquad \text{(eq. 15–10)}$$

where:
n = roughness coefficient
ℓ = limiting length of flow, ft
S = slope, ft/ft

Table 15–3 provides some indication of the limiting flow lengths using this criterion.

(c) Travel time through bodies of water

The potential for detention is the factor that most strongly influences travel time through a body of water. It is best to divide the watershed such that any potential storage area is modeled as storage. If a potential storage area is too small to break out for the watershed model, a subwatershed evaluation can indicate how much detention time should be allowed for travel time through the storage area.

In many cases, the travel time for a water droplet through a body of water is assumed to be nearly instantaneous. The time of concentration is computed by the velocity or watershed lag method to the upstream end of the lake, reservoir, or swamp. At the instant the droplet arrives at the upstream end, it is assumed that the water level in the lake is raised a small amount and this same amount leaves the water body via the outlet.

Table 15–3 Maximum sheet flow lengths using the McCuen-Spiess Limitation Criteria

Cover type	*n* values	Slope (ft/ft)	Length (ft)
Range	.13	.01	77
Grass	.41	.01	24
Woods	.80	.01	12.5
Range	.13	.05	173
Grass	.41	.05	55
Woods	.80	.05	28

(d) Variation in lag and time of concentration

Rao and Delheur (1974) concluded that lag time, and hence time of concentration is not a unique characteristic of the watershed and varies from storm to storm. The reasons include amount, duration and intensity of precipitation, stage of growth, and available temporary storage. Table 15–4 illustrates the variation in lag for three watersheds in Maryland. The precipitation amounts have been included to given an indication of the storm size. These lag times were developed by Thomas, Monde, and Davis (2000) from actual events at USGS stream gages.

Folmar and Miller (2000) found that the velocity approach of calculating time of concentration tends to be an underpredicted or underestimated time of concentration. This underprediction may be attributed to:

- low estimates of stream length from not considering sinuosity
- overestimated flow velocities from not considering pools in the stream

When used in conjunction with unit hydrograph procedures, this results in overestimated design discharges. It was determined from 39 nonurbanized watersheds that the underprediction of time of concentration using the velocity method may be as much as 60 and 90 percent.

(e) Effects of urbanization

- **Surface roughness**—One of the most significant effects of urban development on overland flow is the lowering of retardance to flow causing higher velocities. Undeveloped areas with very slow and shallow overland flow through vegetation become modified by urban development. 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, nonurban 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 constructed

channel designs have efficient hydraulic characteristics, runoff flow velocity increases and travel time decreases.

- **Watersheds with storm sewers**—In watersheds with storm sewers, carefully identify the appropriate hydraulic flow path to estimate time of concentration. Storm sewers generally handle only a small portion of a large event. The rest of the peak flow travels by streets and lawns to the outlet. Any standard hydraulics textbook contains methods to determine average velocity in pipes for either pressure or nonpressure flow.
- **Slope**—Slopes may be increased or decreased by urbanization, depending on the extent of site grading and the extent to which storm sewers and street ditches are used in the design of the water management system. Slopes tend to increase when channels are straightened and decrease when overland flow is directed through storm sewers, street gutters, and diversions. Overland flow slopes may decrease when land is graded to develop nearly level lots.

(f) Geographic information systems

Geographic information systems (GIS) can be used to estimate watershed features, such as watershed boundaries and drainage areas; flow path lengths and slopes; stream and flood plain reach lengths; average watershed land slopes; land cover; and, in some cases, cross-sectional features. This information can then be imported into a number of hydrology computer programs which use the data to estimate times of concentration with basins. One example of this is the NRCS GeoHydro program which gives the user the option of using either the velocity method or the watershed lag method to estimate times of concentration.

Table 15–4 Variation in lag time for selected events for selected streams in Maryland

Stream	USGS number	Area (mi^2)	Event	Date	Lag (h)	Storm duration (min)	Precipitation (in)
Brien run	1585400	1.97	1	8/21/1986	2.35	30	1.85
			2	8/22/1986	1.94	45	0.32
			3	9/8/1987	2.44	120	1.03
Jones Falls	1589440	26.2	1	8/10/1984	4.16	15	1.84
			2	2/12/1985	6.91	285	1.59
			3	12/24/1986	5.2	165	2.47
Deer Creek	1580000	94.4	1	9/8/1987	5.06	75	2.2
			2	9/18/1987	7.15	15	1.02
			3	5/6/1989	9.67	60	5

630.1504 Examples

(a) Example of watershed lag method

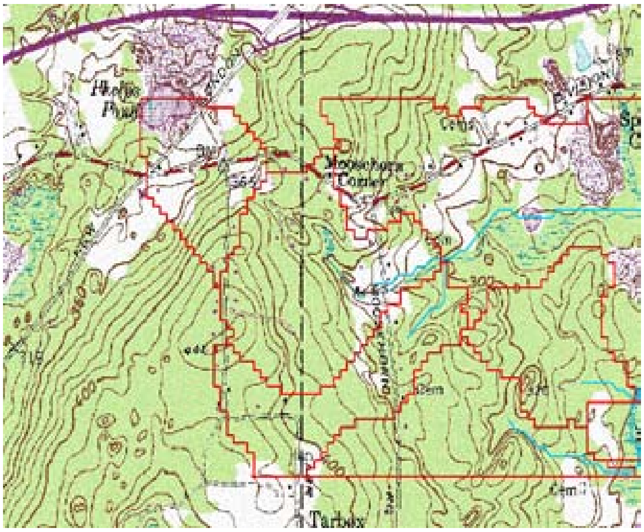
Compute the time of concentration using the watershed lag method for Falls Creek in Kent County, Rhode Island. The topographic map for the watershed is shown in figure 15–3. The watershed has the following attributes:

Drainage area, A = $0.42\ \text{mi}^2$
Curve number, CN = 63–used as a surrogate for cn′
Longest flow path, ℓ = 1,100 ft
Watershed slope, Y = 4.81%

Time of concentration is computed using equation 15–3b:

$$T_c = \ell^{0.8}\frac{(S+1)^{0.7}}{1140Y^{0.5}}$$

Figure 15–3 Watershed map Falls Creek, Kent County, RI



$$S = \left(\frac{1000}{cn'}\right) - 10$$

$$S = \left(\frac{1000}{63}\right) - 10$$

$$S = 5.87$$

$$T_c = \frac{(1100)^{0.8}(5.87+1)^{0.7}}{(1140)(4.81)^{0.5}} - 10$$

$$T_c = 0.42\ \text{h}$$

(b) Example of velocity method

For the watershed shown in figure 15–4, compute the time of concentration for that portion of the watershed above the junction of subareas 4 and 5 (red dot on figure), consisting of subareas 1, 2, 3, and 4 (the shaded area on fig. 15–4). Assume that floodwater retarding structure, FR–1, has not been installed. The 2–year, 24-hour precipitation for watershed is 3.6 inches. Stream hydraulics have been computed using methods outlined in NEH630.14 for all the stream reaches. The flow lengths are:

GS–1 to confluence of subareas 2 and 3	6,000 feet
FR–1 to HH	2,400 feet
HH to GG	2,800 feet
GG to confluence of subareas 4 and 5	900 feet
Total	12,100 feet

Part A Calculate the time of concentration for subarea 1.

Subarea 1 in figure 15–4 has a diversion terrace below a short-grass pasture outletting into a grassed waterway down to a road crossing. The flow length across the pasture down to the diversion terrace is 900 feet with 100 feet of sheet flow length and 800 feet of shallow concentrated flow length.

The length of the diversion terrace is 2,100 feet, with an average slope of the pasture of 8 percent. The grassed waterway is 2,400 feet long with an average slope of 4 percent. A raw gully extends from the road crossing where the grassed waterway terminates to a point where a grade stabilization structure is planned. The length of the gully is 2,700 feet with a 3 percent grade. The designed velocity for the terrace is 1.5 feet per second.

Sheet flow segment—The travel time for the sheet flow segment through the short-grass pasture is computed using equation 15–8. The n value for short grass from table 15–2 is 0.15.

$$T_t = \frac{0.007(n\ell)^{0.8}}{\left[(P_2)^{0.5} S^{0.4}\right]}$$

$$T_t = \frac{0.007\left[(0.15)(100)\right]^{0.8}}{\left[(3.6)^{0.5}(.08)^{0.4}\right]}$$

$$T_t = .09 \text{ h}$$

Shallow concentrated flow segments—The travel times for the remaining portions along the flow path are based on shallow concentrated flow velocities. Given that the majority of conservation practices are not intended to handle large plow depths, this is a reasonable assumption.

Use figure 15–2 to determine the shallow concentrated flow velocities.

Short-grass pasture at 8 percent	2 ft/s
Grassed waterway at 4 percent	3 ft/s
Terrace velocity (given)	1.5 ft/s
Gully at 3 percent	3.5 ft/s

Compute the travel time for each flow segment:

$$T_t(\text{pasture}) = \frac{\left(\frac{800}{3600}\right)}{2} = 0.11 \text{ h}$$

$$T_t(\text{terrace}) = \frac{\left(\frac{2100}{3600}\right)}{1.5} = 0.39 \text{ h}$$

$$T_t(\text{waterway}) = \frac{\left(\frac{2400}{3600}\right)}{3} = 0.22 \text{ h}$$

$$T_t(\text{gully}) = \frac{\left(\frac{2700}{3600}\right)}{3.5} = 0.21 \text{ h}$$

Add the travel times for each flow segment to get the total travel time for subarea 1:

$$T_t = 0.09 + 0.11 + 0.39 + 0.22 + 0.21$$

$$T_t = 1.02 \text{ h}$$

Part B Determine the travel time for reach R–2.

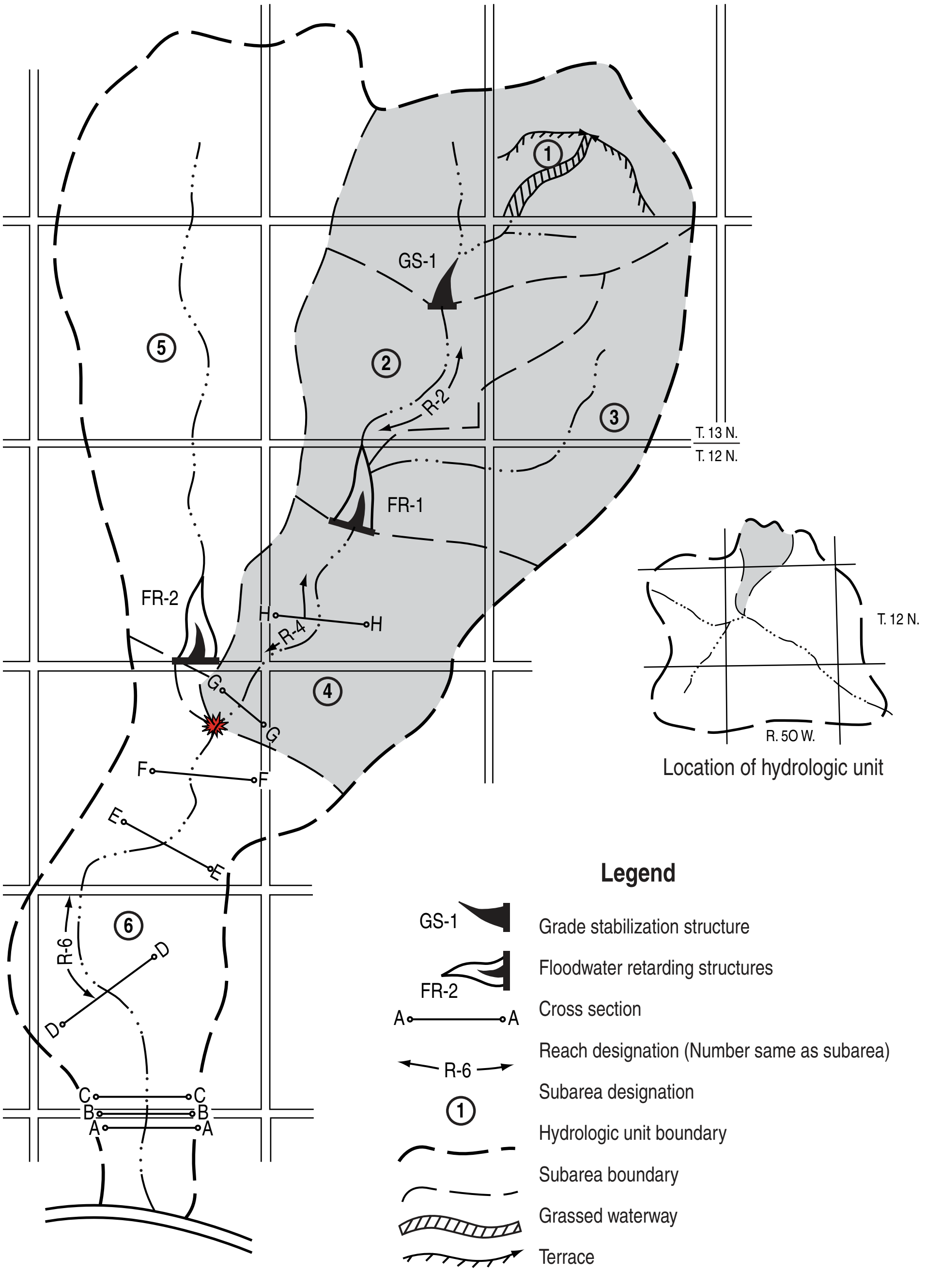
Table 15–5 shows the field data obtained for estimating mean velocity for each segment. The velocities were computed using Manning's equation for open channel flow (eq. 15–9):

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

Table 15–5 Field data and computed velocities at each cross section in reach R–2

Cross section	Bankfull area (a) ft²	Wetted perimeter (Pw) ft	Hydraulic radius (r) ft	$r^{2/3}$	n	$S^{1/2}$	V ft/s
GS–1	48	22	2.18	1.68	0.040	0.10	6.3
H1	55	35	1.57	1.35	0.055	0.10	3.7
H2	55	39	1.41	1.26	0.055	0.10	3.4
H3	50	26	1.92	1.54	0.040	0.10	5.8
H4	56	28	2.00	1.59	0.040	0.10	5.9
FR–1	obtained from water surface profiles						6.1

Figure 15–4 Sample watershed



Since the hand level sections were taken at approximately equal intervals, the velocities are averaged without weighting them with respect to length. The average velocity of all six cross sections in reach R–2 is 5.2 feet per second.

Apply equation 15–7 to determine the travel time through reach R–2:

$$T_t = \frac{(6000)}{(3600)(5.2)}$$

$$T_t = 0.32 \text{ h}$$

Part C Determine the travel time for reach R-4.

Based on the bankfull discharge and cross-sectional area obtained from water surface profiles at surveyed sections GG and HH, mean velocities of 3.6 and 3.8 feet per second, respectively were calculated. Similarly, a velocity of 6. 1 feet per second was computed from the water surface profile at the proposed site FR–1. A surveyed cross section was available at the GS–1 site, but no cross sections were surveyed upstream point of site FR–1. Instead, hand level channel cross sections (H1–H4) were made at four intermediate locations in reach R–2 and an overall gradient estimated. The data and travel times estimated using equation 15–7 for the flow segments between GS–1 and FR–1 are summarized in table 15–6 along with the velocity for each segment computed using equation 15–7 and the travel time for each segment.

The travel time from FR–1 to confluence of subareas 4 and 5 is 0.42 hours.

Part D The total travel time for subarea 1, and reaches R–2 and R–4

T_t for subarea 1	1.02 hours
T_t for reach R–2	0.32 hours
T_t for reach R–4	0.42 hours
Total	1.76 hours

Table 15–6 Field data and computed velocities and travel times for segments along reach R–4

From	To	Distance (ft)	Velocity (ft/s)	Travel time (h)
FR–1	Midway between FR–1 and HH	1200	6.1	0.05
Midway between FR–1 and HH	Midway HH and GG	2600	3.8	0.19
Midway between HH and GG	Confluence of subareas 4 and 5	2300	3.6	0.18
Total		6100		.42

630.1505 References

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Appendix 15A Other Methods for Computing Time of Concentration

This appendix includes procedures developed by users that may have application for NRCS in limited areas or special studies.

Various regression equations have been developed by various agencies that work well to estimate travel times or times of concentration for the regions used in their development. In general, these equations are for existing conditions and cannot be adapted to future condition or urbanization. These equations are included for information.

Please note that whenever possible an effort was made to maintain the form of equations as published by the author. Therefore, the various methods illustrated here may use different units.

Kirpich equation—The Kirpich (1940) equation was developed using data from seven rural watersheds in Tennessee with well-defined channels and steep slopes.

$$T_c = 0.0078\ell^{0.77}S^{-0.385} \qquad \text{(eq. 15A–1)}$$

For small watersheds in Pennsylvania, the Kirpich equation is similar, but not identical.

$$T_c = 0.0013\ell^{0.77}S^{-0.385} \qquad \text{(eq. 15A–2)}$$

where:
T_c = time of concentration, min
ℓ = length of channel from headwater to outlet, ft
S = slope of the longest hydraulic length, ft/ft

Drainage area equations—These equations taken from a 1957 version of NEH–4, were developed using small watershed data.

The following equation was developed from small watershed data in Texas:

$$T_c = 2.4A^{0.6} \qquad \text{(eq. 15A–3)}$$

The following equation was developed from small watershed data in Ohio.

$$T_c = 0.9A^{0.6} \qquad \text{(eq. 15A–4)}$$

The following equation was developed from Coshocton, Ohio, small watershed data.

$$T_c = 0.5A^{0.6} \qquad \text{(eq. 15A–5)}$$

where:
T_c = time of concentration, h
A = drainage area, mi^2

Simas equations—Simas (1996), in an analysis of 116 small agricultural watersheds, developed several regression equations for watershed lag. Lag was defined by Simas as the time between the centroid of effective rainfall and the centroid of direct runoff. Equations were modified to time of concentration using the relationship of lag = $0.6T_c$ or $T_c = 1.67$ Lag. It was found that this relationship was reasonable and consistent with information in NEH630.15.

The simplest form of the equation Simas developed is:

$$T_c = 0.0418A^{0.324} \qquad \text{(eq. 15A–6)}$$

where:
T_c = time of concentration, h
A = the drainage area, acre

The statistically most significant equation Simas developed is:

$$T_c = 0.0085W^{0.594}S^{-0.1505}S_{nat}^{0.3131} \qquad \text{(eq. 15A–7)}$$

where:
T_c = time of concentration, h
W = watershed width, ft (area ft^2/length ft)
S = average watershed slope, ft/ft
S_{nat} = watershed storage and is a function of curve number

where:
S_{nat} = (1000/CN)–10

Sheridan equation—Sheridan (1994) performed a study on nine flatland watersheds located in Georgia and Florida. A regression analysis was performed using many basin characteristics to determine a timing equation. However, it was found that the main channel length was the overwhelming characteristic that correlated with the timing parameter. Therefore, an equation was developed based solely on main channel length to estimate the time of concentration. The equation had a correlation coefficient (R^2) of 96 percent.

$$T_c = 2.20\ell^{.92} \qquad \text{(eq. 15A–8)}$$

where:
T_c = time of concentration, h
ℓ = main channel length, km

Folmar and Miller equation—Folmar and Miller (2000) developed an equation for lag time from 54 watersheds throughout the country. Lag was measured from the centroid of excess precipitation to the peak of the hydrograph. Watersheds ranged in size from approximately 3 acres to 20 square miles. Similar to what was determined by Sheridan (1994), it was found that only the longest hydraulic length as determined by comparing travel time was needed to determine an estimate of lag time, and that the watershed slope and curve number were not needed to estimate lag time. The developed equation had an R^2 value of 85 percent.

$$T_l = \frac{\ell^{0.63}}{141} \qquad \text{(eq. 15A–9)}$$

where:
T_l = lag time, h
ℓ = longest hydraulic length, ft

Papadakis and Kazan—Papadakis and Kazan (1986), from the University of Cincinnati, developed regression equations using data from 84 small ARS watersheds across the United States.

$$T_c = 0.66L^{0.5}n^{0.52}S^{-0.31}i^{-.38} \qquad \text{(eq. 15A–10)}$$

where:
T_c = time of concentration, min
L = length of the longest waterway, ft
S = slope of the flow path, %
i = intensity of the rainfall excess, in/h
n = roughness coefficient (Manning's n value for channel)

Appendix 15B Shallow Concentrated Flow Alternatives

Professional notes from G. Cerrelli (1990) developed a set of curves (fig. 15B–1) to supplement the shallow concentrated flow curves which appeared in Technical Release No. 55 (fig. 15B–2). These curves were developed using the concepts in Technical Paper 61, Handbook of Channel Design for Soil and Water Conservation. The following assumptions were used by Cerrelli to develop the curves.

Cerelli used the assumptions in table 15B–1 with the nV versus n curves from TP–61 on a trial and error basis to determine a relationship of V versus slope. For paved and row crop conventional tillage, Cerelli used Manning's equation to determine a V versus slope curve.

The procedures in Agricultural Handbook 667, Stability Design of Grass-Lined Open Channels can be used to estimate shallow concentrated flow velocities for very unique conditions.

The shallow concentrated flow curves shown in figure 15B–2 are an adaptation of figure 15–2 and appeared in the 1986 TR–55. For urban areas, it was assumed that in a majority of the cases, shallow concentrated flow would occur either in paved areas on in grassed areas.

Table 15B–1 Assumptions used by Cerelli to develop shallow concentrated flow curves

Cover type	Flow shape	Width (ft)	Depth (ft)	Retardance	n value
Wide swale—lawn/mature woods	Parabolic	10	0.4	D	
Wide swale—high grass/brushy	Parabolic	10	0.4	C	
Row crops—no till	Parabolic	3	0.1	E	
Row crops—conventional tillage/bare gully	Parabolic	1	0.25		0.025
Paved	Parabolic	4	.35		0.014

Figure 15B–1 Cerelli's shallow concentrated flow curves

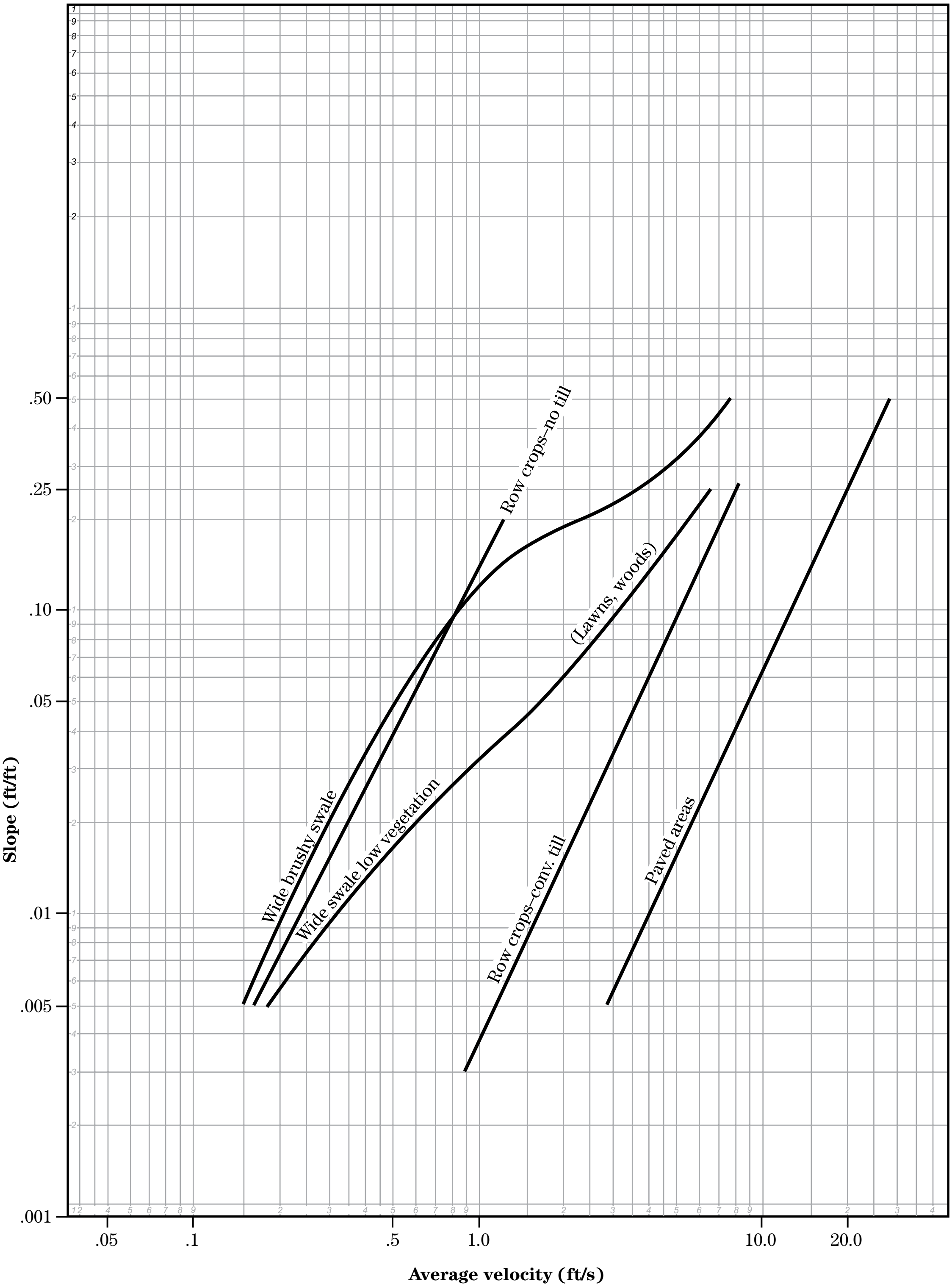
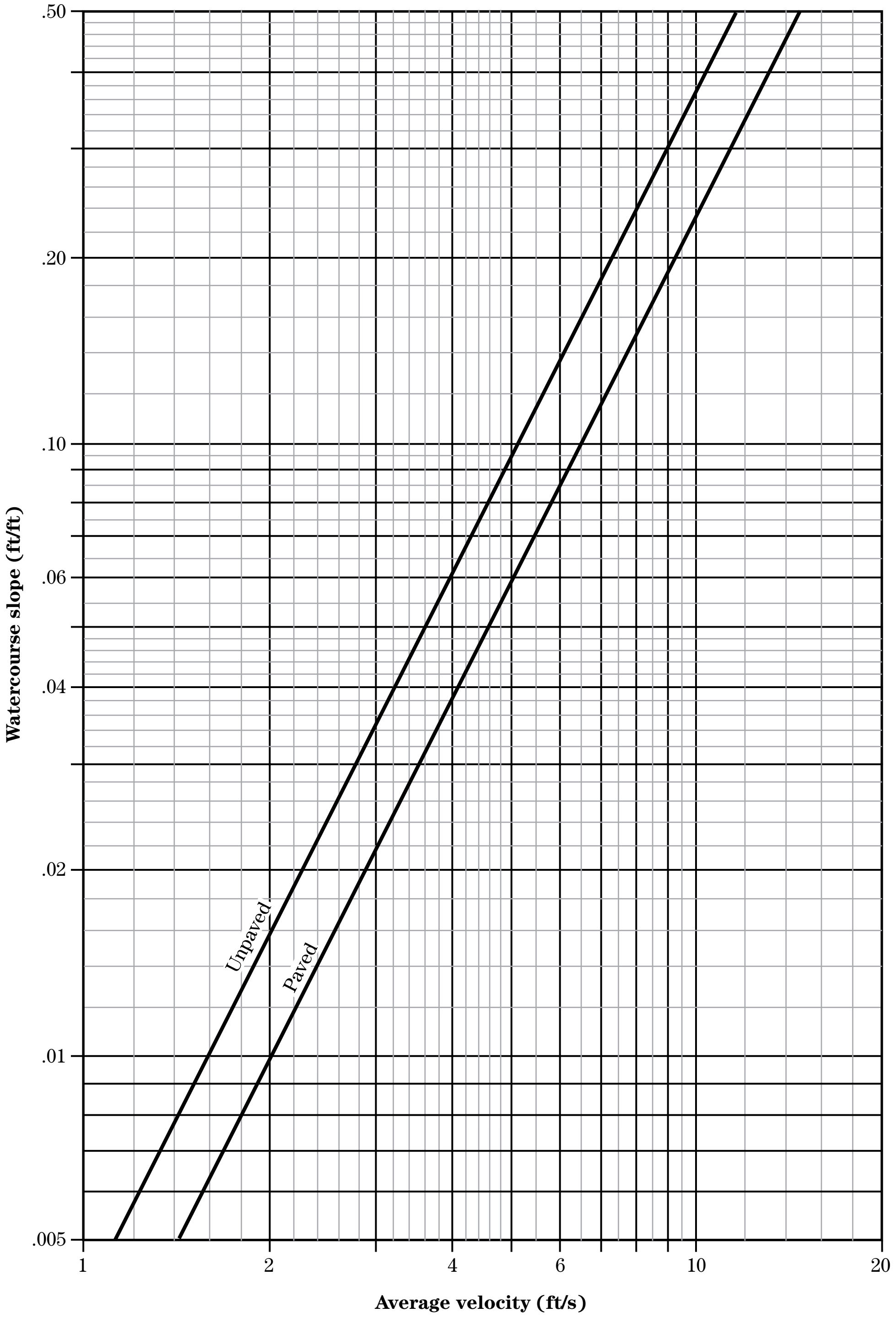


Figure 15B–2 TR–55 shallow concentrated flow curves



Appendix 15C Types of Flow

Water exists in a watershed system as a shapeless mass occurring in varying combinations of surface runoff, interflow, and ground water flow. These components are characterized by the path water takes from where it is generated to the point of reference downstream. Figure 15C–1 shows four types of flow that may occur singly or in combination throughout a watershed.

Surface flow—Travel from point 1 to point 2 in figure 15C–1 is along the surface of the watershed. This is surface runoff (NEH630.10). The flow takes place as sheet flow, shallow concentrated flow or channel flow.

Surface flow with transmission losses—Water traveling toward the watershed outlet is infiltrated into channel material. This type is common in arid, semiarid and subhumid, and in karst areas. The distance from point 3 to point 4 in figure 15C–1 will depend on the amount of runoff, the moisture characteristics of soil, topography, and on hydraulic features of the flow.

Interflow or quick return flow—Water infiltrated at point 5 in figure 15C–1 eventually returns to the surface at point 6, continuing as surface flow to point 7. This flow reappears rapidly in comparison to baseflow and is generally much in excess of normal baseflow. It is common in humid climates and in watersheds with soils of high infiltration capacities and moderate to steep slopes.

Baseflow—Rainfall entering at point 8 in figure 15C–1 goes directly to the ground water table, eventually entering a stream at point 9. This type of flow has little effect on flood peaks in small watersheds. However, if it is a factor, it is usually added to the base of the hydrograph.

On figure 15C–1, flows from points 1 to 2, 3 to 4, and 6 to 7 can be measured directly. Flow from points 5 to 6 and 8 to 9 are usually determined indirectly by storms and hydrograph analyses or by field observation of rainfall and runoff. The distance from point 3 to 4 in figure 15C–1 will depend on the amount and rate of runoff, moisture condition in the soil, topography and hydraulic features of the flow. Ground water movement is determined indirectly by analyses of precipitation, soil moisture movements, and evapotranspiration.

Figure 15C–1 Types of flow