

CHAPTER 2

HYDROLOGY

2.6 SCS Unit Hydrograph

2.6.1 Introduction

The Soil Conservation Service (SCS) hydrologic method requires basic data similar to the Rational Method: drainage area, a runoff factor, time of concentration, and rainfall. The SCS approach, however, is more sophisticated in that it also considers the time distribution of the rainfall, the initial rainfall losses to interception and depression storage, and an infiltration rate that decreases during the course of a storm. Details of the methodology can be found in the SCS National Engineering Handbook, Section 4.

The SCS method includes the following basic steps:

- 2.6.1.1 Determination of curve numbers which represent different land uses within the drainage area.
- 2.6.1.2 Calculation of time of concentration to the study point.
- 2.6.1.3 Using the Type II rainfall distribution, total and excess rainfall amounts are determined.
- 2.6.1.4 Using the unit hydrograph approach, triangular and composite hydrographs are developed for the drainage area.

2.6.2 Equations And Concepts

The following discussion outlines the equations and basic concepts used.

Drainage Area – The drainage area of a watershed is determined from topographic maps and field surveys. For large drainage areas it might be necessary to divide the area into sub-drainage areas to account for major land use changes, obtain analysis results at different points within the drainage area, and route flows to points of interest.

Rainfall – The SCS method applicable to the City of Lawrenceville is based on a storm event, which has a Type II time distribution. Figure 2.6.2-1 shows this distribution. To use this distribution it is necessary for the user to obtain the 24-hour rainfall volume (P_{24} in Figure 2.6.2-1) from Table 2-3 (multiply 24 hours times the table value in in./hr) for the frequency of the design storm. This volume is then distributed according to Figure 2.6.2-1

Rainfall-Runoff Equation – A relationship between accumulated rainfall and accumulated runoff was derived by SCS from experimental plots for numerous soils and vegetative cover conditions. The following SCS runoff equation is used to estimate direct runoff from 24-hour or 1-day storm rainfall. The equation is:

$$Q = (P - I_a)^2 / (P - I_a) + S \quad \text{(Eq 2.6.2-1)}$$

Where: Q= accumulated direct runoff (in.)
P= cumulated rainfall (potential maximum runoff) (in.)
I_a= initial abstraction including surface storage, interception, and infiltration prior to runoff (in.)
S= potential maximum soil retention (in.)

The empirical relationship used in the SCS method for estimating I_a is:

$$I_a = 0.2S \quad \text{(Eq 2.6.2-2)}$$

Substituting 0.2S for I_a in equation 2.6.2-1, the equation becomes:

$$Q = (P - 0.2S)^2 / (P + 0.8S) \quad \text{(Eq 2.6.2-3)}$$

Where: S = (1000/CN) – 10 and CN = SCS curve number

Figure 2.6.2-2 shows a graphical solution of this equation. For example, 4.1 inches of direct runoff would result if 5.8 inches of rainfall occurs on a watershed with a curve number of 85.

Table 2.6.2-1

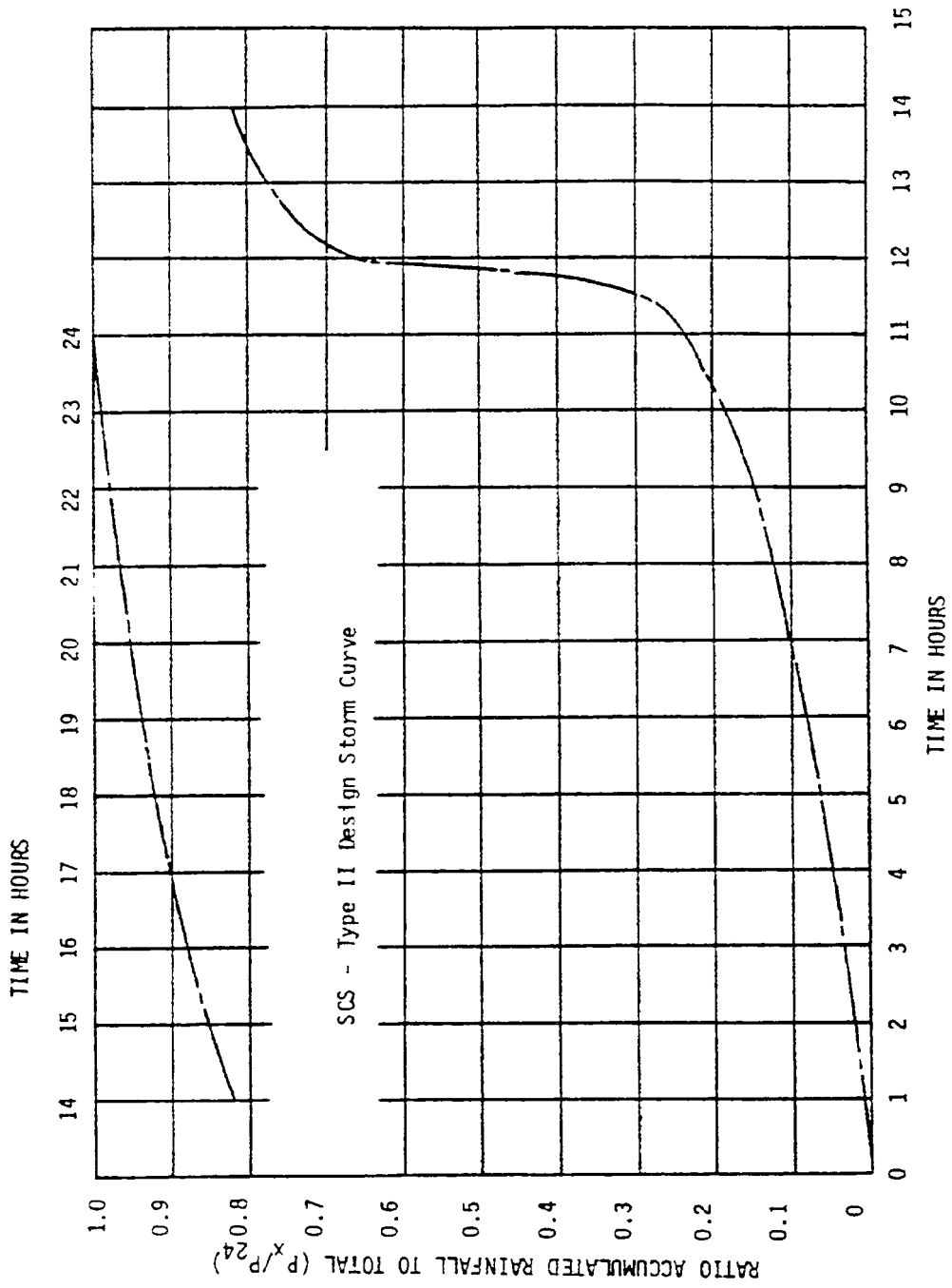
Hydrologic Soils Groups for the City of Lawrenceville

<u>Series Name</u>	<u>Hydrologic Group</u>	<u>Series Name</u>	<u>Hydrologic Group</u>
Altavista	C	Louisa	B
Appling	B	Louisburg	B
Augusta	C	Madison	B
Buncombe	A	Musella	B
Cecil	B	Pacolet	B
Chewacla	C	Red Bay	B
Congaree	B	Wedowee	B
Davidson	B	Wehadkee	D
Durham	B	Wickham	B
Gwinnett	B	Wilkes	C
Helena	C	Worsham	D
Iredell	C/D		

Note: C/D indicates the drained/undrained situation.

Figure 2-6.2-1

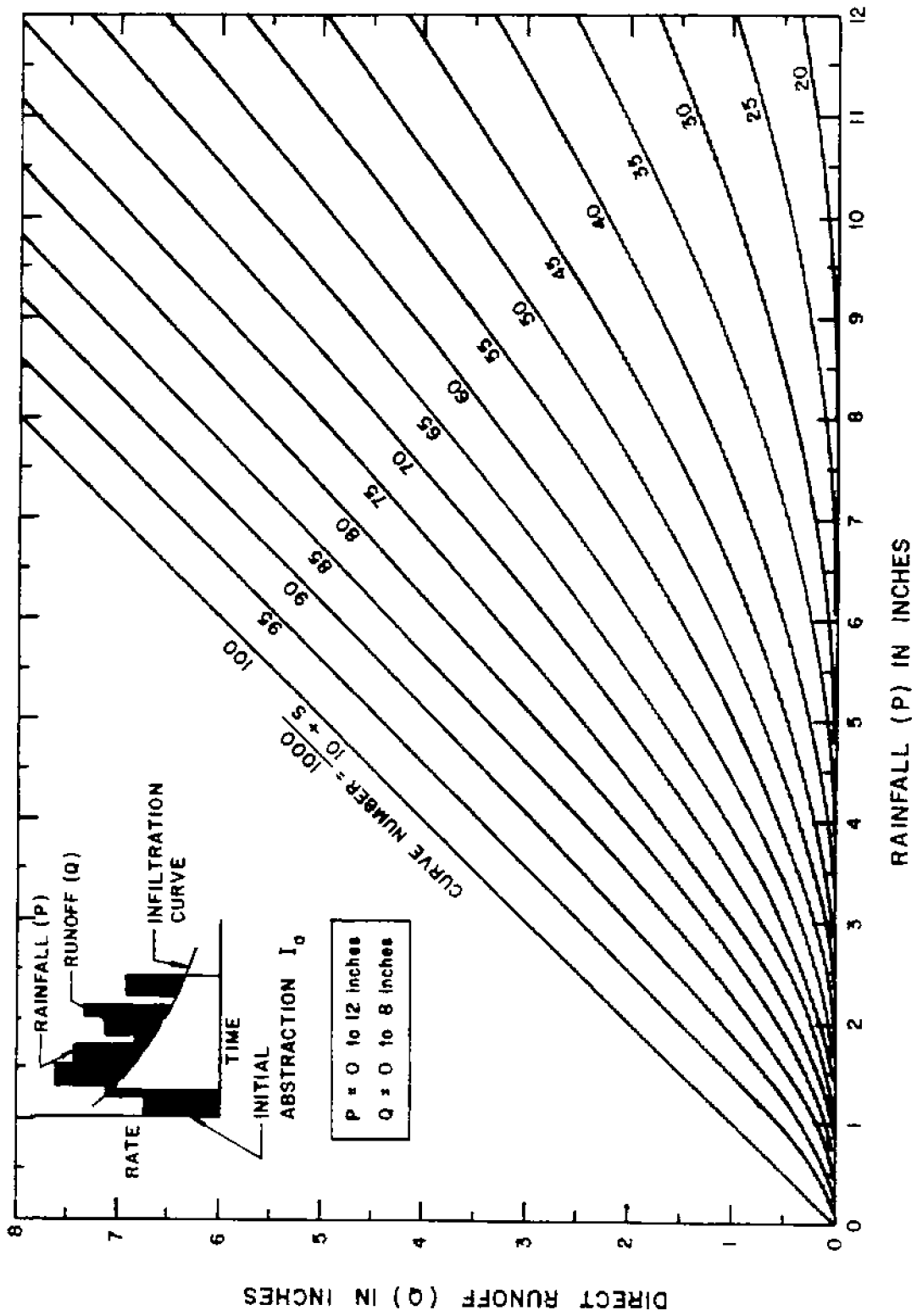
SCS Type II Design Storm Curve



Source: SCS-TP-149

Figure 2-6.2-2

SCS Solution Of The Runoff Equation



**Table 2.6.2-1
Runoff Curve Numbers¹**

Cover description		Curve numbers for hydrologic soil groups			
Cover type and hydrologic condition	Average percent Impervious area ²	A	B	C	D
Cultivated land:					
	without conservation treatment	72	81	88	91
	with conservation treatment	62	71	78	81
Pasture or range land:					
	poor condition	68	79	86	89
	good condition	39	61	74	80
Meadow:					
	good condition	30	58	71	78
Wood or forest land:					
	thin stand, poor cover	45	66	77	83
	good cover	25	55	70	77
Open space (lawns, parks, golf courses, cemeteries, etc.) ³ :					
	Poor condition (grass cover <50%)	68	79	86	89
	Fair condition (grass cover 50% to 75%)	49	69	79	84
	Good condition (grass cover >75%)	39	61	74	80
Impervious areas:					
	Paved parking lots, roofs, driveways, etc. (excluding right-of-way)	98	98	98	98
Streets and roads:					
	Paved; curbs and storm drains (excluding right-of-way)	98	98	98	98
	Paved; open ditches (including right-of-way)	83	89	92	93
	Gravel (including right-of-way)	76	85	89	91
	Dirt (including right-of-way)	72	82	87	89
Urban districts:					
	Commercial and business	85%	89	92	94
	Industrial	72%	81	88	91
Residential districts by average lot size:					
	1/8 acre or less (town houses)	65%	77	85	90
	1/4 acre	38%	61	75	83
	1/3 acre	30%	57	72	81
	1/2 acre	25%	54	70	80
	1 acre	20%	51	68	79
	2 acres	12%	46	65	77
Developing urban areas and newly graded areas (previous areas only, no vegetation)		77	86	91	94

¹Average runoff condition, and $I_a = 0.2S$

²The average percent impervious area shown was used to develop the composite CNs. Other assumptions are as follows: impervious areas are directly connected to the drainage system, impervious areas have a CN of 98, and pervious areas are considered equivalent to open space in good hydrologic condition. If the impervious area is not connected, the SCS method has an adjustment to reduce the effect.

³CNs shown are equivalent to those of pasture. Composite CNs may be computed for other combinations of open space cover type.

Table 2.6.2-1 gives recommended curve number values for a range of different land uses.

2.6.3 Runoff Factor

The principal physical watershed characteristics affecting the relationship between rainfall and runoff are land use, land treatment, soil type, and land slope. The SCS method uses a combination of soil conditions and land uses (ground cover) to assign a runoff factor to an area. These runoff factors, called runoff curve number (CN), indicate the runoff potential of an area. The higher the CN, the higher is the runoff potential. Soil properties influence the relationship between runoff and rainfall since soils have differing rates of infiltration. Based on infiltration rates, the Soil Conservation Service (SCS) has divided soils into four hydrologic soil groups.

- Group A Soils having a low runoff potential due to high infiltration rates. These soils consist primarily of deep, well-drained sands and gravels.

- Group B Soils having a moderately low runoff potential due to moderate infiltration rates. These soils consist primarily of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures.

- Group C Soils having a moderately high runoff potential due to slow infiltration rates. These soils consist primarily of soils in which a layer exists near the surface that impedes the downward movement of water or soils with moderately fine to fine texture.

- Group D Soils having a high runoff potential due to very slow infiltration rates. These soils consist primarily of clays with high swelling potential, soils with permanently high water tables, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious parent material.

A list of soils for the City of Lawrenceville and their hydrologic classification is presented in Table 2.6.2-1. Soil Survey maps can be obtained from local SCS offices.

Consideration should be given to the effects of urbanization on the natural hydrologic soil group. If heavy equipment can be expected to compact the soil during construction or if grading will mix the surface and subsurface and subsurface soils, appropriate changes should be made in the soil group selected. Also runoff curve numbers vary with the antecedent soil moisture conditions. Average antecedent soil moisture conditions (AMC II) are recommended for hydrologic analysis, except in the design of state regulated Category I dams where AMC III may be required.

2.6.4 Urban Modifications

Several factors, such as the percentage of impervious areas and the means of conveying runoff from impervious areas to the drainage system, should be considered in computing CN for urban areas. For example, do the impervious areas connect directly to the drainage system, or do they outlet onto lawns or other pervious areas where infiltration can occur?

The curve number values given in Table 2.6.2-1 are based on directly connected impervious area. An impervious area is considered directly connected if runoff from it flows directly into the drainage system. It is also considered directly connected if runoff from it occurs as concentrated shallow flow that runs over a pervious area and then into a drainage system. It is possible that curve number values from urban areas could be reduced by not directly connecting impervious surfaces to the drainage system. For a discussion of impervious areas and their effect on curve number values see Section 2.11.

2.6.5 Travel Time Estimation

Travel time (T_t) is the time it takes water to travel from one location to another within a watershed, through the various components of the drainage system. Time of concentration (T_c) is computed by summing all the travel times for consecutive components of the drainage conveyance system from the hydraulically most distant point of the watershed to the point of interest within the watershed. Following is a discussion of related procedures and equations (TR-55, 1986).

2.6.5.1 Travel Time

Water moves through a watershed as sheet flow, shallow concentrated flow open channel flow, or some combination of these. The type that occurs is a function of the conveyance system and is best determined by field inspection.

Travel time is the ratio of flow length to flow velocity:

$$T_t = L / 3600V \quad (\text{Eq 2.6.5.1-1})$$

Where: T_t = travel time (hr)

L = flow length (ft)

V = average velocity (ft/s)

3600 = conversion factor from seconds to hours

2.6.5.2 Sheet Flow

Sheet flow can be calculated using the following formulas:

$$T_t = \left[0.42 (nL)^{0.8} / (P_2)^{0.5} (S)^{0.4} \right] \quad (\text{Eq 2.6.5.2.1})$$

Where: T_t = travel time (min),
 n = Manning roughness coefficient (see Table 2.6.5.2-1)

L = flow length (ft),

P_2 = 2-year, 24-hour rainfall = 3.84 in, and

S = slope of hydraulic grade line (land slope ft/ft).

Table 2.6.5.2-1

Roughness Coefficients (Manning's n) for Sheet Flow¹

<u>Surface Description</u>	<u>n</u>
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

¹The n values are a composite of information by Engman (1986).

²Includes species such as weeping lovegrass, bluegrass, buffalo grass, blue grama grass, and native grass mixtures.

³When 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.

Source: SCS, TR-55, Second Edition, June 1986.

Substituting the constant rainfall amount the travel time equation becomes:

$$T_t = [0.214(nL)^{0.8}] / (S)^{0.4} \quad \text{(Eq 2.6.5.2-2)}$$

2.6.5.3 Shallow Concentrated Flow

After a maximum of 300 feet (100 feet in urban areas), sheet flow usually becomes shallow concentrated flow. The average velocity for this flow can be determined from Figure 2.6.5.4-1, in which average velocity is a function of water course slope and type of channel.

Average velocities for estimating travel time for shallow concentrated flow can be computed from using Figure 2.6.5.4-1, or the following equations. These equations can also be used for slopes less than 0.005 ft/ft.

$$\text{Unpaved} \quad V = 16.1345(S)^{0.5} \quad \text{(Eq 2.6.5.3-1)}$$

$$\text{Paved} \quad V = 20.3282(S)^{0.5} \quad \text{(Eq 2.6.5.3-2)}$$

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 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.

After determining average velocity using Figure 2.6.5.4-1 or equations 2.6.5.3-1 or 2.6.5.3-2, use equation 2.6.5.1-1 to estimate travel time for the shallow concentrated flow segment.

2.6.5.4 Open Channels

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

Manning's equation is

$$V = [1.49(r)^{2/3} (s)^{1/2}] / n \quad (\text{Eq 2.6.5.4-1})$$

Where: V = average velocity (ft/ft)

r = hydraulic radius (ft) and is equal to a/p_w

a = cross sectional flow area (ft²)

P_w = wetted perimeter (ft)

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

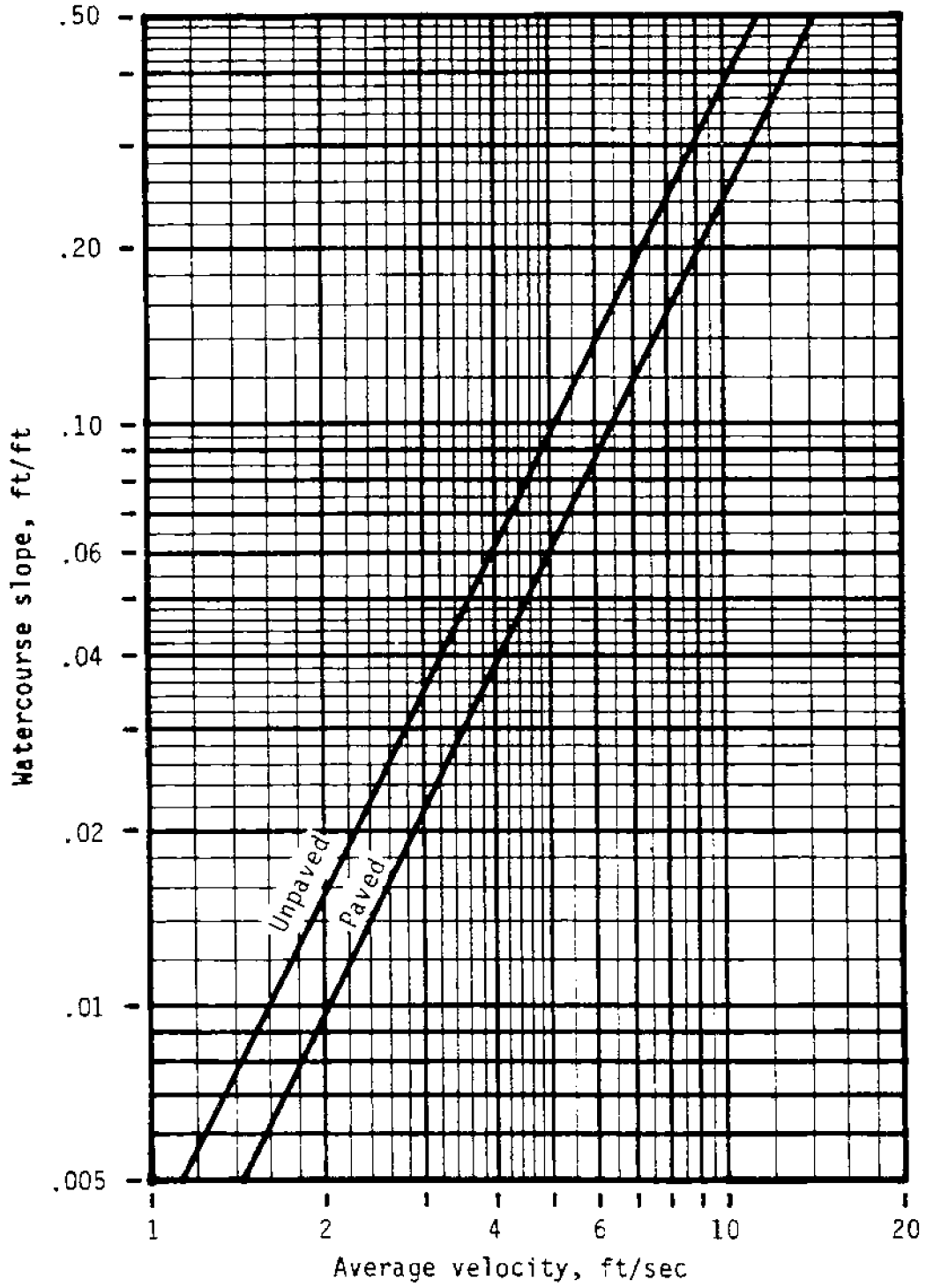
n = Manning's roughness coefficient for open channel flow

After average velocity is computed using equation 2.6.5.4-1, T_t for the channel segment can be estimated using equation 2.6.5.1-1.

Velocity in channels should be calculated from the Manning equation. Cross sections from all channels that have been field checked should be used in the calculations. This is particularly true of areas below dams or other flow control structures.

Figure 2.6.5.4-1

Average Velocities – Shallow Concentrated Flow



2.6.5.5 Limitations

- Equations in this section should not be used for sheet flow longer than 300 feet (100 feet in urban areas).
- In watersheds with storm sewers, carefully identify the appropriate hydraulic flow path to estimate T_c .
- A culvert or bridge can act as a reservoir outlet if there is significant storage, protected by recorded easements, behind it. Detailed storage routing procedures should be used to determine the outflow through the culvert.

2.6.6 Triangular Hydrograph Equation

The triangular hydrograph is a practical representation of excess runoff with only one rise, one peak, and one recession. Its geometric makeup can be easily described mathematically, which makes it very useful in the process of estimating discharge rates, and produces results that are sufficiently accurate for most drainage facility designs. The SCS developed the following equation to estimate the peak rate of discharge for an increment of runoff:

$$qp = (484 A(q)) / (d / 2 + TL) \quad (2.16)$$

Where: q_p = peak rate of discharge (cfs)

A = area (mi^2)

q = storm runoff volume during time interval (in.)
(obtained from equation 2.3)

d = rainfall time increment

T_L = watershed lag time ($T_L = 0.6 T_c$) (hr)

T_p = time to peak ($d/2 + T_L$) (hr)

T_b = time of base ($2.67T_p$) (hr)

The hydrographs from each time increment are summed to obtain the entire hydrograph.

END OF SECTION 2.6