CHAPTER 5

Engineering Calculations

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ENGINEERING CALCULATIONS

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CHAPTER 5

ENGINEERING CALCULATIONS

This chapter is intended to provide site planners and plan reviewers with basic engineering calculation procedures needed to design or evaluate erosion and sediment control and stormwater management structures and systems. The chapter is divided into three parts:

Part I - Estimating Runoff: An attempt is made to standardize the methods used to calculate runoff from a site or watershed. Criteria for selecting an appropriate calculation method are presented along with step-by-step procedures for using three different methods.

Part II - Stormwater Detention: The subject of flood routing is introduced, and a simplified procedure for sizing small, single-stage detention basins is presented.

Part III - Open Channel Flow: This part contains step-by-step procedures for designing new stormwater conveyance channels and for determining the capacity and stability of existing natural channels by using the Manning and Continuity Equations.

Use of the calculation methods outlined in this chapter is not mandated under the state program. Plan-approving authorities may use their discretion to require or accept any calculation method which they feel will best accomplish the desired objective under local conditions.

These engineering procedures are simplified primarily for the benefit of local officials without extensive engineering training who must review erosion and sediment control plans and check design adequacy. These procedures are not recommended for use by non-professionals to design permanent drainage systems or structures.

PART 1

ESTIMATING RUNOFF

Selecting a Calculation Method

Selection of the appropriate method of calculating runoff should be based upon the size of the drainage area and the output information required. Table 5-1 lists acceptable calculation methods for different drainage areas and output requirements. The plan approving authority may require or accept other calculation methods deemed more appropriate for local conditions.

TABLE 5-1

RUNOFF CALCULATION METHODS: SELECTION CRITERIA

Calculation Methods*

1. Rational Method
2. Peak Discharge Method
3. Tabular Method (TR-55)
4. Unit Hydrograph Method

Output Requirements	Drainage Area	Appropriate Calculation Methods
Peak Discharge only	up to 200 acres up to 2000 acres up to 20 sq. mi.	1, 2, 3, 4 2, 3, 4 3, 4
Peak Discharge and Total Runoff Volume	up to 2000 acres up to 20 sq. mi.	2, 3, 4 3, 4
Runoff Hydrograph	up to 20 sq. mi.	3, 4

* The Rational, Graphical Peak Discharge and Tabular methods of runoff determination are described in this chapter. The Unit Hydrograph method is described in the SCS National Engineering Handbook, Section 4, Hydrology.

RATIONAL METHOD

The rational formula is the most commonly used method of determining peak discharge from small drainage areas. This method is traditionally used to size storm sewers, channels, and other drainage structures which handle runoff from drainage areas less than 200 acres. This method is not recommended for routing stormwater through a basin or for developing a runoff hydrograph.

LIMITATIONS THAT AFFECT ACCURACY

(A) Drainage basin characteristics should be fairly homogeneous, otherwise another method should be selected.

(B) The method is less accurate for larger areas and is not recommended for use with drainage areas larger than 200 acres.

(C) The method becomes more accurate as the amount of impervious surface increases.

(D) For this method, it is assumed that a rainfall duration equal to the time of concentration results in the greatest peak discharge.

The rational formula is:

$$Q = CiA$$

where,

Q	=	Peak rate of runoff in cubic feet per second
C	=	Runoff coefficient, an empirical coefficient representing a relationship between rainfall and runoff
i	=	Average intensity of rainfall for the time of concentration (T_c) for a selected design storm
A	=	Drainage area in acres.

The rational method is based on empirical data and hypothetical rainfall-runoff events which are assumed to model natural storm events. During an actual storm event, the peak discharge is dependent on many factors including antecedent moisture conditions; rainfall magnitude, intensity, duration, and distribution; and, the effects of infiltration, detention, retention, and flow routing throughout the watershed.

The accuracy of the rational method is highly dependent upon the judgement and experience of the user. The method's simplicity belies the complexity in predicting a watershed's response to a rainfall event, especially when the rational method is used to predict post-development runoff. For that purpose, the user must select the appropriate runoff coefficient(s) and determine the time of concentration based on plan information (including proposed hydrologic changes) and experience in working with development and its effects on hydrology.

Runoff Coefficients

The engineer must use judgement in selecting the appropriate runoff coefficient within the range of values for the landuse. Generally, areas with permeable soils, flat slopes and dense vegetation should have the lowest values. Areas with dense soils, moderate to steep slopes, and sparse vegetation should be assigned the highest values.

Time of Concentration

Time of concentration is the time required for runoff to flow from the most hydraulically remote part of the drainage area to the point under consideration. The path that the runoff follows is called the hydraulic length or flow path. As the runoff moves down the flow path, the flow is characterized into flow types or flow regimes.

The three types of flow (or flow regimes) are presented below:

> **Overland flow** (or sheet flow) is shallow flow (usually less than one inch deep) over plane surfaces. For purposes of determining time of concentration, overland flow usually exists in the upper reaches of the hydraulic flow path. The recommended maximum length for this type of flow is 300 feet; however, many engineers agree that overland flow should be limited to 200 feet or less. The actual length of overland flow varies considerably according to actual field conditions. The length of overland flow should be verified by field investigation, if possible.
>
> **Shallow concentrated flow** usually begins where overland flow converges to form small rills or gullies and swales. Shallow concentrated flow can exist in small, man-made drainage ditches (paved and unpaved) and in curb and gutters. The recommended maximum length for shallow concentrated flow is 1000 feet.
>
> **Channel flow** occurs where flow converges in gullies, ditches, and natural or man-made water conveyances (including pipes not running full). Channel flow is assumed to exist in perennial streams or wherever there is a well-defined channel cross-section.

Calculation of Time of Concentration

Time of concentration equals the summation of the travel times for each flow regime. There are numerous methods used to calculate the travel time for each of the flow regimes. The following procedure outlines three methods for determining overland or sheet flow. These methods are: (1) Seelye method; (2) kinematic wave; (3) SCS-TR-55. The user must select the appropriate method for the site. A comprehensive discussion of each of these methods is beyond the scope of this handbook; the reader should consult other sources, such as SCS-TR-55, for more information. (See the reference section for a listing of other sources.)

General Procedure for the Rational Method

The general procedure for determining peak discharge using the rational method is as follows:

Step 1 - Determine the drainage area (in acres). Use survey information, USGS Quadrangle sheets, etc.

Step 2 - Determine the runoff coefficient (C) for the drainage area. Table 5-2 presents a range of runoff coefficient values for various landuses. If the landuse and soil cover are homogeneous for the entire drainage area, a runoff coefficient value can be determined directly from Table 5-2. If there are multiple landuses or soil conditions, a weighted average must be calculated as follows:

Weighted Average "C" = (area landuse$_1$) x "C" = CA_1
(area landuse$_2$) x "C" = CA_2
[continue for each landuse]
Total Area Total CA

$$= \frac{\text{Total CA}}{\text{Total Area}}$$

Step 3 - Determine the hydraulic length or flow path that will be used to determine the time of concentration. Also, determine the types of flow (or flow regimes) that occur along the flow path.

Step 4 - Determine the time of concentration (T_c) for the drainage area.

(A) Overland Flow L_o

The travel time for overland flow may be determined by using the following methods as appropriate. If the ground cover conditions are not homogenous for the entire overland flow path, determine the travel time for each ground cover condition separately and add the travel times to get overland flow travel time. Do not use an average ground cover condition. **Note: the hydraulic length for overland flow should be determined for each site. Do not assume that the length of overland flow equals the maximum recommended length.**

(a) Seelye Method: Travel time for overland flow can be determined by using the Seelye chart (Plate 5-1). This method is perhaps the simplest and is most commonly used for small developments where a greater margin of error is acceptable.

Determine the length of overland flow and enter the nomograph on the left axis, "Length of Strip." Intersect the "Character of Ground" to determine the turn point on the "Pivot" line. Intersect the "Percent of slope" and read the travel time for overland flow.

(b) Kinematic Wave Method: This method allows for the input of rainfall intensity values, thereby providing the specific overland flow travel time for the selected design storm. The equation is:

$$T_t = \frac{(0.93)\ L^{0.6}\ n^{0.6}}{i^{0.4}\ S^{0.3}}$$

where,

L = length of overland flow in feet
n = Manning's roughness coefficient (from Table 5-3)
i = rainfall intensity (from Plates 5-4 to 5-18)
S = slope in feet/foot

Since the equation contains two unknown variables (travel time and rainfall intensity), a trial and error process is used to determine the overland flow time. First, assume a rainfall intensity value (from Plates 5-4 to 5-18) or use the Seelye chart for an approximate duration value) and solve the equation for travel time (T_t). Next, compare the assumed rainfall intensity value with the rainfall intensity value (from Plates 5-4 to 5-18) that corresponds with the travel time. If the assumed rainfall intensity value equals the corresponding rainfall intensity value, the process is complete. If not, adjust the assumed rainfall intensity value accordingly and repeat the procedure until the assumed value compares favorably with the corresponding rainfall intensity value. (See the VDOT Drainage Manual for more details.)

(c) SCS-TR-55 method: [See the Graphical Peak Discharge section or the SCS-TR-55 Manual for details.]

(B) Shallow Concentrated Flow L_{sc}
Determine the velocity of the flow by using Plate 5-2. Then calculate the travel time by the following equation:

$$Tt(\text{minutes}) = \frac{L}{60\ V}$$

where,

L = length of shallow concentrated flow in feet
V = velocity (in feet per second, from Plate 5-2)

Note: The calculation of shallow concentrated flow time is frequently not included when using the rational method. However, the procedure is included in this text for consistency with other runoff methods.

(C) <u>Channel Flow</u> L_c

For small drainage basins, Plate 5-3 can be used to calculate the travel time for the channel flow portion of the flow path.

For larger drainage areas, Manning's Equation is the preferable method for calculating channel flow. The following procedure is used:

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

where,

V = average velocity (ft/s)
r = hydraulic radius (ft); $r = a/p_w$
a = cross sectional flow area (ft^2)
p_w = wetted perimeter (ft)
s = slope of the grade line (channel slope, ft/ft)
n = Manning's roughness coefficient.

Calculate the velocity (V), then calculate the travel time by using the following equation:

$$T_{t(minutes)} = \frac{L}{60\ V}$$

where,

L = Length of channel flow in feet
V = Velocity in feet per second

[For more information on use of the Manning Equation, see Part III, Open Channel Flow.]

Step 4 - Add all of the travel times to get the time of concentration (T_c) for the entire hydraulic length or flow path.

Step 5 - Determine the Rainfall Intensity Factor (i) for the selected design storm by using the Rainfall Intensity charts (Plates 5-4 to 5-18). Select the chart for the locality closest to project. Enter the "Duration" axis of the chart with the time of concentration (T_c). Move vertically to intersect the curve of the appropriate design storm, then move horizontally to read the Rainfall Intensity Factor (i) in inches per hour.

Step 6 - Determine the peak discharge (Q) in cubic feet per second by multiplying the runoff coefficient (or weighted average) (C), the rainfall intensity (i), and the drainage area (A):

$$Q = CiA$$

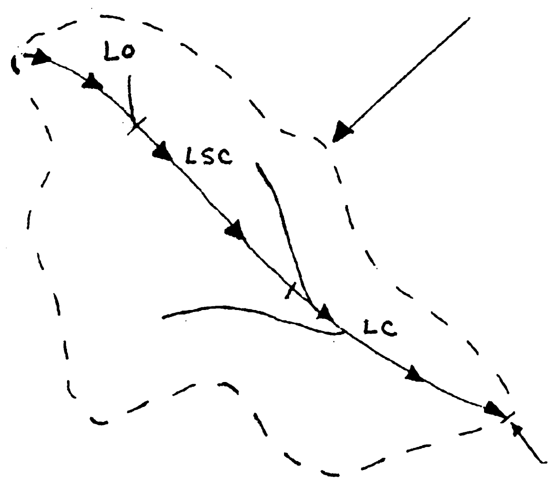
Example 5-1

A project is to be built in southwest Campbell County, Virginia. The following information was determined from field measurement and/or proposed design data:

Drainage Area: 80 acres

30% - Rooftops (24 acres)
10% - Streets and driveways (8 acres)
20% - Average lawns @ 5% slope on sandy soil (16 acres)
40% - Woodland (32 acres)

Watershed = 80 acres at the design point



Design Point

L_o = 200 ft. (4% slope or 0.04 ft./ft.); average grass lawn.

L_{sc} = 1000 ft. (4% slope or 0.04 ft./ft.); paved ditch.

L_c = 2000 ft. (1% slope or 0.01 ft./ft.); stream channel.

Find: Peak runoff rate from the 2-year frequency storm.

Solution:

1. Drainage Area (A) = 80 acres (given).

2. Determine runoff coefficient (C):

Calculate Weighted Average

	Area	x	C (Table 5-2)		
Rooftops	24	x	0.9	=	21.6
Streets	8	x	0.9	=	7.2
Lawns	16	x	0.15	=	2.4
Woodland	32	x	0.10	=	3.2
	80				34.4

$$C = \frac{34.4}{80} = 0.43$$

3. Determine the Time of Concentration (T_c) to the Design Point:

A. Overland flow (L_o)

Using Plate 5-1, T_t = 15 minutes

B. Shallow concentrated flow (L_{sc})

Using Plate 5-2 and the equation, $T_t = \frac{L}{60V}$

1000 ft. length, paved ditch, 4% slope (.04 ft./ft.);
V = 4 fps (from Plate 5-2)

$$L_{sc} = \frac{1100}{60(4)} = 4.2 \text{ minutes}$$

C. Channel Flow (L_c)

Using Plate 5-3:

2000 ft. length and 1% slope (.01 ft./ft.)

(2000) (.01) = 20 ft. height of most remote point of channel above outlet.

L_c = 16 minutes.

4. Add all the travel times to get T_c.

$$15 + 4.2 + 16 = 35.2$$

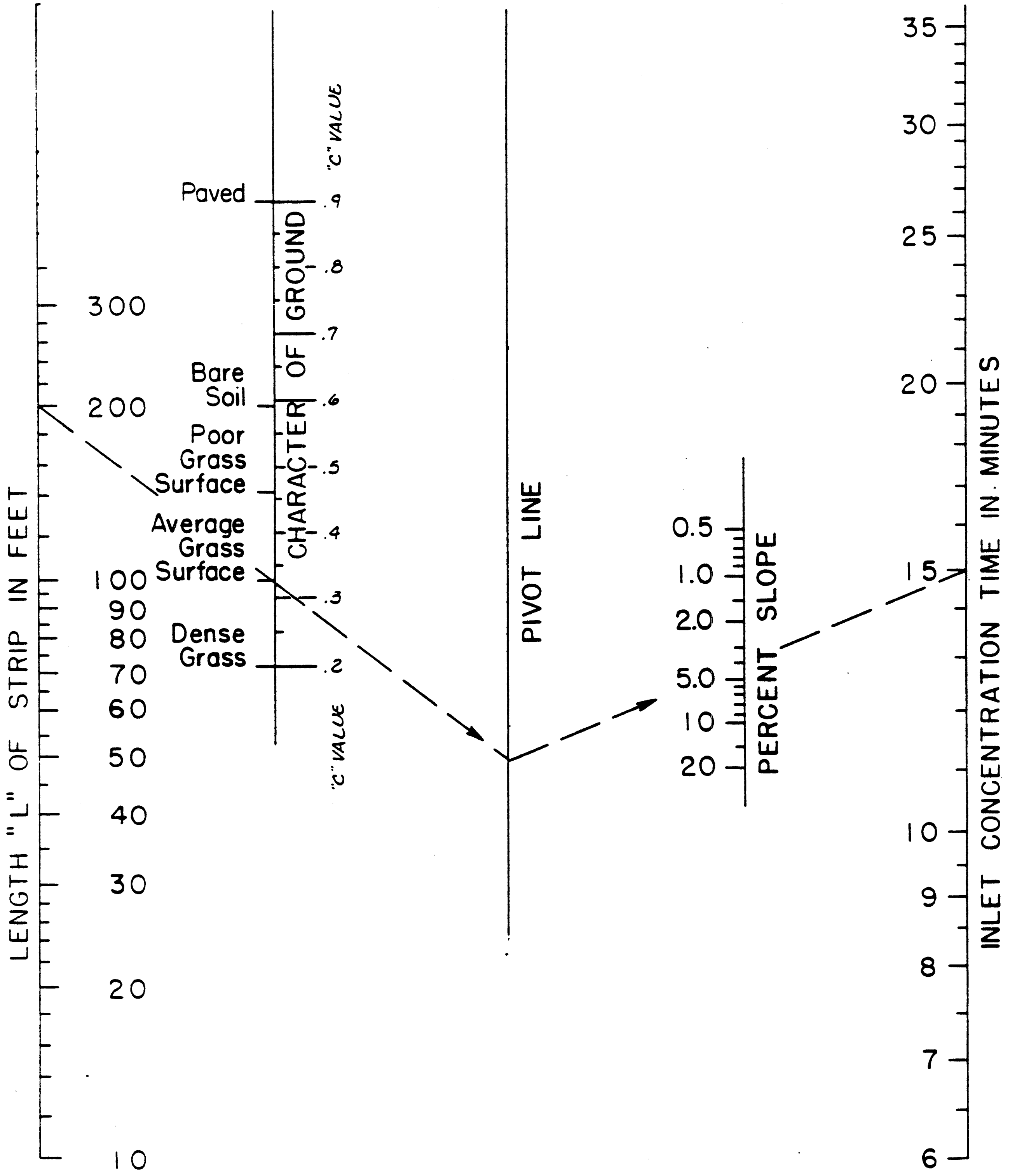
$$T_c = 35.2 \text{ minutes.}$$

5. Determine the Rainfall Intensity value (i) for the 2-year design storm (using Plate 5-4, Lynchburg Chart).

   (i) = 2.1 inches per hour.

6. Determine the peak discharge Q in cfs.

$$\begin{aligned} Q &= (C)\,(i)\,(A) \\ &= (.43)(2.1)(80) \\ &= 72.2 \text{ cfs} \end{aligned}$$



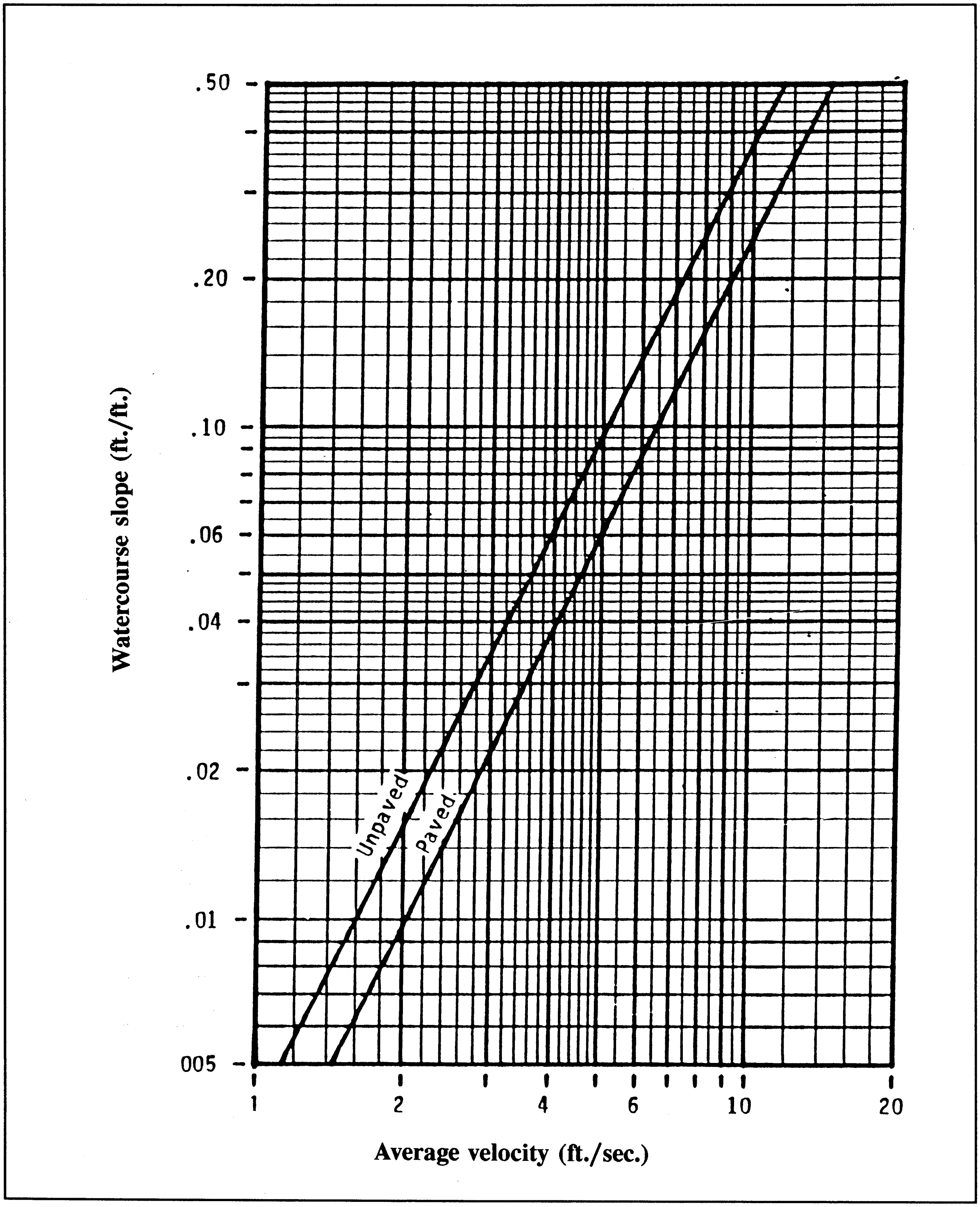
OVERLAND FLOW TIME

(Seelye Chart)

Source: Data Book for Civil Engineers, E.E. Seelye

Plate 5-1

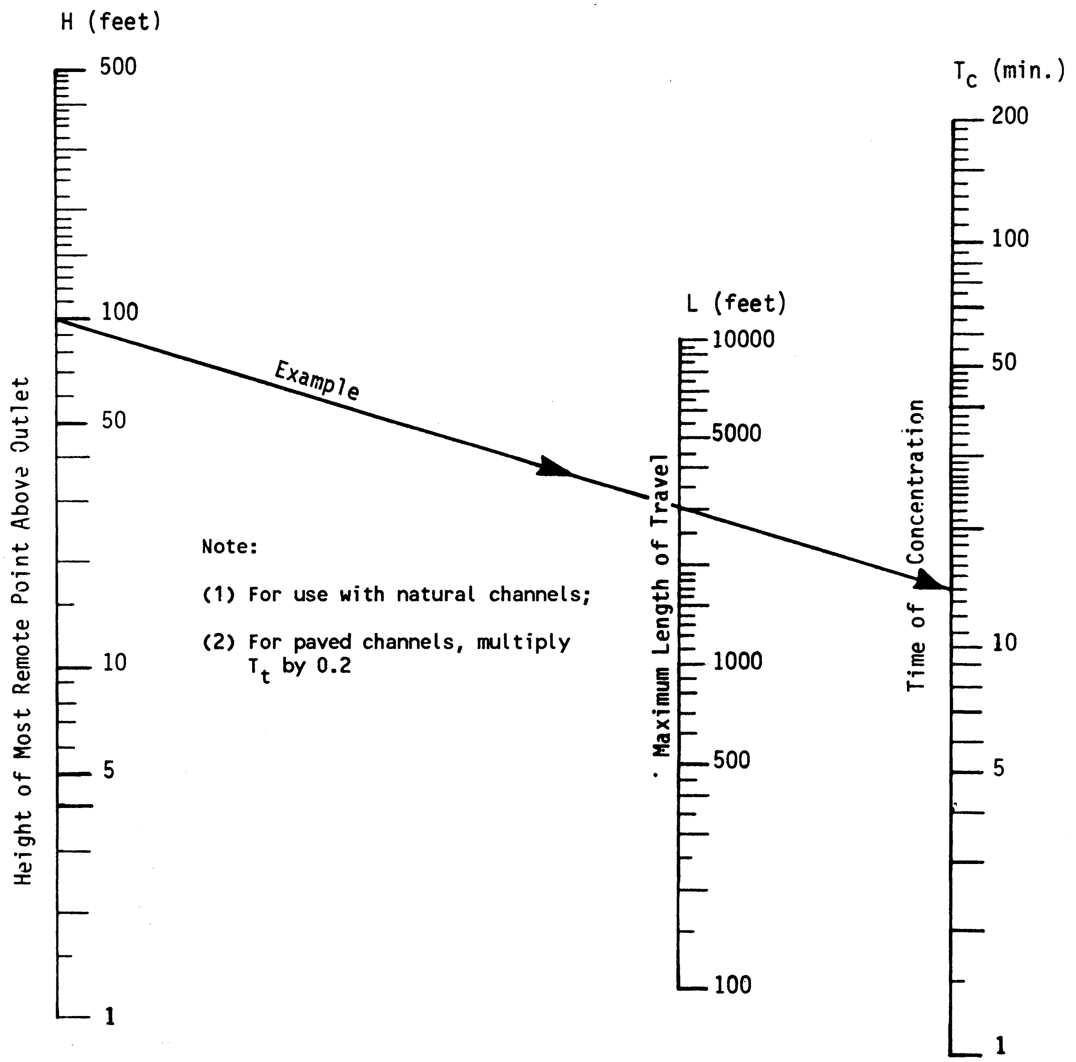
AVERAGE VELOCITIES FOR ESTIMATING TRAVEL TIME FOR SHALLOW CONCENTRATED FLOW



Source: USDA-SCS

Plate 5-2

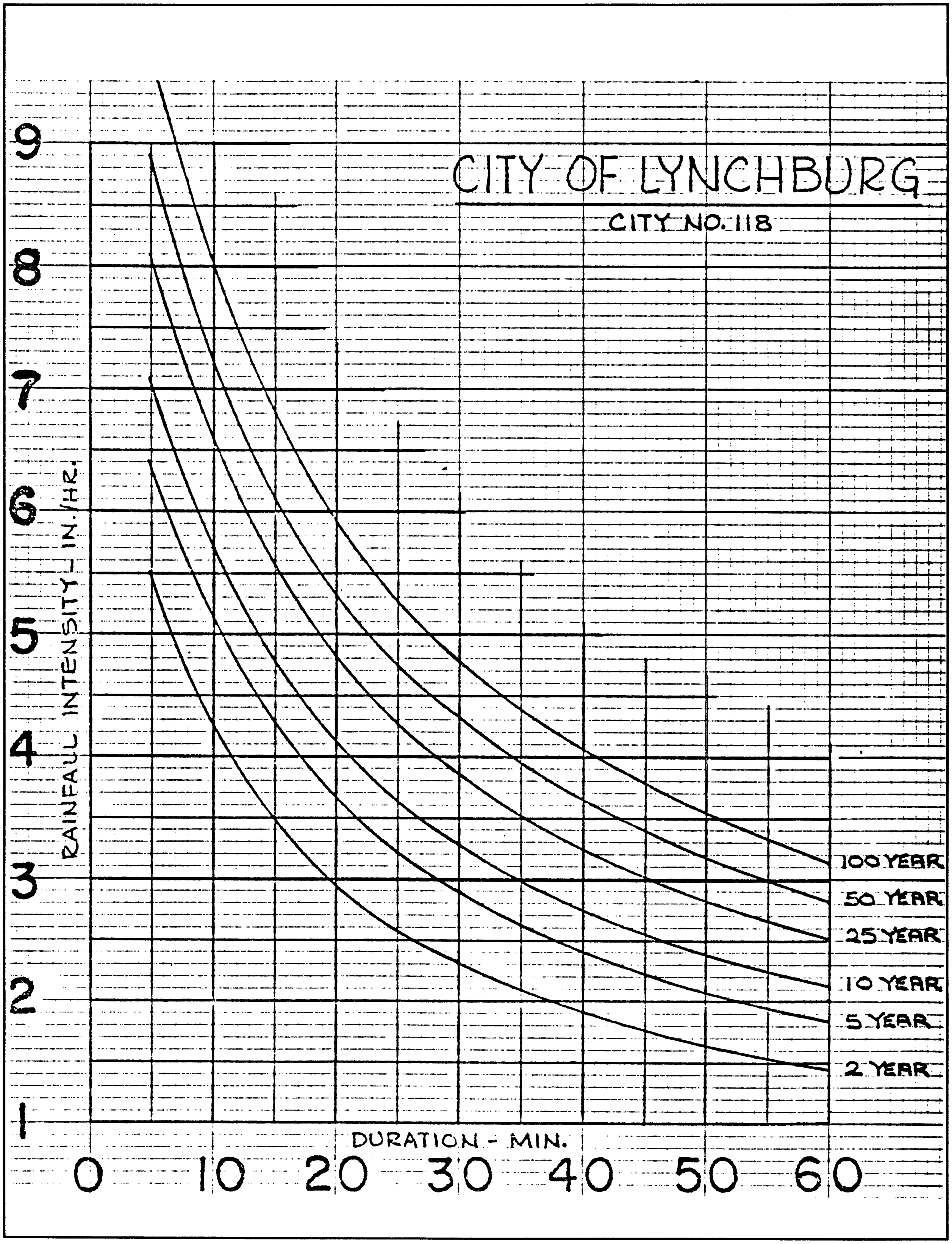
TRAVEL TIME FOR CHANNEL FLOW
(Kirpich Chart)



TIME OF CONCENTRATION OF SMALL DRAINAGE BASINS

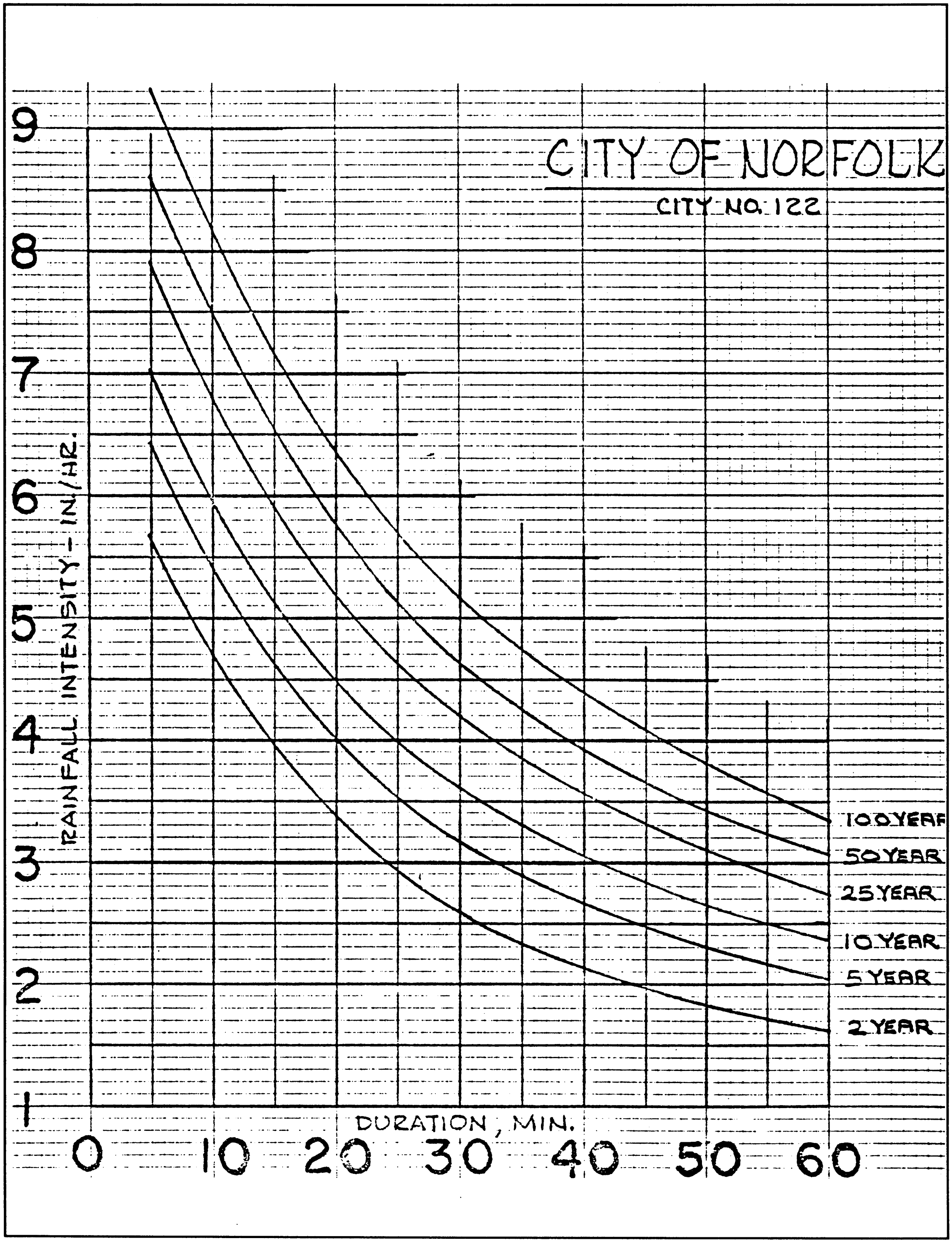
Source: VDOT

Plate 5-3



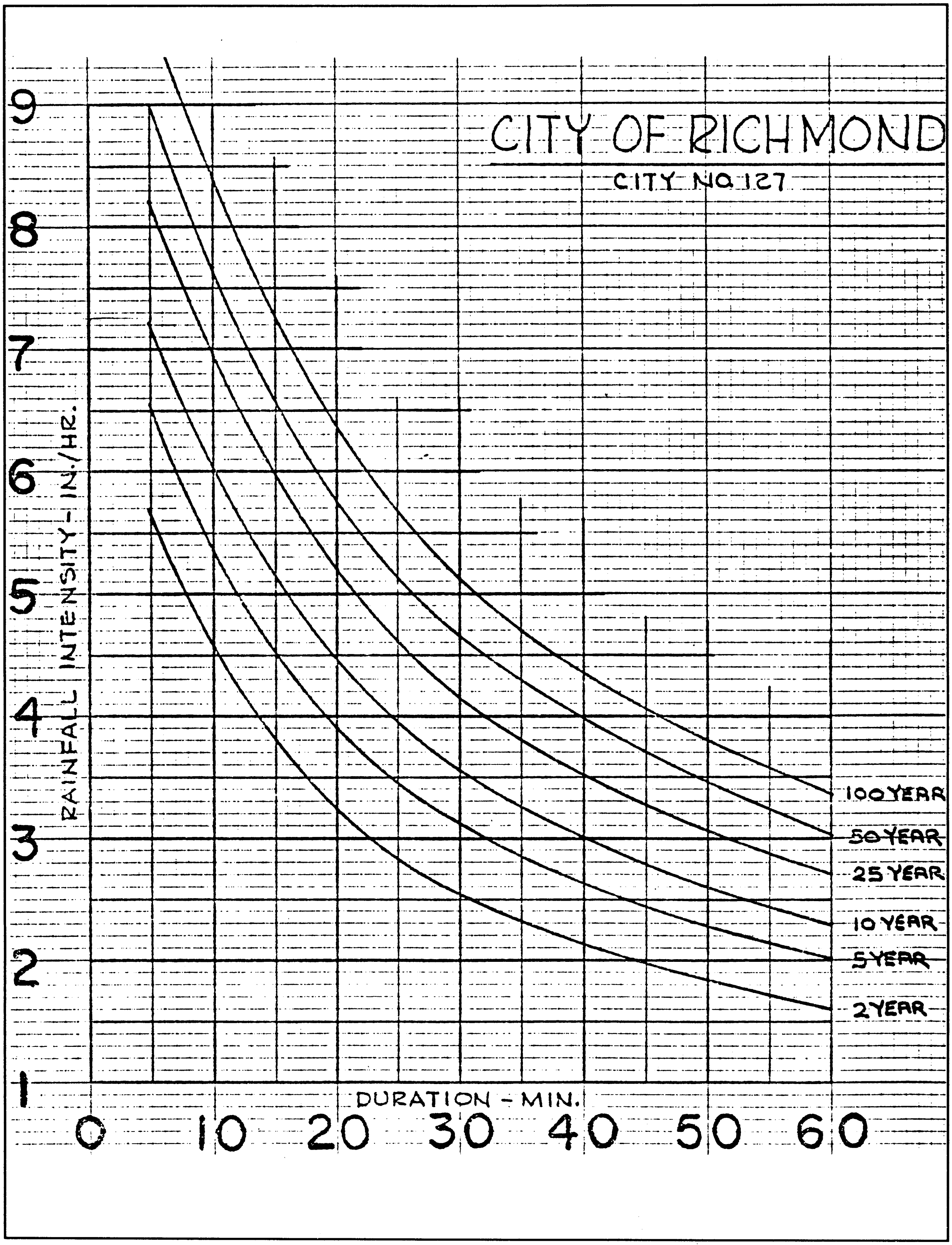
Source: VDOT

Plate 5-4



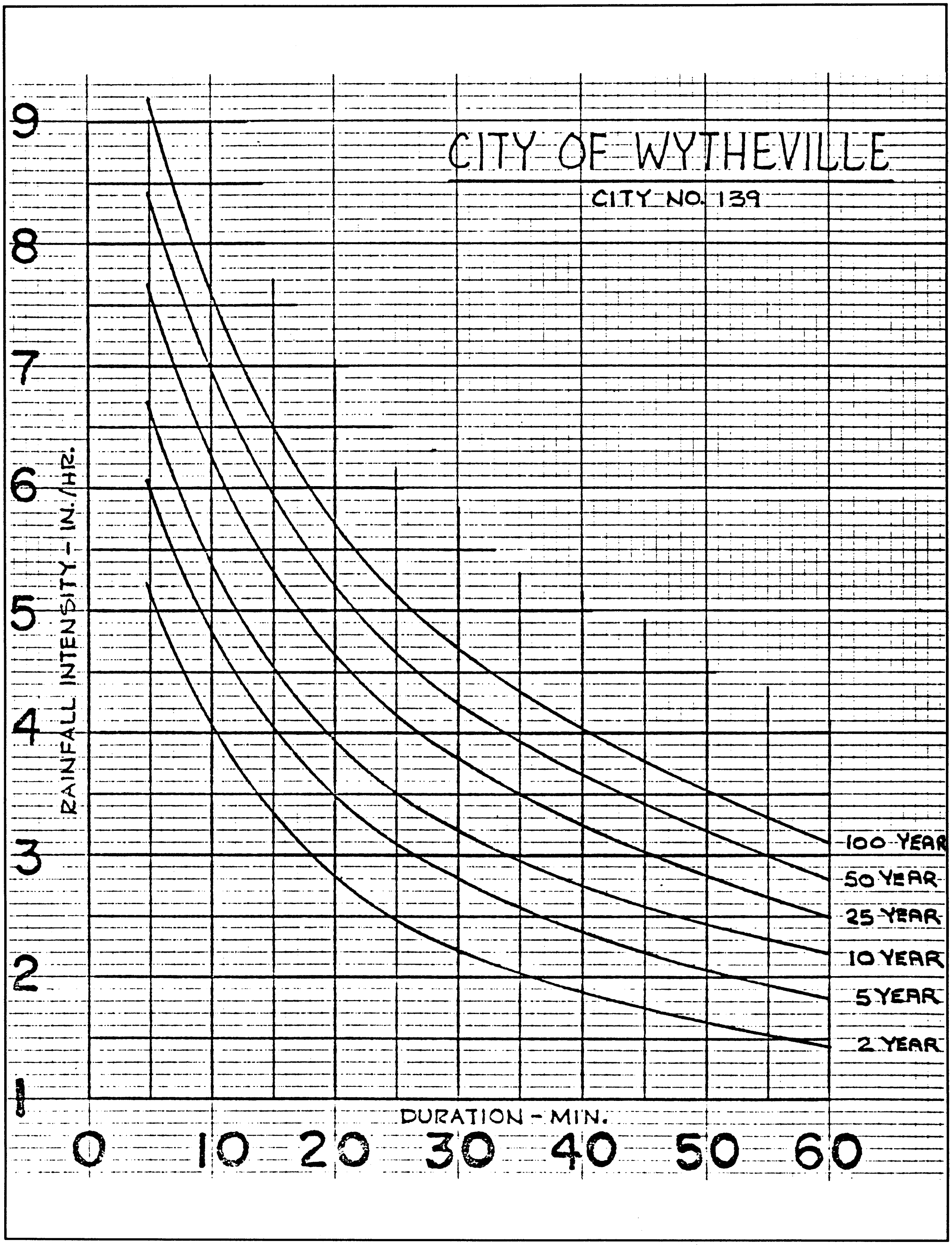
Source: VDOT

Plate 5-5



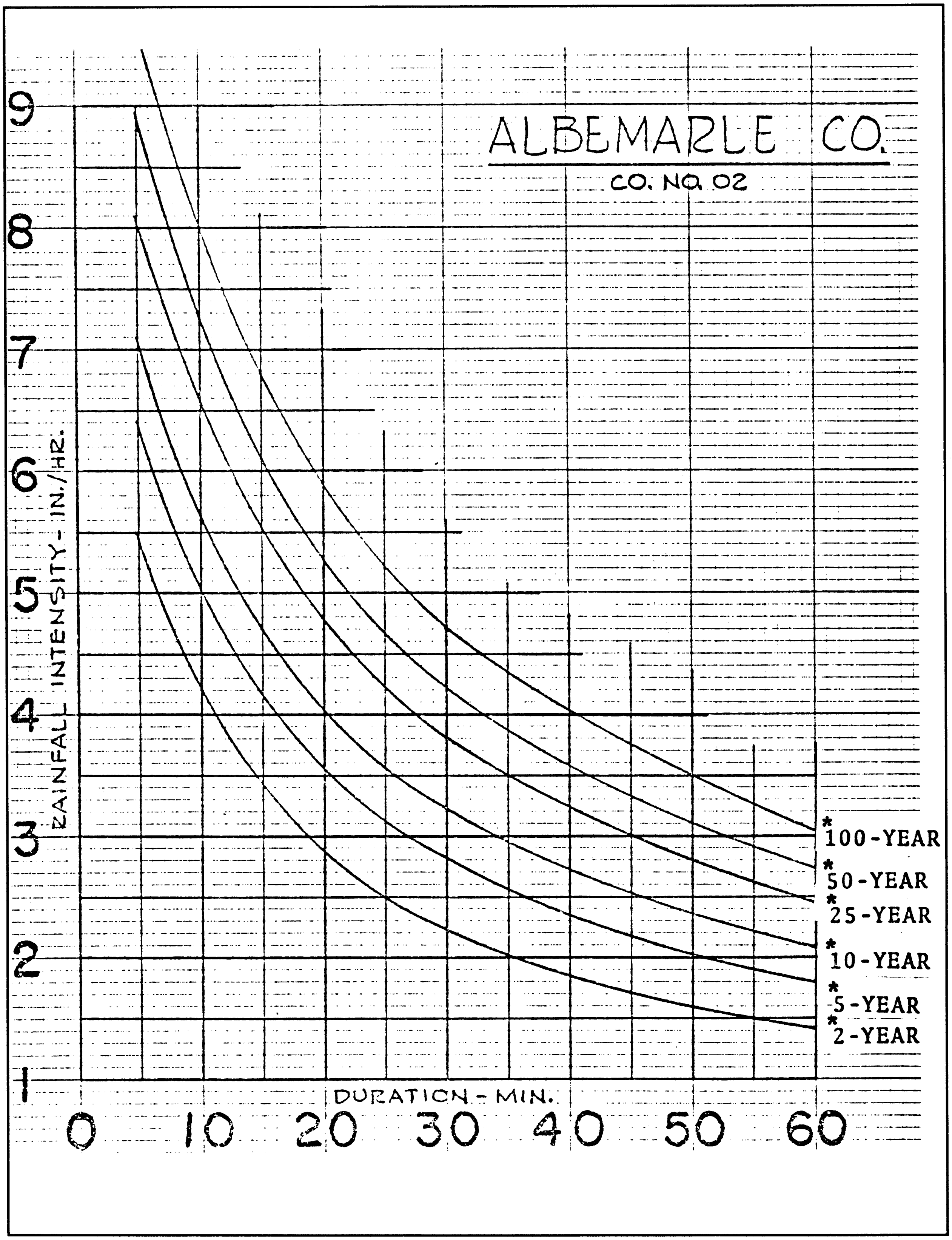
Source: VDOT

Plate 5-6



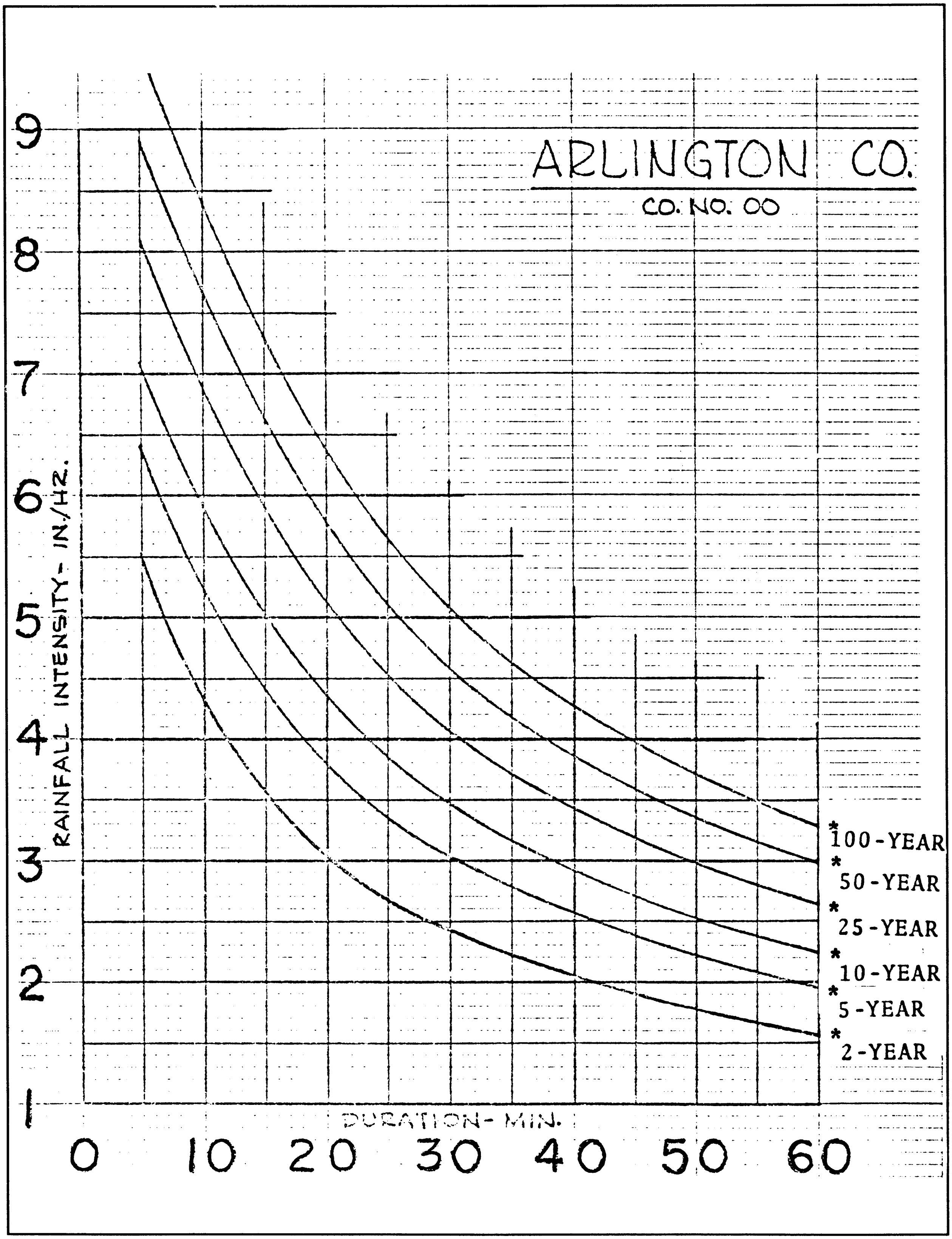
Source: VDOT

Plate 5-7



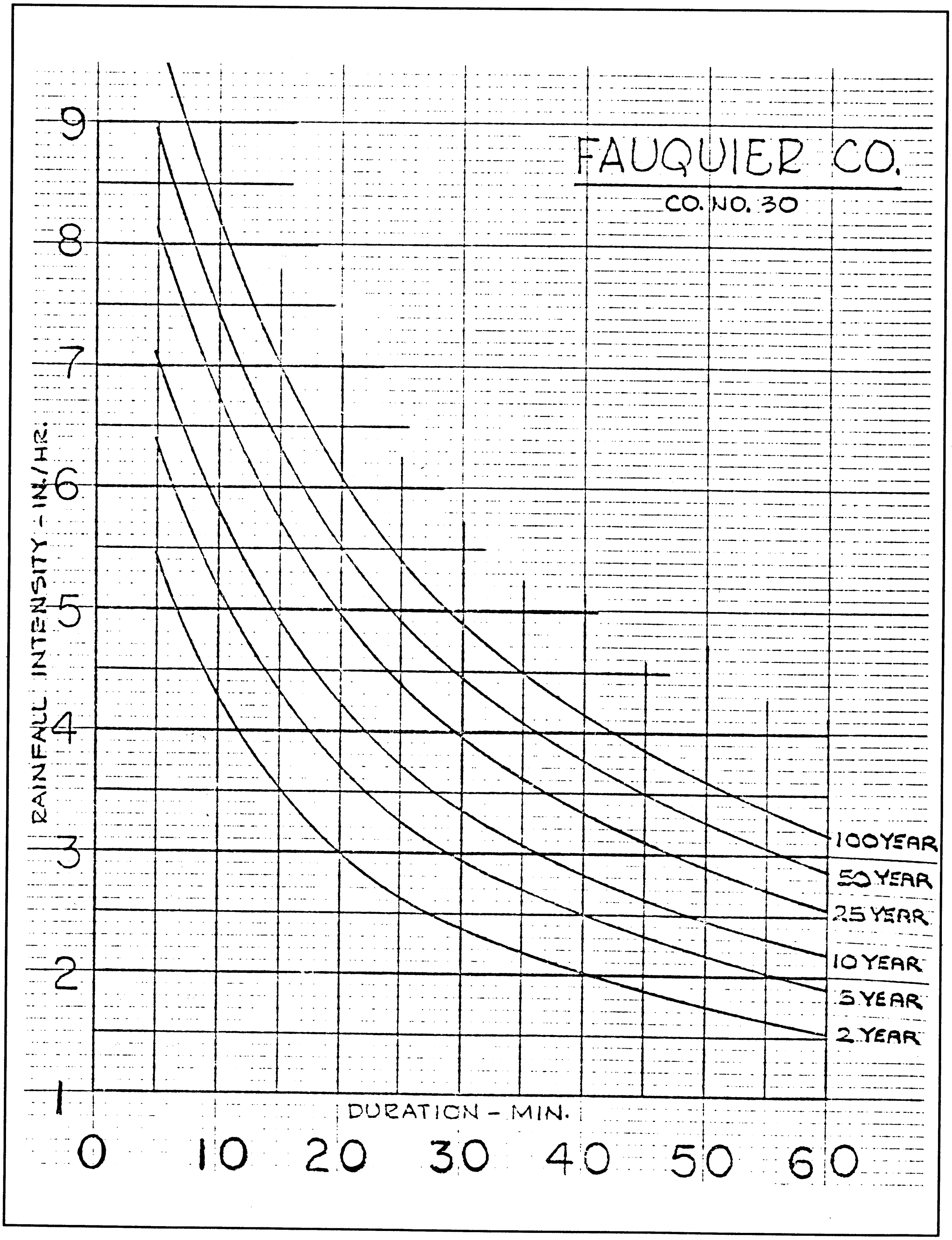
Source: VDOT

Plate 5-8



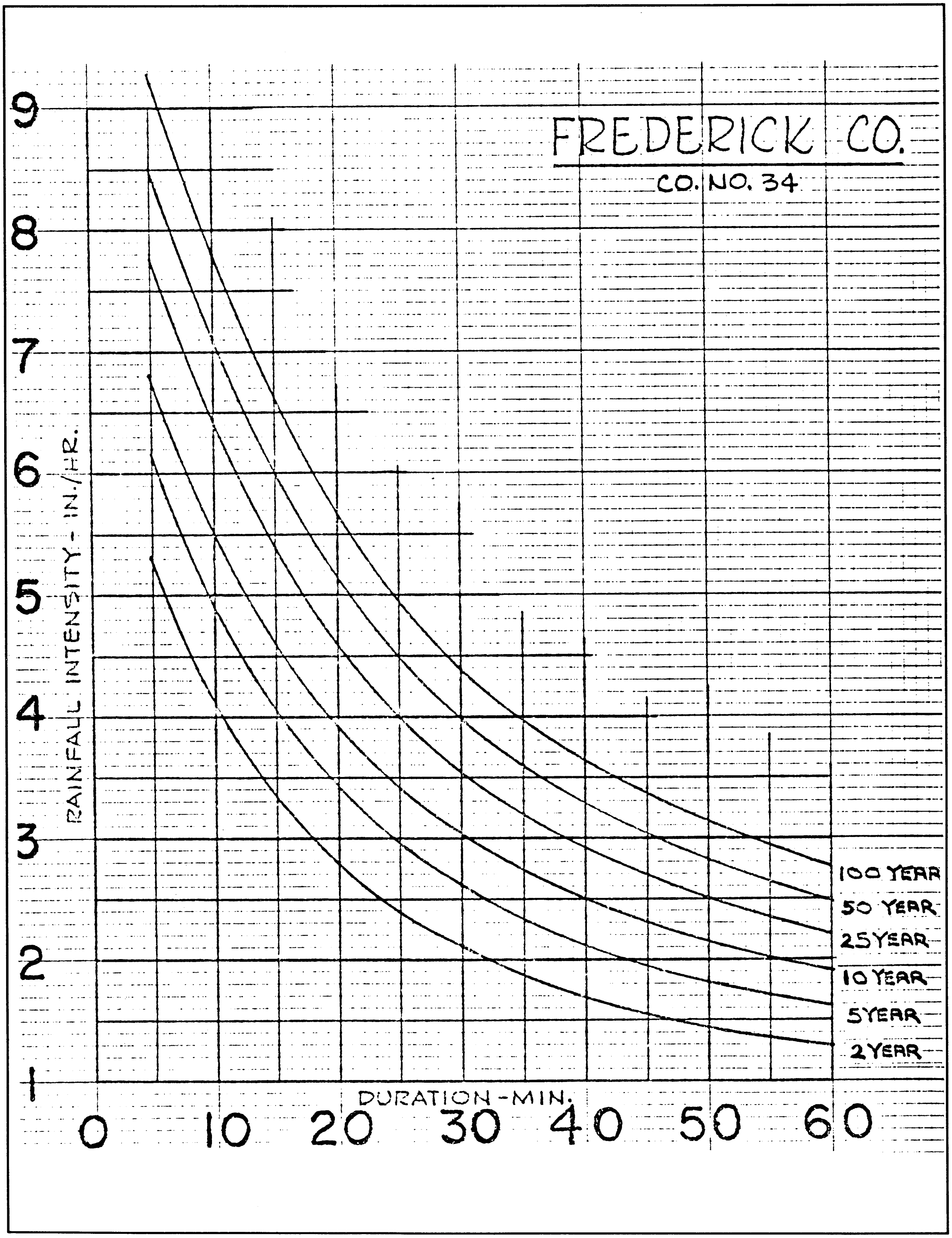
Source: VDOT

Plate 5-9



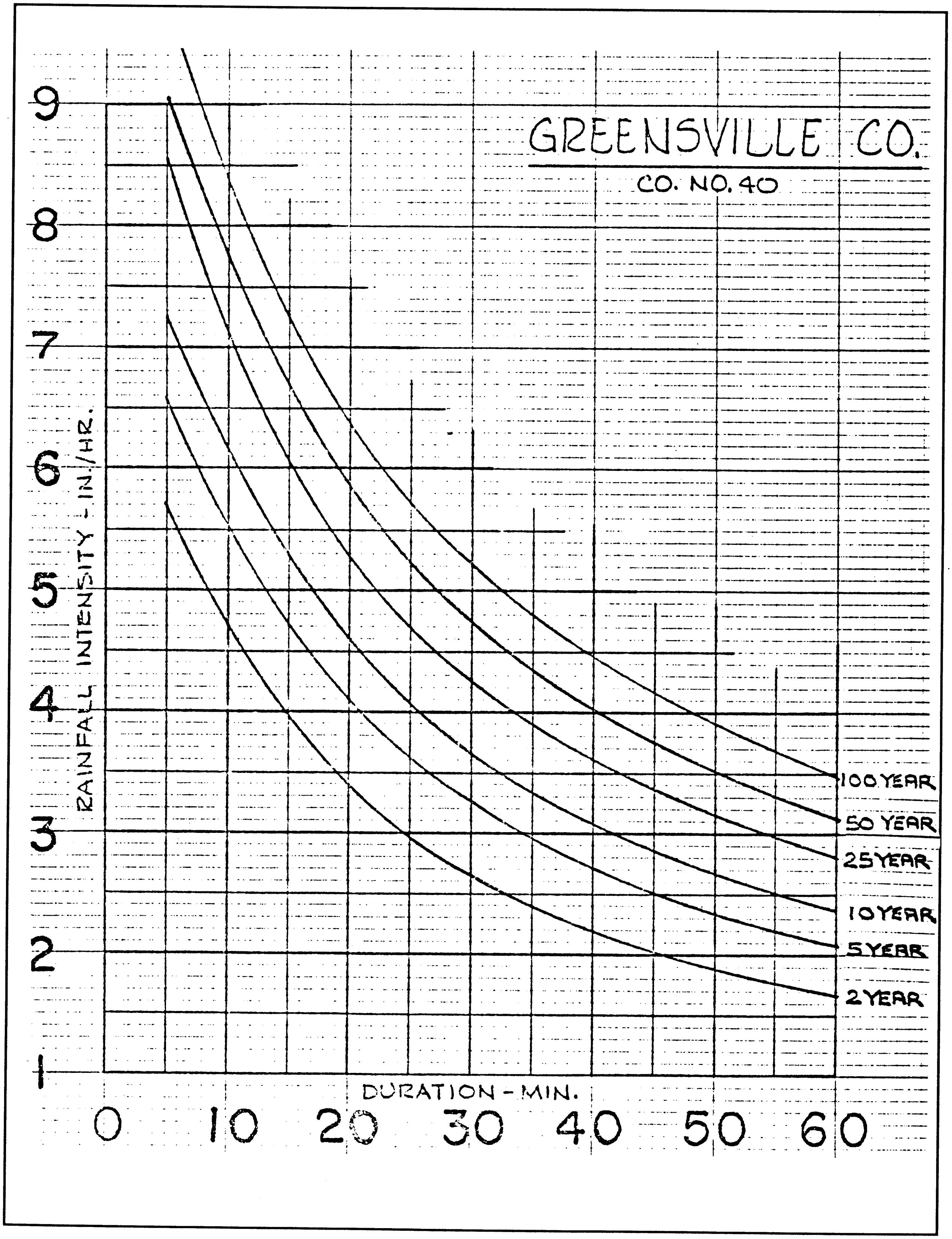
Source: VDOT

Plate 5-10



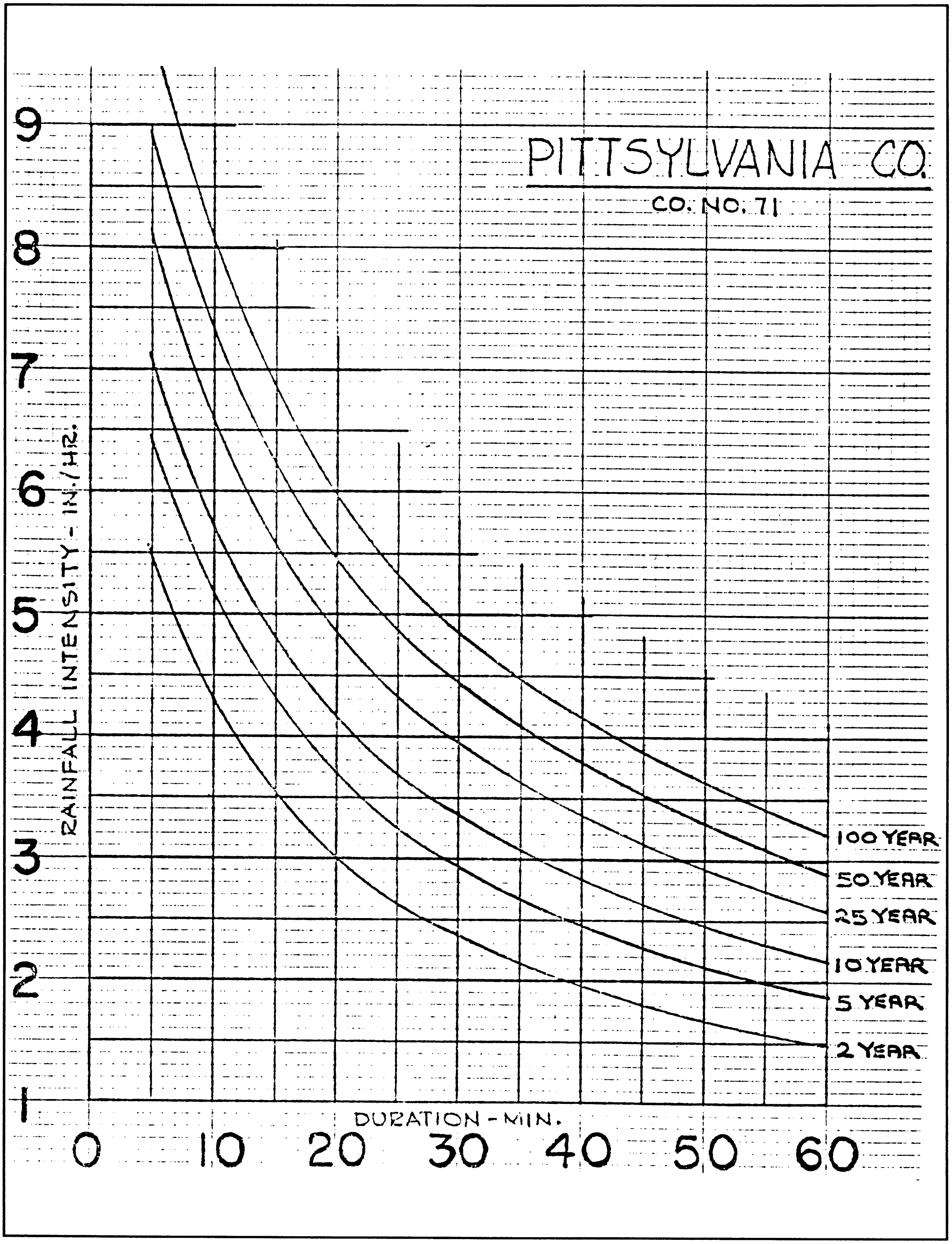
Source: VDOT

Plate 5-11



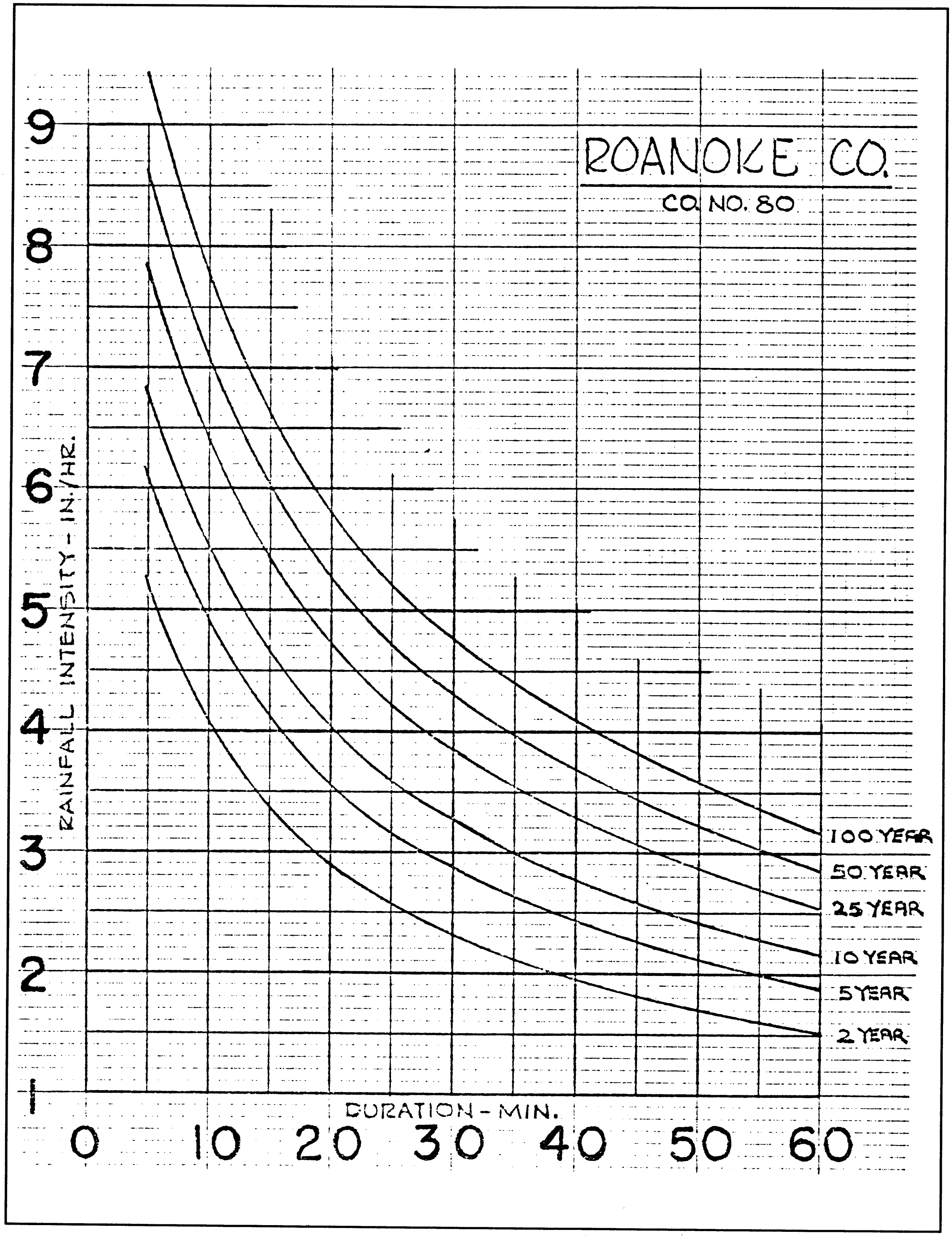
Source: VDOT

Plate 5-12



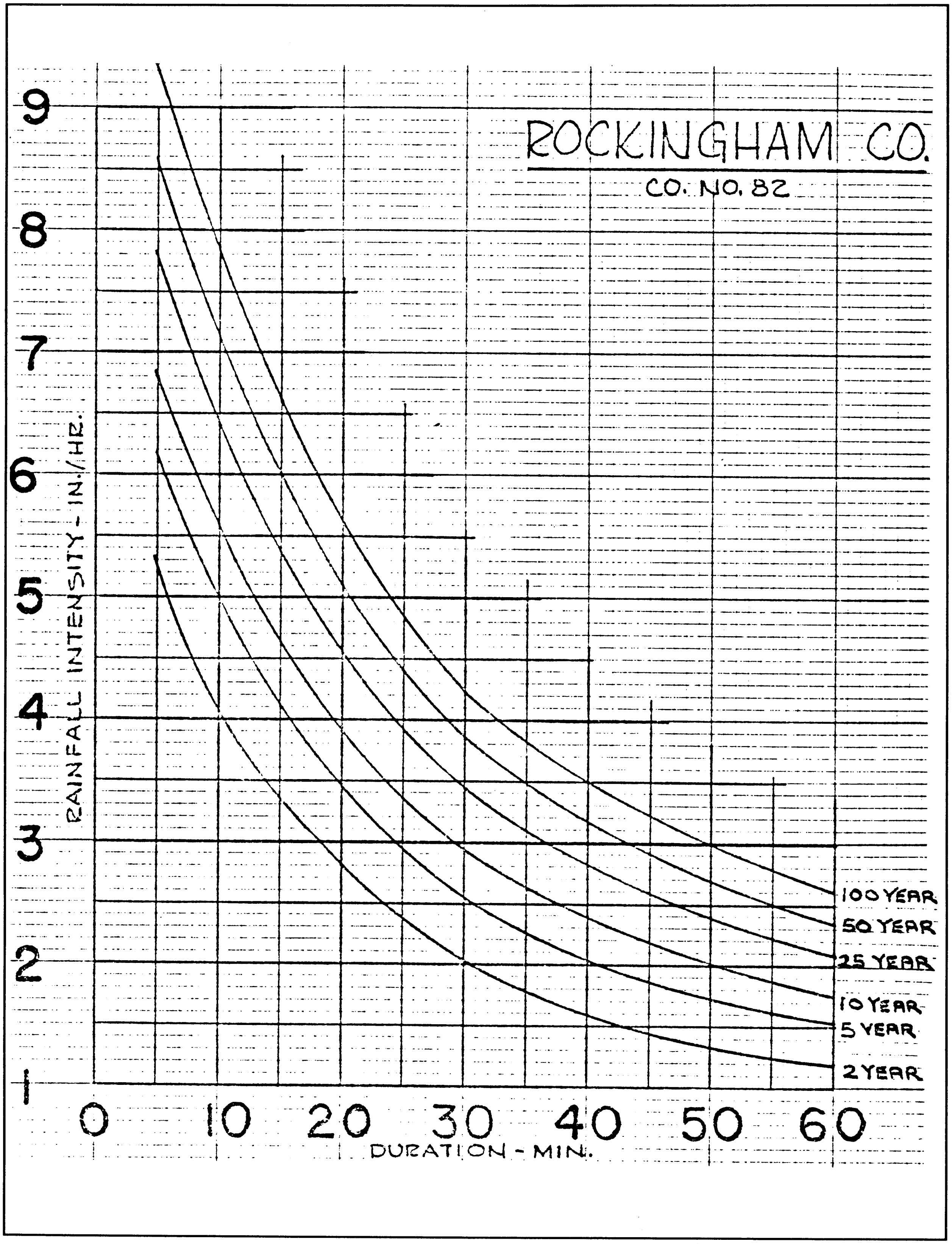
Source: VDOT

Plate 5-13



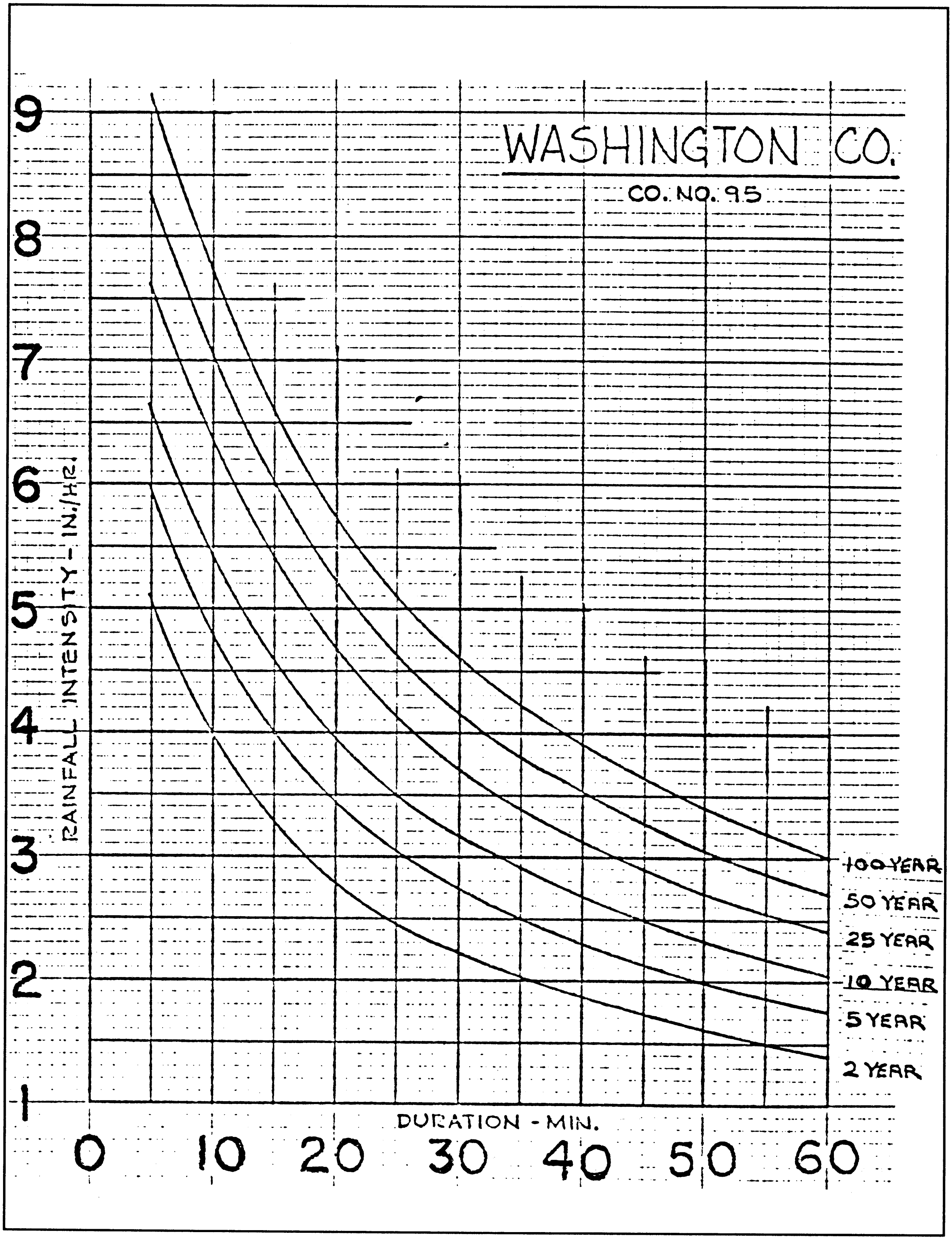
Source: VDOT

Plate 5-14



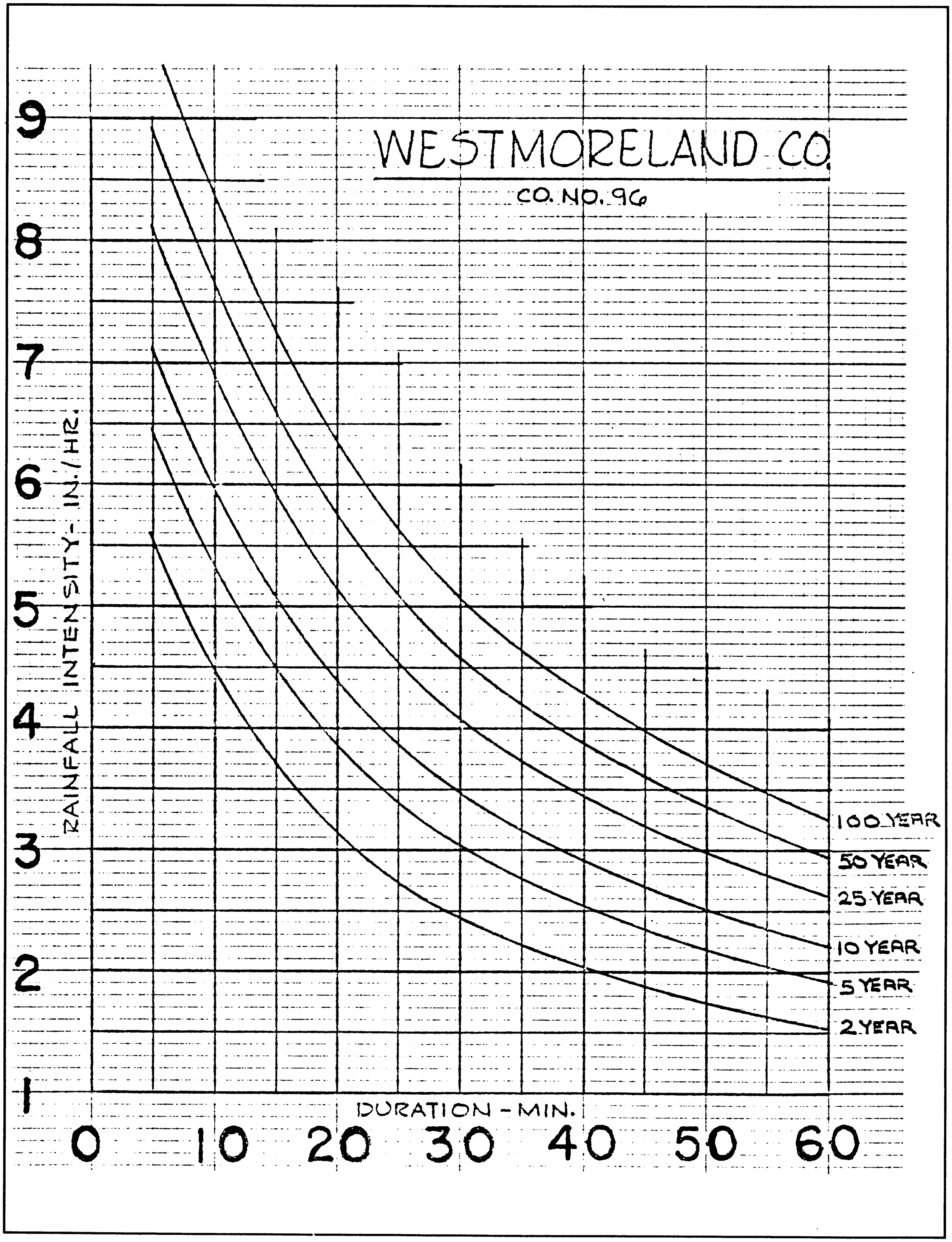
Source: VDOT

Plate 5-15



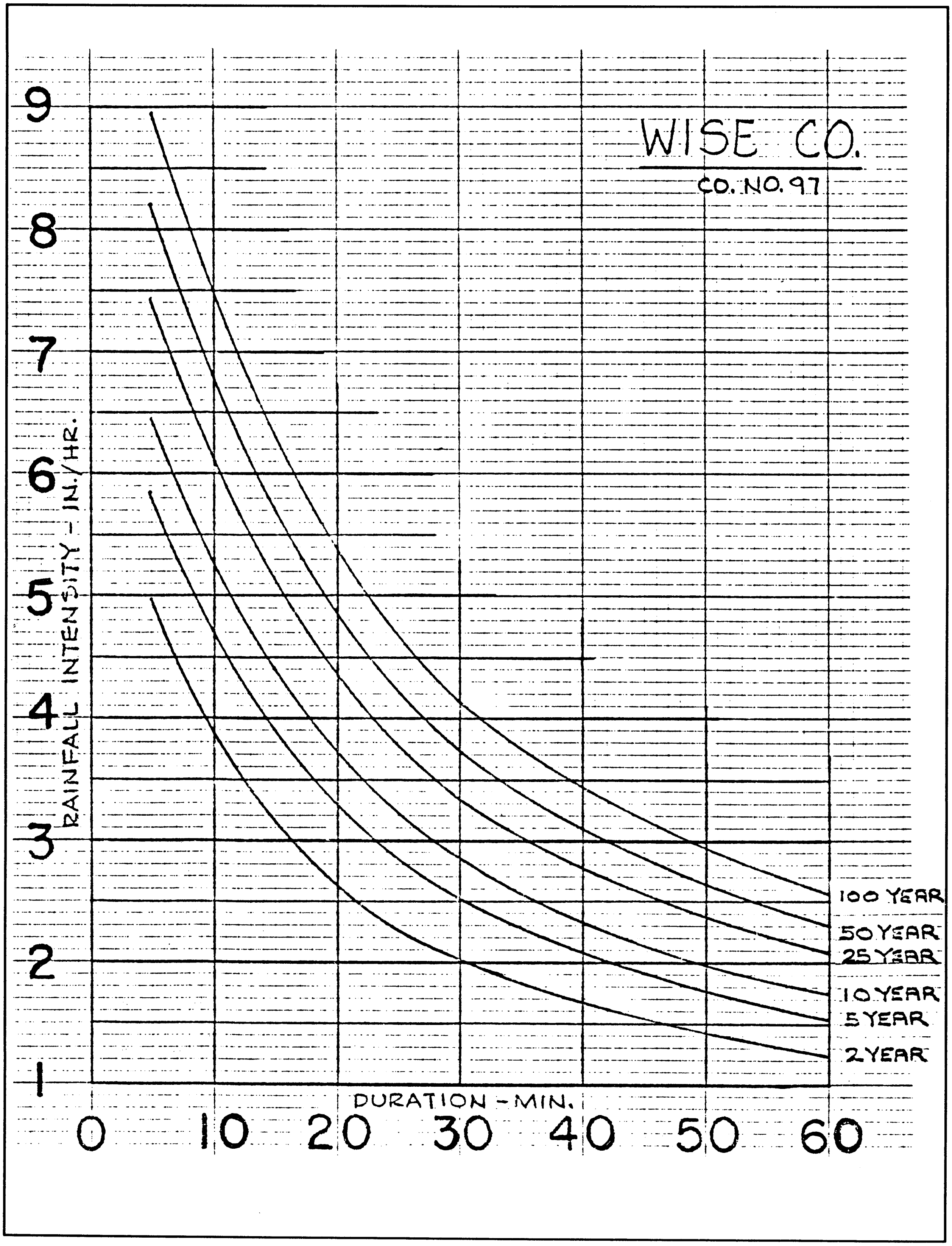
Source: VDOT

Plate 5-16



Source: VDOT

Plate 5-17



Source: VDOT

Plate 5-18

TABLE 5-2
VALUES OF RUNOFF COEFFICIENT (C) FOR RATIONAL FORMULA

Land Use	C	Land Use	C
Business:		Lawns:	
Downtown areas	0.70-0.95	Sandy soil, flat, 2%	0.05-0.10
Neighborhood areas	0.50-0.70	Sandy soil, average, 2-7%	0.10-0.15
		Sandy soil, steep, 7%	0.15-0.20
		Heavy soil, flat, 2%	0.13-0.17
		Heavy soil, average, 2-7%	0.18-0.22
		Heavy soil, steep, 7%	0.25-0.35
Residential:		Agricultural land:	
Single-family areas	0.30-0.50	Bare packed soil	
Multi units, detached	0.40-0.60	* Smooth	0.30-0.60
Multi units, attached	0.60-0.75	* Rough	0.20-0.50
Suburban	0.25-0.40	Cultivated rows	
		* Heavy soil, no crop	0.30-0.60
		* Heavy soil, with crop	0.20-0.50
		* Sandy soil, no crop	0.20-0.40
		* Sandy soil, with crop	0.10-0.25
		Pasture	
		* Heavy soil	0.15-0.45
		* Sandy soil	0.05-0.25
		Woodlands	0.05-0.25
Industrial:		Streets:	
Light areas	0.50-0.80	Asphaltic	0.70-0.95
Heavy areas	0.60-0.90	Concrete	0.80-0.95
		Brick	0.70-0.85
Parks, cemeteries	0.10-0.25	Unimproved areas	0.10-0.30
Playgrounds	0.20-0.35	Drives and walks	0.75-0.85
Railroad yard areas	0.20-0.40	Roofs	0.75-0.95

Note: The designer must use judgement to select the appropriate "C" value within the range. Generally, larger areas with permeable soils, flat slopes and dense vegetation should have the lowest C values. Smaller areas with dense soils, moderate to steep slopes, and sparse vegetation should be assigned the highest C values.

Source: American Society of Civil Engineers

TABLE 5-3
ROUGHNESS COEFFICIENTS
(MANNING'S "N") FOR SHEET FLOW

Surface Description	n[1]
Smooth surfaces (concrete, asphalt, gravel, or bare soil)	0.011
Fallow (no residue)	0.05
Cultivated soils:	
Residue cover ≤ 20%	0.06
Residue cover > 20%	0.17
Grass:	
Short grass prairie	0.15
Dense grasses[2]	0.24
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, buffalo grass, blue grama grass, and native grass mixtures.

[3] When selecting n, consider cover to a height of about 0.1 ft. This is the only part of the plant cover that will obstruct sheet flow.

Source: USDA-SCS

Graphical Peak Discharge Method

The graphical peak discharge method of calculating runoff was developed by the USDA - Soil Conservation Service and is contained in SCS Technical Release No. 55 (210-VI-TR-55, Second Ed., June 1986) entitled Urban Hydrology for Small Watersheds. (62)

This method of runoff calculation yields a total runoff volume as well as a peak discharge. It takes into consideration infiltration rates of soils, as well as land cover and other losses to obtain the net runoff. As with the rational formula, it is an empirical model and its accuracy is dependent upon the judgement of the user.

The information presented in this section is intended as (1) an introduction to the graphical peak discharge method, and (2) an illustration of how the E&S program requirements should be applied to the method. This information should not be used as a set of guidelines in lieu of the source document.

Following is the procedure to use the peak discharge method of runoff determination:

Step 1 - Measure the drainage area. Use surveyed topography, USGS Quadrangle sheets, aerial photographs, soils maps, etc.

Step 2 - Calculate a curve number (CN) for the drainage area.

The curve number (CN) is similar to the runoff coefficient of the rational formula. It is an empirical value which establishes a relationship between rainfall and runoff based upon characteristics of the drainage area.

The soil type also influences the curve number. Each soil belongs to a different hydrologic soil group. Table 5-4 describes the hydrologic soil groups.

Appendix 6C (Chapter 6) lists various soil names and their corresponding hydrologic soil group. If the soil name is unknown, a judgement must be made based upon a knowledge of the soils and the soil group description. Soil names can be obtained from county soil surveys, the local Soil Conservation Service office, or analysis of actual soil borings.

Table 5-5 contains curve number values for different landuse/cover conditions and hydrologic soil groups.

TABLE 5-4

HYDROLOGIC SOIL GROUPS

Soil Group A	Represents soils having a low runoff potential due to high infiltration rates. These soils consist primarily of deep, well-drained sands and gravels.
Soil Group B	Represents soils having a moderately low runoff potential due to moderate infiltration rates. These soils consist primarily of moderately deep to deep, moderately well-drained to well-drained soils with moderately fine to moderately coarse textures.
Soil Group C	Represents 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.
Soil Group D	Represents soils having a high runoff potential due to very slow infiltration rates. These soils consist primarily of clays with high water tables, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious parent material.

If the watershed has uniform landuse and soils, the curve number value can be easily determined directly from Table 5-5. Curve numbers for non-homogeneous watersheds may be determined by dividing the watershed into homogeneous sub-areas and performing a weighted average.

$$CN = \frac{\Sigma\ (CN\ of\ sub\text{-}area\ \ x\ \ sub\text{-}area)}{Total\ Area}$$

Step 3 - Determine <u>runoff depth and volume</u> for the design storm.

a. The <u>rainfall depth</u> (in inches) can be determined from the maps contained on Plates 5-19 through 5-21 for the selected design storm. (For the examples in this section, the design storms are based upon the

SCS Type II 24-hour rainfall distribution. See the SCS-TR-55 document for other rainfall distributions.)

b. The <u>runoff depth</u> (in inches) can be determined from the graph contained on Plate 5-22. Enter the graph with the rainfall depth (inches) at the bottom, move vertically to intersect the appropriate curve, then move horizontally and read inches of runoff. The equations on Plate 5-22 can also be used, as well as Table 5-6 to determine runoff depth. The volume of runoff from the site can be calculated by simply multiplying the drainage area of the site by the runoff depth.

$$\frac{\text{(in. runoff)} \quad \text{x} \quad \text{acres}}{12 \text{ in./ft.}} = \text{acre-foot}$$

or

$$\frac{\text{(in. runoff)} \quad \text{x} \quad \text{sq. ft.}}{12 \text{ in./ft.}} = \text{cubic feet}$$

Step 4 - Determine time of concentration.

This can be done by using the method outlined in TR-55 or as in the rational method. (See Chapter 5, Part I, Rational Method.) In TR-55, Tc is a summation of travel time for sheet flow, shallow concentrated flow and channel flow as determined by the point of interest in the watershed.

Overland flow or sheet flow:

The maximum flow length (as defined by TR-55) for overland flow is 300 feet; however, it is generally accepted that overland flow is limited to flow paths of less than 200 feet. The engineer should use information from the site to make this determination.

Use Manning's kinematic equation to compute travel time:

$$T_t = \frac{0.007\ (nL)^{0.8}}{(P_2)^{0.5}\ s^{0.4}}$$

where:

T_t	=	travel time (hr)
n	=	Manning's roughness coefficient (Table 5-7)
L	=	flow length (ft)
P_2	=	2-year, 24-hour rainfall (in)
s	=	slope of hydraulic grade line (feet/foot).

After a maximum of 300 feet, sheet flow usually becomes shallow concentrated flow. The average velocity for this flow can be determined from Plate 5-23.

Open channels are well defined on the landscape and usually are represented by surveyed cross sections representing certain reach lengths. Manning's equation for open channel flow is used to calculate the average velocity for flow at bank-full elevation for the represented channel reach. A nomograph for solving Manning's equation is provided in Plate 5-24.

Manning's equation is:

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

where:

V	=	average velocity (ft/s)
r	=	hydraulic radius (ft) and is 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 roughness coefficient for open channel flow. Manning's "n" values for open channel flow can be obtained from Table 5-8, or from standard textbooks such as Chow (1959) or Linsley et al. (1982). (See Chapter 5, Part III, Open Channel Flow, for details.)

After average velocity is obtained, travel time is computed using the following equation for shallow concentrated flow and for open channel flow:

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

where:

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

Sometimes it is necessary to estimate the velocity of flow through a reservoir or lake at the outlet of a watershed. This travel time is normally very small and can be assumed to be zero.

Step 5 - Determine initial abstraction (I_a).

Initial abstraction (I_a) refers to all losses that occur before runoff begins. It includes water retained in surface depressions, water intercepted by vegetation, and evaporation and infiltration. I_a is highly variable but generally is correlated with soil and cover parameters. The relationship of I_a to curve number is presented in Table 5-9.

Step 6 - Determine the unit peak discharge.

Divide the initial abstraction by the rainfall to obtain the I_a/P ratio. Enter Plate 5-25 with the calculated T_c in hours, move up to the I_a/P ratio (this can be a linear interpolation) and read the unit peak discharge (q_u) on the left in cubic-feet per second per square mile of drainage area per inch of runoff (csm/in).

To determine the peak discharge (q), multiply the value obtained from Plate 5-25 (q_u) by the drainage area in square miles and by the runoff in inches.

$$q = Q_u \ A_m \ Q$$

where:

q	=	peak discharge in cfs
q_u	=	unit peak discharge in cfs/sq.mi./in. (csm/in.),
A_m	=	drainage area in square miles, and
Q	=	runoff in inches.

Step 7 - Determine whether ponding and swampy conditions in the watershed area will affect the peak discharge. This adjustment is not always needed. Ponds or swamps on the main stream or that are in the path used for calculating time of concentration (T_c) are not considered here. Only ponds and swamps scattered throughout the watershed that are not in the T_c path are considered.

Table 5-10 contains the adjustment factors for ponds and swamps spread throughout the watershed. Measure or estimate the area covered by ponds and/or swamps, convert to percentage of the watershed drainage area, enter the Table and read (or interpolate) the multiplying factor (F_p).

If the F_p adjustment is needed, then the discharge from step 5 is multiplied by the Table value to obtain the final peak discharge (q_p).

$$q_p = (q) \ (F_p)$$

Example 5-2 (present or pre-development condition)

The watershed is located in eastern Campbell County, Virginia and covers 250 acres. Fifty percent of the watershed is Appling soil which is hydrologic soil group B. Fifty percent is Helena soil which is hydrologic soil group C.

Given: Landuse cover and treatment by soil group

Row crops, contour, good	- B soils - 10%
Pasture, good	- C Soils - 30%
Woods, fair	- B Soils - 40%
Woods, good	- C Soils - 20%

Find: Composite (weighted) curve numbers (CN) and runoff volume (Q) in watershed inches for the 2-year and 10-year, 24 hour storms.

Solution:

1. See worksheet 2 (at the end of solution for Example 5-2) for runoff curve number and runoff depth.

2. Determine hydrologic soil group by using Appendix 6C in Chapter 6.

Soil Name	Hydrologic Soil Group
Appling	B
Helena	C

3. Determine runoff curve number for each cover and condition for each hydrologic soil group from Table 5-5.

Cover Description	Soil Group	CN
Row crops, contour, good	B	75
Pasture, good condition	C	74
Woods, fair condition	B	60
Woods, good condition	C	70

4. Perform weighted average curve number computation.

	% Area	x	CN		
Row crops, contour, good	10	x	75	=	750
Pasture, good	30	x	74	=	2200
Woods, fair	40	x	60	=	2400
Woods, good	20	x	70	=	1400
	100				6770

$$CN = \frac{6770}{100} = 67.70 \text{ or } 68$$

5. Determine rainfall (P) on Plates 5-19 and 5-20 in eastern Campbell County for the 2-year and 10-year storms.

   2-year P = 3.5 inches and 10-year P = 5.5 inches.

6. Determine runoff (Q) in watershed inches from Table 5-6, Plate 5-22 or the equations on Plate 5-22.

   2-year Q = 0.90 inches and 10-year Q = 2.24 inches

Worksheet 2: Runoff curve number and runoff

Project Defiance Ridge By ESC Date 2-4-91

Location Campbell County, Virginia Checked SWM Date 2-5-91

Circle one: Present Developed D.A. 250 Acres

1. Runoff curve number (CN)

Soil name and hydrologic group (appendix 6C	Cover description (cover type, treatment, and hydrologic condition; percent impervious; unconnected/connected impervious area ratio)	CN [1/] Table 5.5	CN [1/] Fig. 2-3	CN [1/] Fig. 2-4	Area ☐ acres ☐ mi² ☑ %	Product of CN x area
Appling, B	Row Crop, Contour, Good	75			10	750
Helena, C	Pasture, Good Condition	74			30	2220
Appling, B	Woods, Fair Condition	60			40	2400
Helena, C	Woods, Good Condition	70			20	1400
				Totals =	100	6770

1/ Use only one CN source per line.

CN (weighted) = $\frac{\text{total product}}{\text{total area}} = \frac{6770}{100} = 67.7$; Use CN = $\boxed{68}$

2. Runoff

		Storm #1	Storm #2	Storm #3
Frequency	yr	2	10	
Rainfall, P (24-hour) (Plates 5-19, 5-20)	in	3.5	5.5	
Runoff, Q (Use P and CN with table 5-6, Plate 5-22 or eqs. on Plate 5-22	in	0.90	2.24	

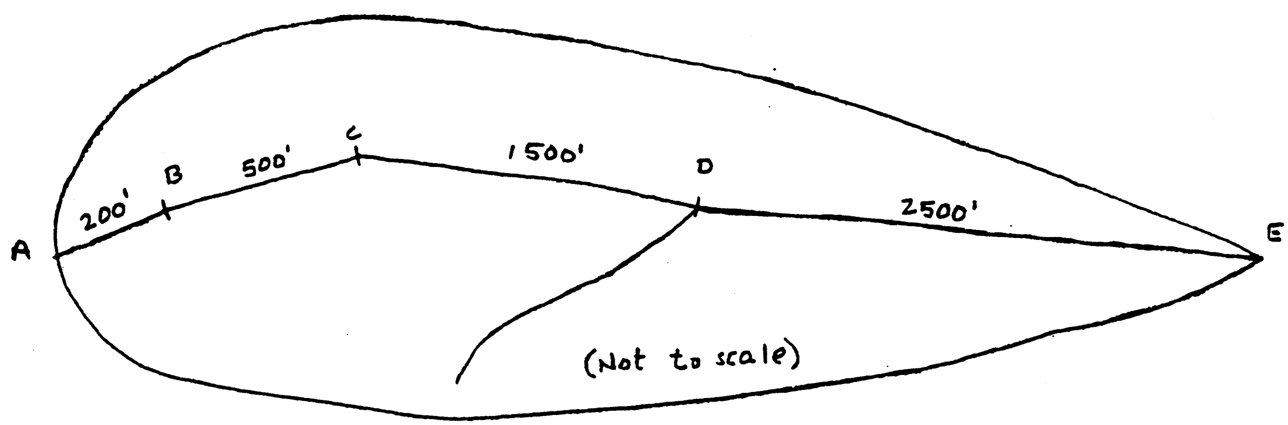
Example 5-3

Given: For present conditions, the flow path was determined to be 4700 feet long by using field surveys and topographic maps. Reach AB is 200 feet of sheet flow in woods and light brush at 2% slope.

Reach BC is 500 feet of shallow concentrated flow at 4% slope.

Reach CD is 1500 feet in a natural channel with 8 square feet cross sectional area, 7.6 feet wetted perimeter, 2% slope and a Manning's "n" of 0.08.

Reach DE is 2500 feet in a natural channel with 27 square feet cross sectional area 21.6 feet wetted perimeter, 0.5% slope and a Manning's "n" of 0.06.



Find: Time of concentration (T_c) for the watershed for the present or pre-developed condition. (See worksheet 3 at the end of solution for Example 5-3.)

Solution:

1. Calculate sheet flow travel time by using Manning's kinematic equation.

$$T_t = \frac{0.007\ (nL)^{0.8}}{(P_2)^{0.5}\ s^{0.4}}$$

where,

$$\begin{aligned} n &= 0.40 \text{ (from Table 5-7)} \\ L &= 200 \text{ ft.} \\ P_2 &= 3.5 \text{ in. (from Plate 5-19)} \\ s &= 0.02 \text{ ft./ft.} \end{aligned}$$

$$T_t = \frac{0.007\ (0.40 \times 200)^{0.8}}{(3.5)^{0.5}\ (0.02)^{0.4}} = 0.60\ hr.\quad (Reach\ AB)$$

2. Calculate travel time for shallow concentrated flow.
Surface description: unpaved

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

where,

$$\begin{aligned} L &= 500 \text{ ft.} \\ S &= 0.04 \text{ ft./ft.} \\ V &= 3.2 \text{ ft./s (Plate 5-23)} \end{aligned}$$

$$T_t = \frac{500}{3600(3.2)} = 0.04 \text{ hr. (Reach BC)}$$

3. Calculate travel time for first channel reach, using Manning's equation for open channel flow. (See also Plate 5-24 for nomograph solution to equation.)

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

where,

$$\begin{aligned} a &= 8 \text{ ft.}^2 \\ p_w &= 7.6 \text{ ft.} \\ r &= a/p_w = 8/7.6 = 1.05 \text{ ft.} \\ s &= 0.02 \text{ ft/ft} \\ n &= 0.08 \end{aligned}$$

$$V = \frac{1.49(1.05)^{2/3}(0.02)^{1/2}}{.08} = 2.72 \text{ ft./s}$$

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

$$L = 1500 \text{ ft.}$$

$$T_t = \frac{1500}{3600(2.72)} = 0.15 \text{ hr. (Reach CD)}$$

4. Calculate travel time for second channel reach, using Manning's equation for open channel flow.

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

where,

$a = 27 \text{ ft.}^2$
$p_w = 21.6 \text{ ft.}$
$r = a/p_w = 27/21.6 = 1.25$
$s = 0.005 \text{ ft/ft}$
$n = 0.06$

$$V = \frac{1.49\,(1.25)^{2/3}(0.005)^{1/2}}{0.06} = 2.04 \text{ ft./s}$$

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

$$L = 2500 \text{ ft.}$$

$$T_t = \frac{2500}{3600\,(2.04)} = 0.34 \text{ hr. (Reach DE)}$$

5. Find T_c by adding the travel times (T_t):

$$T_c = \Sigma T_t = 0.60 + 0.04 + 0.15 + 0.34 = 1.13 \text{ hr.}$$

Worksheet 3: Time of concentration (T_c) or travel time (T_t)

Project Defiance Ridge By ESC Date 2-4-91

Location Campbell County, Virginia Checked SWM Date 2-5-91

Circle one: Present Developed

Circle one: T_c T_t through subarea

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

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

Sheet flow (Applicable to T_c only)	Units	Segment ID: AB		Total
1. Surface description (table 5-7)		Woods, lt.brush		
2. Manning's roughness coeff., n (table 5-7)		0.40		
3. Flow length, L (total L $\le$ 300 ft)	ft	200		
4. Two-yr 24-hr rainfall, P_2 (worksheet 2)	in	3.5		
5. Land slope, s	ft/ft	0.02		
6. $T_t = \frac{0.007\ (nL)^{0.8}}{P_2^{0.5}\ s^{0.4}}$ Compute T_t	hr	0.60	+	= 0.60

Shallow concentrated flow	Units	Segment ID: BC		Total
7. Surface description (paved or unpaved)		Unpaved		
8. Flow length, L	ft	500		
9. Watercourse slope, s	ft/ft	0.04		
10. Average velocity, V (Plate 5-23)	ft/s	3.2		
11. $T_t = \frac{L}{3600\ V}$ Compute T_t	hr	0.04	+	= 0.04

Channel flow	Units	Segment ID: CD	DE	Total
12. Cross sectional flow area, a	ft^2	8.0	27	
13. Wetted perimeter, p_w	ft	7.6	21.6	
14. Hydraulic radius, $r = \frac{a}{p_w}$ Compute r	ft	1.05	1.25	
15. Channel slope, s	ft/ft	0.02	0.005	
16. Manning's roughness coeff., n		0.08	0.06	
17. $V = \frac{1.49\ r^{2/3}\ s^{1/2}}{n}$ Compute V	ft/s	2.72	2.04	
18. Flow length, L	ft	1500	2500	
19. $T_t = \frac{L}{3600\ V}$ Compute T_t	hr	0.15	+ 0.34	= 0.49

20. Watershed or subarea T_c or T_t (add T_t in steps 6, 11, and 19) .... hr 1.13

Example 5-4

Given: Drainage Area = 250 Acs. (0.39 mi^2)

$CN = 68$
$T_c = 1.13$ hr.

Find: Pre-developed peak discharge for 2-year and 10-year storms.

Solution: (See worksheet 4 at the end of solution for Example 5-4.)

2-year storm	10-year storm
P_2 = 3.5 in. (Plate 5-19)	P_{10} = 5.5 in. (Plate 5-20)
I_a = 0.941 in.	I_a = 0.941 in. (Table 5-9)
$I_a/P_2 = \frac{0.941}{3.5} = 0.27$	$I_a/P_{10} = \frac{0.941}{5.5} = 0.17$

Peak discharge: $q = q_u A_m Q$ $\qquad A_m = 250/640 = 0.39 \text{ mile}^2$

2-year storm	10-year storm
q_{u2} = 290 csm/in	q_{u10} = 320 csm/in (Plate 5-25)
Q_2 = 0.90	Q_{10} = 2.24 (Plate 5-22)
q_2 = 290 x 0.39 x 0.90 = 102 cfs	q_{10} = 320 x 0.39 x 2.24 = 280cfs

Since there are no ponds or swamps, the correction factor (F_p) is 1.0. Therefore, peak discharges are correct as computed above.

Worksheet 4: Graphical Peak Discharge method

Project Defiance Ridge By ESC Date 2-4-91

Location Campbell County, Virginia Checked SWM Date 2-5-91

Circle one: Present Developed

1. Data:

Drainage area .... A_m = 0.39 mi^2 (acres/640)

Runoff curve number .... CN = 68 (From worksheet 2)

Time of concentration .. T_c = 1.13 hr (From worksheet 3)

Rainfall distribution type = II (I, IA, II, III) (From Plate 5-27)

Pond and swamp areas spread throughout watershed ...... = 0 percent of A_m (0 acres or mi^2 covered)

			Storm #1	Storm #2	Storm #3
2.	Frequency	yr	2	10	
3.	Rainfall, P (24-hour) (Worksheet 2)...................	in	3.5	5.5	
4.	Initial abstraction, I_a .... (Use CN with table 5-5 .)	in	0.941	0.941	
5.	Compute I_a/P		0.27	0.17	
6.	Unit peak discharge, q_u .... (Use T_c and I_a/P with Plate 5-25)	csm/in	290	320	
7.	Runoff, Q .... (From worksheet 2).	in	0.90	2.24	
8.	Pond and swamp adjustment factor, F_p .... (Use percent pond and swamp area with table 5-10. Factor is 1.0 for zero percent pond and swamp area.)		1.0	1.0	
9.	Peak discharge, q_p .... (Where $q_p = q_u A_m Q F_p$)	cfs	102	280	

<u>Example 5-5 (developed condition):</u>

The same watershed as in the previous examples is subdivided and developed. The project is named Defiance Ridge. 40% of the 250 acres is 1/2 acre lots on the Appling soil; 10% is commercial on the Appling soil; 30% is 1/2 acre lots on the Helena soil; and 20% is open space on the Helena soil. All hydrologic conditions are good cover. The streets are paved with curb and gutter. They are laid out in such a way as to decrease overland flow to 100' in a lawn. Then water flows onto the streets and paved gutters and continues until it reaches the natural channel. (This is the same point at which channel flow began in pre-developed conditions.) Total length of street and gutter flow is 700′ at an average of 3% grade.

<u>Find</u>: The post-development runoff curve number for the drainage area, the runoff for the 2-year and 10-year storms, the time of concentration, and the peak discharges for the 2-year and 10-year storms.

<u>Solution</u>: See worksheets 2, 3, and 4, labeled example 5-5 "developed condition," (next three pages) for the solutions.

Since the development of Defiance Ridge will increase the peak discharge of the 2-year storm over the pre-developed conditions, provisions must be made to address the increase in runoff. (The 1/100 rule does not apply since the project area is greater than one percent of total drainage area at the discharge end of the project. See Chapter 4 for more details.)

The site design could include measures that would reduce the volume of runoff (by using infiltration and retention), reduce the peak discharge rate (detention), or improve the receiving channel to convey the increased runoff. Note that any improvements to the channel should be based on the post-development hydrology. See Chapter 4 and the E&S Regulations, Minimum Standard #19, for more details. Detention storage can be provided at the lower end of the development to store and release the post-development 2-year storm runoff at the pre-development 2-year storm peak. See Chapter 5, Part II, Stormwater Detention, for more information.

Worksheet 2: Runoff curve number and runoff

Project Defiance Ridge By ESC Date 2-4-91

Location Campbell County, Virginia Checked SWM Date 2-5-91

Circle one: Present Developed D.A. 250 acs.

1. Runoff curve number (CN)

Soil name and hydrologic group Appendix 6C	Cover description (cover type, treatment, and hydrologic condition; percent impervious; unconnected/connected impervious area ratio)	CN 1/ Table 5-5	CN 1/ Fig. 2-3	CN 1/ Fig. 2-4	Area ☐ acres ☐ mi² ☑ %	Product of CN x area
Appling, B	1/2 Ac. Lots, Good Condition	70			40	2800
Appling, B	Commercial	92			10	920
Helena, C	1/2 Ac. Lots, Good Condition	80			30	2400
Helena, C	Open Space, Good Condition	74			20	1480
				Totals =	100	7600

1/ Use only one CN source per line.

CN (weighted) = $\frac{\text{total product}}{\text{total area}} = \frac{7600}{100} = 76$; Use CN = $\boxed{76}$

2. Runoff

	Storm #1	Storm #2	Storm #3
Frequency .... yr	2	10	
Rainfall, P (24-hour) (Plates 5-19,5-20) in	3.5	5.5	
Runoff, Q .... in (Use P and CN with table 5-6, Plate 5-20 or eqs. Plate 5-22)	1.36	2.95	

Worksheet 3: Time of concentration (T_c) or travel time (T_t)

1992

Project: Defiance Ridge   By: ESC   Date: 2-4-91

Location: Campbell County, Virginia   Checked: SWM   Date: 2-5-91

Circle one: Present **Developed**

Circle one: **T_c** T_t through subarea

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

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

Sheet flow (Applicable to T_c only)

	Units	Segment ID: AB	Segment ID: (blank)	Total
1. Surface description (table 5-7)		Lawn		
2. Manning's roughness coeff., n (table 5-7)		0.24		
3. Flow length, L (total L $\leq$ 300 ft)	ft	100		
4. Two-yr 24-hr rainfall, P_2 (Worksheet 2)	in	3.5		
5. Land slope, s (From Problem # 5-3)	ft/ft	0.02		
6. $T_t = \dfrac{0.007\,(nL)^{0.8}}{P_2^{\,0.5}\,s^{0.4}}$ Compute T_t	hr	0.23	+	= 0.23

Shallow concentrated flow

	Units	Segment ID: BC	Segment ID: (blank)	Total
7. Surface description (paved or unpaved)		Paved		
8. Flow length, L	ft	700		
9. Watercourse slope, s	ft/ft	0.03		
10. Average velocity, V (Plate 5-23)	ft/s	3.5		
11. $T_t = \dfrac{L}{3600\,V}$ Compute T_t	hr	0.06	+	= 0.06

Channel flow

	Units	Segment ID: CD	Segment ID: DE	Total
12. Cross sectional flow area, a	ft^2	8	27	
13. Wetted perimeter, p_w	ft	7.6	21.6	
14. Hydraulic radius, $r = \dfrac{a}{p_w}$ Compute r	ft	1.05	1.25	
15. Channel slope, s	ft/ft	0.02	0.005	
16. Manning's roughness coeff., n		0.08	0.06	
17. $V = \dfrac{1.49\,r^{2/3}\,s^{1/2}}{n}$ Compute V	ft/s	2.70	2.04	
18. Flow length, L	ft	1500	2500	
19. $T_t = \dfrac{L}{3600\,V}$ Compute T_t	hr	0.15	+ 0.34	= 0.49

20. Watershed or subarea T_c or T_t (add T_t in steps 6, 11, and 19) .... hr **0.78**

Worksheet 4: Graphical Peak Discharge method

Project Defiance Ridge By ECC Date 2-4-91

Location Campbell County, Virginia Checked SWM Date 2-5-91

Circle one: Present Developed

1. Data:

Drainage area .... A_m = 0.39 mi^2 (acres/640)

Runoff curve number .... CN = 76 (From worksheet 2)

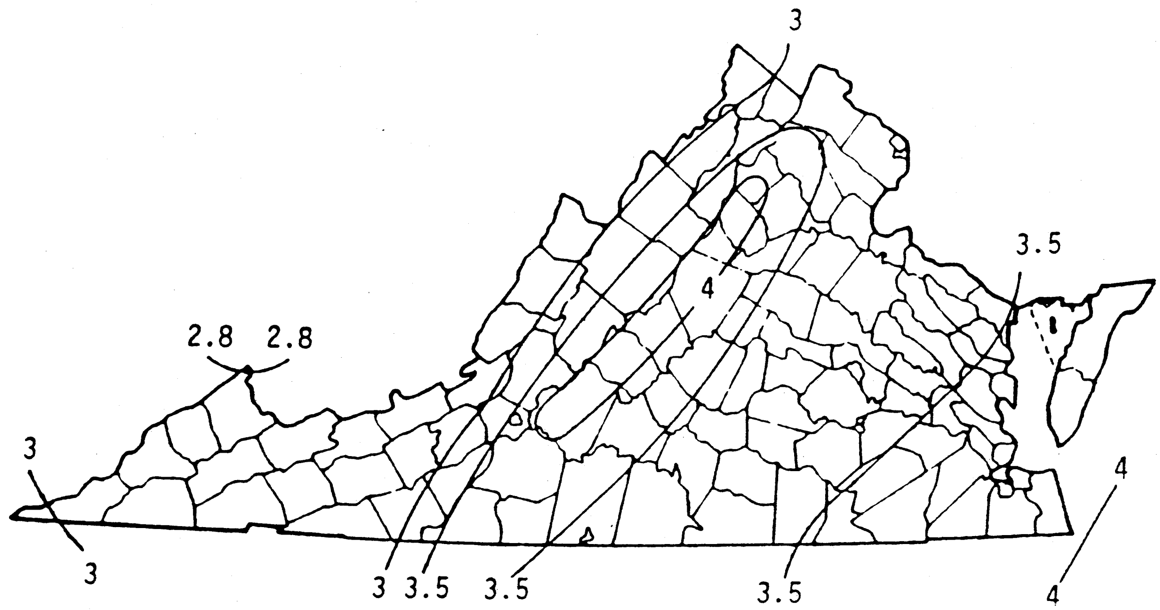
Time of concentration .. T_c = 0.78 hr (From worksheet 3)

Rainfall distribution type = II (I, IA, II, III)

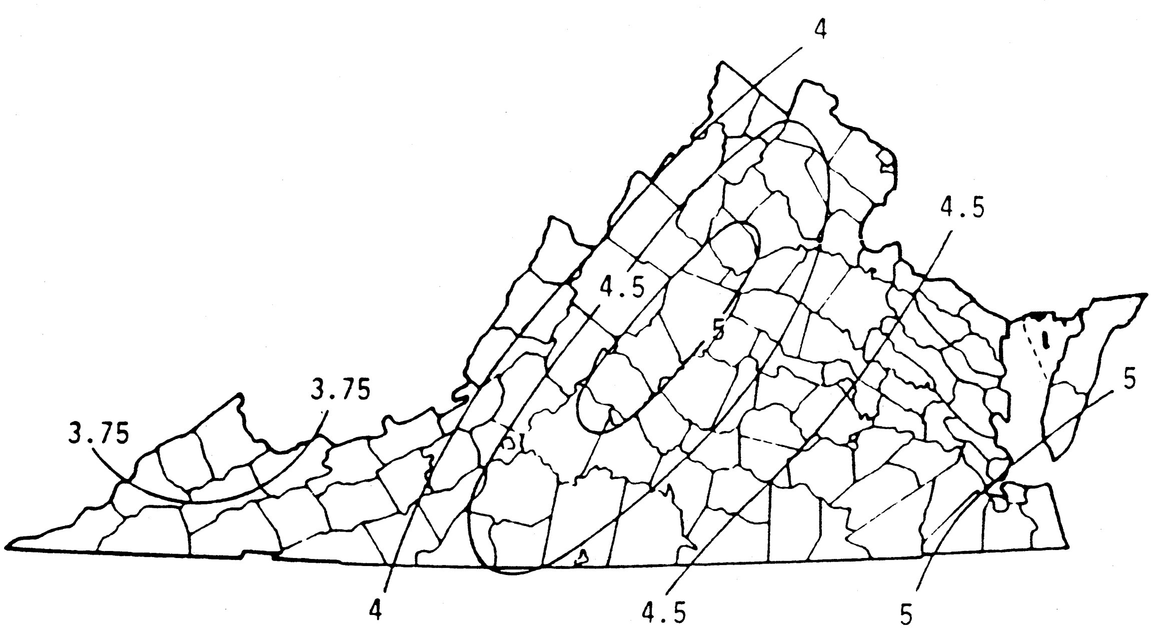
Pond and swamp areas spread throughout watershed ...... = 0 percent of A_m (0 acres or mi^2 covered)

			Storm #1	Storm #2	Storm #3
2.	Frequency	yr	2	10	
3.	Rainfall, P (24-hour) (Worksheet 2)	in	3.5	5.5	
4.	Initial abstraction, I_a .... (Use CN with table 5-5)	in	0.632	0.632	
5.	Compute I_a/P		0.18	0.11	
6.	Unit peak discharge, q_u .... (Use T_c and I_a/P with Plate 5-25)	csm/in	380	410	
7.	Runoff, Q .... (From worksheet 2).	in	1.36	2.95	
8.	Pond and swamp adjustment factor, F_p .... (Use percent pond and swamp area with table 5-10. Factor is 1.0 for zero percent pond and swamp area.)		1.0	1.0	
9.	Peak discharge, q_p .... (Where $q_p = q_u A_m Q F_p$)	cfs	202	472	

RAINFALL DEPTHS FOR SELECTED DESIGN STORMS



2-YEAR 24-HOUR RAINFALL (INCHES)

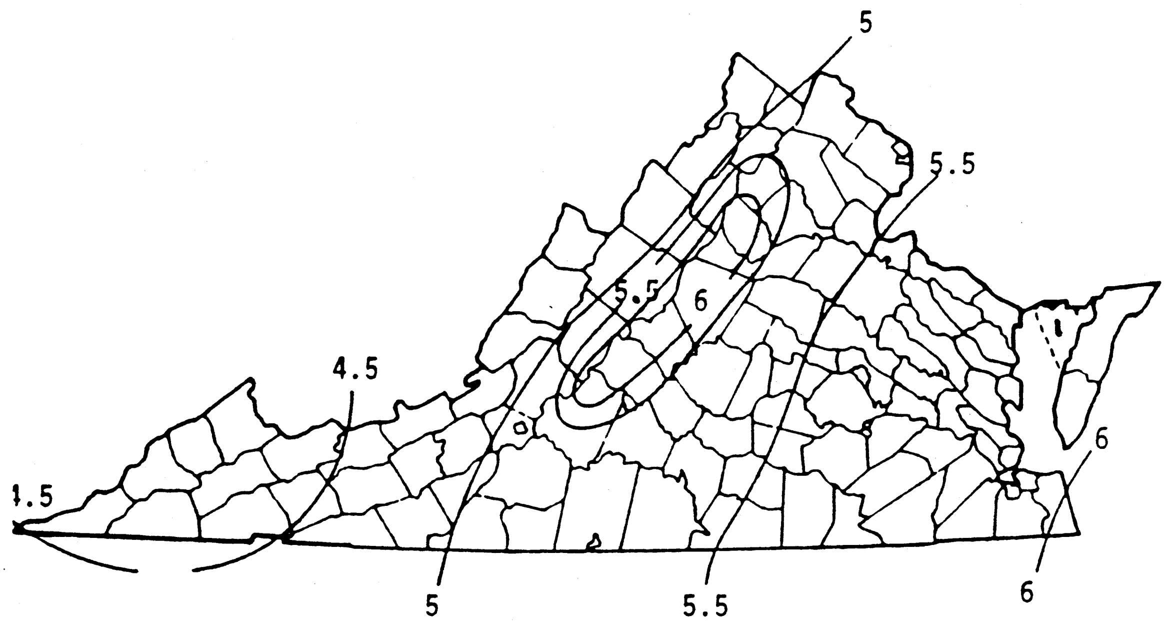


5-YEAR 24-HOUR RAINFALL (INCHES)

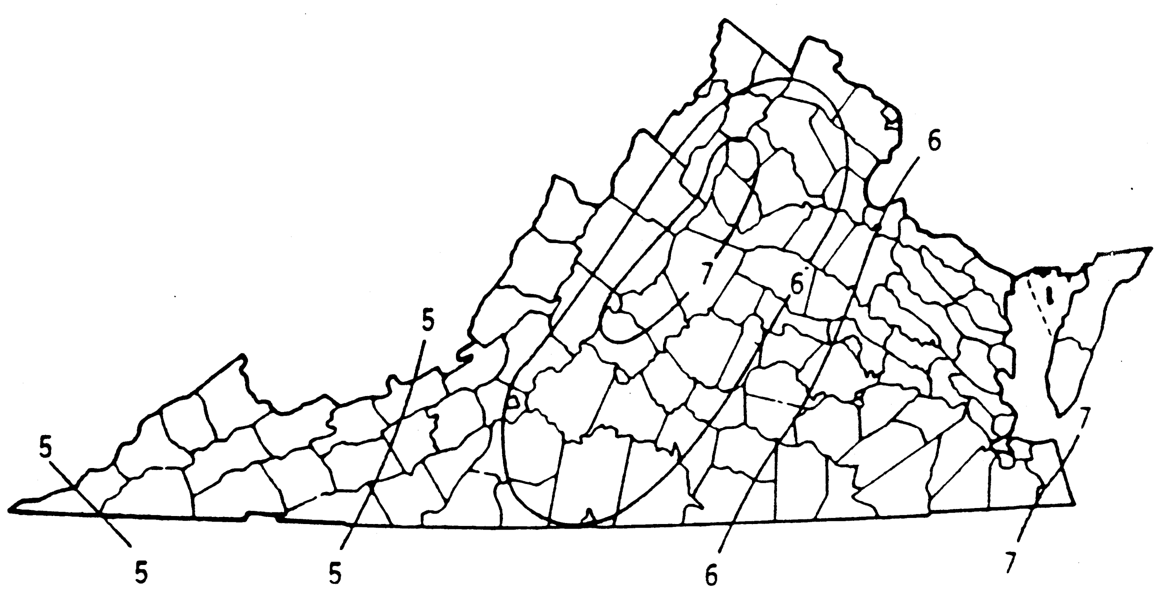
Source: USDA-SCS and U.S. Weather Bureau

Plate 5-19

RAINFALL DEPTHS FOR SELECTED DESIGN STORMS (continued)



10-YEAR 24-HOUR RAINFALL (INCHES)

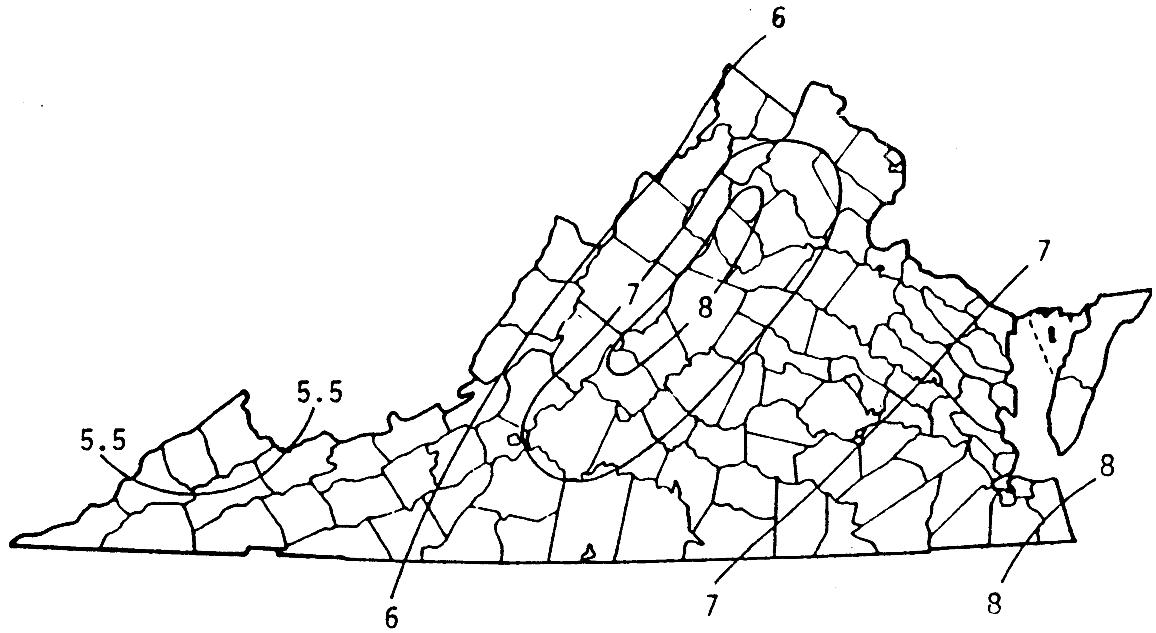


25-YEAR 24-HOUR RAINFALL (INCHES)

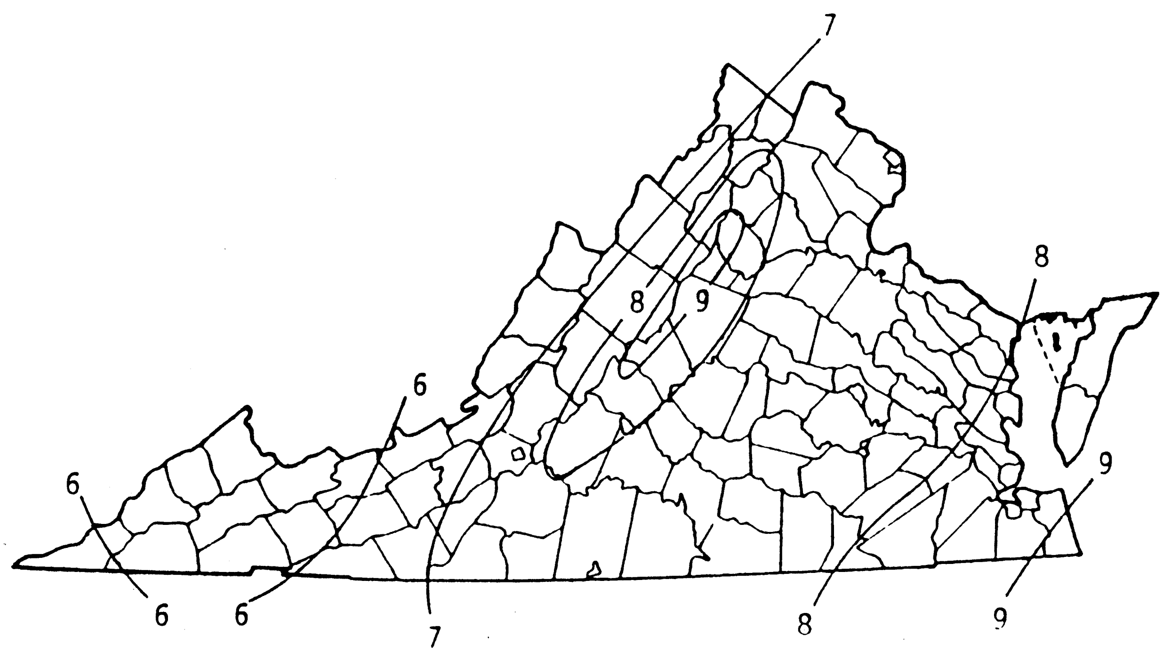
Source: USDA-SCS and U.S. Weather Bureau

Plate 5-20

RAINFALL DEPTHS FOR SELECTED DESIGN STORMS (continued)



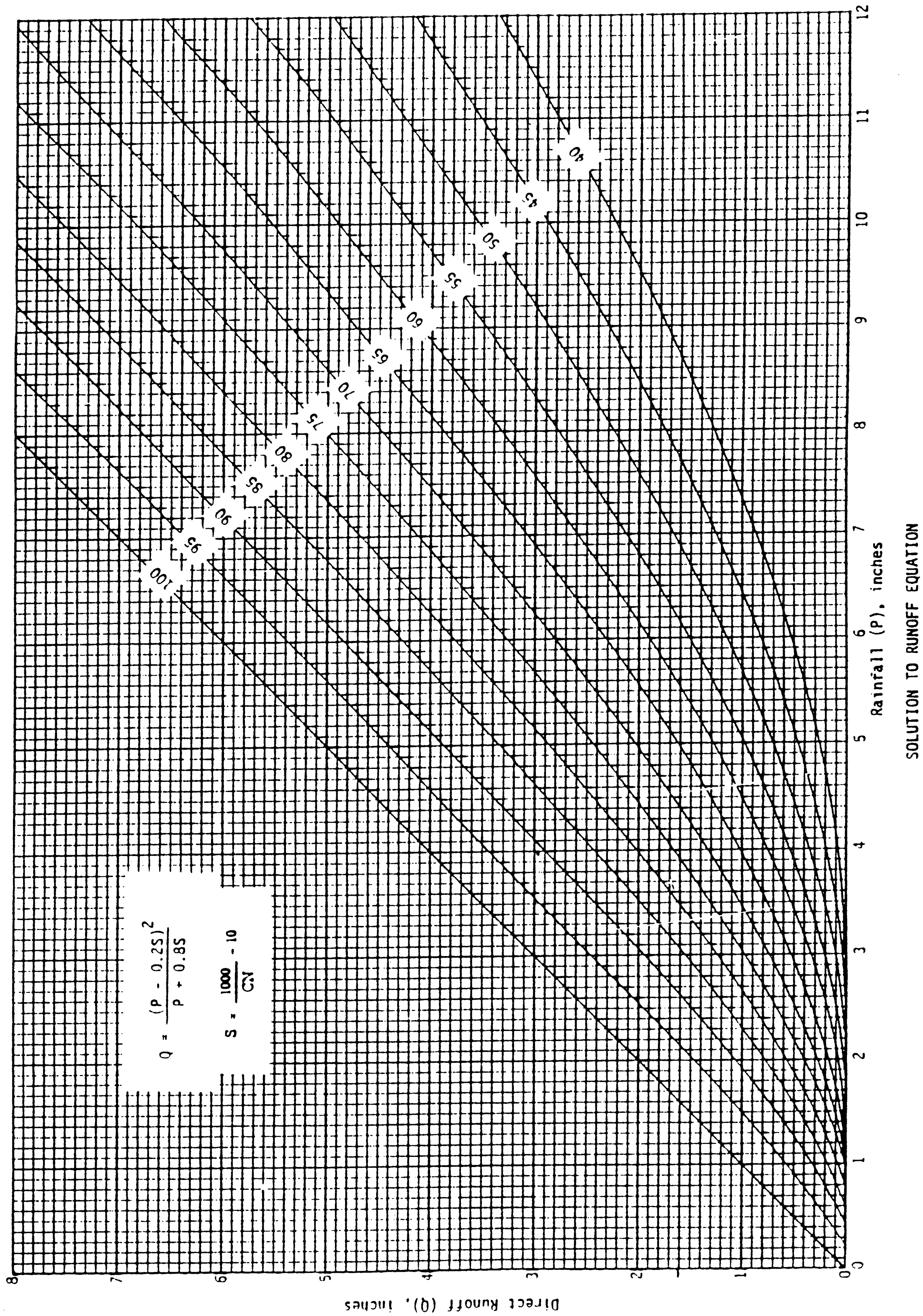
50-YEAR 24-HOUR RAINFALL (INCHES)



100-YEAR 24-HOUR RAINFALL (INCHES)

Source: USDA-SCS and U.S. Weather Bureau

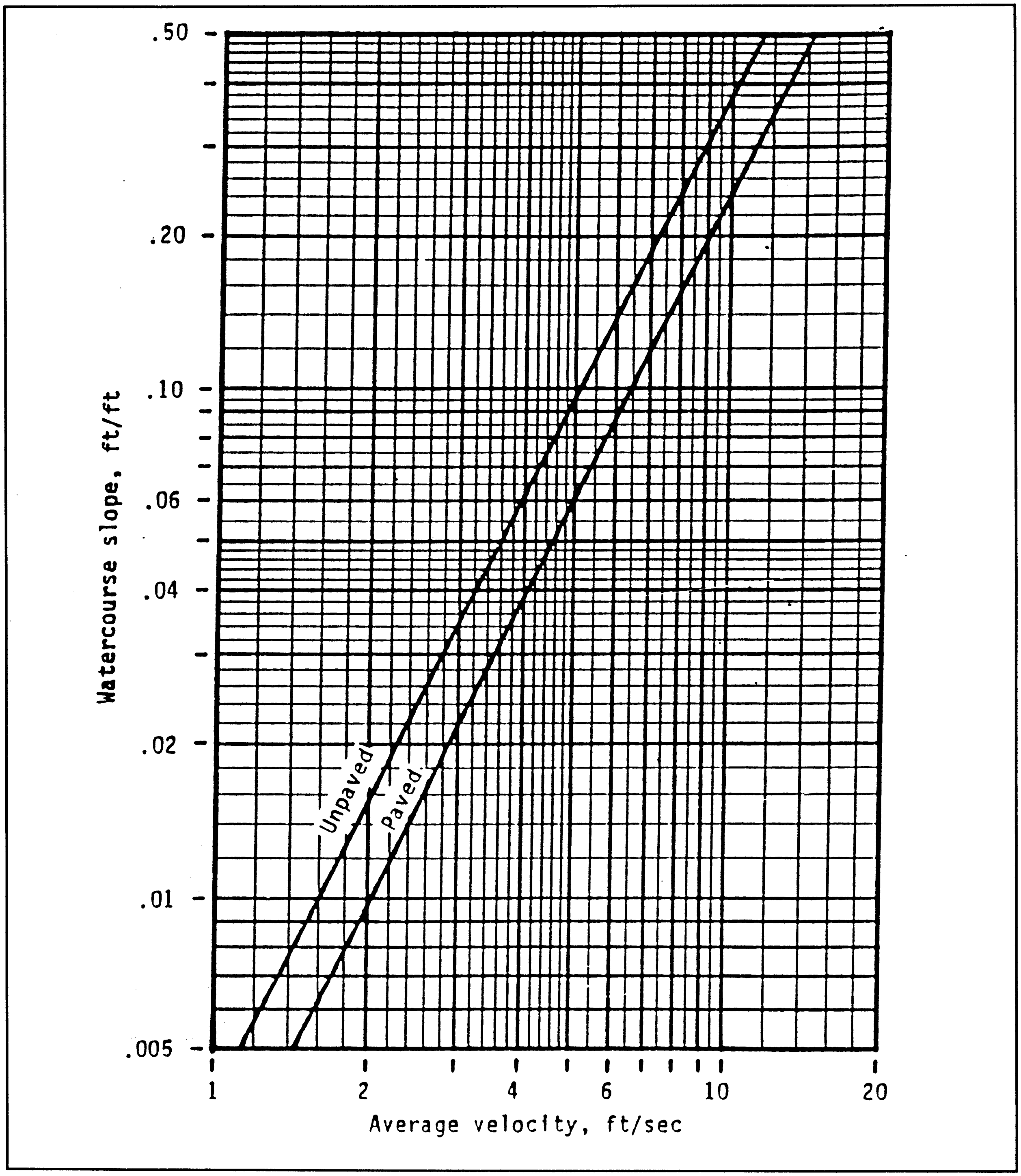
Plate 5-21



Source: USDA-SCS

Plate 5-22

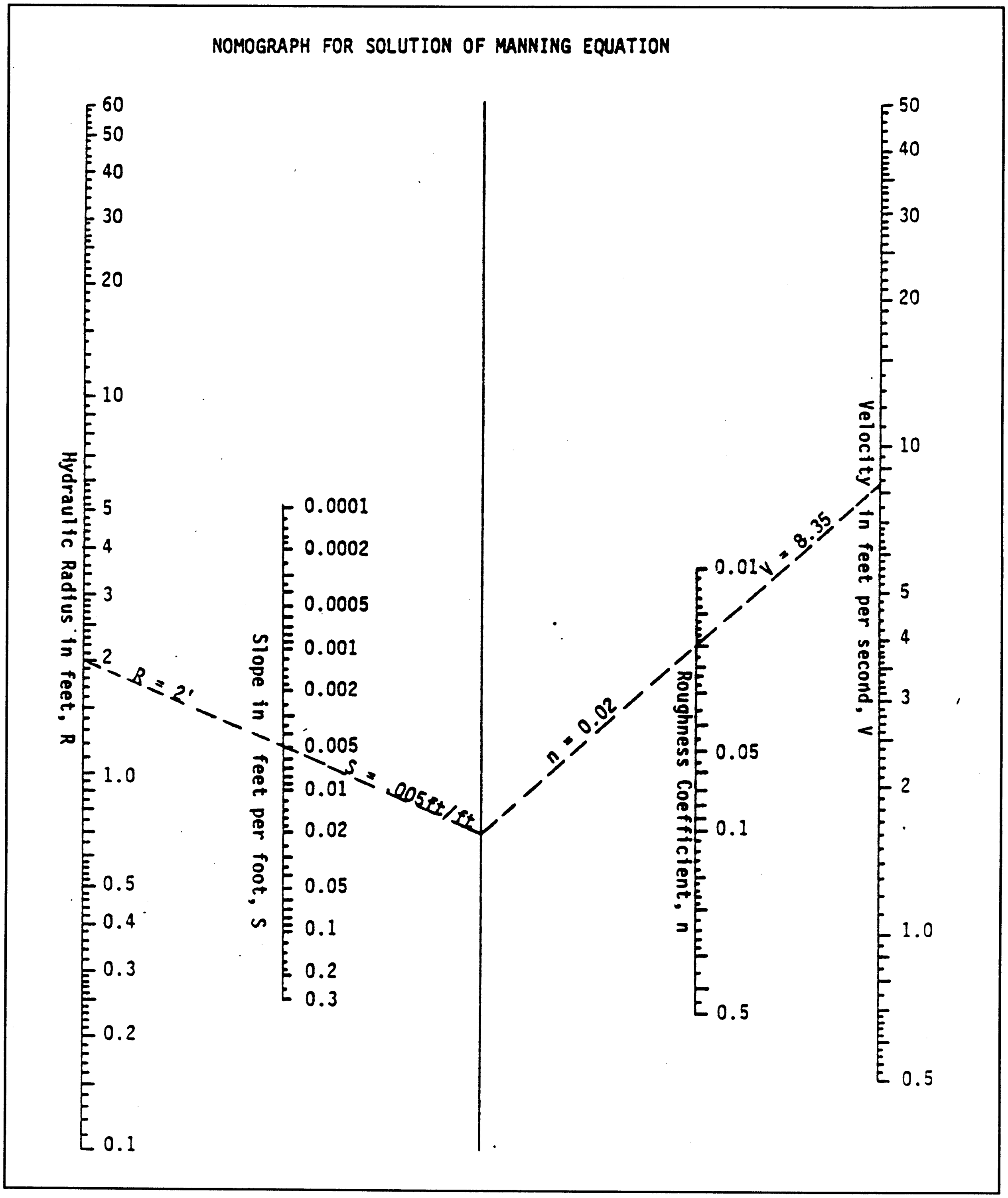
AVERAGE VELOCITIES FOR ESTIMATING TRAVEL TIME FOR SHALLOW CONCENTRATED FLOW



Source: USDA-SCS

Plate 5-23

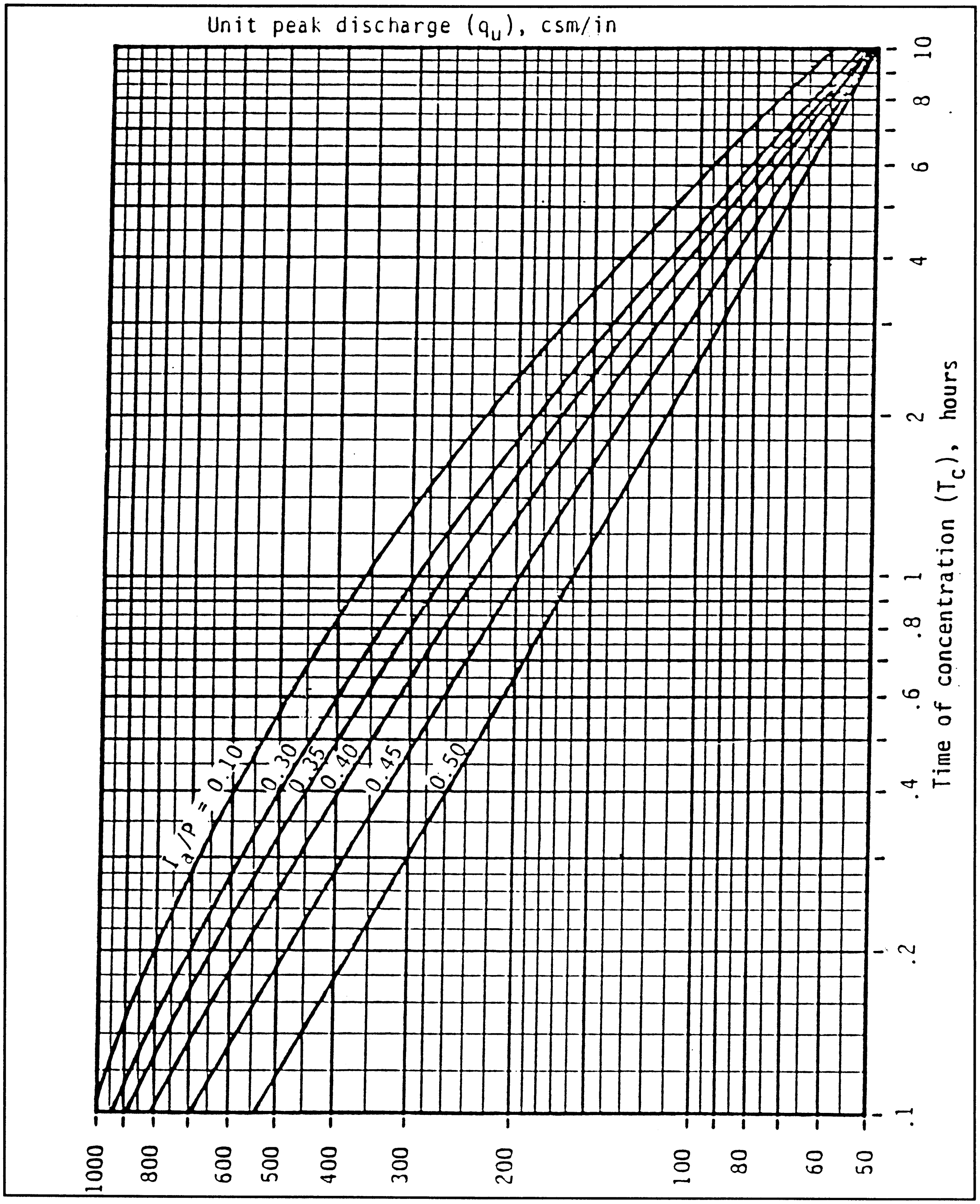
NOMOGRAPH FOR SOLUTION OF MANNING EQUATION



Source: VDOT

Plate 5-24

UNIT PEAK DISCHARGE (q_u) FOR SCS TYPE II RAINFALL DISTRIBUTION



Source: USDA-SCS

Plate 5-25

TABLE 5-5*

RUNOFF CURVE NUMBERS FOR GRAPHICAL PEAK DISCHARGE METHOD

COVER DESCRIPTION			HYDROLOGIC SOIL GROUP A	B	C	D
Fully Developed Urban Areas (Vegetation Established)						
Open Space (lawns, parks, etc.)	Poor Condition; Grass		68	79	86	89
	Fair Condition; Grass 50 - 75% cover		49	69	79	84
	Good Condition; Grass > 75% cover		39	61	74	80
Impervious Areas	Paved parking lots, roofs, driveways		98	98	98	98
Streets and Roads	Paved; curbs and storm sewers		98	98	98	98
	Paved; open ditches (w/right-of-way)		83	89	92	93
	Gravel (with right-of-way)		76	85	89	91
	Dirt (with right-of-way)		72	82	87	89
Urban Districts		Average % Impervious				
	Commercial and Business	85	89	92	94	95
	Industrial	72	81	88	91	93

* Refer to the TR-55 document for a complete table of runoff curve numbers and additional information on selecting the runoff curve number.

Source: USDA-SCS

TABLE 5-5* (continued)
RUNOFF CURVE NUMBERS FOR
GRAPHICAL PEAK DISCHARGE METHOD

COVER DESCRIPTION			HYDROLOGIC SOIL GROUP A	B	C	D
		Average % Impervious				
Residential Districts (by average lot size)	1/8 acre (town house)	65	77	85	90	92
	1/4 acre	38	61	75	83	87
	1/3 acre	30	57	72	81	86
	1/2 acre	25	54	70	80	85
	1 acre	20	51	68	79	84
	2 acres	12	46	65	77	82
Urban Areas - Development Underway, No Vegetation Established						
Newly graded area			81	89	93	95
Pavement and Roofs, Commercial & Business Areas			98	98	98	98
Row Houses, Town Houses and Residential w/lot sizes:	1/8 acre or less		93	96	97	98
	1/4 acre		88	93	95	97
	1/2 acre		85	91	94	96
	1 acre		82	90	93	95
	2 acres		81	89	92	94
Cultivated Agricultural Lands						
Fallow:	Bare Soil		77	86	91	94
	Crop Residue (CR) poor		76	85	90	93
	Crop Residue (CR) good		74	83	88	90

* Refer to the TR-55 document for a complete table of runoff curve numbers and additional information on selecting the runoff curve number.

TABLE 5-5* (continued)

RUNOFF CURVE NUMBERS FOR GRAPHICAL PEAK DISCHARGE METHOD

COVER DESCRIPTION		HYDROLOGIC SOIL GROUP A	B	C	D
Cultivated Agricultural Lands (continued)					
Row Crops:	Straight row (SR) poor	72	81	88	91
	Straight row (SR) good	67	78	85	89
	Contoured (C) poor	70	79	84	88
	Contoured (C) good	65	75	82	86
	Contoured and Terraced (C&T) poor	66	74	80	82
	Contoured and Terraced (C&T) good	62	71	78	81
Other Agricultural Lands					
Pasture, grassland or range	poor	68	79	86	89
	fair	49	69	79	84
	good	39	61	74	80
Meadow		30	58	71	78
Brush - brush, weed, grass mix	poor	48	67	77	83
	fair	35	56	70	77
	good	30	48	65	73
Woods - grass combination	poor	57	73	82	86
	fair	43	65	76	82
	good	32	58	72	79

* Refer to the TR-55 document for a complete table of runoff curve numbers and additional information selecting the runoff curve number.

TABLE 5-5* (continued)

RUNOFF CURVE NUMBERS FOR GRAPHICAL PEAK DISCHARGE METHOD

COVER DESCRIPTION		HYDROLOGIC SOIL GROUP			
		A	B	C	D
Other Agricultural Lands (continued)					
Woods	poor	45	66	77	83
	fair	36	60	73	79
	good	30	55	70	77
Porous Pavement**					
	Gravel Subbase Thickness (inches)				
Porous Pavement (Properly Maintained)	10	57	66	69	75
	18	53	61	64	69
	24	52	58	61	66
	36	47	52	55	58
Porous Pavement (Not Properly Maintained)	10 - 36	98	98	98	98

* Refer to the TR-55 document for a complete table of runoff curve numbers and additional information on selecting runoff curve number.

** This information is not intended for design purposes.

TABLE 5-6
RUNOFF DEPTH FOR SELECTED CN's AND RAINFALL AMOUNTS[1]

Runoff depth for curve number of ____

Rainfall	40	45	50	55	60	65	70	75	80	85	90	95	98
							inches						
1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.08	0.17	0.32	0.56	0.79
1.2	.00	.00	.00	.00	.00	.00	.03	.07	.15	.27	.46	.74	.99
1.4	.00	.00	.00	.00	.00	.02	.06	.13	.24	.39	.61	.92	1.18
1.6	.00	.00	.00	.00	.01	.05	.11	.20	.34	.52	.76	1.11	1.38
1.8	.00	.00	.00	.00	.03	.09	.17	.29	.44	.65	.93	1.29	1.58
2.0	.00	.00	.00	.02	.06	.14	.24	.38	.56	.80	1.09	1.48	1.77
2.5	.00	.00	.02	.08	.17	.30	.46	.65	.89	1.18	1.53	1.96	2.27
3.0	.00	.02	.09	.19	.33	.51	.71	.96	1.25	1.59	1.98	2.45	2.77
3.5	.02	.08	.20	.35	.53	.75	1.01	1.30	1.64	2.02	2.45	2.94	3.27
4.0	.06	.18	.33	.53	.76	1.03	1.33	1.67	2.04	2.46	2.92	3.43	3.77
4.5	.14	.30	.50	.74	1.02	1.33	1.67	2.05	2.46	2.91	3.40	3.92	4.26
5.0	.24	.44	.69	.98	1.30	1.65	2.04	2.45	2.89	3.37	3.88	4.42	4.76
6.0	.50	.80	1.14	1.52	1.92	2.35	2.81	3.28	3.78	4.30	4.85	5.41	5.76
7.0	.84	1.24	1.68	2.12	2.60	3.10	3.62	4.15	4.69	5.25	5.82	6.41	6.76
8.0	1.25	1.74	2.25	2.78	3.33	3.89	4.46	5.04	5.63	6.21	6.81	7.40	7.76
9.0	1.71	2.29	2.88	3.49	4.10	4.72	5.33	5.95	6.57	7.18	7.79	8.40	8.76
10.0	2.23	2.89	3.56	4.23	4.90	5.56	6.22	6.88	7.52	8.16	8.78	9.40	9.76
11.0	2.78	3.52	4.26	5.00	5.72	6.43	7.13	7.81	8.48	9.13	9.77	10.39	10.76
12.0	3.38	4.19	5.00	5.79	6.56	7.32	8.05	8.76	9.45	10.11	10.76	11.39	11.76
13.0	4.00	4.89	5.76	6.61	7.42	8.21	8.98	9.71	10.42	11.10	11.76	12.39	12.76
14.0	4.65	5.62	6.55	7.44	8.30	9.12	9.91	10.67	11.39	12.08	12.75	13.39	13.76
15.0	5.33	6.36	7.35	8.29	9.19	10.04	10.85	11.63	12.37	13.07	13.74	14.39	14.76

[1] Interpolate the values shown to obtain runoff depths for CN's or rainfall amounts not shown.

Source: USDA-SCS

TABLE 5-7
ROUGHNESS COEFFICIENTS
(MANNING'S "n") FOR SHEET FLOW

Surface Description	n[1]
Smooth surfaces (concrete, asphalt, gravel, or bare soil)	0.011
Fallow (no residue)	0.05
Cultivated soils:	
Residue cover ≤ 20%	0.06
Residue cover > 20%	0.17
Grass:	
Short grass prairie	0.15
Dense grasses[2]	0.24
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, buffalo grass, blue grama grass, and native grass mixtures.

[3] When selecting n, consider cover to a height of about 0.1 ft. This is the only part of the plant cover that will obstruct sheet flow.

Source: USDA-SCS

TABLE 5-8

MANNING'S "n" VALUES

Surface	Best	Good	Fair	Bad
Uncoated cast-iron pipe	0.012	0.013	0.014	0.015
Coated cast-iron pipe	0.011	0.012*	0.013*	
Commercial wrought-iron pipe, black	0.012	0.013	0.014	0.015
Commercial wrought-iron pipe, galvanized	0.013	0.014	0.015	0.017
Riveted and spiral steel pipe	0.013	0.015*	0.017*	
Common clay drainage tile	0.011	0.012*	0.014*	0.017
Neat cement surfaces	0.010	0.011	0.012	0.013
Cement mortar surfaces	0.011	0.012	0.013*	0.015
Concrete pipe	0.012	0.013	0.015*	0.016
Concrete-lined channels	0.012	0.014*	0.016*	0.018
Cement-rubble surface	0.017	0.020	0.025	0.030
Dry-rubble surface	0.025	0.030	0.033	0.035
Canals and ditches:				
Earth, straight and uniform	0.017	0.020	0.0225*	0.025
Rock cuts, smooth and uniform	0.025	0.030	0.033	0.035
Rock cuts, jagged and irregular	0.035	0.040	0.045	
Winding sluggish canals	0.0225	0.025*	0.0275	0.030
Dredged earth channels	0.025	0.0275*	0.030	0.033
Canals with rough stony beds, weeds on earth banks	0.025	0.030	0.035*	0.040
Earth bottom, rubble sides	0.028	0.030*	0.033*	0.035

* Values commonly used in designing.

Source: King

TABLE 5-8 (continued)

MANNING'S "n" VALUES

Surface	Best	Good	Fair	Bad
Natural Stream Channels:				
1. Clean, straight bank, full stage, no rifts or deep pools	0.025	0.0275	0.030	0.033
2. Same as #1, but some weeds and stones	0.030	0.033	0.035	0.040
3. Winding, some pools and shoals, clean	0.033	0.035	0.040	0.045
4. Same as #3, lower stages, more ineffective slope and sections	0.040	0.045	0.050	0.055
5. Same as #3, some weeds and stones	0.035	0.040	0.045	0.050
6. Same as #4, stony sections	0.045	0.050	0.055	0.060
7. Sluggish river reaches, rather weedy or with very deep pools	0.050	0.060	0.070	0.080
8. Very weedy reaches	0.075	0.100	0.125	0.150

* Values commonly used in designing.

Source: King

TABLE 5-9

I_a VALUES FOR RUNOFF CURVE NUMBERS

Curve Number	I_a (inches)	Curve Number	I_a (inches)	Curve Number	I_a (inches)
40	3.000	60	1.333	80	0.500
41	2.878	61	1.279	81	0.469
42	2.762	62	1.226	82	0.439
43	2.651	63	1.175	83	0.410
44	2.545	64	1.125	84	0.381
45	2.444	65	1.077	85	0.353
46	2.348	66	1.030	86	0.326
47	2.255	67	0.985	87	0.299
48	2.167	68	0.941	88	0.273
49	2.082	69	0.899	89	0.247
50	2.000	70	0.857	90	0.222
51	1.922	71	0.817	91	0.198
52	1.846	72	0.778	92	0.174
53	1.774	73	0.740	93	0.151
54	1.704	74	0.703	94	0.128
55	1.636	75	0.667	95	0.105
56	1.571	76	0.632	96	0.083
57	1.509	77	0.597	97	0.062
58	1.448	78	0.564	98	0.041
59	1.390	79	0.532		

Source: USDA-SCS

TABLE 5-10

ADJUSTMENT FACTOR (F_p) FOR POND AND SWAMP AREAS SPREAD THROUGHOUT THE WATERSHED

Percentage of pond and swamp areas	F_p
0	1.00
0.2	0.97
1.0	0.87
3.0	0.75
5.0	0.72

Source: USDA-SCS

Tabular Method

The Tabular Method of runoff calculation is also described in TR-55 Urban Hydrology for Small Watersheds (62). This method may be used to develop a runoff hydrograph that shows the rate of runoff from the watershed with respect to time for a selected design storm.

The Tabular Method can be used when hydrographs are needed to measure runoff from watersheds which are divided into sub-areas. It is especially applicable for measuring the effects of changed landuse in a part of the watershed. It can also be used to determine the effects of structures and combinations of structures, including channel modifications, at different locations in a watershed. In this procedure, timing of the flow from the different sub-areas becomes very important.

The accuracy of the Tabular Method decreases as the complexity of the watershed increases. Drainage areas of individual sub-areas should not differ by a factor of five (5) or more. For most watershed conditions, however, this procedure is adequate to determine the effects of urbanization on peak rates of discharge for drainage areas up to approximately 20 square miles in size.

It is recommended that the user become familiar with the Peak Discharge Method before attempting the Tabular Method. The user is encouraged to refer to TR-55 for a complete presentation of the Tabular Method.

The basic data needed to use the Tabular Method include:

1. The drainage area of each sub-area.
2. The time of concentration (T_c) for each sub-area.
3. The travel time (T_t) for each routing reach.
4. The runoff curve number (CN) for each sub-area.
5. The 24-hour rainfall for the selected frequency design storm.
6. The runoff depth (in inches) from each sub-area.
7. The initial abstraction (I_a) for each sub-area.

Tables in Exhibit 5-II contain the tabular discharge values for the Type II rainfall distribution used in Example 5-6. Tabular discharges, in terms of CSM (cubic feet per second per square mile) per inch of runoff, are given for a range of T_c values from 0.1 to 2.0 hours and T_t values from 0 to 3.0 hours. (Tables for Type I, IA, and III distributions can be found in SCS-TR-55 but are not included here.)

The general procedure for generating a composite hydrograph using the Tabular Method is as follows:

Step 1 - Prepare worksheet 5a, as in example 5-6, which provides a summary of all basic data needed for the tabular hydrograph. The following basic information is needed for the worksheet:

a. Define the drainage areas and determine the area of each sub-area in square miles (A_m). Also define the main channel reaches that drain each sub-area.

b. Determine the time of concentration (T_c) for each sub-area (e.g., the time of flow from the most remote point in the sub-area to the outlet of sub-area, in hours).

c. Determine a runoff curve number (CN) for each sub-area. (See step 2 of the graphical peak discharge method.)

d. List rainfall (P) from Plates 5-19 through 5-21 and determine the runoff depth (in inches) for each sub-area. (See step 3a and 3b of the graphical peak discharge method.)

e. Determine the travel time (T_t) in the main channel reaches of sub-areas through which runoff from other sub-areas is routed.

f. Determine I_a from Table 5-9 and divide by rainfall (P) for each sub-area.

Step 2 - On worksheet 5b, place the basic watershed data used by rounding T_c, T_t, and I_a/P values to the nearest Table values in Exhibit 5-II. Use the value that is closest to the sum of the actual values of the sum of T_c and T_t. I_a/P can be the nearest Table value or unit discharge (CSM/in) interpolation between I_a/P values.

Step 3 - Develop individual hydrographs for each sub-area at the point of interest by multiplying the tabular value by the drainage area (A_m) and the runoff (Q). (A_mQ were previously determined on worksheet 5a, so all that remains is to multiply A_mQ by each tabular value under each time selected on Worksheet 5b.)

Note: Time values should be selected from Exhibit 5-II that will produce the composite hydrograph peak. **The composite hydrograph peak does not necessarily coincide with the peak of the individual sub-area at the point of interest in the watershed.**

Step 4 - The composite hydrograph is the summation of the individual hydrographs for each sub-area that have been routed to the point of interest in the watershed. Develop the composite hydrograph by summation of each column on worksheet 5b.

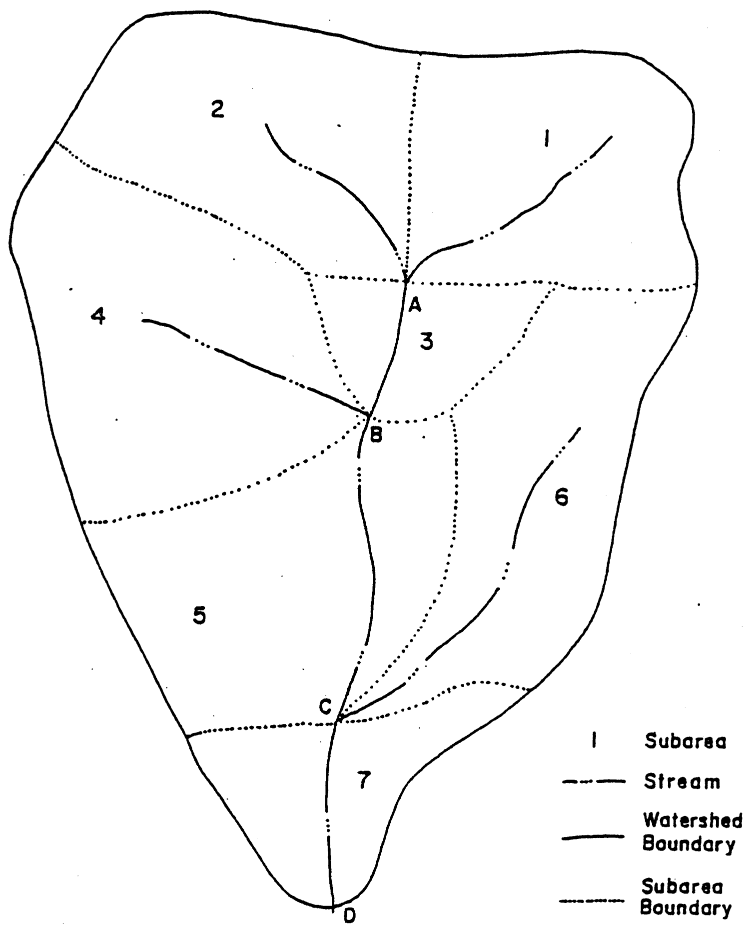
Example 5-6

The 1.65 square mile watershed (shown below) is to be developed according to a pre-conceived landuse plan. The current proposal is to develop sub-areas 5,6 and 7. The development includes a variety of landuses ranging from single-family dwellings and industrial parks.

<u>Find:</u> The effect of the development would have on the 2-year discharge at the lower end of sub-area 7.

<u>EXAMPLE 5-6</u>

The 1.65-square-mile watershed below is to be developed according to a pre-conceived land use plan. Proposed land use ranges from one-half acre residential lots in sub-area 1 to an industrial district in sub-area 7. Determine what effect the development would have on the 2-year discharge at the lower end of sub-area 7.



In solving example 5-6, the following information should be noted:

1. Information required in steps 1a-f was determined for both the "present" condition and the "developed" condition of the watershed for the 2-year frequency design storm. The data was measured from the map and derived from a landuse plan for the watershed and is summarized on worksheet 5a. Separate worksheets are used for "present" and "developed" conditions.

2. Drainage areas (A_m) were multiplied by runoff (Q) and placed on Worksheet 5a and later transferred to Worksheet 5b.

3. Sub-area T_c and ΣT_t used were the computed values as no rounding was necessary to fit the values in the Tables. I_a/P values were rounded to the nearest values in the Tables.

4. The appropriate sheet from Exhibit 5-II was selected for each sub-area based on T_c listed in the middle of that sheet. The I_a/P value was then selected and a straight edge placed on the line for the appropriate travel time (ΣT_t) on the left edge of the sheet.

5. Hydrograph time values were selected to best define the composite hydrograph from the top of the sheet and placed at the top of Worksheet 5b.

6. Unit discharge values (CSM/in) for each time value were selected at the straight edge and multiplied by the A_mQ value determined in 2 above. This process was followed for each sub-area.

7. The columns under each hydrograph time were added to produce the composite hydrograph at the lower end of sub-area 7.

Worksheet 5a: Basic watershed data

Project Sugar Hill   Location Campbell County, Va.   By EC   Date 2-5-91

Circle one: Present Developed ____   Frequency (yr) 2   Checked SM   Date 2-6-91

Subarea name	Drainage area A_m (mi^2)	Time of concentration T_c (hr)	Travel time through subarea T_t (hr)	Downstream subarea names	Travel time summation to outlet ΣT_t (hr)	24-hr Rainfall P (in)	Runoff curve number CN	Runoff Q (in)	A_mQ (mi^2-in)	Initial abstraction I_a (in)	I_a/P
1	0.30	1.50	--	3, 5, 7	2.50	3.5	65	0.75	0.23	1.077	0.31
2	0.20	1.25	--	3, 5, 7	2.50	3.5	70	1.01	0.20	0.857	0.24
3	0.10	0.50	0.50	5, 7	2.00	3.5	75	1.30	0.13	0.667	0.19
4	0.25	0.75	--	5, 7	2.00	3.5	70	1.01	0.25	0.857	0.24
5	0.20	1.50	1.25	7	0.75	3.5	75	1.30	0.26	0.667	0.19
6	0.40	1.50	--	7	0.75	3.5	70	1.01	0.40	0.857	0.24
7	0.20	1.25	0.75	--	0	3.5	75	1.30	0.26	0.667	0.19

From worksheet 3 (Time of concentration, Travel time through subarea) · From worksheet 2 (Runoff curve number, Runoff) · From table 5-7 (Initial abstraction)

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Worksheet 5b: Tabular hydrograph discharge summary

Project Sugar Hill Location Campbell County, Va. By EC Date 2-5-91

Circle one: Present Developed ______ ¹Frequency (yr) 2 Checked SM Date 2-6-91

Subarea name	Basic watershed data used 1/				Select and enter hydrograph times in hours from exhibit 5-II 2/											
	Sub-area T_c (hr)	ΣT_t to outlet (hr)	I_a/P	A_mQ (mi^2-in)	12.7	12.8	13.0	13.2	13.4	13.6	13.8	14.0	14.3	14.6	15.0	15.5
					Discharges at selected hydrograph times 3/ --(cfs)--											
1	1.50	2.50	0.3	0.23	0	0	0	0	0	0	0	0	2	7	20	37
2	1.25	2.50	0.3	0.20	0	0	0	0	0	0	0	1	3	9	24	37
3	0.50	2.00	0.1	0.13	2	2	2	3	5	8	16	26	39	36	24	11
4	0.75	2.00	0.3	0.25	0	0	0	0	1	3	10	21	44	57	50	32
5	1.50	0.75	0.1	0.26	8	11	20	33	47	58	62	61	50	38	27	17
6	1.50	0.75	0.3	0.40	2	4	16	27	46	64	76	79	72	59	44	32
7	1.25	0	0.1	0.26	67	74	81	69	55	42	34	27	20	16	12	10
Composite hydrograph at outlet					79	91	119	132	154	175	198	215	230	222	201	176

1/ Worksheet 5a. Rounded as needed for use with exhibit 5-II
2/ Enter rainfall distribution type used.
3/ Hydrograph discharge for selected times is A_mQ multiplied by tabular discharge from appropriate exhibit 5-II

Worksheet 5a: Basic watershed data

Project Sugar Hill Location Campbell County, Va. By EC Date 2-5-91

Circle one: Present (Developed) ____ Frequency (yr) 2 Checked SM Date 2-6-91

Subarea name	Drainage area A_m (mi^2)	Time of concentration T_c (hr)	Travel time through subarea T_t (hr)	Downstream subarea names	Travel time summation to outlet ΣT_t (hr)	24-hr Rainfall P (in)	Runoff curve number CN	Runoff Q (in)	A_mQ (mi^2-in)	Initial abstraction I_a (in)	I_a/P
1	0.30	1.50	--	3,5,7	2.00	3.5	65	0.75	0.23	1.077	.31
2	0.20	1.25	--	3,5,7	2.00	3.5	70	1.01	0.20	0.857	.24
3	0.10	0.50	0.50	5,7	1.50	3.5	75	1.30	0.13	0.667	.19
4	0.25	0.75	--	5,7	1.50	3.5	70	1.01	0.25	0.857	.24
5	0.20	1.50	1.00	7	0.50	3.5	85	2.02	0.40	0.353	.10
6	0.40	1.00	--	7	0.50	3.5	75	1.30	0.52	0.667	.19
7	0.20	0.75	0.50	--	0	3.5	90	2.45	0.49	0.198	.06

From worksheet 3 (Time of concentration, Travel time through subarea); From worksheet 2 (Runoff curve number, Runoff); From table 5-7 (Initial abstraction)

Worksheet 5b: Tabular hydrograph discharge summary

Project Sugar Hill Location Campbell County, Va. By EC Date 2-5-91

Circle one: Present **Developed** Frequency (yr) 2 Checked SM Date 2-6-91

Subarea name	Basic watershed data used [1/]				Select and enter hydrograph times in hours from exhibit 5-II [2/]											
	Subarea T_c (hr)	ΣT_t to outlet (hr)	I_a/P	$A_m Q$ (mi^2-in)	12.7	12.8	13.0	13.2	13.4	13.6	13.8	14.0	14.3	14.6	15.0	15.5
					Discharges at selected hydrograph times [3/] (cfs)											
1	1.50	2.00	0.3	0.23	0	0	0	0	0	0	1	3	10	22	37	41
2	1.25	2.00	0.3	0.20	0	0	0	0	0	0	1	4	13	26	39	35
3	0.50	1.50	0.1	0.13	3	4	6	12	23	35	42	40	29	18	10	6
4	0.75	1.50	0.3	0.25		0	0	2	9	23	41	55	60	49	33	21
5	1.50	0.50	0.1	0.40	24	32	54	78	95	100	94	82	62	46	32	22
6	1.00	0.50	0.1	0.52	59	83	132	162	156	131	101	77	53	38	28	21
7	0.75	0	0.1	0.49	201	181	123	84	60	46	36	30	24	20	17	15
Composite hydrograph at outlet					287	300	315	338	343	335	316	291	251	219	196	161

1/ Worksheet 5a. Rounded as needed for use with exhibit 5.
2/ Enter rainfall distribution type used.
3/ Hydrograph discharge for selected times is $A_m Q$ multiplied by tabular discharge from appropriate exhibit 5.

Exhibit 5-II: Tabular hydrograph unit discharges (csm/in) for type II rainfall distribution

HYDROGRAPH TIME (HOURS)

TRVL TIME (HR)	11.0	11.3	11.6	11.9	12.0	12.1	12.2	12.3	12.4	12.5	12.6	12.7	12.8	13.0	13.2	13.4	13.6	13.8	14.0	14.3	14.6	15.0	15.5	16.0	16.5	17.0	17.5	18.0	19.0	20.0	22.0	26.0
IA/P = 0.10														* * * TC =0.1 HR * * *														IA/P = 0.10				
0.0	24	34	53	334	647	1010	623	217	147	123	104	86	76	66	57	51	46	42	38	34	32	29	26	23	21	20	19	18	15	13	12	0
.10	21	29	43	134	267	520	847	701	378	224	157	122	98	75	64	56	50	45	41	36	33	30	27	24	21	20	19	18	16	13	12	0
.20	18	25	35	61	110	215	418	704	702	486	312	209	151	94	73	62	54	49	44	38	34	31	28	25	22	21	19	18	16	14	12	0
.30	17	23	33	56	92	174	337	582	662	545	359	269	190	109	79	65	56	50	45	39	35	32	29	25	22	21	20	18	16	14	12	0
.40	15	20	28	41	51	78	142	272	478	601	563	447	328	172	104	76	63	55	49	42	37	33	29	26	23	21	20	19	17	14	12	0
.50	14	19	26	39	47	68	117	220	392	531	553	482	380	209	121	84	67	57	51	43	38	33	30	27	23	21	20	19	17	14	12	0
.75	12	15	21	29	33	38	49	73	126	224	343	432	464	385	252	156	103	76	62	50	43	36	31	28	25	22	21	19	17	15	12	0
1.0	9	12	15	21	23	26	29	33	40	55	86	148	238	406	434	317	205	130	89	62	50	41	34	30	27	24	22	20	18	16	12	0
1.5	7	8	10	14	15	16	18	20	22	25	29	34	45	101	220	339	373	320	234	131	80	53	40	34	30	27	24	21	19	17	12	2
2.0	4	6	7	9	9	10	11	12	13	15	16	18	20	25	37	72	150	252	336	312	216	109	58	42	34	30	27	24	20	18	13	8
2.5	3	4	5	6	7	7	8	8	9	10	11	12	13	16	19	25	39	75	142	262	303	229	108	58	41	34	30	27	22	19	14	11
3.0	1	2	3	4	4	5	5	6	6	7	7	8	8	10	12	14	17	22	31	76	169	288	236	122	64	43	35	30	24	20	16	11
IA/P = 0.30														* * * TC =0.1 HR * * *														IA/P = 0.30				
0.0	0	0	0	154	568	936	524	217	172	149	126	107	97	86	76	69	63	58	53	48	46	42	38	34	31	30	28	27	24	20	19	0
.10	0	0	0	19	109	415	762	603	346	230	176	143	119	96	84	74	68	62	57	50	47	44	40	35	32	30	29	27	24	21	19	0
.20	0	0	0	0	13	77	302	609	605	432	297	217	167	115	94	81	73	66	60	53	48	45	41	37	33	31	29	28	25	21	19	0
.30	0	0	0	0	9	54	219	479	563	476	357	263	199	129	99	85	75	68	62	54	49	45	41	37	33	31	29	28	25	21	19	0
.40	0	0	0	0	0	6	38	159	372	500	484	399	309	183	123	96	82	73	66	58	51	46	42	38	34	31	30	28	25	22	19	0
.50	0	0	0	0	0	4	27	115	287	429	465	421	346	213	138	103	86	76	68	59	52	47	43	39	34	32	30	29	25	22	19	0
.75	0	0	0	0	0	0	1	10	46	132	246	338	381	341	243	165	119	94	80	67	58	50	45	41	37	33	31	29	26	23	19	0
1.0	0	0	0	0	0	0	0	1	4	22	69	149	241	357	331	246	170	122	96	76	64	54	47	42	38	34	32	30	27	24	19	0
1.5	0	0	0	0	0	0	0	0	0	0	0	1	4	41	142	258	310	285	224	142	97	71	55	47	43	39	35	32	29	25	20	4
2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	10	49	130	221	279	255	182	108	70	55	47	42	38	34	30	27	20	11
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	14	52	119	224	256	193	107	70	55	47	42	38	32	28	22	17
3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	9	52	141	240	199	117	74	56	48	43	35	30	24	18
IA/P = 0.50														* * * TC =0.1 HR * * *														IA/P = 0.50				
0.0	0	0	0	0	70	539	377	196	171	154	134	117	108	99	89	83	77	72	67	61	59	56	51	46	43	42	40	38	34	30	28	0
.10	0	0	0	0	47	375	376	256	199	169	146	126	114	102	92	85	79	73	68	62	59	56	52	47	43	42	40	38	34	30	28	0
.20	0	0	0	0	0	31	260	338	283	227	189	160	138	112	99	90	83	77	72	64	60	57	53	48	44	42	41	39	35	30	28	0
.30	0	0	0	0	0	0	21	180	285	284	246	208	176	131	110	97	88	82	76	68	62	59	54	50	45	43	41	39	36	31	28	0
.40	0	0	0	0	0	0	14	125	232	266	253	223	192	142	115	100	91	83	77	69	63	59	55	50	45	43	41	40	36	31	28	0
.50	0	0	0	0	0	0	9	86	183	239	248	231	205	154	122	104	93	85	79	71	64	59	55	51	46	43	41	40	36	32	28	0
.75	0	0	0	0	0	0	3	31	87	147	190	211	213	184	147	121	103	92	84	75	67	61	57	52	47	44	42	40	37	32	28	0
1.0	0	0	0	0	0	0	0	0	1	13	45	92	141	205	197	165	134	112	98	84	75	65	[illegible]	55	50	46	43	41	38	34	28	0
1.5	0	0	0	0	0	0	0	0	0	0	0	2	9	51	118	170	183	167	143	111	92	77	65	59	54	50	45	43	39	35	28	2
2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	15	51	103	148	168	156	127	96	76	65	58	54	49	45	41	37	29	12
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	9	31	69	131	159	140	101	78	66	59	54	50	43	39	31	24
3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	11	46	101	151	134	99	77	65	59	54	45	41	33	26

RAINFALL TYPE = II * * * TC = 0.1 HR * * * SHEET 1 OF 10

Exhibit 5-II, continued: Tabular hydrograph unit discharges (csm/in) for type II rainfall distribution

TRVL TIME (HR)	HYDROGRAPH TIME (HOURS) 11.0	11.3	11.6	11.9	12.0	12.1	12.2	12.3	12.4	12.5	12.6	12.7	12.8	13.0	13.2	13.4	13.6	13.8	14.0	14.3	14.6	15.0	15.5	16.0	16.5	17.0	17.5	18.0	19.0	20.0	22.0	26.0
IA/P = 0.10														* * * TC =0.2 HR * * *																IA/P = 0.10		
0.0	23	31	47	209	403	739	800	481	250	166	128	102	86	70	61	54	49	44	40	35	33	30	27	24	21	20	19	18	16	13	12	0
.10	19	26	39	86	168	325	601	733	565	355	229	161	122	83	69	59	53	47	43	37	34	31	28	25	22	21	19	18	16	14	12	0
.20	17	23	32	49	74	136	262	488	652	594	435	298	207	115	81	67	58	51	46	40	35	32	29	26	23	21	20	19	16	14	12	0
.30	16	22	30	46	64	112	212	396	566	585	485	360	258	139	90	71	60	53	48	41	36	32	29	26	23	21	20	19	16	14	12	0
.40	14	19	25	37	43	57	94	173	322	485	551	507	409	227	129	87	68	58	52	44	38	33	30	27	24	21	20	19	17	14	12	0
.50	13	18	24	35	40	52	80	142	262	410	504	506	441	269	153	98	73	61	53	45	39	34	30	27	24	22	20	19	17	15	12	0
.75	10	13	17	23	26	30	34	40	55	86	150	247	349	438	360	240	151	101	75	57	47	39	33	29	26	23	21	20	18	15	12	0
1.0	9	11	14	19	21	24	26	30	35	44	62	101	167	337	413	353	245	157	104	68	53	42	35	31	28	24	22	20	18	16	12	0
1.5	6	8	10	13	14	15	17	19	21	23	26	30	37	73	166	288	356	337	264	154	91	57	42	35	30	27	24	22	19	17	13	3
2.0	4	5	7	8	9	10	10	11	12	14	15	16	18	23	31	55	114	206	291	324	239	125	63	44	35	31	28	24	20	18	14	9
2.5	3	4	5	6	6	7	7	8	9	9	10	11	12	15	18	22	32	58	111	227	298	246	122	63	43	35	31	27	22	19	15	11
3.0	1	2	3	4	4	4	5	5	6	6	7	7	8	9	11	13	16	19	27	59	138	280	248	137	70	46	36	31	25	21	16	11
IA/P = 0.30														* * * TC =0.2 HR * * *																IA/P = 0.30		
0.0	0	0	0	39	180	545	697	497	276	198	158	130	110	93	81	73	67	61	56	49	46	43	39	35	32	30	29	27	24	21	19	0
.10	0	0	0	2	27	129	407	600	532	361	252	190	150	108	90	79	71	65	59	52	48	44	41	36	32	31	29	28	25	21	19	0
.20	0	0	0	2	19	92	302	501	521	415	306	228	176	119	95	82	73	67	61	53	48	45	41	37	33	31	29	28	25	21	19	0
.30	0	0	0	0	1	13	66	223	408	484	438	350	269	163	114	93	80	72	65	57	51	46	42	38	34	31	30	28	25	22	19	0
.40	0	0	0	0	1	9	47	164	327	431	436	379	306	189	127	98	83	74	67	58	52	47	43	38	34	31	30	28	25	22	19	0
.50	0	0	0	0	0	0	6	33	120	258	374	415	391	271	173	121	95	81	72	62	55	48	44	40	35	32	30	29	26	22	19	0
.75	0	0	0	0	0	0	2	13	50	126	221	302	348	323	240	167	121	96	81	68	59	50	45	41	37	33	31	29	26	23	19	0
1.0	0	0	0	0	0	0	0	0	1	6	24	69	139	285	331	280	204	145	109	82	68	56	48	43	39	35	32	30	27	24	19	0
1.5	0	0	0	0	0	0	0	0	0	0	0	0	1	16	79	186	271	288	247	165	110	76	58	49	44	40	35	32	29	26	20	5
2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	24	80	163	235	262	202	123	76	58	49	43	39	35	30	27	21	13
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	6	28	77	179	242	207	120	75	57	48	43	39	32	29	22	17
3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	30	101	207	227	130	80	59	49	44	35	30	24	18
IA/P = 0.50														* * * TC =0.2 HR * * *																IA/P = 0.50		
0.0	0	0	0	0	7	98	371	322	221	182	158	137	120	104	94	86	80	74	69	62	60	57	52	47	44	42	40	39	35	30	28	0
.10	0	0	0	0	4	67	270	305	249	204	174	149	130	108	97	88	82	76	71	64	60	57	53	48	44	42	41	39	35	30	28	0
.20	0	0	0	0	0	3	45	195	268	255	221	189	163	125	106	95	87	80	75	67	62	58	54	49	45	43	41	39	35	31	28	0
.30	0	0	0	0	0	2	31	140	226	245	229	203	176	134	111	98	89	82	76	68	62	59	55	50	45	43	41	39	36	31	28	0
.40	0	0	0	0	0	1	21	101	184	225	228	211	183	144	117	101	91	84	78	69	63	59	55	50	45	43	41	40	36	31	28	0
.50	0	0	0	0	0	0	1	14	72	146	199	218	213	175	137	113	99	89	82	73	66	60	56	52	47	43	42	40	36	32	28	0
.75	0	0	0	0	0	0	0	5	28	71	121	162	186	193	161	133	112	98	88	78	70	62	57	53	48	44	42	41	37	33	28	0
1.0	0	0	0	0	0	0	0	0	0	2	13	38	77	154	186	174	147	122	105	89	78	68	60	56	51	46	43	42	38	34	28	0
1.5	0	0	0	0	0	0	0	0	0	0	0	0	2	22	71	129	163	168	150	120	98	80	67	60	55	51	46	43	40	36	28	4
2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	25	65	112	146	157	134	103	79	67	60	55	50	46	41	38	29	14
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	8	26	60	117	148	136	101	79	66	59	54	50	43	39	31	24
3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	9	40	90	142	130	99	78	66	59	54	45	41	33	26

RAINFALL TYPE = II * * * TC = 0.2 HR * * * SHEET 2 OF 10

Exhibit 5-II, continued: Tabular hydrograph unit discharges (csm/in) for type II rainfall distribution

HYDROGRAPH TIME (HOURS)

IA/P = 0.10 * * * TC =0.3 HR * * * IA/P = 0.10

TRVL TIME (HR)	11.0	11.3	11.6	11.9	12.0	12.1	12.2	12.3	12.4	12.5	12.6	12.7	12.8	13.0	13.2	13.4	13.6	13.8	14.0	14.3	14.6	15.0	15.5	16.0	16.5	17.0	17.5	18.0	19.0	20.0	22.0	26.0
0.0	20	28	41	118	235	447	676	676	459	283	196	146	114	80	66	57	51	46	42	37	33	31	28	24	22	20	19	18	16	13	12	0
.10	19	26	39	99	189	361	571	641	520	362	251	181	136	89	70	60	53	48	43	37	34	31	28	25	22	21	19	18	16	14	12	0
.20	17	23	32	53	83	154	292	478	587	542	422	308	223	127	86	68	58	52	46	40	35	32	29	26	23	21	20	19	16	14	12	0
.30	16	22	30	49	72	127	237	398	524	536	460	359	268	151	97	73	61	53	48	41	36	32	29	26	23	21	20	19	16	14	12	0
.40	14	19	25	37	45	63	105	193	330	459	510	477	398	237	139	92	70	59	52	44	38	34	30	27	24	21	20	19	17	14	12	0
.50	13	18	24	35	42	56	89	158	272	397	472	475	424	274	163	104	76	62	54	46	39	34	30	27	24	22	20	19	17	15	12	0
.75	11	14	19	26	30	34	42	59	95	160	250	339	417	398	299	196	128	89	69	54	45	37	32	29	26	23	21	20	17	15	12	0
1.0	9	11	14	19	21	24	27	30	36	46	68	109	174	328	396	346	248	163	109	70	54	43	35	31	28	24	22	20	18	16	12	0
1.5	6	8	10	13	14	15	17	19	21	23	26	31	38	77	169	282	347	330	264	158	94	58	42	35	31	27	24	22	19	17	13	3
2.0	4	5	7	8	9	10	10	11	12	14	15	16	18	23	32	57	116	205	285	317	239	128	64	44	36	31	28	25	20	18	14	9
2.5	2	4	5	6	6	7	7	8	9	9	10	11	12	15	18	23	33	60	113	223	293	245	125	65	44	35	31	27	22	19	15	11
3.0	1	2	3	4	4	4	5	5	6	6	7	7	8	9	11	13	16	20	27	61	138	275	246	139	72	46	36	31	25	21	16	11

IA/P = 0.30 * * * TC =0.3 HR * * * IA/P = 0.30

TRVL TIME (HR)	11.0	11.3	11.6	11.9	12.0	12.1	12.2	12.3	12.4	12.5	12.6	12.7	12.8	13.0	13.2	13.4	13.6	13.8	14.0	14.3	14.6	15.0	15.5	16.0	16.5	17.0	17.5	18.0	19.0	20.0	22.0	26.0
0.0	0	0	0	11	64	251	525	574	454	303	221	173	140	104	88	77	70	64	58	51	47	44	40	36	32	31	29	28	24	21	19	0
.10	0	0	0	0	7	45	183	411	520	476	360	268	205	133	101	85	76	69	62	55	49	45	41	37	33	31	30	28	25	21	19	0
.20	0	0	0	0	5	32	132	318	452	468	396	310	240	151	109	90	78	70	64	56	50	46	42	38	33	31	30	28	25	22	19	0
.30	0	0	0	0	0	3	22	96	244	383	440	411	344	217	142	105	87	76	69	60	53	47	43	39	35	32	30	29	26	22	19	0
.40	0	0	0	0	0	2	16	69	186	317	399	407	365	246	160	115	92	79	71	61	54	48	43	39	35	32	30	29	26	22	19	0
.50	0	0	0	0	0	0	2	11	50	140	258	352	389	327	223	149	110	89	77	66	57	50	45	41	36	33	31	29	26	23	19	0
.75	0	0	0	0	0	0	1	4	20	63	135	219	290	335	281	205	146	110	89	72	62	52	46	42	38	34	31	30	27	23	19	0
1.0	0	0	0	0	0	0	0	0	0	2	9	32	78	216	320	306	243	176	128	90	72	59	49	44	40	36	33	31	28	24	19	1
1.5	0	0	0	0	0	0	0	0	0	0	0	0	2	20	84	185	264	281	246	168	112	77	58	49	44	40	36	32	29	26	20	5
2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	12	50	121	200	257	224	141	83	61	50	44	40	36	31	28	21	14
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	16	51	145	239	223	137	82	60	50	44	40	33	29	22	17
3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	19	74	184	224	146	89	63	51	45	36	31	24	18

IA/P = 0.50 * * * TC =0.3 HR * * * IA/P = 0.50

TRVL TIME (HR)	11.0	11.3	11.6	11.9	12.0	12.1	12.2	12.3	12.4	12.5	12.6	12.7	12.8	13.0	13.2	13.4	13.6	13.8	14.0	14.3	14.6	15.0	15.5	16.0	16.5	17.0	17.5	18.0	19.0	20.0	22.0	26.0
0.0	0	0	0	0	1	25	151	299	277	219	187	162	141	113	100	90	84	78	72	65	61	58	53	48	44	42	41	39	35	31	28	0
.10	0	0	0	0	1	17	106	235	263	234	202	175	152	120	104	93	85	79	73	66	61	58	54	49	44	42	41	39	35	31	28	0
.20	0	0	0	0	0	0	12	75	182	236	234	213	188	144	116	101	91	84	78	70	63	59	55	50	45	43	41	40	36	31	28	0
.30	0	0	0	0	0	0	8	52	138	203	224	217	197	154	123	105	94	86	79	71	64	59	55	51	46	43	42	40	36	32	28	0
.40	0	0	0	0	0	0	5	37	105	170	206	213	203	164	131	110	97	88	81	72	65	60	56	51	46	43	42	40	36	32	28	0
.50	0	0	0	0	0	0	0	4	26	78	140	184	203	191	155	126	107	95	86	76	69	62	57	53	48	44	42	41	37	33	28	0
.75	0	0	0	0	0	0	0	1	10	34	73	117	153	184	173	146	122	105	94	82	73	64	58	54	49	45	43	41	37	33	28	0
1.0	0	0	0	0	0	0	0	0	0	0	4	17	42	114	168	178	159	134	114	94	82	70	61	57	52	47	44	42	39	35	28	0
1.5	0	0	0	0	0	0	0	0	0	0	0	0	1	10	44	98	144	163	157	130	105	84	69	61	56	52	47	44	40	36	29	6
2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	14	44	87	127	153	141	110	83	69	61	56	51	47	42	38	30	17
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	16	42	97	138	145	107	82	68	60	55	51	43	40	32	25
3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	5	27	71	127	139	105	81	68	60	55	46	41	33	27

RAINFALL TYPE = II * * * TC = 0.3 HR * * * SHEET 3 OF 10

Source: USDA-SCS

Exhibit 5-II, continued: Tabular hydrograph unit discharges (csm/in) for type II rainfall distribution

HYDROGRAPH TIME (HOURS)

TRVL TIME (HR)	11.0	11.3	11.6	11.9	12.0	12.1	12.2	12.3	12.4	12.5	12.6	12.7	12.8	13.0	13.2	13.4	13.6	13.8	14.0	14.3	14.6	15.0	15.5	16.0	16.5	17.0	17.5	18.0	19.0	20.0	22.0	26.0
IA/P = 0.10														* * * TC =0.4 HR * * *														IA/P = 0.10				
0.0	18	25	36	77	141	271	468	592	574	431	298	216	163	104	77	63	55	49	44	38	34	31	28	25	22	21	20	18	16	14	12	0
.10	18	24	34	67	116	219	385	523	557	473	357	263	196	119	84	67	57	51	46	39	35	32	29	25	22	21	20	19	16	14	12	0
.20	15	20	28	44	59	97	179	316	454	523	489	401	309	178	112	81	65	56	49	42	37	33	30	26	23	21	20	19	17	14	12	0
.30	15	20	27	41	53	82	147	260	389	478	486	429	349	210	129	89	69	58	51	43	38	33	30	27	24	21	20	19	17	14	12	0
.40	13	17	23	33	38	48	71	121	214	331	429	467	442	308	189	120	85	66	56	47	41	35	31	28	24	22	20	19	17	15	12	0
.50	12	16	22	31	36	44	62	102	176	279	379	438	440	339	218	137	94	71	59	49	42	35	31	28	25	22	21	19	17	15	12	0
.75	10	13	17	24	26	30	35	45	65	106	170	251	326	393	341	245	164	112	81	59	48	39	33	30	26	23	21	20	18	15	12	0
1.0	8	10	13	17	19	21	24	27	31	37	50	75	118	251	360	376	292	205	138	83	60	45	36	32	28	25	22	21	18	16	12	1
1.5	6	7	9	12	13	14	15	17	19	21	23	26	31	56	121	224	311	333	293	192	115	66	45	36	31	28	25	22	19	17	13	4
2.0	4	5	6	8	8	9	10	10	11	12	14	15	16	20	27	43	85	159	243	306	264	154	74	47	37	32	28	25	21	18	14	9
2.5	2	3	4	5	6	6	7	7	8	9	9	10	11	13	16	20	27	46	85	184	285	262	147	74	47	37	32	28	22	19	15	11
3.0	1	2	2	3	4	4	4	5	5	6	6	7	7	8	10	12	14	17	23	47	109	227	268	160	83	50	38	32	25	21	16	11
IA/P = 0.30														* * * TC =0.4 HR * * *														IA/P = 0.30				
0.0	0	0	0	4	26	113	296	480	495	413	306	234	186	127	100	84	74	67	61	54	49	45	41	37	33	31	29	28	25	21	19	0
.10	0	0	0	0	2	18	81	224	395	462	430	347	272	172	121	96	82	73	66	57	51	46	42	38	34	31	30	28	25	22	19	0
.20	0	0	0	0	2	13	59	169	320	414	424	373	305	196	134	103	85	75	67	59	52	47	43	39	34	32	30	29	25	22	19	0
.30	0	0	0	0	0	1	9	42	127	255	361	403	383	274	181	127	99	83	73	63	55	48	44	40	36	32	30	29	26	23	19	0
.40	0	0	0	0	0	1	6	30	94	202	308	372	379	298	203	141	106	87	76	65	56	49	44	40	36	32	31	29	26	23	19	0
.50	0	0	0	0	0	0	0	4	21	70	158	258	334	364	270	187	133	102	85	70	60	51	46	41	37	33	31	30	26	23	19	0
.75	0	0	0	0	0	0	0	2	8	30	76	145	219	321	305	241	177	130	102	78	65	55	47	43	38	34	32	30	27	24	19	0
1.0	0	0	0	0	0	0	0	0	0	1	4	15	42	150	267	308	272	209	154	103	79	62	51	45	41	37	33	31	28	25	19	1
1.5	0	0	0	0	0	0	0	0	0	0	0	0	1	10	51	136	226	274	263	195	131	85	62	51	45	41	36	33	29	26	20	6
2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	6	31	86	162	252	239	162	93	64	52	45	41	37	31	28	21	15
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	9	33	112	202	235	155	92	64	52	45	41	33	29	23	18
3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	21	76	182	221	148	90	63	51	45	36	31	24	13
IA/P = 0.50														* * * TC =0.4 HR * * *														IA/P = 0.50				
0.0	0	0	0	0	0	7	59	168	245	257	213	186	163	128	109	96	88	81	75	67	62	58	54	50	45	43	41	39	35	31	28	0
.10	0	0	0	0	0	0	5	41	125	205	240	222	198	154	123	106	94	86	79	71	64	60	56	51	46	43	42	40	36	32	28	0
.20	0	0	0	0	0	0	3	28	93	168	216	220	205	164	131	110	97	88	81	72	65	60	56	51	46	43	42	40	36	32	28	0
.30	0	0	0	0	0	0	0	2	20	69	135	189	209	192	155	126	107	95	86	77	69	62	57	53	48	44	42	41	37	33	28	0
.40	0	0	0	0	0	0	0	1	14	50	106	161	193	202	163	133	112	98	89	78	70	62	58	53	48	44	42	41	37	33	28	0
.50	0	0	0	0	0	0	0	1	9	37	83	135	174	194	171	140	117	102	91	80	71	63	58	54	49	45	43	41	37	33	28	0
.75	0	0	0	0	0	0	0	0	0	3	15	40	76	147	177	169	146	124	107	90	79	68	60	56	51	47	43	42	38	34	28	0
1.0	0	0	0	0	0	0	0	0	0	0	1	7	21	78	141	173	167	146	125	101	86	73	63	58	53	48	45	42	39	35	28	1
1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	5	26	71	121	153	159	139	113	89	72	63	57	53	48	44	40	37	29	7
2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	16	45	86	138	150	125	93	74	64	58	53	48	42	39	31	20
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	17	59	112	143	121	91	73	63	57	53	45	40	32	26
3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	11	40	101	138	117	90	73	63	57	48	42	34	27

RAINFALL TYPE = II * * * TC = 0.4 HR * * * SHEET 4 OF 10

Exhibit 5-II, continued: Tabular hydrograph unit discharges (csm/in) for type II rainfall distribution

HYDROGRAPH TIME (HOURS)

IA/P = 0.10 — * * * TC =0.5 HR * * *

TRVL TIME (HR)	11.0	11.3	11.6	11.9	12.0	12.1	12.2	12.3	12.4	12.5	12.6	12.7	12.8	13.0	13.2	13.4	13.6	13.8	14.0	14.3	14.6	15.0	15.5	16.0	16.5	17.0	17.5	18.0	19.0	20.0	22.0	26.0
0.0	17	23	32	57	94	170	308	467	529	507	402	297	226	140	96	74	61	53	47	41	36	32	29	26	23	21	20	19	16	14	12	0
.10	16	22	30	51	80	140	252	395	484	499	434	343	265	162	108	80	65	55	49	42	36	33	29	26	23	21	20	19	16	14	12	0
.20	14	19	25	38	47	69	116	207	332	434	477	449	378	238	149	101	77	62	53	45	39	34	30	27	24	22	20	19	17	14	12	0
.30	13	18	24	35	43	60	97	170	278	382	446	448	401	270	171	114	83	66	56	46	40	34	31	27	24	22	20	19	17	15	12	0
.40	12	15	21	29	33	40	53	83	141	233	332	408	434	361	243	157	107	79	64	51	43	36	32	28	25	22	21	20	17	15	12	0
.50	11	15	20	28	31	37	48	71	118	194	286	367	412	378	271	178	119	86	68	53	44	37	32	29	25	23	21	20	17	15	12	0
.75	9	11	14	19	21	24	27	31	37	49	74	118	182	319	374	328	244	169	117	76	56	43	35	31	28	25	22	21	18	16	12	1
1.0	7	9	12	16	17	19	21	24	27	32	40	55	83	188	309	359	322	245	172	102	68	49	38	32	29	26	23	21	19	16	12	1
1.5	5	7	8	11	12	13	14	15	17	19	21	23	27	43	89	175	269	322	309	225	140	77	49	38	32	29	25	23	20	17	13	5
2.0	3	4	6	7	8	8	9	10	10	11	12	14	15	18	23	35	65	123	202	297	280	181	88	52	39	33	29	26	21	19	14	10
2.5	2	3	4	5	5	6	6	7	7	8	9	[illegible]	10	12	15	18	24	36	66	150	244	278	171	87	52	39	33	29	23	20	15	11
3.0	1	1	2	3	3	4	4	4	5	5	6	6	7	8	9	11	13	16	20	37	86	198	263	182	96	56	40	33	26	21	16	11

IA/P = 0.30 — * * * TC =0.5 HR * * *

TRVL TIME (HR)	11.0	11.3	11.6	11.9	12.0	12.1	12.2	12.3	12.4	12.5	12.6	12.7	12.8	13.0	13.2	13.4	13.6	13.8	14.0	14.3	14.6	15.0	15.5	16.0	16.5	17.0	17.5	18.0	19.0	20.0	22.0	26.0
0.0	0	0	0	1	9	53	157	314	433	439	379	299	237	159	118	95	81	71	65	56	50	46	42	38	34	31	30	28	25	22	19	0
.10	0	0	0	0	1	6	37	117	248	372	416	391	330	218	150	113	92	79	70	60	53	47	43	39	35	32	30	29	26	22	19	0
.20	0	0	0	0	1	4	26	87	194	313	382	388	349	244	167	122	97	82	72	62	54	48	43	39	35	32	30	29	26	22	19	0
.30	0	0	0	0	0	0	3	19	64	151	259	341	372	316	223	156	117	94	80	67	58	50	45	41	36	33	31	29	26	23	19	0
.40	0	0	0	0	0	0	2	13	47	116	211	298	354	328	245	172	127	100	83	69	59	51	45	41	37	33	31	29	26	23	19	0
.50	0	0	0	0	0	0	0	1	9	34	89	170	255	341	303	225	161	120	96	76	64	54	47	42	38	34	31	30	27	24	19	0
.75	0	0	0	0	0	0	0	1	4	14	41	89	152	270	305	268	207	155	118	87	70	57	48	44	39	35	32	30	27	24	19	0
1.0	0	0	0	0	0	0	0	0	0	0	2	7	22	98	212	295	285	237	181	120	88	67	53	46	42	38	34	31	28	25	19	2
1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	5	30	95	183	249	265	217	152	96	66	53	46	41	37	34	30	26	20	8
2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	18	59	125	221	245	182	105	69	54	47	42	38	32	28	22	16
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	5	21	84	174	230	172	103	69	54	46	42	34	30	23	18
3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	13	56	157	217	163	101	68	53	46	37	31	25	18

IA/P = 0.50 — * * * TC =0.5 HR * * *

TRVL TIME (HR)	11.0	11.3	11.6	11.9	12.0	12.1	12.2	12.3	12.4	12.5	12.6	12.7	12.8	13.0	13.2	13.4	13.6	13.8	14.0	14.3	14.6	15.0	15.5	16.0	16.5	17.0	17.5	18.0	19.0	20.0	22.0	26.0
0.0	0	0	0	0	0	2	26	89	170	217	229	200	179	144	119	104	93	85	78	70	64	59	55	51	46	43	41	40	36	32	28	0
.10	0	0	0	0	0	0	1	18	65	135	190	216	205	170	137	115	101	91	83	74	67	61	56	52	47	44	42	40	36	32	28	0
.20	0	0	0	0	0	0	1	12	47	106	162	198	203	178	145	121	105	94	85	76	68	61	57	52	48	44	42	40	37	32	28	0
.30	0	0	0	0	0	0	0	1	8	34	82	135	177	194	168	139	117	102	92	80	71	63	58	54	49	45	43	41	37	33	28	0
.40	0	0	0	0	0	0	0	0	6	25	63	111	155	189	174	146	122	106	94	82	73	64	58	54	50	45	43	41	37	33	28	0
.50	0	0	0	0	0	0	0	0	4	18	48	90	133	184	177	152	128	110	97	84	74	65	59	55	50	45	43	41	38	33	28	0
.75	0	0	0	0	0	0	0	0	1	7	22	47	80	142	169	164	144	124	108	91	79	68	61	56	51	47	44	42	38	34	28	0
1.0	0	0	0	0	0	0	0	0	0	0	1	3	11	51	112	155	166	154	134	109	91	76	65	59	54	49	45	43	39	35	28	2
1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	2	16	50	97	136	154	145	121	95	75	64	58	54	49	45	41	37	29	10
2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	18	47	86	134	146	125	94	75	64	58	53	49	42	39	31	21
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	11	44	95	140	127	97	77	65	58	54	45	41	33	26
3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	7	29	86	135	122	95	76	65	58	49	43	35	27

RAINFALL TYPE = II — * * * TC = 0.5 HR * * * — SHEET 5 OF 10

Exhibit 5-II, continued: Tabular hydrograph unit discharges (csm/in) for type II rainfall distribution

HYDROGRAPH TIME (HOURS)

TRVL TIME (HR)	11.0	11.3	11.6	11.9	12.0	12.1	12.2	12.3	12.4	12.5	12.6	12.7	12.8	13.0	13.2	13.4	13.6	13.8	14.0	14.3	14.6	15.0	15.5	16.0	16.5	17.0	17.5	18.0	19.0	20.0	22.0	26.0
IA/P = 0.10														* * * TC =0.75 HR * * *														IA/P = 0.10				
0.0	13	18	24	36	46	68	115	194	294	380	424	410	369	252	172	123	93	74	61	49	41	35	31	27	24	22	20	19	17	15	12	0
.10	13	17	23	34	42	59	97	162	250	337	395	405	381	279	191	135	100	79	65	51	42	36	31	28	25	22	21	19	17	15	12	0
.20	11	15	20	28	32	39	52	82	135	211	295	362	391	351	255	178	127	95	75	57	46	38	32	29	26	23	21	20	17	15	12	0
.30	11	14	19	26	30	36	47	70	113	179	256	326	379	360	277	196	140	103	80	60	48	38	33	29	26	23	21	20	18	15	12	0
.40	10	12	16	22	25	28	33	42	61	96	151	221	291	367	336	255	182	131	98	69	54	42	34	30	27	24	22	20	18	16	12	0
.50	9	12	16	21	24	27	31	39	53	82	128	190	258	358	343	274	200	144	106	74	56	43	35	30	27	24	22	20	18	16	12	0
.75	8	10	13	17	18	21	23	26	31	39	55	82	122	230	314	329	281	217	161	104	72	51	38	33	29	26	23	21	19	16	12	1
1.0	6	8	10	13	14	15	17	19	21	23	27	32	42	89	177	272	319	303	249	163	105	66	45	36	31	27	24	22	19	17	13	3
1.5	4	6	7	9	10	10	11	12	14	15	16	18	20	27	46	90	163	241	295	275	204	119	66	45	35	31	27	24	20	18	13	7
2.0	3	4	5	6	7	7	8	9	9	10	11	12	13	16	20	28	48	89	151	245	274	213	115	65	44	35	30	27	22	19	14	10
2.5	1	2	3	4	4	5	5	6	6	7	7	8	8	10	12	14	17	24	37	86	170	260	219	127	71	47	36	31	24	20	16	11
3.0	1	1	2	3	3	3	4	4	4	5	5	5	6	7	8	10	11	14	17	30	64	157	247	205	122	70	46	36	27	22	17	12
IA/P = 0.30														* * * TC =0.75 HR * * *														IA/P = 0.30				
0.0	0	0	0	0	1	6	30	86	174	266	326	348	328	246	181	138	110	92	79	66	57	49	44	40	36	32	31	29	26	23	19	0
.10	0	0	0	0	0	1	4	22	65	137	223	292	329	303	228	170	131	106	89	73	61	52	46	41	37	33	31	29	26	23	19	0
.20	0	0	0	0	0	0	3	15	48	108	185	256	305	321	245	184	141	112	93	75	63	53	46	42	37	34	31	30	27	23	19	0
.30	0	0	0	0	0	0	2	11	36	84	151	221	277	308	260	199	152	120	98	78	65	54	47	42	38	34	31	30	27	23	19	0
.40	0	0	0	0	0	0	0	1	8	27	65	122	188	286	301	243	187	144	114	87	71	57	48	43	39	35	32	30	27	24	19	1
.50	0	0	0	0	0	0	0	1	6	20	50	98	158	263	292	254	200	155	122	91	74	59	49	44	40	35	32	30	27	24	19	1
.75	0	0	0	0	0	0	0	0	0	2	8	23	51	140	231	269	253	211	167	119	90	68	53	46	42	37	34	31	28	25	19	2
1.0	0	0	0	0	0	0	0	0	0	0	0	1	4	29	96	186	249	261	231	169	120	84	61	50	44	40	36	33	29	26	20	5
1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	1	8	34	91	163	220	241	197	131	83	61	50	44	40	35	31	27	21	12
2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	11	36	85	174	226	200	127	82	60	49	44	39	32	29	22	17
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	6	37	105	196	214	135	87	62	51	44	36	31	24	18
3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	24	96	205	189	130	85	62	50	39	32	26	18
IA/P = 0.50														* * * TC =0.75 HR * * *														IA/P = 0.50				
0.0	0	0	0	0	0	0	2	16	45	92	137	166	185	170	146	125	110	98	89	79	70	63	58	53	48	44	42	41	37	33	28	0
.10	0	0	0	0	0	0	0	1	11	34	73	115	149	180	163	141	122	107	96	84	74	65	59	54	50	45	43	41	38	33	28	0
.20	0	0	0	0	0	0	0	1	8	25	57	96	131	173	166	146	126	111	99	86	76	66	59	55	50	46	43	41	38	34	28	0
.30	0	0	0	0	0	0	0	0	1	5	18	44	79	143	170	160	141	122	108	92	81	69	61	56	52	47	44	42	38	34	28	1
.40	0	0	0	0	0	0	0	0	0	4	14	34	64	127	166	162	145	127	111	95	82	70	62	57	52	47	44	42	38	34	28	1
.50	0	0	0	0	0	0	0	0	0	0	2	10	26	82	138	162	157	140	123	103	88	75	64	58	53	49	45	43	39	35	28	2
.75	0	0	0	0	0	0	0	0	0	0	1	4	12	47	98	139	154	148	135	113	96	80	67	60	55	50	46	43	39	36	29	3
1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	30	73	119	146	151	134	113	91	74	63	58	53	48	45	41	37	29	7
1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	9	30	66	105	143	143	117	90	73	63	57	52	48	42	39	30	18
2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	11	30	77	121	137	114	88	72	63	57	52	44	40	32	25
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	19	55	111	132	111	87	71	62	56	47	42	34	27
3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	12	51	112	128	108	86	71	62	51	44	36	27

RAINFALL TYPE = II * * * TC = 0.75 HR * * * SHEET 6 OF 10

Exhibit 5-II, continued: Tabular hydrograph unit discharges (csm/in) for type II rainfall distribution

HYDROGRAPH TIME (HOURS)

TRVL TIME (HR)	11.0	11.3	11.6	11.9	12.0	12.1	12.2	12.3	12.4	12.5	12.6	12.7	12.8	13.0	13.2	13.4	13.6	13.8	14.0	14.3	14.6	15.0	15.5	16.0	16.5	17.0	17.5	18.0	19.0	20.0	22.0	26.0
IA/P = 0.10														* * * TC =1.0 HR * * *															IA/P = 0.10			
0.0	11	15	20	29	35	47	72	112	168	231	289	329	357	313	239	175	133	103	83	63	50	40	33	29	26	23	21	20	17	15	12	0
.10	10	13	17	24	27	33	42	62	95	144	202	260	306	340	293	222	165	126	98	72	56	43	35	30	27	24	22	20	18	15	12	0
.20	10	13	17	23	26	30	38	54	82	123	176	232	281	332	303	238	179	136	105	76	59	45	35	30	27	24	22	20	18	16	12	1
.30	9	12	16	22	24	28	35	48	70	105	152	205	256	323	310	254	193	146	113	81	61	46	36	31	27	24	22	20	18	16	12	1
.40	8	11	14	19	21	23	27	32	42	61	91	132	181	276	318	294	237	181	138	95	70	51	39	32	28	25	23	21	18	16	12	1
.50	8	10	13	18	20	22	25	30	38	53	78	114	159	253	311	300	251	195	149	102	74	53	40	33	29	25	23	21	18	16	12	1
.75	7	8	11	14	16	17	19	21	25	30	38	53	76	146	228	284	293	256	208	143	99	66	46	36	31	27	24	22	19	17	13	2
1.0	5	7	8	11	12	13	14	16	17	19	22	25	31	57	111	188	256	286	272	208	144	90	56	41	33	29	26	23	20	17	13	4
1.5	4	5	6	8	8	9	10	11	12	13	14	15	17	22	33	59	107	171	231	268	235	157	88	56	41	33	29	25	21	18	14	8
2.0	2	3	4	5	5	6	6	7	7	8	9	9	10	12	15	19	27	44	78	157	231	252	167	96	59	42	34	29	23	20	15	11
2.5	1	2	2	3	4	4	4	5	5	6	6	7	7	8	10	12	15	19	27	58	120	214	241	159	94	59	42	34	26	21	16	11
3.0	0	1	1	2	2	3	3	3	4	4	4	5	5	6	7	8	10	12	14	22	44	113	214	231	152	91	58	42	29	23	17	12
IA/P = 0.30														* * * TC =1.0 HR * * *															IA/P = 0.30			
0.0	0	0	0	0	1	4	16	42	83	137	195	243	271	292	227	178	143	117	98	79	66	55	47	42	38	34	31	30	27	23	19	0
.10	0	0	0	0	0	0	3	12	32	66	113	168	218	279	260	213	169	136	113	88	72	59	49	43	39	35	32	30	27	24	19	1
.20	0	0	0	0	0	0	2	9	24	52	93	143	193	271	271	225	180	145	119	92	75	60	50	44	39	35	32	30	27	24	19	1
.30	0	0	0	0	0	0	1	6	18	41	75	120	169	246	264	234	191	153	125	96	78	62	51	44	40	36	33	31	27	24	19	1
.40	0	0	0	0	0	0	0	1	4	14	32	61	100	190	251	259	222	181	146	109	86	67	53	46	41	37	33	31	28	25	19	2
.50	0	0	0	0	0	0	0	1	3	10	24	49	83	168	237	254	230	191	155	115	90	69	54	47	42	37	34	31	28	25	19	2
.75	0	0	0	0	0	0	0	0	0	1	4	12	25	76	150	213	239	228	198	149	112	82	61	50	44	39	35	32	29	26	20	4
1.0	0	0	0	0	0	0	0	0	0	0	0	1	2	15	51	113	182	226	234	197	150	104	72	56	47	42	38	34	30	27	20	7
1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	18	51	104	162	220	210	158	102	71	56	47	42	37	31	28	22	13
2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	5	20	49	121	187	209	152	100	70	55	47	41	34	29	23	17
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	7	32	87	171	199	146	98	69	54	46	37	31	24	18
3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	13	62	158	192	151	103	73	56	41	34	26	18
IA/P = 0.50														* * * TC =1.0 HR * * *															IA/P = 0.50			
0.0	0	0	0	0	0	0	1	7	21	42	71	101	126	160	154	138	123	110	100	87	77	67	60	55	50	46	43	41	38	34	28	1
.10	0	0	0	0	0	0	0	1	5	15	33	58	87	134	156	149	134	120	108	93	82	71	62	57	52	47	44	42	38	34	28	1
.20	0	0	0	0	0	0	0	1	4	12	26	48	74	123	153	153	137	123	111	95	84	72	63	57	52	47	44	42	38	34	28	1
.30	0	0	0	0	0	0	0	0	3	9	20	38	62	111	143	150	140	127	114	98	86	73	63	58	53	48	45	42	39	35	28	1
.40	0	0	0	0	0	0	0	0	0	2	6	16	31	75	120	145	148	137	123	106	91	77	66	59	54	49	45	43	39	35	29	2
.50	0	0	0	0	0	0	0	0	0	1	5	12	25	64	109	139	146	139	127	108	94	79	67	60	55	50	46	43	39	36	29	3
.75	0	0	0	0	0	0	0	0	0	0	2	5	12	39	78	115	136	140	134	117	101	84	70	62	56	51	47	44	40	36	29	4
1.0	0	0	0	0	0	0	0	0	0	0	0	0	1	7	26	59	96	125	139	133	117	97	78	66	59	54	49	46	41	37	29	8
1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	9	26	54	86	123	133	119	95	77	66	59	54	49	43	39	31	17
2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	10	25	64	104	129	116	93	76	65	58	53	45	41	33	24
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	10	34	84	125	117	96	78	66	59	49	43	35	27
3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	6	32	89	122	114	94	77	66	53	45	37	27

RAINFALL TYPE = II * * * TC = 1.0 HR * * * SHEET 7 OF 10

Exhibit 5-II, continued: Tabular hydrograph unit discharges (csm/in) for type II rainfall distribution

HYDROGRAPH TIME (HOURS)

TRVL TIME (HR)	11.0	11.3	11.6	11.9	12.0	12.1	12.2	12.3	12.4	12.5	12.6	12.7	12.8	13.0	13.2	13.4	13.6	13.8	14.0	14.3	14.6	15.0	15.5	16.0	16.5	17.0	17.5	18.0	19.0	20.0	22.0	26.0
IA/P = 0.10														* * * TC =1.25 HR * * *														IA/P = 0.10				
0.0	10	13	18	25	29	38	54	81	118	163	213	256	284	311	266	212	163	129	104	78	61	47	37	31	27	24	22	20	18	16	12	1
.10	10	13	17	23	27	34	47	69	102	143	189	234	267	297	274	226	175	138	111	82	64	48	38	31	27	24	22	20	18	16	12	1
.20	9	11	15	20	22	26	31	42	60	88	124	168	212	280	292	261	212	166	131	95	72	53	40	33	28	25	23	21	18	16	12	1
.30	8	11	14	19	21	24	29	38	53	76	108	148	190	263	288	268	224	177	140	101	76	55	41	34	29	25	23	21	18	16	12	2
.40	8	10	13	18	20	23	27	34	46	66	94	130	170	245	282	273	235	188	149	107	80	58	42	34	29	26	23	21	19	16	12	2
.50	7	9	12	16	17	19	22	25	31	41	58	82	114	190	256	279	262	222	178	127	93	65	46	36	31	27	24	22	19	17	13	2
.75	6	8	10	14	15	17	19	21	25	31	41	56	78	139	207	254	265	245	208	152	110	75	51	39	32	28	25	22	19	17	13	3
1.0	5	6	8	10	11	13	14	15	17	19	22	26	33	60	109	173	230	261	255	208	153	100	64	46	36	30	26	24	20	18	13	5
1.5	3	4	5	7	7	8	9	9	10	11	12	13	15	19	27	45	79	130	186	247	239	180	108	68	48	37	31	27	22	19	14	10
2.0	2	3	4	5	6	6	7	7	8	8	9	10	11	13	16	22	35	59	98	171	236	236	156	95	62	44	35	30	23	20	15	11
2.5	1	2	2	3	4	4	4	5	5	5	6	6	7	8	10	12	14	19	28	58	114	197	226	163	102	65	46	36	26	21	16	11
3.0	0	1	1	2	2	2	2	3	3	3	4	4	4	5	6	7	9	10	13	19	35	88	184	218	169	109	70	49	31	24	18	12
IA/P = 0.30														* * * TC =1.25 HR * * *														IA/P = 0,30				
0.0	0	0	0	0	0	2	9	25	50	86	130	174	208	253	235	201	164	136	115	92	76	61	51	44	39	35	32	30	27	24	19	1
.10	0	0	0	0	0	0	1	6	19	40	71	110	153	217	247	227	191	157	131	103	84	66	53	46	41	36	33	31	28	24	19	2
.20	0	0	0	0	0	0	1	4	14	31	58	93	133	202	239	231	199	165	138	108	87	68	55	47	41	37	33	31	28	25	19	2
.30	0	0	0	0	0	0	0	1	3	10	24	46	77	152	210	236	222	190	158	122	97	74	58	49	43	38	34	32	28	25	20	3
.40	0	0	0	0	0	0	0	0	2	8	19	37	64	134	196	232	225	198	166	127	101	77	59	50	43	38	35	32	28	25	20	3
.50	0	0	0	0	0	0	0	0	0	2	6	14	30	82	151	206	228	217	189	146	113	85	64	52	45	40	36	33	29	26	20	5
.75	0	0	0	0	0	0	0	0	0	1	2	7	15	49	105	164	205	218	205	166	129	95	69	55	47	41	37	33	29	26	20	6
1.0	0	0	0	0	0	0	0	0	0	0	0	0	1	9	32	77	134	185	214	203	166	120	83	63	52	45	39	35	30	27	21	10
1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	11	33	72	121	184	203	171	117	82	62	51	44	39	32	29	22	15
2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	7	21	67	132	194	174	123	86	64	52	45	35	31	24	13
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	13	46	121	187	166	119	84	63	52	39	32	25	18
3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	8	44	129	180	160	116	83	63	44	35	27	18
IA/P = 0.50														* * * TC =1.25 HR * * *														IA/P = 0.50				
0.0	0	0	0	0	0	0	1	5	13	26	44	68	91	125	142	142	128	117	107	94	83	72	63	57	52	47	44	42	38	34	28	2
.10	0	0	0	0	0	0	0	0	3	10	20	36	57	100	129	140	136	125	114	100	88	76	65	59	54	49	45	43	39	35	29	3
.20	0	0	0	0	0	0	0	0	2	7	16	30	48	90	122	139	139	127	117	102	90	77	66	60	54	49	45	43	39	35	29	3
.30	0	0	0	0	0	0	0	0	0	2	5	12	24	59	98	126	137	134	125	109	96	82	69	61	56	51	46	44	40	36	29	4
.40	0	0	0	0	0	0	0	0	0	1	4	10	19	51	89	119	134	136	127	112	98	83	70	62	56	51	47	44	40	36	29	5
.50	0	0	0	0	0	0	0	0	0	1	3	7	15	43	79	112	131	135	129	114	100	85	71	63	57	52	47	44	40	36	29	6
.75	0	0	0	0	0	0	0	0	0	0	0	1	3	15	39	71	102	123	130	125	112	94	78	67	60	54	49	46	41	37	29	9
1.0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	17	40	71	101	121	129	121	103	84	71	62	56	51	47	42	38	30	13
1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	10	26	51	92	119	125	105	86	72	63	57	52	44	40	32	23
2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	11	35	72	112	122	103	85	71	63	56	47	42	34	26
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	7	24	66	111	119	101	83	71	62	51	44	36	27
3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	23	71	110	116	99	82	70	55	46	37	27

RAINFALL TYPE = II * * * TC = 1.25 HR * * * SHEET 8 OF 10

Exhibit 5-II, continued: Tabular hydrograph unit discharges (csm/in) for type II rainfall distribution

HYDROGRAPH TIME (HOURS)

TRVL TIME (HR)	11.0	11.3	11.6	11.9	12.0	12.1	12.2	12.3	12.4	12.5	12.6	12.7	12.8	13.0	13.2	13.4	13.6	13.8	14.0	14.3	14.6	15.0	15.5	16.0	16.5	17.0	17.5	18.0	19.0	20.0	22.0	26.0
IA/P = 0.10														* * * TC =1.5 HR * * *														IA/P = 0.10				
0.0	9	11	15	21	25	31	41	58	82	112	147	184	216	255	275	236	198	159	129	98	76	57	43	35	30	25	23	21	18	16	12	1
.10	8	10	13	18	20	23	28	37	51	72	98	131	166	226	265	254	226	187	151	113	86	63	46	37	31	26	23	21	19	16	13	2
.20	8	10	13	17	19	22	26	33	45	63	87	116	149	212	259	259	233	197	160	119	90	66	48	38	32	27	24	22	19	16	13	2
.30	7	9	12	16	18	21	24	30	40	55	76	103	134	197	244	255	238	206	169	125	95	68	49	38	32	27	24	22	19	17	13	2
.40	7	8	11	14	15	17	19	23	28	36	49	67	91	151	208	247	252	230	196	146	109	77	54	41	34	29	25	22	19	17	13	3
.50	6	8	10	13	15	16	18	21	26	33	43	59	80	136	194	238	249	235	204	154	115	81	56	42	34	29	25	23	20	17	13	3
.75	5	7	8	11	12	13	14	16	18	21	25	32	42	76	125	179	222	240	233	193	148	102	67	48	38	32	27	24	20	18	13	5
1.0	4	5	7	8	9	10	11	12	13	14	16	18	22	34	59	101	152	201	236	230	193	135	86	59	44	35	30	26	21	18	14	7
1.5	3	4	5	6	6	7	8	8	9	10	11	12	13	16	22	34	58	95	141	203	226	197	131	84	58	43	35	29	23	20	15	10
2.0	1	2	3	4	4	5	5	6	6	7	7	8	9	10	12	16	22	34	56	110	172	218	187	126	82	57	43	34	25	21	16	11
2.5	1	1	2	2	3	3	3	4	4	4	5	5	6	7	8	9	11	14	18	34	69	141	210	190	133	87	60	44	30	23	17	12
3.0	0	0	1	1	2	2	2	2	3	3	3	3	4	5	5	6	8	9	11	16	27	66	149	204	181	128	85	58	35	25	18	12
IA/P = 0.30														* * * TC =1.5 HR * * *														IA/P = 0.30				
0.0	0	0	0	0	0	1	6	15	31	53	80	112	144	193	225	208	186	157	134	108	89	70	56	48	42	37	34	31	28	25	20	2
.10	0	0	0	0	0	0	1	4	12	25	43	68	97	157	198	219	203	178	151	120	98	77	60	50	44	38	35	32	28	25	20	3
.20	0	0	0	0	0	0	0	1	3	9	19	35	57	114	168	201	213	196	171	135	108	84	64	53	46	40	36	33	29	26	20	4
.30	0	0	0	0	0	0	0	1	2	7	15	29	48	100	155	193	210	200	177	140	113	87	66	54	46	41	36	33	29	26	20	5
.40	0	0	0	0	0	0	0	0	2	5	12	23	39	87	141	184	207	202	182	146	117	89	68	55	47	41	36	33	29	26	20	5
.50	0	0	0	0	0	0	0	0	0	1	4	9	18	51	101	153	190	205	197	164	131	99	73	58	49	43	38	34	30	26	20	7
.75	0	0	0	0	0	0	0	0	0	0	2	4	9	30	68	116	160	189	197	179	147	110	80	62	52	45	39	35	30	27	21	8
1.0	0	0	0	0	0	0	0	0	0	0	0	0	1	5	20	49	92	138	175	195	178	137	97	72	57	48	42	37	31	28	21	12
1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	7	21	47	85	145	187	178	133	95	71	57	48	42	34	29	23	16
2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	13	45	97	162	180	138	99	74	58	49	38	32	25	18
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	8	31	89	161	174	133	97	72	58	42	34	26	18
3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	5	29	98	160	169	129	95	71	48	37	28	19
IA/P = 0.50														* * * TC =1.5 HR * * *														IA/P = 0.50				
0.0	0	0	0	0	0	0	0	3	8	16	27	42	59	92	115	128	130	121	112	100	90	78	67	60	55	50	46	43	39	35	29	4
.10	0	0	0	0	0	0	0	2	6	12	22	35	51	84	110	125	128	123	114	102	91	79	68	61	55	50	46	43	39	35	29	4
.20	0	0	0	0	0	0	0	0	1	4	10	18	29	60	91	114	126	128	120	108	97	83	71	63	57	52	47	44	40	36	29	5
.30	0	0	0	0	0	0	0	0	1	3	8	14	24	52	83	108	123	126	122	110	98	85	72	63	57	52	48	44	40	36	29	6
.40	0	0	0	0	0	0	0	0	0	1	2	6	12	31	60	90	112	124	126	116	104	90	75	66	59	54	49	45	41	37	29	8
.50	0	0	0	0	0	0	0	0	0	0	2	4	9	26	53	83	106	121	125	118	106	91	77	67	60	54	49	46	41	37	29	8
.75	0	0	0	0	0	0	0	0	0	0	1	2	5	16	36	62	88	108	119	122	112	97	81	69	62	56	51	47	42	38	30	11
1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	10	26	49	75	98	118	121	108	90	76	66	59	54	49	43	39	31	16
1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	11	25	45	80	107	118	106	89	75	65	59	53	45	41	32	23
2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	11	32	63	100	115	104	87	74	65	58	48	42	34	26
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	16	48	94	113	105	89	76	66	53	45	36	27
3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	15	54	96	111	103	88	75	58	48	38	28

RAINFALL TYPE = II * * * TC = 1.5 HR * * * SHEET 9 OF 10

Exhibit 5-II, continued: Tabular hydrograph unit discharges (csm/in) for type II rainfall distribution

TRVL TIME (HR)	HYDROGRAPH TIME (HOURS) 11.0	11.3	11.6	11.9	12.0	12.1	12.2	12.3	12.4	12.5	12.6	12.7	12.8	13.0	13.2	13.4	13.6	13.8	14.0	14.3	14.6	15.0	15.5	16.0	16.5	17.0	17.5	18.0	19.0	20.0	22.0	26.0
IA/P = 0.10 * * * TC =2.0 HR * * * IA/P = 0.10																																
0.0	7	9	12	16	18	21	27	36	49	64	82	104	127	171	201	226	208	193	171	132	105	79	58	45	36	30	26	23	20	17	13	3
.10	6	8	10	14	15	17	20	25	33	43	57	74	94	139	179	204	218	205	188	150	118	88	63	48	38	32	27	24	20	17	13	4
.20	6	8	10	13	14	16	19	23	29	39	51	66	84	128	169	198	213	207	192	157	123	91	65	49	39	33	28	24	20	17	13	4
.30	6	7	9	12	14	15	18	21	27	35	45	59	76	117	159	191	211	208	196	163	128	95	68	51	40	33	28	25	20	18	13	4
.40	5	6	8	11	12	13	15	17	20	24	31	41	53	87	128	167	197	209	205	180	145	106	75	55	43	35	30	26	21	18	14	5
.50	5	6	8	10	11	13	14	16	18	22	28	37	48	78	118	158	190	208	208	185	151	111	77	57	44	36	30	26	21	18	14	5
.75	4	6	7	9	10	11	12	13	15	18	22	27	35	58	91	129	164	191	202	194	167	125	87	63	48	38	32	27	22	18	14	6
1.0	3	4	6	7	8	8	9	10	11	12	14	16	18	28	46	74	110	147	178	201	193	156	108	76	56	43	35	30	23	19	14	8
1.5	2	3	3	5	5	5	6	6	7	8	8	9	10	12	16	23	36	57	86	137	178	195	160	113	79	58	45	36	26	21	16	11
2.0	1	2	2	3	3	4	4	4	5	5	6	6	7	8	10	12	16	23	35	67	112	169	190	154	110	78	57	44	30	23	17	11
2.5	0	1	1	2	2	2	3	3	3	4	4	4	5	6	7	8	9	12	16	28	52	105	170	185	149	107	76	56	35	26	18	12
3.0	0	0	1	1	1	1	1	2	2	2	2	3	3	3	4	5	6	7	8	12	18	41	99	161	180	152	112	80	45	30	19	12
IA/P = 0.30 * * * TC =2.0 HR * * * IA/P = 0.30																																
0.0	0	0	0	0	0	1	3	8	15	25	38	54	74	115	148	168	185	170	159	131	110	89	70	57	49	42	38	34	29	26	20	5
.10	0	0	0	0	0	0	0	2	6	12	21	32	47	85	124	153	169	180	168	145	120	96	75	60	51	44	39	35	30	26	20	6
.20	0	0	0	0	0	0	0	2	4	10	17	27	41	75	114	146	165	175	170	149	124	99	76	62	52	45	39	35	30	27	21	6
.30	0	0	0	0	0	0	0	0	1	3	7	14	23	49	86	122	151	170	174	160	136	107	82	66	54	47	41	37	31	27	21	8
.40	0	0	0	0	0	0	0	0	1	2	6	11	19	43	77	113	144	165	173	163	140	111	85	67	55	47	41	37	31	27	21	8
.50	0	0	0	0	0	0	0	0	1	2	4	9	16	37	68	104	136	160	171	165	144	114	87	69	56	48	42	37	31	27	21	9
.75	0	0	0	0	0	0	0	0	0	0	1	2	5	15	34	62	96	127	152	167	160	132	100	77	62	52	45	40	32	28	22	11
1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	10	24	48	79	111	150	166	153	118	90	71	58	49	43	34	29	23	14
1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	10	24	45	98	130	161	148	115	88	70	57	48	37	31	24	17
2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	10	32	68	122	157	143	113	87	68	56	42	34	26	18
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	16	51	114	153	144	116	89	70	49	38	27	19
3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	15	59	118	150	140	113	88	57	42	29	19
IA/P = 0.50 * * * TC =2.0 HR * * * IA/P = 0.50																																
0.0	0	0	0	0	0	0	0	1	4	8	13	20	28	51	73	92	104	111	112	106	97	86	75	66	60	54	49	46	41	37	30	7
.10	0	0	0	0	0	0	0	1	3	6	11	17	24	45	68	87	101	109	112	107	98	88	76	67	60	55	50	46	41	37	30	8
.20	0	0	0	0	0	0	0	1	2	5	9	14	21	40	62	82	98	107	111	108	100	89	77	68	61	55	50	47	41	37	30	8
.30	0	0	0	0	0	0	0	0	0	2	4	7	12	26	46	67	86	100	108	111	104	93	80	70	63	57	52	48	42	38	30	10
.40	0	0	0	0	0	0	0	0	0	1	3	6	10	22	41	62	81	96	106	110	105	94	81	71	63	57	52	48	42	38	30	11
.50	0	0	0	0	0	0	0	0	0	0	1	2	4	13	27	46	67	85	99	110	108	98	85	74	66	59	54	49	43	39	31	13
.75	0	0	0	0	0	0	0	0	0	0	0	1	2	7	18	33	52	71	88	104	108	102	89	77	68	61	55	50	44	39	31	15
1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	5	13	25	43	62	87	103	108	97	84	73	65	59	53	45	41	32	20
1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	5	12	24	48	74	99	106	95	83	72	64	58	48	43	34	25
2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	5	17	37	69	99	104	94	82	72	64	52	45	36	27
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	8	27	65	95	102	95	83	73	58	49	38	28
3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	8	32	68	95	101	93	82	64	52	40	28

RAINFALL TYPE = II * * * TC = 2.0 HR * * * SHEET 10 OF 10

PART II

STORMWATER DETENTION

Flow Routing

A stormwater detention basin acts as a constriction in the stream. When the capacity of the outlet structure is exceeded, a portion of the flow backs up and is temporarily stored. Flow routing (or flood routing) is the procedure used to determine the volume of water that will be stored behind the detention structure during a rainfall event. In order to design a detention basin, a flow routing procedure must be used to determine the required storage volume for the selected design storm and the allowable release rate.

Storage-Indication Method

One of the most widely used methods of determining the required storage volume in detention basins is the Storage-Indication Method. This mathematical flow routing procedure consists of a trial and error process based upon the Continuity Equation. The basic premise is that the volume of water entering the basin minus the volume of water leaving the basin (over a given time interval) equals the required storage volume. The design procedure for implementing the Storage-Indication Method can be quite lengthy and time consuming when done manually.

Rather than present an in-depth explanation or an over-simplified version of the subject of flood routing in this handbook, the reader is referred to the Soil Conservation Service National Engineering Handbook, Section 4, Chapter 17 (68). That reference provides a good explanation of flood routing along with design procedures for the Storage-Indication Method and other acceptable techniques of calculating detention storage volumes.

Graphical Storage Method

A simpler, but less accurate method of estimating detention storage volume is the Graphical Storage Method. This method was developed by the Soil Conservation Service and is explained fully in the SCS Technical Release No. 55 (62). It involves the use of one graph which was developed based upon average storage and routing effects of many structures using the Storage-Indication Method of flood routing.

The primary advantages of this method are its simplicity and its compatibility with SCS runoff calculation procedures described in Part I of this chapter. It is particularly suited for small detention basin design and for estimating the required size of basins during the project planning phase.

A design procedure for the Graphical Storage Method is presented here; however, its use is subject to the following limitations:

1. Failure of the structure must not endanger or result in loss of life or major property damage.

2. An error in calculated storage volume of +/- 25% must be tolerable.

3. This method may be used for single- and multiple- stage outflow devices providing: (a) each stage requires a design storm and a computation of the related storage; (b) the discharge of the upper stage(s) includes the discharge of the lower stage(s).

The following design procedure will only determine the required storage volume of the basin. The design of an appropriate discharge structure, which will maintain the allowable release rate at the design storage elevation, should be done by a qualified engineer.

DESIGN PROCEDURE - GRAPHICAL STORAGE METHOD

Step 1: Determine the allowable peak release rate (Q_o) for the basin in CFS or CSM.

The most common procedure in determining Q_o is to limit the downstream discharge rate to the 2-year pre-developed discharge rate. (See Chapter 4 for a more detailed discussion of the runoff criteria of the E&S Regulations.)

Step 2: Calculate the peak inflow rate (Q_i) for the "developed" conditions.

Step 3: Calculate the ratio Q_o/Q_i of design release rate (Q_o) to the inflow rate (Q_i) in the same units.

Step 4: Using Graph (Plate 5-27), enter the graph with Q_o/Q_i; move vertically to intersect the curve; then move horizontally to read the value for the ratio V_s/V_r.

Step 5: Calculate the required storage volume (V_s) in watershed inches by multiplying the V_s/V_r ratio by the volume of runoff (V_r) in inches for the "developed" condition.

Step 6: Convert V_s from watershed inches to acre-ft. by multiplying V_s (inches) by the watershed area (acres) and dividing by 12 in./ft.

Step 7: Proportion the storage basin and design the discharge structure so that the allowable release rate is not exceeded and the maximum water storage elevation is known.

Design Examples

The following examples represent three typical design problems. Example 5-7 and 5-8 require the use of the graph (Plate 5-27) to design a single-site detention basin. Example 5-9 requires the use of the same graph for a multi-site design in a watershed with seven sub-areas. In the following examples, the required storage volumes are determined, but the actual basin sizing and discharge structure design are beyond the scope of this text and are not included.

Example 5-7

A developer proposes to develop a 75-acre tract of woodland into a residential subdivision. The 75-acre tract is the entire drainage area of a main channel which intersects a natural stream at the property boundary. The developer is required to detain stormwater in a basin to be constructed on the main channel below the development so that the peak rate of runoff entering the natural stream after development does not exceed the pre-development peak runoff rate for a 2-year frequency design storm. This example uses the Type II storm distribution since the project is located in south-central Virginia.

Find: The required storage volume of the basin.

Step 1: Determine the allowable release rate, Q_o.

The peak discharge method was used to calculate the pre-development and post-development peak flow rates and runoff depths for a 2-year storm. The results are as follows:

Pre-development		Post-development	
Q_{peak} =	35 cfs	Q_{peak} =	90 cfs
V_r =	1 inch	V_r =	2 inches

Therefore,

Q_o = 35 cfs $\qquad$ Q_i = 90 cfs

Step 2: Determine the post-development peak discharge, Q_i.

In this example, Q_i is given. $\qquad$ Q_i = 90 cfs

Step 3: Determine $\dfrac{Q_0}{Q_i}$.

$$\frac{Q_0}{Q_i} = \frac{35\ cfs}{90\ cfs} = 0.389$$

Step 4: From the graph (Plate 5-27), determine, $\dfrac{V_s}{V_r}$.

Entering the graph with $\dfrac{Q_0}{Q_i} = 0.389$ and intersecting the curve,

$$\frac{V_s}{V_r} = 0.326$$

Step 5: Calculate the required storage volume, V_S.

$$\frac{V_s}{V_r} = 0.326 \quad and \quad V_r = 2\ inches$$

$$V_s = (V_r)\left(\frac{V_s}{V_r}\right) = (2\ inches)\ (.326)$$

$$V_s = .652\ inches$$

Step 6: Convert V_S to acre-feet.

$$V_s = (.652\ inches)\left(\frac{75\ acres}{12\ in./ft.}\right) = 4.1\ acre\text{-}feet$$

Note: The next step would require the development of an elevation-storage curve for the basin, and an elevation-discharge curve for the proposed outlet structures. The objective would be to select an outlet structure which will discharge at the allowable release rate when the water reaches the maximum storage elevation. This step is beyond the scope of this text and, therefore, is not included.

Example 5-8

The developer is required to detain the stormwater runoff calculated in example 5-4 so that the peak rate of runoff after development does not exceed the peak pre-development rate of runoff for a 2-year frequency design storm.

Examples 5-4 and 5-5 use the graphical peak discharge method to determine the following:

Pre-development	Post-development
$Q_{peak} = 102$ cfs	$Q_{peak} = 202$ cfs
$V_r = 0.9$ in.	$V_r = 1.36$ in.

Therefore,

$Q_o = 102$ cfs	$Q_i = 202$ cfs

Find: The required storage volume of the basin.

Step 1: Determine Q_o

In this example, Q_o is given. $Q_o = 102$ cfs.

Step 2: Determine Q_i

Again, this value is given. $Q_i = 202$ cfs.

Step 3: Determine $\frac{Q_o}{Q_i}$.

$$\frac{Q_o}{Q_i} = \frac{102\ cfs}{202\ cfs} = 0.50$$

Step 4: From the graph (Plate 5-27), determine $\frac{V_s}{V_r}$.

Entering the graph with $\frac{Q_o}{Q_i} = 0.50$ and intersecting the curve,

$$\frac{V_s}{V_r} = 0.278$$

Step 5: Calculate the required storage volume V_s.

$$\frac{V_s}{V_r} = 0.278 \quad and \quad V_r = 1.36 \; inches$$

$$V_s = (V_r)\left(\frac{V_s}{V_r}\right) = (1.36 \; in.)\;(0.278)$$

$$V_s = 0.378 \; inches$$

Step 6: Convert V_s to acre-feet.

$$V_s = (0.378 \; in.)(0.39 \; sq.mi.)\left(\frac{53.33 \; ac.ft.}{in.\text{-}sq.mi.}\right)$$

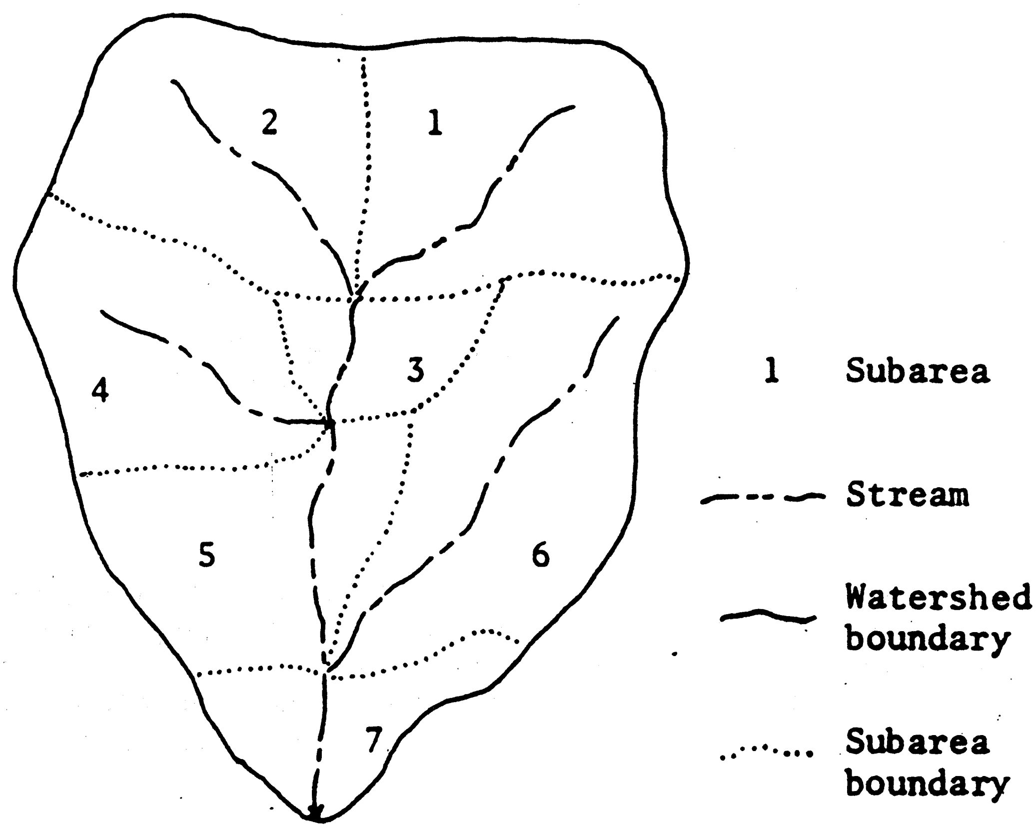
$$V_s = 7.86 \; acre\text{-}feet$$

Note: This step would require the development of an elevation-storage curve for the detention basin, and an elevation-discharge curve for the proposed outlet structures. The objective would be to select an outlet structure which would discharge at the allowable release rate when the water reaches the maximum storage elevation. This step is beyond the scope of this handbook and, therefore, is not included.

Example 5-9

The watershed illustrated below is to be developed according to a predetermined plan. The tabular method was used in Example 5-6 to develop the tabular hydrographs shown on Worksheet 5b for both the present and future watershed conditions.

Find: Determine the peak release rates and required storage volumes for stormwater detention basins located at the outlets of sub-areas 4 and 6 so that the composite peak discharge rate at the outlet of sub-area 7 will not increase after development for the selected design storm.



In order to determine the allowable release rates for the detention basins in this example, an analysis of the appropriate tabular hydrographs is necessary. The future flow condition contributions by sub-areas 4 and 6 are subtracted from the future composite hydrograph as follows:

(SUB) AREA NAME	Time (in hours)				
	13.2	13.4	13.6	13.8	14.0
	Discharges (cfs)				
Composite Discharge	338	343	335	316	291
Sub-Area 4 Discharge	2	9	23	41	55
Sub-Area 6 Discharge	162	156	131	101	77
Composite minus sub-areas 4 & 6:	174	178	**181**	174	159

The partial composite peak discharge is 181 cfs. From Worksheet 5B in example 5-6, the present condition composite hydrograph shows an allowable peak release rate of 230 cfs. Therefore, the allowable release rate from sub-areas 4 and 6 combined is:

230 cfs - 181 cfs = <u>49 cfs</u>.

It is now necessary to decide the distribution of the 49 cfs release rate between the two detention basins. For a first trial, assume the basin at the outlet of sub-area 6 (structure 6A) to have a 30 cfs release rate, and the basin at the outlet of sub-area 4 (structure 4A) to have a 19 cfs release rate.

DETERMINE STORAGE REQUIRED IN STRUCTURE 6A

1. $Q_o = 30 \text{ cfs} = \dfrac{30 \text{ cfs}}{0.4 \text{ mi}^2} = 75 \text{ CSM}$

2. Q_i must be determined for sub-area 6. Do not use the peak rate of 162 cfs shown on the tabular hydrograph (Worksheet 5b for developed conditions), because that discharge represents only the sub-area contribution at the outlet of sub-area 7, not the peak discharge at the sub-area 6.

   Go to Exhibit 5-II for Type II rainfall, $T_c = 1.00$ hr. and $T_t = 0$. Interpolate between Ia/p values to obtain Q_i for Ia/p = 0.19, read Q_i = 318 CSM per inch of runoff.

   Therefore, $Q_i = 318 \dfrac{\text{CSM}}{\text{in.}} (V_r) = 318 \dfrac{\text{CSM}}{\text{in.}} (1.3 \text{ in.}) = 413 \text{ CSM}.$

3. $$\frac{Q_o}{Q_i} = \frac{75\ CSM}{413\ CSM} = 0.18$$

4. From the Graph (Plate 5-27, Type II rainfall distribution)

$$\frac{V_s}{V_r} = 0.47$$

5. Since the future condition runoff volume V_r = 1.30 in. (from Worksheet 5a for developed conditions):

$$V_s = (V_r)\left(\frac{V_s}{V_r}\right) = 1.30\ (0.47) = 0.61\ in.$$

6. $$V_s = \frac{0.61\ in.\ (640\ acre/mi.^2)(0.40\ mi.^2)}{12\ in./ft.}$$

$$V_s = 13.0\ acre\text{-}feet$$

DETERMINE STORAGE REQUIRED IN STRUCTURE 4A

1. $Q_o = 19\text{ cfs} = \dfrac{19\text{ cfs}}{0.25\text{ mi}^2} = 76\text{ CSM}$

2. Find Q_i by using Exhibit 5-II for Type II rainfall, T_c = 0.75 and T_t = 0. Interpolate between Ia/p values to obtain Q_i for Ia/p = 0.24. Read Q_i = 367 CSM per inch of runoff.

Therefore, $Q_i = 367\ \dfrac{\text{CSM}}{\text{in.}}\ (V_r) = 367\ \dfrac{\text{CSM}}{\text{in.}}\ (1.01\text{ in.}) = 371\text{ CSM}$

3. $$\frac{Q_o}{Q_i} = \frac{76\ CSM}{371\ CSM} = 0.2$$

4. From the Graph (Plate 5-27)

$$\frac{V_s}{V_r} = 0.455$$

5. Since V_r = 1.01 (From Worksheet 5a for developed conditions)

$$V_s = 1.01(0.455) = 0.46 \text{ in.}$$

6. $$V_s = \frac{0.46\ in.\ (640\ acre/mi.^2)(0.25\ mi.^2)}{12\ in./ft.}$$

$$V_s = 6.1\ acre\text{-}feet$$

SUMMARY

Structure	Drainage Area	Q_o	Storage Volume
4A	0.25 $mi.^2$	19 cfs	6.1 acre-ft.
6A	0.40 $mi.^2$	30 cfs	13.0 acre-ft.
Total		49 cfs	19.1 acre-ft.

The structures may now be designed using elevation storage curves for the impoundment sites and elevation-discharge curves for the selected discharge structures.

Other trial calculations can be made, if desired, to determine the most economical allocation of storage between the two detention basins that still maintain a combined release rate of 49 cfs.

* Note: Curve for types I and IA is not applicable in the State of Virginia.

APPROXIMATE GEOGRAPHIC BOUNDARIES FOR SCS RAINFALL DISTRIBUTION

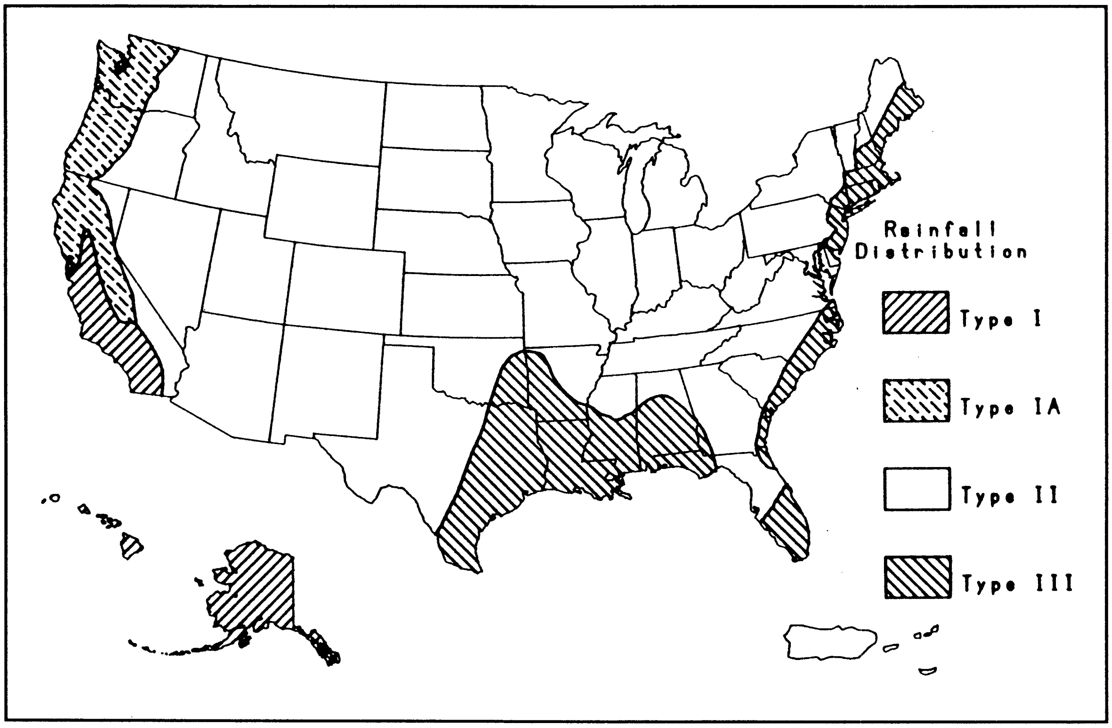
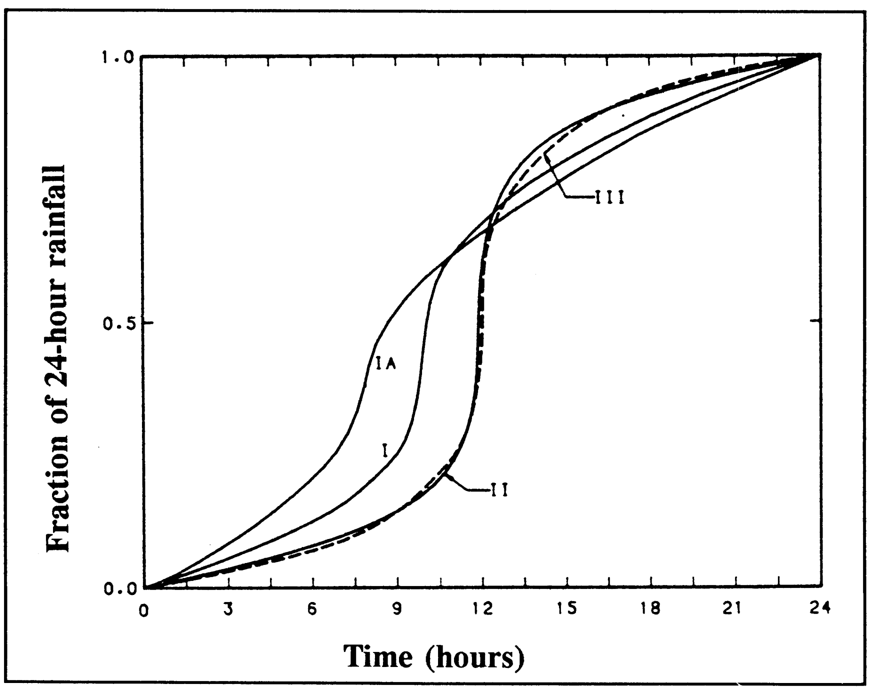


Plate 5-26A

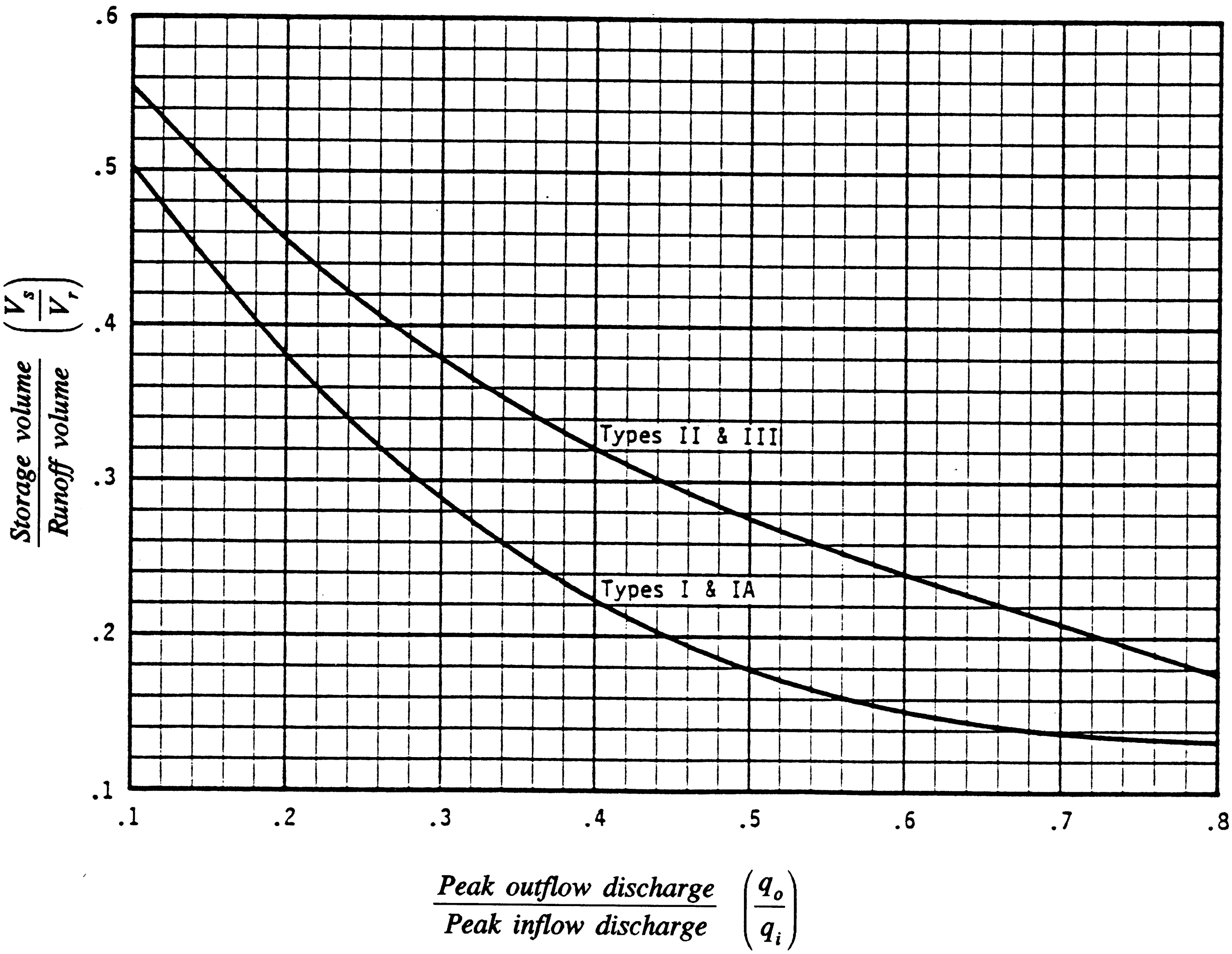
SCS 24-HOUR RAINFALL DISTRIBUTIONS



Source: USDA-SCS, TR-55

Plate 5-26B

APPROXIMATE DETENTION BASIN ROUTING
FOR RAINFALL TYPES I, IA, II, AND III



Source: USDA-SCS, TR-55

Plate 5-27

PART III

OPEN CHANNEL FLOW

INTRODUCTION

Discussion of open channel flow has been divided into two sections. The first section, Constructed Stormwater Conveyance Channels, deals with the design of new stormwater conveyance channels in accordance with the Virginia Erosion and Sediment Control Handbook. The second section, Natural Channels, deals with undisturbed natural stream channels. Both of these sections provide information to allow the determination of an adequate channel as required by the Erosion and Sediment Control Regulations, Minimum Standard #19.

In order to simplify the hydraulic calculations, it is assumed that the channel can be divided into segments in which uniform flow exists. Uniform flow describes a condition where the depth of flow, area, velocity and discharge at every section of the channel segment are constant. In reality, these conditions are seldom met. The channel can, however, be divided into segments which have similar cross-sections and slope, and the flow can be considered at one point in time, such as the peak flow, when the quantity of flow would be more or less constant.

The two methods of analyzing the erosion resistance of a channel are the Maximum Permissible Velocity method and the Tractive Force method. An explanation of the Maximum Permissible Velocity method is given in the following pages of this chapter.

The following information is based on the assumption that the reader has some basic knowledge of hydraulic engineering principles and terms.

Design Criteria for Constructed Channels

The Virginia Erosion and Sediment Control Regulations (VESCR) contain two primary requirements for the design of man-made channels. First, the channel must have sufficient capacity to convey the peak flow expected from the 10-year frequency storm. Second, the channel lining must be resistant to erosion for the velocity of flow expected from the 2-year storm. These are statewide minimum requirements. The designer should investigate the specific drainage area to determine if more stringent design criteria are required.

Both the capacity of the channel and the velocity of flow are functions of the channel lining, cross-sectional area and slope. The channel must have a cross-section and lining that will provide sufficient capacity, erosion resistance, and stability to convey the runoff.

Channel Slope

The slope of the channel is generally fixed by the topography and proposed route of the channel. Often, there is little a designer can do to alter the slope. A field survey can provide accurate information on slope.

Channel Cross-Section

The most commonly used channel cross-sections are vee, parabolic, and trapezoidal shapes. Chapter 3 (Std. & Spec. 3.17) contains guidelines for selecting an appropriate shape based upon size, intended use, and lining of the channel. Selection of the proper channel design is a trial and error process by which the designer attempts to accommodate the flow without exceeding the maximum permissible velocity for the lining.

Channel Lining

There are a number of possible channel linings from which to choose. Commonly used channel linings include grass, riprap and concrete.

For design purposes, erosion resistance of a particular lining is stated in terms of the maximum velocity that the lining can withstand without experiencing erosion problems. Other factors should also be considered such as the duration of flow, impact of extreme storm events, flooding problems, etc.

Concrete and similar structural linings generally do not erode and the design is not restricted by maximum permissible flow velocities. However, riprap and grass-lined channels do have maximum permissible velocities above which erosion will occur.

For grass lined channels, the maximum permissible velocity is usually based upon the erosion resistance of a mature stand of vegetation. Newly seeded areas or areas with immature vegetation are very susceptible to erosion damage. Therefore, it is recommended that a temporary channel lining should be used to prevent channel erosion until the vegetation is established. When used properly, temporary lining materials can greatly increase the success in achieving an adequate stand of vegetation. (See Chapter 3 for more information on temporary lining materials.)

DESIGNING A STORMWATER CONVEYANCE CHANNEL

CALCULATION OF CHANNEL CAPACITY AND VELOCITY

In this section, the following two equations are used to calculate flow and velocity in open channels:

(A) Manning's Equation

$$V = \frac{1.49}{n} R^{\frac{2}{3}} S^{\frac{1}{2}}$$

where,

V	=	the average velocity in the channel (ft./sec.)
n	=	Manning's roughness coefficient, based on channel lining
R	=	the hydraulic radius (feet) = A/P
S	=	the slope of the channel (feet/foot).

(B) Continuity Equation - Initial estimates of the required cross-sectional area of the channel can be made by manipulating this equation.

$$Q = VA$$

where,

Q	=	Flow rate ($ft.^3/sec.$) in the channel
V	=	Average velocity in the channel (ft./sec.) from Manning's equation
A	=	Cross-sectional area of the channel ($ft.^2$). See Plate 5-28 for formulas used to calculate cross-sectional area and hydraulic radius.

Additional design aids have also been placed at the end of this section for channel velocity calculation, and calculation of flow capacities based on various channel linings and configurations.

Manning's "n"

Manning's "n" value is a dimensionless number used to assign a value to the roughness of a channel. The Manning "n" value is dependent on a number of variables, the most important of which is the channel roughness, or hydraulic resistance of the material forming the channel side walls and bed. For some smooth channel lining materials such as concrete, the Manning "n" is taken to be a constant value based only on the estimated surface roughness. For bed materials such as rock riprap, the Manning "n" varies with the average size of the rock exposed to the flow. Grass and other vegetative linings produce a very complex relationship between Manning "n" and a variety of factors because the vegetation behaves in various ways depending on the type and height of the vegetation and the velocity of flow.

In addition to the bed roughness, the Manning "n" also tends to vary slightly with channel size. While this variation can normally be neglected, it should be kept in mind that the Manning "n" for small channels, such as street gutters, is larger than the Manning "n" for larger drainage ditches lined with similar material. Similarly, the Manning "n" for small drainage ditches is larger than the "n" for very large ditches. For determination of the "n" factor used in solving the Manning Equation, see the Channel Lining Design unit.

CHANNEL LINING DESIGN

Channel linings are used to help stabilize channels, thus preventing erosion and sedimentation damages. Linings may be installed in either natural or man-made channels, and can be utilized either in the initial design of the channel or as a remedy to an existing erosion problem.

Channel linings may be classified generally as either rigid (concrete or asphalt) or flexible (rock riprap or vegetation). Each of these lining types has certain advantages and disadvantages. Some of these are outlined in the following table.

TABLE 5-11

ADVANTAGES AND DISADVANTAGES OF RIGID AND FLEXIBLE CHANNEL LININGS

Type of Channel Lining	Advantages	Disadvantages
Rigid	Good capacity Low flow resistance Can be used for steep channels Can be used when width is restricted Underlying soil is completely protected	High velocities at outlet Unnatural appearance Prevent infiltration Hydrostatic pressure failure May be destroyed by undercutting
Flexible	Generally less expensive Safer for roadsides Self-healing Permit infiltration and exfiltration Filter contaminants Provide energy dissipation (higher Manning "n") Lower velocity at outlet Natural appearance	Higher depth of flow Require wider right-of-way Lower flow capacity Some erosion damage may occur during high floods

Source: Va. DSWC

Determination of "n" Values

Ranges of values for Mannings "n" have been determined for various types of channel linings. The lower the Manning value, the more hydraulically efficient the lining is. For example, the range of values for formed concrete is between .013 and .017. Therefore, .013 represents the best attainable "n" value and the most hydraulically efficient value for formed concrete, while .017 represents the least hydraulically efficient.

It is good practice to use a higher "n" value within the range of a lining material in order to achieve a conservative design. It is usually unacceptable to use the lowest value since some minor imperfections in the channel lining are likely and the lining will become somewhat less hydraulically efficient over time.

Rigid Channel Linings

Table 5-12 lists the Mannings "n" values for many of the commonly used channel linings.

Flexible Channel Linings

Riprap:

The Manning "n" value varies with mean stone size, as follows:

$$n = 0.0395 \ (d_{50})^{1/6}$$

where,

d_{50} = the median size (feet) of the stone riprap.

Thus, the following "n" values apply for common stone sizes:

d_{50} (ft.)	n
0.25	0.0314
0.50	0.0352
0.75	0.0377
1.00	0.0395
1.50	0.0423

Vegetative Linings:

Manning "n" values vary with hydraulic radius, velocity, as well as roughness. While usually not considered important for moderate size rigid-lined channels, the effect of velocity on Manning "n" values is considered especially significant when related to vegetative linings. Accordingly, curves have been developed to represent the interaction between hydraulic radius, velocity and roughness coefficient as related to various vegetative retardances. (See Plate 5-29 and Table 5-13.)

For grass-lined channels, Mannings "n" value can be determined by the following procedure:

1. Determine the maximum permissible velocity (V) for the grass to be used. (See Table 5-14 and Plate 5-30.)

2. Calculate the hydraulic radius (R) of the channel. (See Plate 5-28.)

3. From Table 5-13, determine the retardance class of the grass to be used. When calculating channel capacity, the highest retardance class of the grass should be used (e.g., long condition). When calculating velocity, the lowest retardance class should be used (e.g., mowed condition).

4. Enter Plate 5-29 with the product of: V x R. Move vertically until the correct retardance curve is intersected. Read "n" on the left axis.

Determination of Maximum Permissible Velocity

Once Mannings "n" has been selected and the average velocity has been determined, the velocity is compared with the maximum permissible velocity for the selected channel lining. If the velocity is less than the permissible velocity, then the channel design is considered to be acceptable with respect to erosion resistance.

When properly constructed, rigid channel linings can resist very high velocities without erosion damage or failure. Therefore, hydraulic capacity is usually the primary design consideration. However, the overall design should include measures to prevent erosion damage to the receiving channel due to excessive discharge velocities. (See Chapter 3 for details on outlet protection.)

For channels with flexible channel linings, selection of the proper channel lining is critical. Both the hydraulic capacity of the channel and its erosion resistance (the maximum permissible velocity) are directly related to the channel lining. Because of the variability of conditions within the watershed, it is good design practice to maintain a safety margin between the maximum permissible velocity of the channel lining and the calculated channel velocity.

Flexible Channel Linings

The method described below is adapted from Hydraulic Engineering Circular No. 15 of the Federal Highway Administration. It is applicable to both straight and curved sections of channel where the flow is parallel to the bank of the channel.

For Straight Sections of Channel:

This design method determines a stable rock size for straight and curved sections of channels. It is assumed that the shape, depth of flow, and slope of channel are known. A stone size is chosen based on the maximum depth of flow. If the sides of the channel are steeper than 3:1, the stone size must be modified accordingly. The final design size will be stable on both the sides and bottom of the channel.

1. Enter Plate 5-31 with the maximum depth of flow (feet) and channel slope (feet/foot). Where the two lines intersect, choose the d_{50} size of stone. (Select the d_{50} for the diagonal line above the point of intersection.)

2. If channel side slopes are steeper than 3:1, continue with step 3; if not, the procedure is complete.

3. Enter Plate 5-32 with the side slope and the base width to maximum depth ratio (B/d). Where the two lines intersect, move horizontally left to read K_1.

4. Determine from Plate 5-33 the angle of repose for the d_{50} size of stone. (Use 42° for d_{50} greater than 1.0 feet ±.) Do not use riprap on slopes steeper than the angle of repose for the size of stone.

5. Enter Plate 5-34 with the side slope of the channel and the angle of repose for the d_{50} size of stone. Where the two lines intersect, move vertically down to read K_2.

6. Compute $d_{50} \times K_1/K_2 = d'_{50}$. to determine the correct size stone for the bottom and side slopes of straight sections of channel.

For Curved Sections of Channel:

1. Compute the radius of the curve (Ro) measured at the outside edge of the bottom.

2. Compute the ratio of the top width of water surface (Bs) to the radius of the curve (Ro), Bs/Ro.

3. Enter Plate 5-35 with the ratio Bs/Ro. Move vertically until the curve is intersected. Move horizontally left to read K_3.

4. Compute $d'_{50} \times K_3 = d_{50c}$ to determine the correct size stone for bottom and side slopes of curved sections of channel.

<u>Other Design Considerations</u>

1. <u>Adjustment for average channel depth</u>. When other conditions are the same, a deep channel can convey water at a higher mean velocity, without erosion, than a shallow one. Thus, a correction for flow depth should be applied to the permissible velocity. Plate 5-30 shows the suggested correction factors.

2. <u>Side Slopes</u>. When riprap-lined channels have side slopes steeper than 3:1 or the channel is curved (or is sinuous), the rock size must be adjusted accordingly. (Follow the procedure outlined in the <u>Flexible Lining Section</u>.) Minimum side slopes for channels excavated in various materials are shown in Table 5-15.

3. <u>Freeboard and Height of Bank</u>. For lined channels (other than vegetative linings), the channel lining should extend above the expected surface water

elevation. The recommended height of the channel lining above the water surface depends on several factors related to the particular watershed under consideration. The channel should be designed to convey a larger (or less frequent) storm event if the 10-year storm design is not adequate to prevent flooding or property damage during these events.

CHANNEL DESIGN PROCEDURE

Rigid Linings

For rigid channel linings, the design procedure is as follows:

Step 1 - Determine the flow into the channel. Perform hydrologic computations for peak Q_{10} and Q_2 flows.

Step 2 - Determine the slope of the existing or proposed channel.

$$\frac{Rise\ (ft.)}{Run\ (ft.)} = Slope\ \frac{feet}{foot}$$

Step 3 - Determine the minimum side slope necessary to maintain channel stability (from Table 5-15 in subsection titled "Other Design Considerations").

Step 4 - Choose a channel shape from Plate 5-28 (e.g., vee, parabolic, or trapezoidal). If vee or trapezoidal configuration, choose the angle of the channel wall side slope.

Step 5 - Select a channel lining, then determine the Mannings "n" value (from subsection titled "Determination of "n" Values for Use in the Mannings Equation").

Step 6 - Choose a desirable design depth.

Step 7 - For the channel slope, geometry and depth of flow, calculate the channel capacity by using a combination of the Mannings/Continuity Equation.

Determine by trial and error that the cross-sectional channel is adequate to carry the peak Q_{10} flow. Compare each calculated cross-sectional area to the area required to provide adequate Q_{10} capacity.

$$\frac{Q_{10}\ n}{1.49\ s^{1/2}} = A\ R^{2/3}$$

Note: At a minimum, man-made channels must convey the flow from the 10-year frequency storm without overtopping its banks. If the channel capacity is less than the peak 10-year runoff flow, increase the width and/or depth, and recheck the capacity. Repeat until the channel capacity is adequate.

Step 8 - Check to ensure that recommended freeboard, if necessary, exists above Q_{10} water surface elevation. Make channel adjustment as necessary.

Step 9 - Using the 2-year frequency storm velocity, verify that the designed channel will not erode.

$$V_2 = \frac{Q_2}{A_2}$$

(A_2 is also determined by trial and error.)

Also, if outlet velocity exceeds the maximum permissible velocity of the receiving stream, outlet protection must be used in accordance with Chapter 3, Section 3.18.

Flexible Linings

The following procedure can be used for the design of flexible channel linings:

Step 1 - Determine the flow into the channel. Perform hydrologic computations for the peak Q_{10} and Q_2 flows.

Step 2 - Determine the slope of the existing or proposed channel:

$$\frac{Rise\ (ft.)}{Run\ (ft.)} = Slope\ \frac{feet}{foot}$$

Step 3 - Determine the minimum side slope necessary to maintain channel stability from Table 5-15 in subsection titled "Other Design Considerations."

Step 4 - Choose a channel shape from Plate 5-28 (e.g., vee, parabolic or trapezoidal).

Step 5 - Select a channel lining and determine maximum permissible velocity of the lining.

Step 6 - Make an initial estimate of the cross-sectional area that is required to carry the Q_{10} flow by using the Continuity Equation:

$$A = \frac{Q}{V}$$

where,

Q	=	flow into channel
V	=	M.P.V. of lining selected in Step 5.

Step 7 - Select initial channel dimensions that will provide the cross-sectional area estimated in Step 6.

Step 8 - Calculate Hydraulic Radius (R) of the channel from the formulas listed on Plate 5-28.

Step 9 - Multiply the maximum permissible velocity (of the selected lining) by the hydraulic radius.

Step 10 - Determine the roughness coefficient "n" for the lining to be used (from the subsection titled "Determination of "n" Values for Use in Mannings Equation").

Note: If a vegetated lining is used, assume a retardance (from Table 5-13) for an unmowed or uncut condition to calculate capacity and retardance for a mowed or cut condition to check velocity.

Step 11 - Check Q_{10} capacity using the combined equations: Manning/ Continuity.

$$Q = \frac{1.49}{n} R^{2/3} S^{1/2} A$$

where,

A	=	cross-sectional area required to carry Q_{10} flow (from Step 6).

Step 12 - Check velocity (for the 2-year storm) by using the Manning Equation: (Use the hydraulic radius for the flow depth of the 2-year storm.)

$$V = \frac{1.49}{n} R^{2/3} S^{1/2}$$

Compare velocity to maximum permissible velocity of the selected channel lining.

Step 13 - If capacity is adequate and the velocity does not exceed the maximum permissible velocity, proceed to Step 14. If capacity or lining is not adequate, make the appropriate design modifications and repeat the procedure.

Step 14 - Check to ensure the recommended freeboard, if necessary, exists above Q_{10} water surface elevation. Make channel adjustments as necessary.

Note: The solution to the following problems are provided for illustrative purposes. There may be numerous designs which would solve these problems.)

Example 5-10: Rigid linings

Given: Peak Q_{10} flow = 255 cfs. Peak Q_2 flow = 200 cfs. Slope of the proposed channel = 1% or .01 ft./ft.

Find: An adequate channel design to convey the 10-year storm flow.

Solution:

Step 1 - Choose channel shape from Plate 5-28. Trapezoidal configuration with 2:1 side slopes was selected.

Step 2 - Select a channel lining and determine "n" value. Concrete ("n" = .014) was selected.

Step 3 - Determine depth of flow. Use 1.5 depth.

Step 4 - Using the Manning/Continuity Equation, determine by trial and error the bottom width (B) required to convey the Q_{10} flow.

$$\frac{Qn}{1.49\ S^{1/2}} = AR^{2/3}$$

where,

Q	=	255 cfs
n	=	0.014 (Float Finish Concrete)
S	=	0.010 ft./ft.
A	=	$Bd + Zd^2 = B(1.5) + 2(1.5)^2 = 1.5B + 4.5$ (formula from Plate 5-28 for determining cross-sectional area of trapezoidal section).
R	=	A/P
P	=	$B + 2(Z^2 + 1)^{1/2}\ (d)$
	=	$B + 2(2^2 + 1)^{1/2}\ (1.5)$
	=	$B + 6.7$

$$\frac{Qn}{1.49\ S^{1/2}} = \frac{255\ (.014)}{1.49\ (.010)^{1/2}} = 24.0$$

Trial	B	A = 1.5B + 4.5	P = B + 6.7	R = A/P	$R^{2/3}$	$AR^{2/3}$
1	11	21	17.7	1.19	1.12	23.5 < 24.0 cross-section insufficient
2	12	22.5	18.7	1.20	1.13	25.4 > 24.0 cross-section too large
3	11.5	21.75	18.2	1.20	1.13	24.5 ≈ 24.0 cross-section adequate

Therefore, a trapezoidal channel with an 11.5 ft. bottom width and 2:1 side slope will be adequate to convey 255 cfs with a depth of 1.5 ft. No check for erosion resistance capability is necessary, since rigid channel linings are not subject to scour at velocities up to about 20 feet per second.

Step 5 - Check velocity in the channel. Note that it is rather high (A_2 = 18.2; V = Q_2/A_2 = 200/18.2 = 11.0 fps.) and that a scour-control device will probably be necessary to re-adjust the flow at the downstream end of the proposed channel.

Example 5-11: Flexible Lining

Given: A trapezoidal channel: 3-feet deep, 8-feet bottom, 2:1 side slopes, and a 2% slope.

Find: Riprap size for the bottom and side slopes of channel.

Solution:

Step 1 - From Plate 5-31, for a 3-foot deep channel on a 2% grade, d_{50} = 0.75 feet or 9 inches.

Step 2 - Since the side slopes are steeper than 3:1, continue with Step 3.

Step 3 - From Plate 5-32, B/d = 8/3 = 2.67; Z = 2; K_1 = 0.82.

Step 4 - From Plate 5-33, for d_{50} = 9 inches, o = 41°.

Step 5 - From Plate 5-34, for Z = 2 and o = 41°, K_2 = 0.73.

Step 6 - $d_{50} \times K_1/K_2 = d'_{50} = 0.75 \times 0.82/0.73 = .84$ feet.

$$0.84\ ft.\ x\ \frac{12\ inches}{1\ foot} = 10.08 \quad (Use\ d_{50} = 10\ inches.)$$

Given: The preceding channel has a curved section with a radius of 50 feet.

Find: A stable riprap size for the bottom and side slopes of the curved section of channel.

Solution:

Step 1 - Ro = 50 feet

Step 2 - Bs/Ro = 20/50 = 0.40.

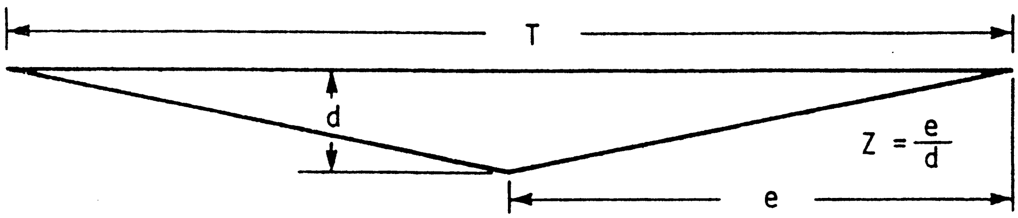
Step 3 - From Plate 5-35, for Bs/Ro = 0.40, K_3 = 1.1.

Step 4 - $d'_{50} \times K_3 = d_{50c} = 0.84 \times 1.1 = 0.92$ ft.

$$0.92\ ft.\ x\ \frac{12\ inches}{1\ foot} = 11.0\ inches$$

CHANNEL GEOMETRY

V - Shape

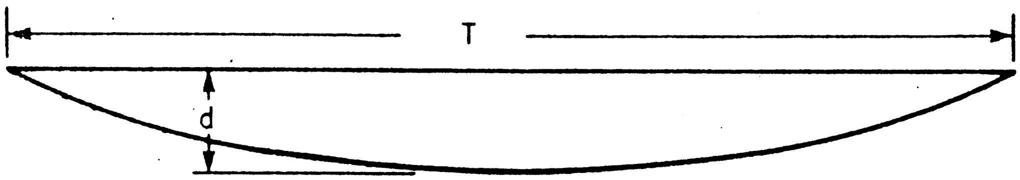


Cross-Sectional Area (A) = Zd^2

Top Width (T) = $2dZ$

Hydraulic Radius (R) = $\dfrac{Zd}{2\sqrt{Z^2 + 1}}$

Parabolic Shape

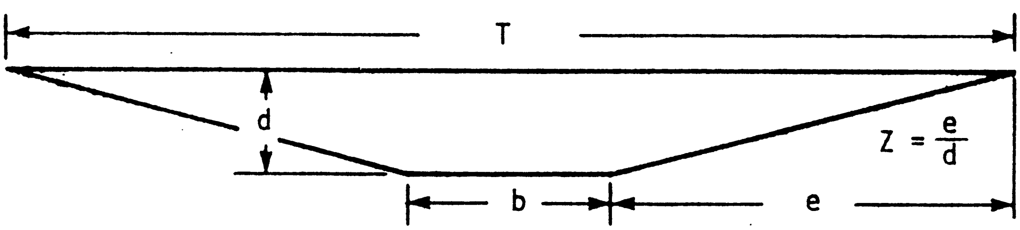


Cross-Sectional Area (A) = $\frac{2}{3}Td$

Top Width (T) = $\dfrac{1.5\ A}{d}$

Hydraulic Radius = $\dfrac{T^2d}{1.5T^2 + 4d^2}$

Trapezoidal Shape



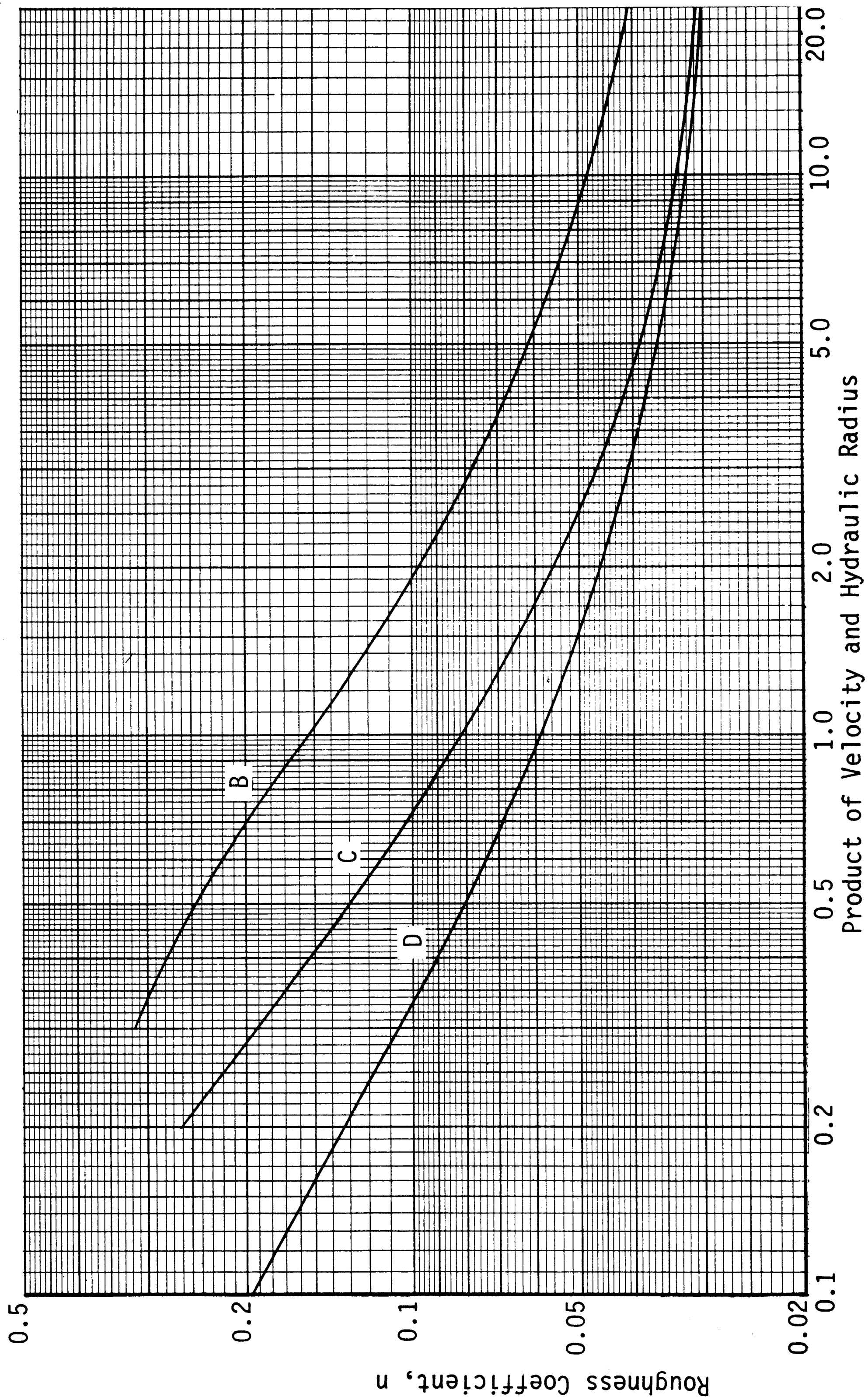
Cross-Sectional Area (A) = $bd + Zd^2$

Top Width (T) = $b + 2dZ$

Hydraulic Radius = $\dfrac{bd + Zd^2}{b + 2d\sqrt{Z^2 + 1}}$

Source: USDA-SCS

Plate 5-28



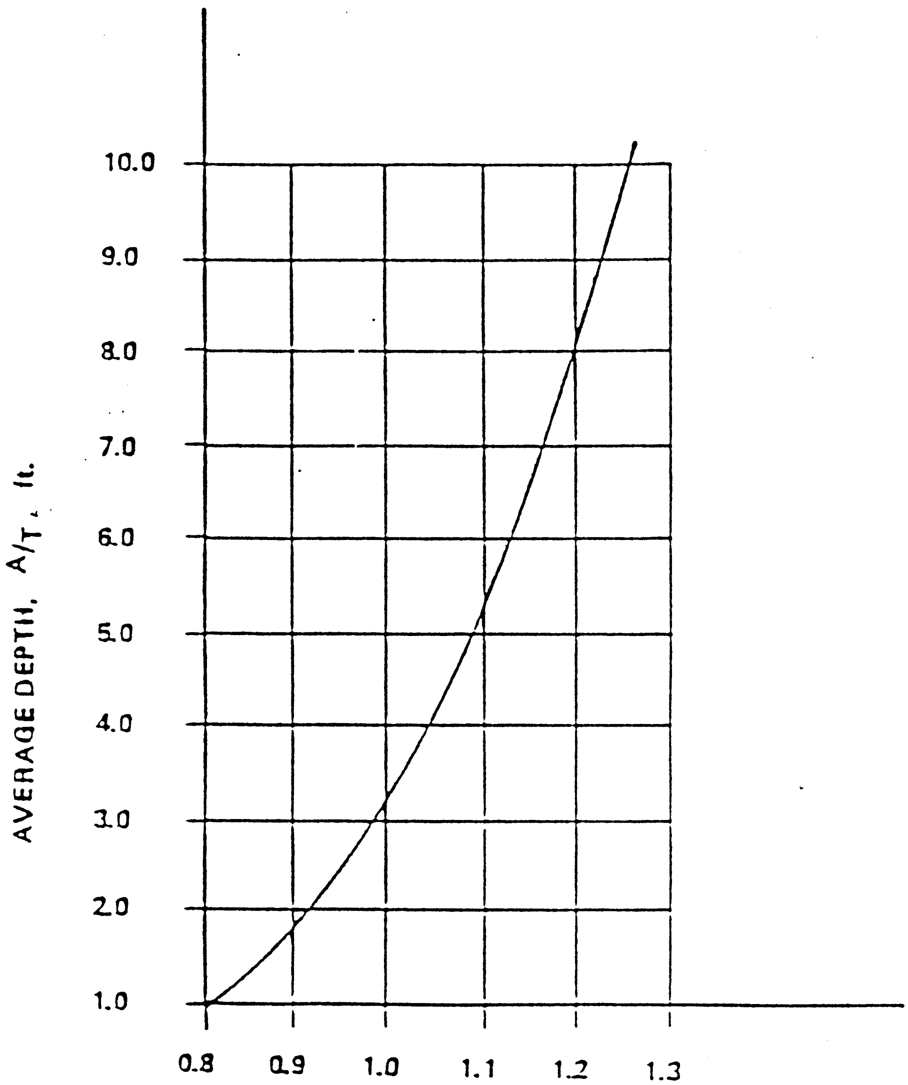
ROUGHNESS COEFFICIENT AS A FUNCTION OF v x R FOR VARIOUS RETARDANCE CLASSES

Source: USDA-SCS

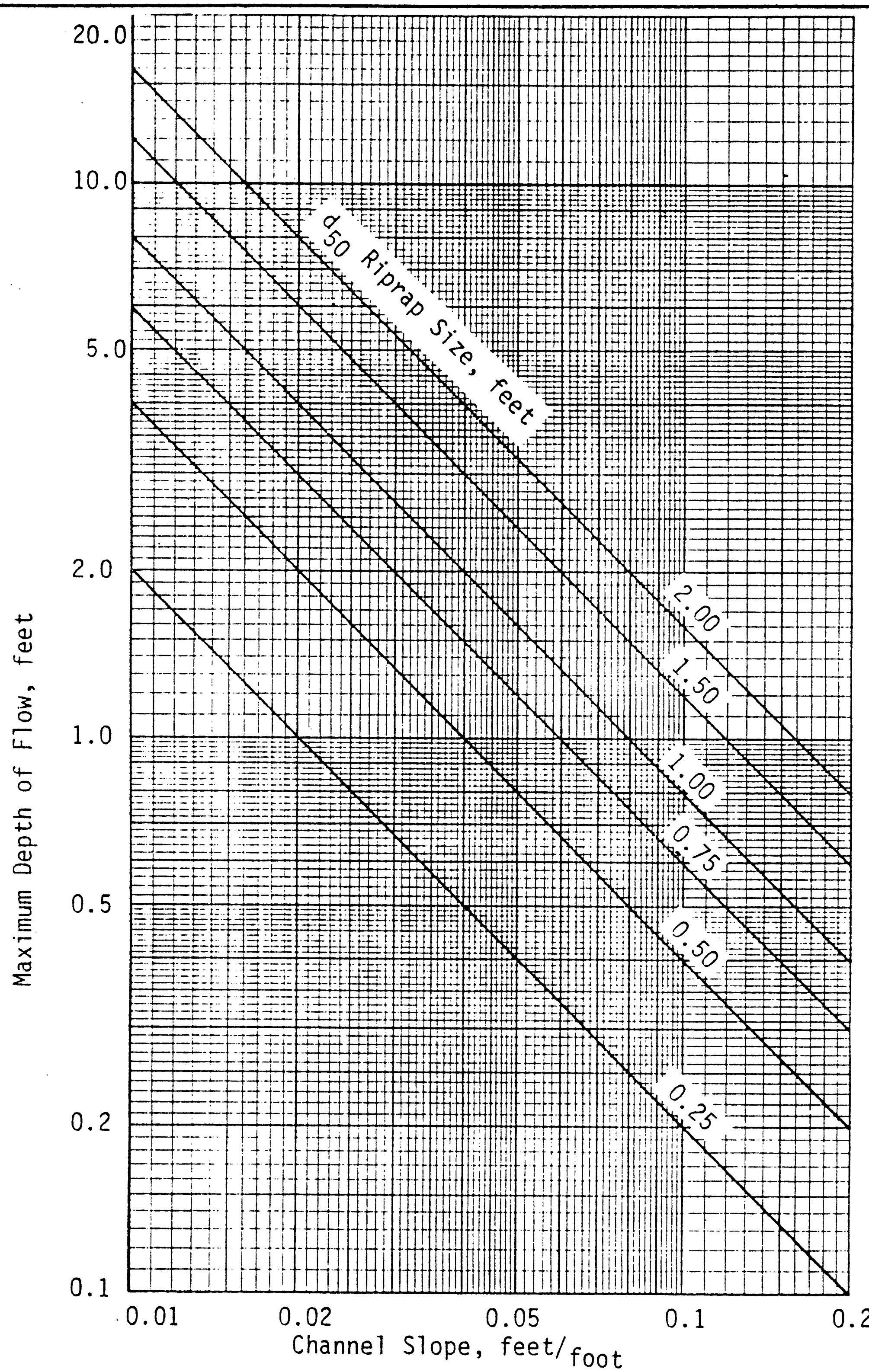
Plate 5-29

PLATE 5-30

CORRECTION FACTORS BASED FOR PERMISSIBLE VELOCITY BASED ON AVERAGE DEPTH OF FLOW



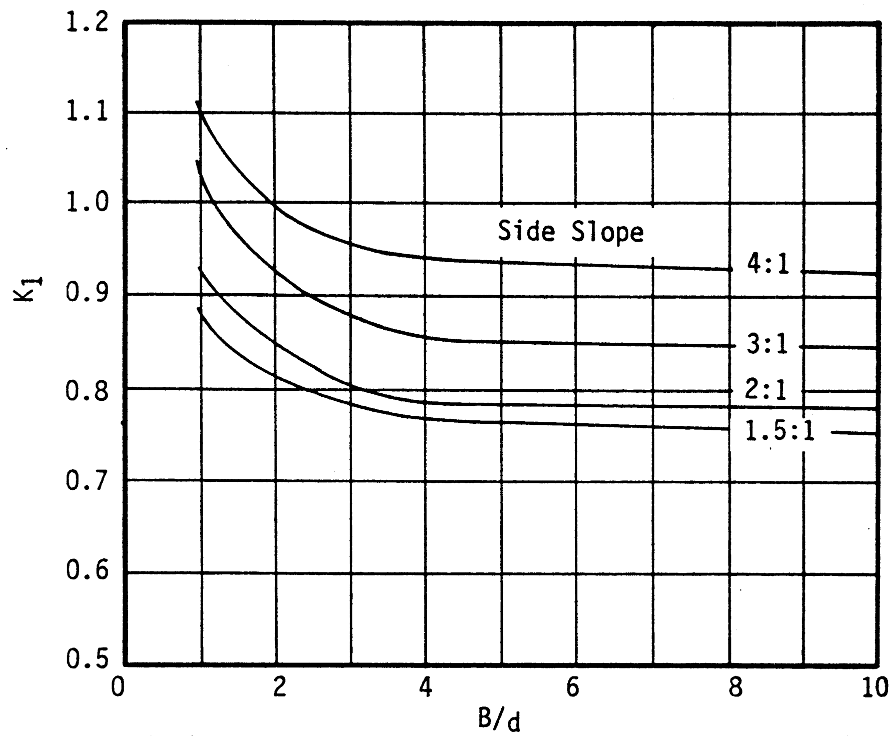
Source: Va. DSWC



MAXIMUM DEPTH OF FLOW FOR RIPRAP LINED CHANNELS

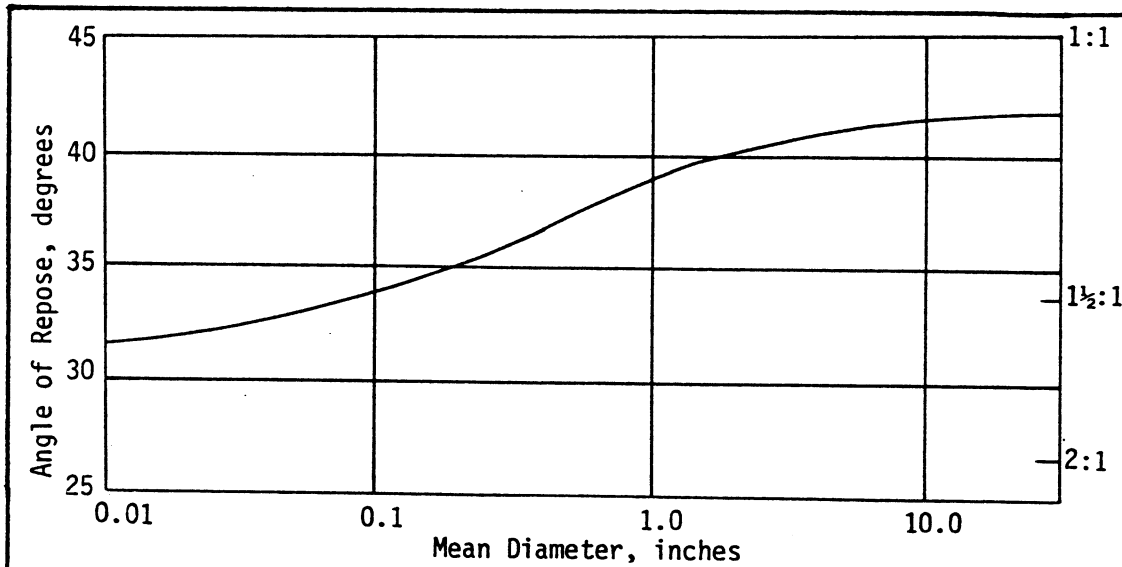
Source: VDOT Drainage Manual

Plate 5-31



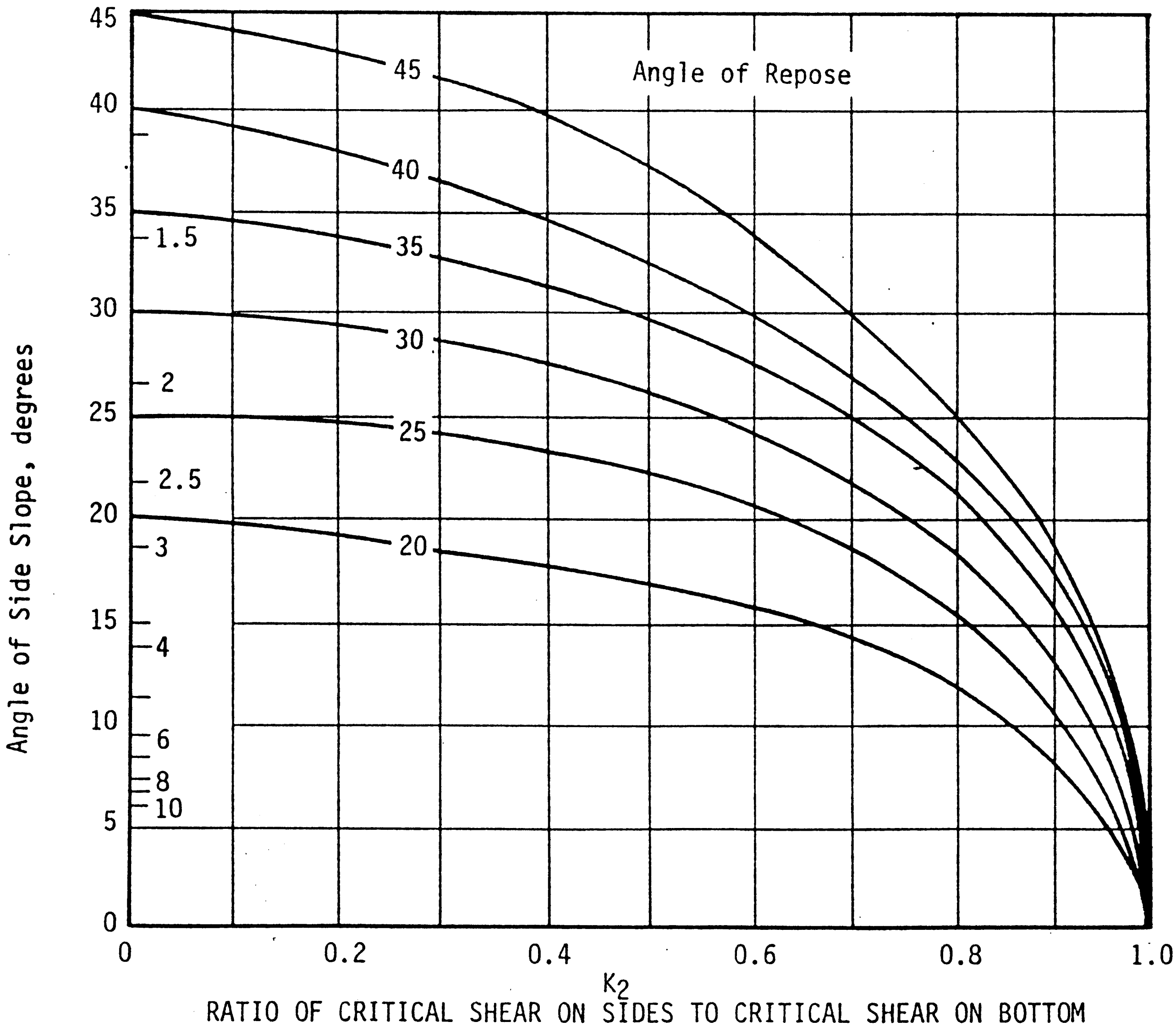
DISTRIBUTION OF BOUNDARY SHEAR AROUND WETTED PERIMETER
OF TRAPEZOIDAL CHANNEL

Source: VDOT Drainage Manual — Plate 5-32



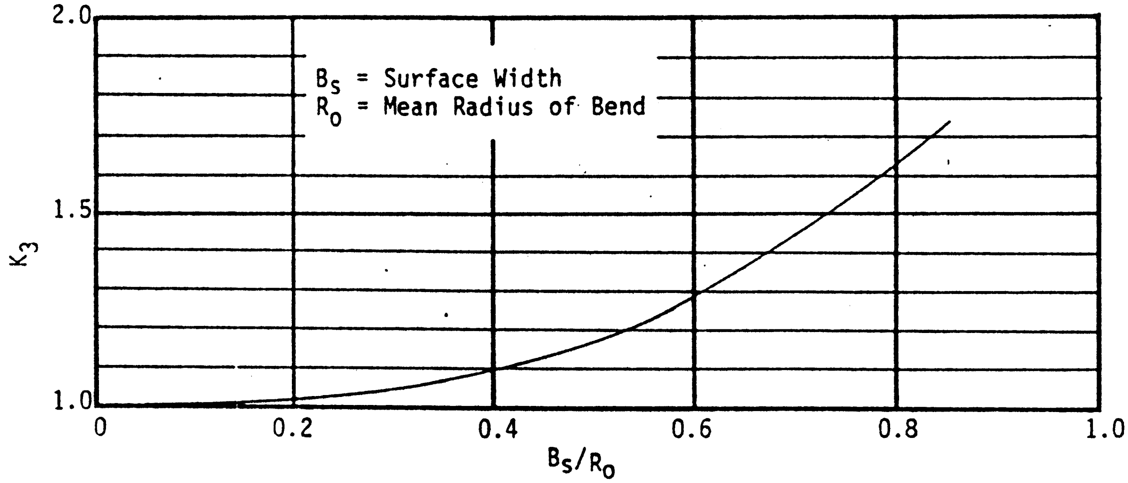
ANGLE OF REPOSE FOR RIPRAP STONES

Source: VDOT Drainage Manual — Plate 5-33



Source: VDOT Drainage Manual

Plate 5-34



RATIO OF MAXIMUM BOUNDARY SHEAR IN BENDS TO MAXIMUM BOTTOM SHEAR IN STRAIGHT REACHES

Source: VDOT Drainage Manual

Plate 5-35

TABLE 5-12

MANNING "n" VALUES FOR SELECTED CHANNEL LINING MATERIALS

Material	Range of "n" Values
Concrete	
- Formed	0.013 - 0.017
- Trowel Finish	0.012 - 0.014
- Float Finish	0.013 - 0.015
- Gunite	0.016 - 0.022
Gravel Bed, Formed Concrete Sides	0.017 - 0.020
Asphalt Concrete	
- Smooth	0.013
- Rough	0.016
Corrugated Metal	
- 2-2/3" x 1/2" Corrugations	0.024
- 6" x 2" Corrugations	0.032
Concrete Pipe	0.011 - 0.013

Source: Va. DSWC

TABLE 5-13

RETARDANCE CLASSIFICATIONS FOR VEGETATIVE CHANNEL LININGS

Retardance		Stand	Condition
B	Tall fescue	Good	Unmowed - 18"
	Sericea lespedeza	Good	Unmowed - 18"
	Grass-legume mixture	Good	Unmowed - 20"
	Small grains, mature	Good	Uncut - 19"
	Bermudagrass	Good	Tall - 12"
	Reed Canarygrass	Good	Mowed - 14"
C	Bermudagrass	Good	Mowed - 6"
	Redtop	Good	Headed - 18"
	Grass-legume mix., summer	Good	Unmowed - 7"
	Kentucky bluegrass	Good	Headed - 9"
	Small grains, mature	Poor	Uncut - 19"
	Tall fescue	Good	Mowed - 6"
D	Bermudagrass	Good	Mowed - 2.5"
	Red fescue	Good	Headed - 15"
	Grass-legume mixture, spring and fall	Good	Unmowed - 5"
	Sericea lespedeza	Good	Mowed - 2"

Source: USDA-SCS

TABLE 5-14

PERMISSIBLE VELOCITIES FOR GRASS-LINED CHANNELS

Channel Slope	Lining	Velocity* (ft./sec.)
0 - 5%	Bermudagrass	6
	Reed canarygrass Tall fescue Kentucky bluegrass	5
	Grass-legume mixture	4
	Red fescue Redtop Sericea lespedeza Annual lespedeza Small grains Temporary vegetation	2.5
5 - 10%	Bermudagrass	5
	Reed canarygrass Tall fescue Kentucky bluegrass	4
	Grass-legume mixture	3
Greater than 10%	Bermudagrass	4
	Reed canarygrass Tall fescue Kentucky bluegrass	3

* For highly erodible soils, decrease permissible velocities by 25%.

Source: Soil and Water Conservation Engineering, Schwab, et. al. and American Society of Civil Engineers.

TABLE 5-15

MINIMUM SIDE SLOPES FOR CHANNELS EXCAVATED IN VARIOUS MATERIALS

Material	Side Slope
Rock	Nearly vertical
Earth w/stone riprap lining	2:1
Firm clay or earth w/vegetative lining	2:1
Loose sandy earth, sandy loam or porous clay w/vegetative lining	3:1
Earth w/concrete lining extending to top of channel banks	1½:1

DETERMINATION OF AN "ADEQUATE CHANNEL"

The Virginia Erosion and Sediment Control Regulations (Minimum Standard #19) require that runoff from new development must be discharged into an "adequate channel." An adequate channel is defined as a watercourse that will convey a chosen frequency storm event without overtopping its banks or causing erosive damage to the bed, banks and overbanks sections of the channel.

Determination of flow capacity and velocity in a natural channel involves considerable judgement. The results cannot be determined with as great a certainty as for a man-made channel. Variations in cross-section, alignment and roughness in the channel, and the changing quantities of flowing water make the determination of capacity and velocity an approximation, at best.

The following procedure involves the use of the Manning's Equation, the Continuity Equation and the Maximum Permissible Velocity method of calculation. The procedure is not exact and will yield only capacity and velocity estimates for each channel reach without regard to backwater effects due to channel constrictions such as culverts or bridges. If the purpose of the channel investigation is to determine a flood plain or profile, a more sophisticated analysis should be undertaken. However, to determine channel capacity and stability, which is the primary objective here, this procedure will be considered adequate.

Survey of the Stream Channel

A survey must first be made of each channel segment (called a reach) to determine the relevant channel characteristics (e.g., slope, cross section, roughness, etc.). This data is then utilized in a design procedure to check the adequacy of the stream channel. Following are recommended elements of such a survey:

Survey Procedure

1. Develop a profile of the channel bottom along the centerline of the stream. Such a profile can be developed from a good topographic map, if available, or from a field level run, if necessary.

2. Control points should be selected along the centerline to define independent stream channel reaches to be tested. Good control points would include points of entry of major tributaries, points of significant change in grade or cross-section, or bridges or culverts which obstruct the design flow.

3. Obtain sufficient cross-sections, at right angles to the centerline in each reach, to determine the average channel cross-section. This portion of the survey should be done in the field, not from a map.

4. Note the relevant physical characteristics of the stream channel between control

points (including significance of meanders, the material comprising the channel bed and banks, vegetation, obstructions and other factors needed to determine a roughness coefficient "n"). This information must also be obtained in the field.

Note that an "n" factor for each stream channel reach must be determined. If the channel is man-made, "n" can be determined by one of the methods described in the section for design of constructed stormwater conveyance channels. If the channel is natural, the following procedure should be used.

This procedure assumes that "n" is influenced by several factors. Each of these factors should be evaluated independently without regard to each other. The roughness coefficient "n" can be computed as follows:

A. Selection of a basic "n" value, (n_1): Select a basic "n" value from Table 5-16 for a straight, uniform, smooth channel cut into the natural material involved. The channel of each reach should be visualized as straight and uniform in cross-section, with smooth sides and bottom, and cut into the natural material of the channel.

B. Selection of modifying values for surface irregularity, (n_2): Select a modifying value from Table 5-17. Consider surface irregularity, first, in relation to the degree of smoothness attainable in the natural materials involved and, second, in relation to the depths of flow under consideration. A value of zero would correspond to the best surface attainable in the materials involved.

C. Selection of modifying values for variations in the and shape of cross-section, (n_3): Select the modifying value from Table 5-18. The effect of changes in size may be best visualized by considering, primarily, the frequency with which large and small sections alternate and, secondarily, on the magnitude of the changes. Shape variations depend upon the degree to which the changes cause the greatest depth of flow to shift from one side of the channel to the other in the shortest distance.

D. Selection of modifying values for obstructions, (n_4): (Select modifying values from Table 5-19). Care should be taken not to re-evaluate effects already considered in Steps B and C (above). The obstruction should be judged by:

1. The degree to which the obstructions occupy or reduce the average cross-sectional area.

2. The character of the obstructions. (Sharp-edged or angular objects induce greater turbulence than curved, smooth-surfaced objects.)

3. The position and spacing of obstructions laterally and longitudinally in the reach under consideration.

E. Selection of modifying values for vegetation, (n_5): (Select modifying values from

Table 5-20). The retarding effect of vegetation should be judged by the following criteria:

1. Height in relation to depth of flow.

2. Capacity to resist bending.

3. The degree to which the cross-section is occupied or blocked out.

4. The lateral and longitudinal distribution of different types of vegetation.

5. The density and height of vegetation in the reach considered.

F. Selection of a modifying value for the degree meandering, (n_6): Select the appropriate value from Table 5-21. Calculate the ratio of meandering length to straight length in the reach considered.

G. Sum the values found in Steps A-E. Multiply the sum by the value found in Step F. Add this to the sum of Steps A-E to compute the composite "n" for the reach.

$$n = (n_1 + n_2 + n_3 + n_4 + n_5) \quad x \quad (n_6) + (n_1 + n_2 + n_3 + n_4 + n_5)$$

Design Procedure

After the channel has been divided into reaches, the following procedure may be used to determine adequacy. The procedure should be applied to each reach, beginning at the outlet of the development site, and progressing downstream until the total drainage area is at least 100 times greater than the area of the development site under consideration. (See Chapter 8 for a discussion of Minimum Standard #19.)

Step 1 - Determine the peak runoff rate for the stream channel using the 2-year storm. Calculate runoff from the entire contributing drainage area (including the proposed development site) at the bottom end (outlet) of the reach. (See Part 1 of this chapter for appropriate method(s) of calculating peak runoff rates.)

Step 2 - Determine the average bankfull cross-sectional area, hydraulic radius, slope and permissible velocity in the channel reach. (See survey procedure, Steps 1 through 3, for determining slope and average cross-section.)

Use Plate 5-16 for calculation of cross-sectional area and hydraulic radius.

The permissible velocity in natural channels should be determined for the most erodible condition along the reach, (e.g., exposed soil). Table 5-22 gives permissible velocities for channels cut into different types of soil.

Use Table 5-23 to determine if a reduction in permissible velocity is required due to channel sinuosity.

Note: Even though a channel may be fairly straight, it is recommended to assume slight sinuosity and use a 5% reduction in the permissible velocity.

Plate 5-39 is used to determine adjustment in permissible velocity based on average depth of flow.

Step 3 - Determine the roughness coefficient (n) for the reach. (See Survey Procedure, Step 4.)

Step 4 - Calculate bankfull velocity (V) and capacity (Q) using the Manning and Continuity Equations. These equations are explained in the section "Constructed Stormwater Conveyance Channels."

Step 5 - Compare actual channel capacity (Q) with the peak rate of runoff (from Step 1); and compare the actual flow velocity (V) with the permissible velocity (from Step 2). If the capacity of the channel is greater than the peak runoff rate from a 2-year storm, the velocity (V) should be computed using the actual depth of the 2-year storm flow.

If the existing channel is adequate with respect to both capacity and erosion resistance, the channel can be considered adequate to convey the increased discharge. If not, on-site measures and/or channel improvements must be incorporated into the site design.

Stream Channel Improvements (Modifications)

A. Design/Construction Requirements

1. If channel improvements are to be used, then MS #19 requires that:

   (a) the channel be capable of containing the 10-year frequency design storm within its banks; and

   (b) a 2-year frequency storm will not cause erosion to the channel bed or bank.

2. Improvement of the channel shall continue downstream until channel adequacy can be demonstrated, or to the point where the total drainage area above the improved channel section is 100 times greater than the contributing drainage area of the project-area watershed.

3. Prior written permission of all property owners is required prior to

constructing any channel improvements or modifications.

4. Evidence of approval from all applicable regulatory agencies to undertake channel improvements is required. Approval may require the acquisition of permits to complete the proposed work.

B. Channel Modification (Practices and Restrictions)

VEGETATIVE STREAMBANK STABILIZATION (Std. & Spec. 3.22) and/or STRUCTURAL STREAMBANK STABILIZATION (Std. & Spec. 3.23) may be used to reduce or eliminate erosion potential. Stable rock sizes for riprap linings can be determined from procedures outlined in the section titled "Designing a Stormwater Conveyance Channel."

[Refer to the previous sections (Part III, Open Channel Flow) for techniques that could be utilized in the improvement of natural stream channels.]

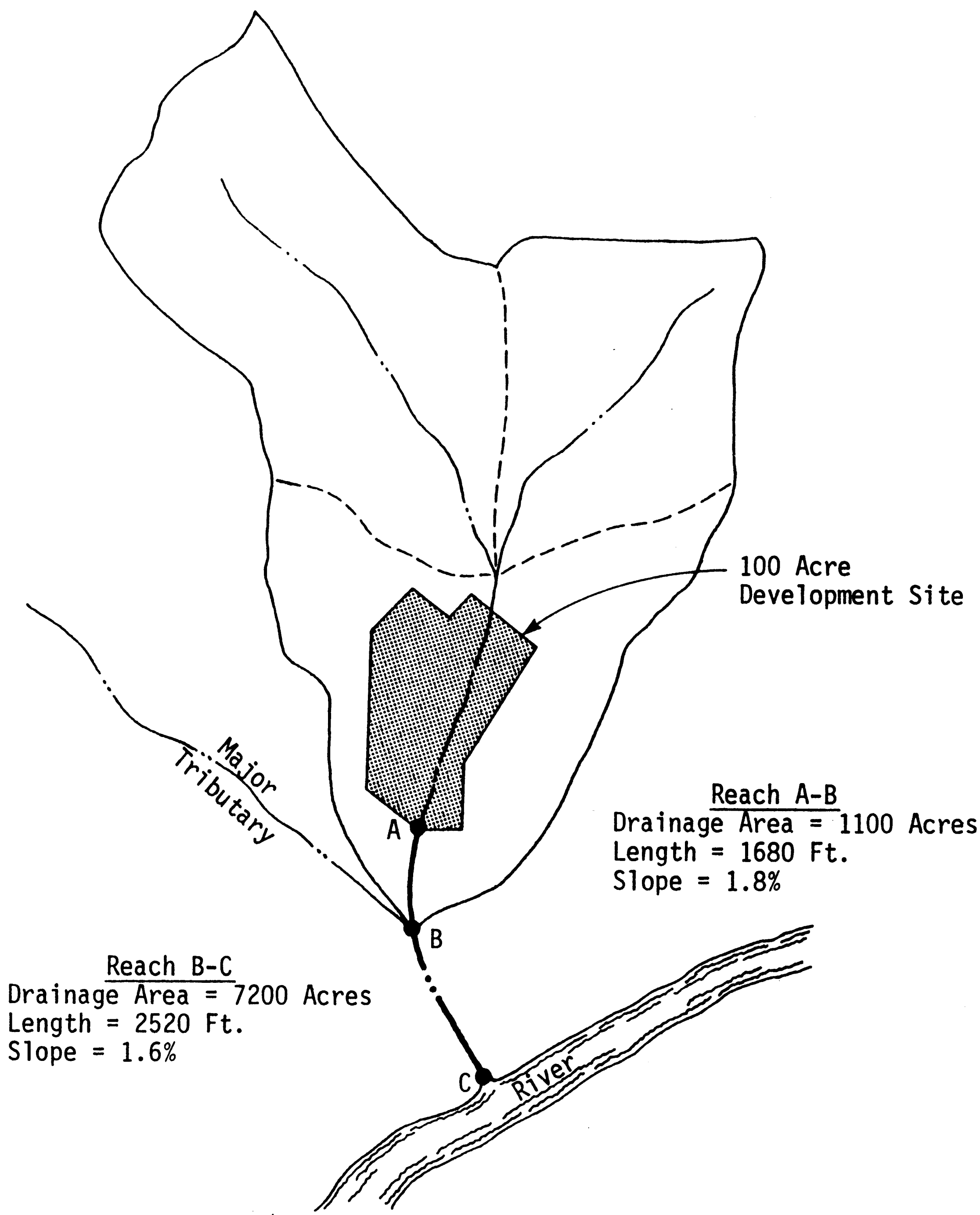
Channel modification should be undertaken only when necessary. Poorly planned and designed modifications can have an adverse impact on:

1. Aesthetics
2. Water quality
3. Aquatic life
4. Terrestrial life
5. Recreation
6. Groundwater

When a channel modification must be performed, care should be taken to attempt to duplicate the natural stream characteristics. Otherwise, the result may be unsightly, a constant source of maintenance problems, and an ecological disaster.

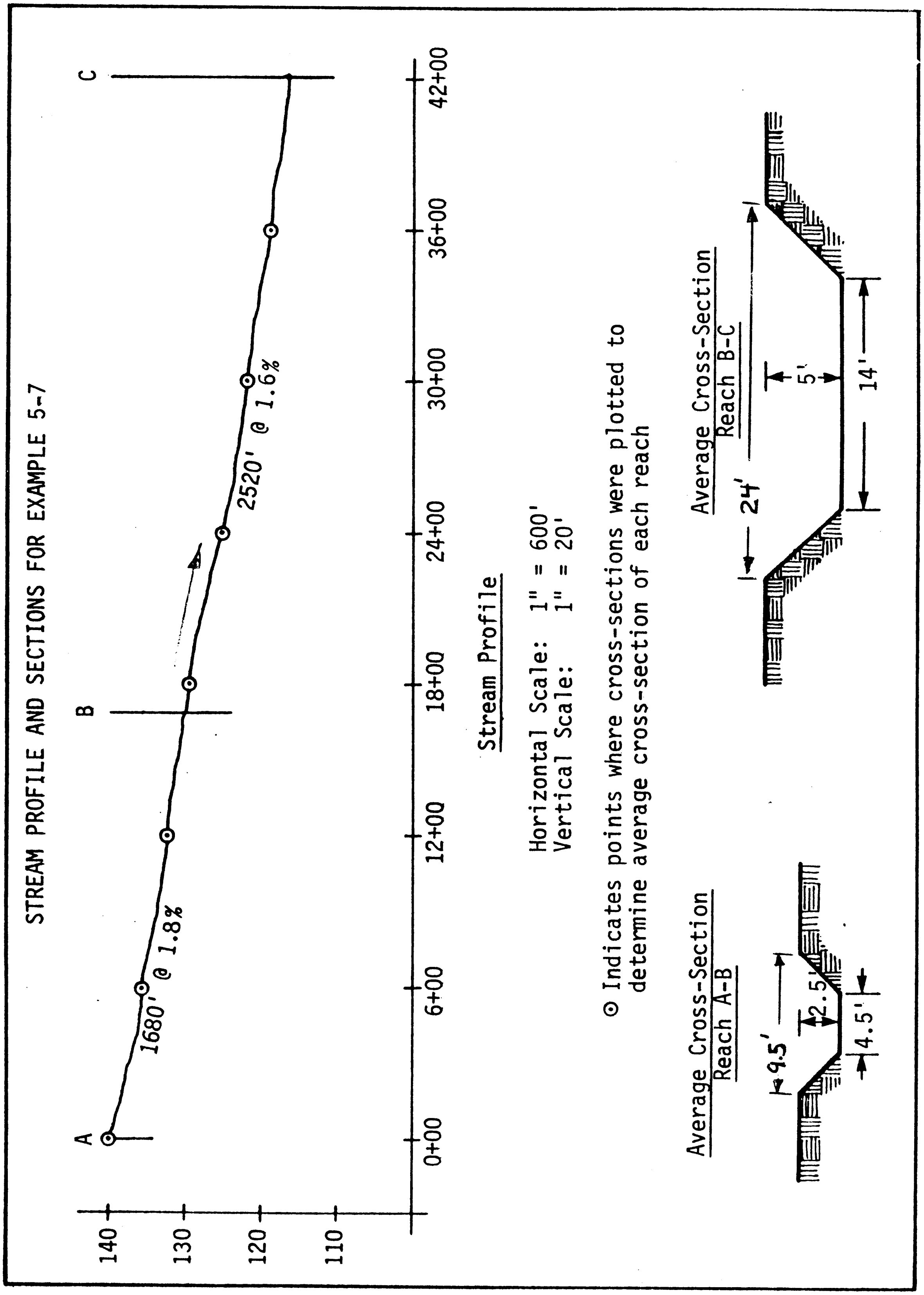
Example 5-12

A 100-acre shopping mall is to be constructed in a watershed as shown on Plate 5-36. The developer wants to analyze the existing stream channels before incorporating on-site runoff measures into the development plan. The following information represents the procedure and conclusion of the channel analysis.



Source: Va DSWC

Plate 5-36



Source: Va DSWC

Plate 5-37

The natural stream channel receiving runoff from the site has been divided into two reaches. Reach A-B extends from the outlet of the development (point A) to the confluence of a major tributary (point B). Reach B-C extends from point B to the confluence with a river (point C). The analysis ends at the river since the drainage area of the river is at least 100 times greater than the drainage area of the development site.

A field survey and watershed analysis provides the following information about each channel reach.

Reach A-B

1. Peak runoff (2-year storm) at point B:

   Pre-development = 95 cfs; Post-development = 170 cfs

2. Channel length = 1680 ft.

3. Channel slope = 1.8%

4. An average channel cross-section is approximated by a trapezoidal section with a 4.5-ft. bottom width, 2.5 ft. depth; and 1:1 side slopes. (See Plate 5-37.)

5. The channel is described as having a fine gravel bed with stiff clay banks; a fairly constant cross-section; few obstructions; very little vegetation in the channel; and slight meandering.

Reach B-C

1. Peak runoff (2-year storm) at point C:

   Pre-development = 500 cfs; Post-development = 585 cfs

2. Channel length = 2520 ft.

3. Channel slope = 1.6%.

4. An average channel cross-section is approximated by a trapezoidal section with a 14-ft. bottom width; 5 ft. depth; and 1:1 side slopes. (See Plate 5-37.)

5. The basic channel roughness characteristics are the same as Reach A-B except there is moderate meandering (e.g., the ratio of meandering length to straight length equals 1.3:1).

The information from the stream channel survey (above) is analyzed and presented in the following steps. Note that the post-development peak discharge rate is used since the purpose of this analysis is to determine whether or not the existing stream channel is adequate to convey the increased runoff from the proposed development. The 2-year storm is used in the analysis because the receiving channel is a natural stream presumedly with an established floodplain. [If the receiving stream channel were a man-made channel, the E&S Regulations (MS-19) would require an analysis using the 2-year storm for erosion resistance and the 10-year storm for capacity.]

<u>Test Reach A-B for Adequacy</u>

Step 1 - Required Q = 170 cfs

Step 2 -
- a. A = 17.5 $ft.^2$
- b. Slope = 1.8%
- c. R = 1.53 (Plate 5-38)
- d. Permissible Velocity (V) = 5 ft./sec. (Table 5-22)
- e. Adjusted Permissible Velocity (V) = 4.3 ft./sec. (Table 5-23 & Plate 5-39).

Step 3 - From the procedure for determining "n" for a natural channel:

- a. The channel is cut into fine gravel, n_1 = 0.024
- b. Moderate surface irregularities, n_2 = 0.010
- c. Changes in cross-section gradual, n_3 = 0.0
- d. Obstructions have minor effect, n_4 = 0.012
- e. Very little vegetation in channel, n_5 = 0.0
- f. Meandering minor, n_6 = 0

$$n = (0.024 + 0.010 + 0.012) = 0.046$$

Step 4 - Calculate (V) and (Q).

$$V = \frac{1.49}{0.046} (1.53)^{2/3} (.018)^{1/2} = 5.77 \ ft./sec.$$

$$Q = VA = (5.77)(17.5) = 101 \ cfs$$

Step 5 - The channel reach is <u>inadequate</u> since the permissible velocity is exceeded (5.77 > 4.3 ft./sec.) and the capacity is insufficient (170 > 101 cfs).

Test Reach B-C for Adequacy

Step 1 - Required Q = 585 cfs

Step 2 -
a. $A = 95\ ft.^2$
b. Slope = 1.6%
c. R = 3.38 (Plate 5-38)
d. Permissible Velocity (V) = 5 ft./sec. (Table 5-27)
e. Adjusted Permissible Velocity (V) = 4.6 ft./sec. (Table 5-28 & Plate 5-39)

Step 3 -
$n_1 = 0.024$
$n_2 = 0.010$
$n_3 = 0.0$ } same as Reach B-C
$n_4 = 0.012$
$n_5 = 0.0$
$n_6 = 0.15$

$$n = (0.024 + 0.010 + 0.012)\ (0.15) + (0.024 + 0.010 + 0.012) = 0.053$$

Step 4 - Calculate (V) and (Q)

$$V = \frac{1.49}{.053}\ (3.38)^{2/3}\ (.016)^{1/2} = 8.04\ \textit{ft./sec.}$$

$$Q = 763.8$$

Step 5 - The capacity of the channel is adequate (763.8 > 585 cfs). However, the velocity should be re-tested using a depth which represents the flow from the 2-year storm.

Try 3.5 ft. depth

New $R = 2.56\ ft.^2$

New A = 61.25 ft.

$$V = \frac{1.49}{.053}\ (2.56)^{2/3}\ (.016)^{1/2} = 6.67\ \textit{ft./sec.}\quad \text{(still too high)}$$

$Q = 6.67\ ft./sec. \times 61.25\ ft.^2$

Q = 408 cfs (too low)

Therefore, the channel is not adequate from a velocity standpoint (6.67 > 5 ft./sec.). Note that choosing the correct (or actual) depth is a trial and error process. The 2-year flow depth would yield a discharge (Q) equal to the 2-year discharge. For this example, additional trials are not necessary since the actual velocity would be within the range of velocities in trials above, and, subsequently, would exceed the allowable velocity.

Conclusion

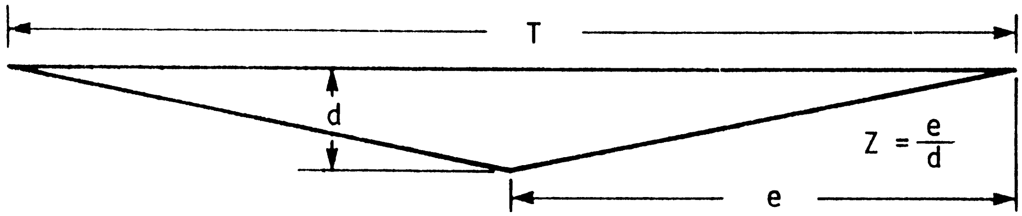
Reach A-B is inadequate for both capacity and velocity; Reach B-C is inadequate for velocity only. Therefore, the developer may choose the option of improving the entire stream channel (4200 ft.) to an "adequate" condition to contain the 10-year storm peak discharge, and with erosion resistance compatible with the 2-year storm.[1] Or, the developer may choose to detain runoff on the site so that the 2-year post-development discharge rate does not exceed the 2-year pre-development discharge rate.[2]

[1] The developer must have permission from the property owners before any off-site channel modifications can be made. Channel modifications may require other permits as well.

[2] A typical design solution might include an on-site, multi-purpose basin that provides sediment control and runoff quantity control during the land-disturbing phase and provides runoff quantity control as well as water quality benefits after adequate stabilization has been achieved.

CHANNEL GEOMETRY

V - Shape

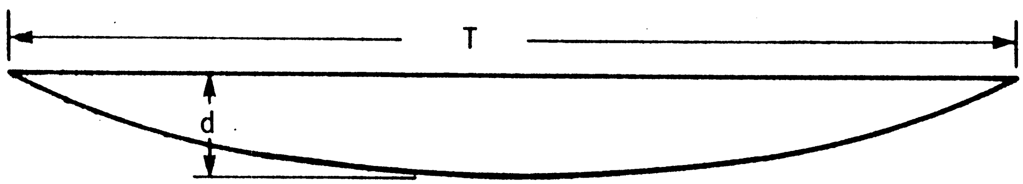


Cross-Sectional Area (A) = Zd^2

Top Width (T) = $2dZ$

Hydraulic Radius (R) = $\frac{Zd}{2\sqrt{Z^2 + 1}}$

Parabolic Shape

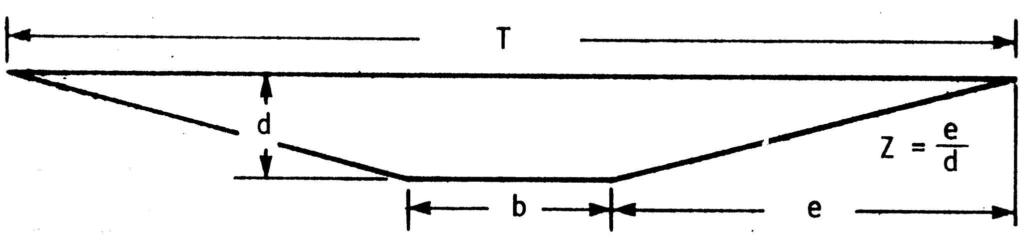


Cross-Sectional Area (A) = $\frac{2}{3}Td$

Top Width (T) = $\frac{1.5A}{d}$

Hydraulic Radius = $\frac{T^2 d}{1.5T^2 + 4d^2}$

Trapezoidal Shape



Cross-Sectional Area (A) = $bd + Zd^2$

Top Width (T) = $b + 2dZ$

Hydraulic Radius = $\frac{bd + Zd^2}{b + 2d\sqrt{Z^2 + 1}}$

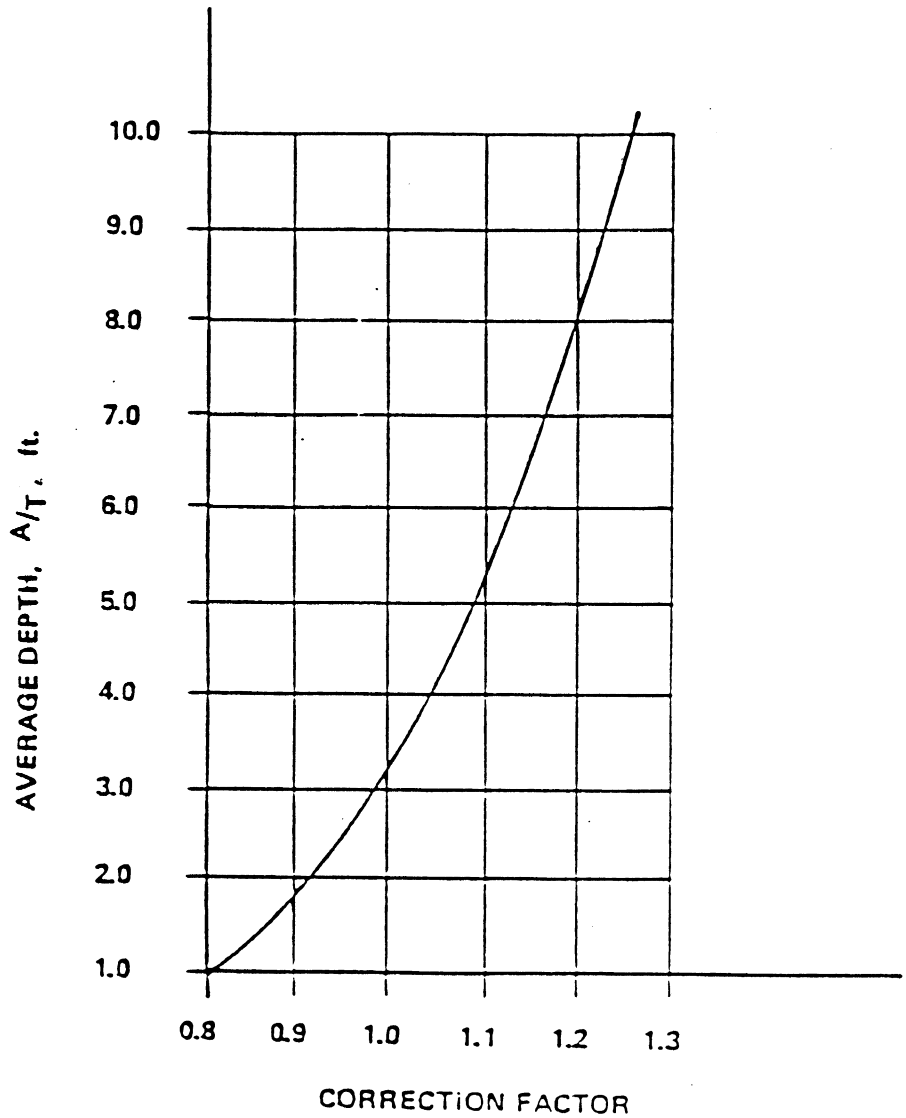
Source: USDA-SCS

Plate 5-38

When other conditions are the same, a deep channel will convey water at a higher mean velocity (without erosion) than a shallow one. Thus, a correction for flow depth should also be applied to the permissible velocity. Plate 5-39 shows the suggested correction factors to be applied.

CORRECTION FACTORS FOR PERMISSIBLE VELOCITY BASED ON AVERAGE DEPTH OF FLOW

$$\frac{\textit{Cross-Sectional Area of Channel}}{\textit{Top Width of Channel}} = \frac{A}{T}$$



Source: Va DSWC

Plate 5-39

MANNING'S ROUGHNESS COEFFICIENT MODIFYING TABLES FOR NATURAL CHANNELS

Table 5-16
ROUGHNESS COEFFICIENT MODIFIER (n_1)

Character of Channel	Basic n
Channels in earth	0.02
Channels cut into rock	0.025
Channels in fine gravel	0.024
Channels in coarse gravel	0.028

Source: "Estimating Hydraulic Roughness Coefficients," Cowan.

TABLE 5-17
ROUGHNESS COEFFICIENT MODIFIER (n_2)

Degree of Irregularity	Surface Comparable To	Modifying Value
Smooth	The best attainable for the materials involved	0.000
Minor	Good dredged channels, slightly eroded or scoured side slopes of canals or drainage channels	0.005
Moderate	Fair to poor dredged channels, moderately sloughed or eroded side slopes of canals or drainage channels	0.010
Severe	Badly sloughed banks of natural streams; badly eroded or sloughed sides of canals or drainage channels; unshaped, jagged and irregular surfaces of channels excavated in rock	0.020

Source: "Estimating Hydraulic Roughness Coefficients," Cowan.

TABLE 5-18
ROUGHNESS COEFFICIENT MODIFIER (n_3)

Character of Variations of Size and Shape of Channel Cross Sections	Modifying Value
Change in size or shape occurring gradually	0.000
Large and small sections alternating occasionally or shape changes causing occasional shifting of main flow from side to side	0.005
Large and small sections alternating frequently or shape changes causing frequent shifting of main flow from side to side	0.010 to 0.015

Source: "Estimating Hydraulic Roughness Coefficients," Cowan.

TABLE 5-19
ROUGHNESS COEFFICIENT MODIFIER (n_4)

Relative effect of obstructions	Modifying value
Negligible	0.000
Minor	0.010 to 0.015
Appreciable	0.020 to 0.030
Severe	0.040 to 0.060

Source: "Estimating Hydraulic Roughness Coefficients," Cowan.

TABLE 5-20

ROUGHNESS COEFFICIENT MODIFIER (n_5)

Vegetation and Flow Conditions Comparable To:	Degree of Effect on "n"	Range in Modifying Value
Dense growths of flexible turf grasses or weeds, of which bermudagrass and bluegrass are examples, where the average depth of flow is two or more times the height of the vegetation.	Low	0.005 to 0.010
Supple seedling tree switches such as willow, cottonwood or salt cedar where the average depth of flow is three or more times the height of the vegetation.		
Turf grasses where the average depth of flow is one to two times the height of the vegetation.	Medium	0.010 to 0.020
Stemmy grasses, weeds or tree seedlings with moderate cover where the average depth of flow is two to three times the height of the vegetation.		
Bushy growths, moderately dense, similar to willows one to two years old, dormant season, along side slopes with no significant vegetation along bottom, where the hydraulic radius is greater than two.		

Source: "Estimating Hydraulic Roughness Coefficients," Cowan.

TABLE 5-20 (continued)
ROUGHNESS COEFFICIENT MODIFIER (n_5)

Vegetation and Flow Conditions Comparable To:	Degree of Effect on "n"	Range in Modifying Value
Turf grasses where the average depth of flow is about equal to the height of vegetation.	High	0.025 to 0.050
Willow or cottonwood trees 8- to 10-years old intergrown with some weeds and brush, dormant season, where the hydraulic radius is 2 to 4 ft.		
Bushy willows about one year old interwoven with some weeds is full foliage along side slopes, no significant vegetation along channel bottom where hydraulic radius is 2 to 4 ft.		
Turf grasses where the average depth of flow is less than one-half the height of the vegetation.	Very High	0.050 to 0.100
Bushy willows about one year old intergrown with weeds along side slopes, dense growth of cattails along channel bottom, all vegetation is full foliage, any value of hydraulic radius up to 10 or 12 ft.		
Trees intergrown with weeds and brush, all vegetation in full foliage, any value of hydraulic radius up to 10 to 12 ft.		

Source: "Estimating Hydraulic Roughness Coefficients," Cowan.

TABLE 5-21
ROUGHNESS COEFFICIENT MODIFIER (n_6)

(Sinuosity) Ratio of meander length to straight length	Degree of meander	Modifying Value
1.0 to 1.2	Minor	0.000
1.2 to 1.5	Appreciable	* $0.15n_s$
1.5 and greater	Severe	* $0.30n_s$

* $n_s = (n_1 + n_2 + n_3 + n_4 + n_5)$

Source: "Estimating Hydraulic Roughness Coefficients," Cowan.

TABLE 5-22

PERMISSIBLE VELOCITIES FOR UNLINED EARTHEN CHANNELS

Soil Types	Permissible Velocity (ft./sec.)
Fine Sand (noncolloidal)	2.5
Sandy Loam (noncolloidal)	2.5
Silt Loam (noncolloidal)	3.0
Ordinary Firm Loam	3.5
Fine Gravel	5.0
Stiff Clay (very colloidal)	5.0
Graded, Loam to Cobbles (noncolloidal)	5.0
Graded, Silt to Cobbles (noncolloidal)	5.5
Alluvial Silts (noncolloidal)	3.5
Alluvial Silts (colloidal)	5.0
Coarse Gravel (noncolloidal)	6.0
Cobbles and Shingles	5.5
Shales and Hard Pans	6.0

Source: American Society of Civil Engineers

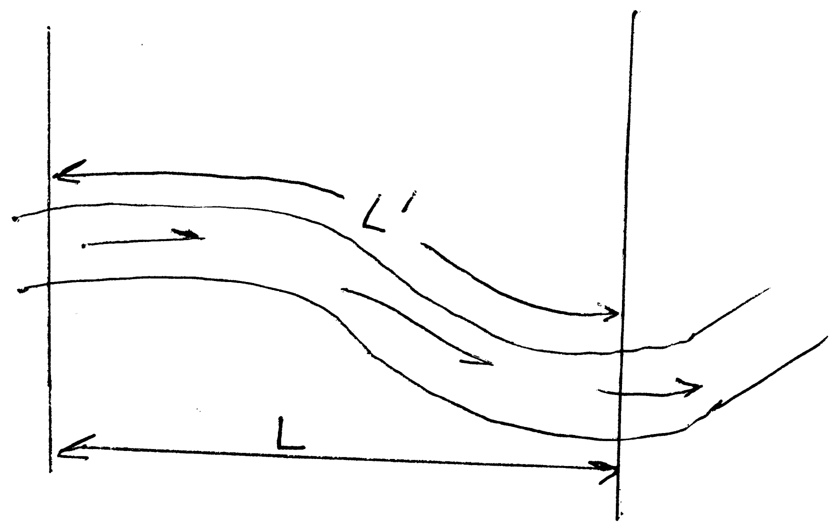
Maximum permissible velocities from Table 5-22 are for straight channels. For curved (sinuous) channels, the reductions shown in Table 5-23 should be applied to the maximum permissible velocities:

TABLE 5-23

REDUCTION IN PERMISSIBLE VELOCITY BASED ON SINUOSITY

Sinuosity*	Percent Reduction in Permissible Velocity
Slight (1.0 to 1.2)	5%
Moderate (1.2 to 1.5)	13%
Very Sinuous (1.5 and greater)	22%

* Sinuosity - degree of curvature of channel.



Sinuosity = L'/L

Source: Chow