CHAPTER 2

HYDROLOGY

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Chapter Two - Hydrology

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APPENDICES

2.1 Overview

2.1.1 Introduction

Estimation of the peak rate of runoff, volume of runoff, and time distribution of flow is fundamental to the design of drainage facilities. Errors in the estimation will result in a structure that is either undersized and causes drainage problems (e.g., flooding, safety, nuisance, etc.) or oversized and costs more than necessary. On the other hand, it must be realized that any hydrologic analysis is only an approximation. The relationship between the amount of precipitation on a drainage basin and the amount of runoff from the basin is complex. Too few data are available on the factors influencing the rural and urban rainfall-runoff relationship to expect exact solutions.

2.1.2 Factors Affecting Floods

In the hydrologic analysis for a drainage structure, there are many factors that affect floods. Some of the factors which need to be recognized and considered on a site-by-site basis are:

<u>Drainage Basin Characteristics</u>

Size and Shape
Slope
Ground Cover and Land Use
Geology
Soil Types
Surface Infiltration
Ponding and Storage
Watershed Development Potential

<u>Stream Channel Characteristics</u>

Geometry and Configuration
Natural Controls
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Agradation - Degradation
Debris
Manning's "n"
Slope

<u>Floodplain Characteristics</u>

Slope
Vegetation
Alignment
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Location of Structures
Obstructions to Flow

<u>Meteorological Characteristics</u>

Time Rate and Amounts of Precipitation
Historical Flood Heights

2.1.3 Hydrologic Method Selection

Many hydrologic methods have been developed and used in urban watersheds. Table 2-1 lists two recommended methods. Other methods may be used if they received prior approval from the Director of Public Works and Utility and if they are calibrated to local conditions and tested for accuracy and reliability. In addition, complete source documentation must be submitted for approval.

Methods listed in Table 2-1 have been selected for use in Lincoln, Nebraska based on several considerations, including the following:

- Verification of their accuracy in duplicating local hydrologic estimates of a range of design storms.
- Availability of equations, nomographs, and computer programs.
- Use and familiarity with the methods used by local municipalities and consulting engineers.

Table 2-1 Recommended Hydrologic Methods[1]

Method	Size Limitations[2]	Comments
Rational	0 - 150 Acres	Method can be used for estimating peak flows and the design of small subdivision-type storm drain systems. (Method shall not be used for design of storage facilities.)
SCS[3] Curve Number	0 - 2,000[4] Acres	Method can be used for estimating peak flows and hydrographs. Method shall be used for the design of all drainage structures and shall be used for design of any storage facility or any other facility with a drainage basin greater than 150 acres.

1 The Lincoln Public Works and Utilities Department has selected the HEC-HMS computer program for stormwater master planning efforts and recommends that this program be used for stormwater system design.

2 Size limitation refers to the subwatershed size to the point where the stormwater management facility (i.e., culvert, inlet) is located.

3 SCS is the Soil Conservation Service Method. Although the SCS is now called the Natural Resources Conservation Service, the hydrologic method is still called SCS.

4 Will likely be less than 2000 acres in urban areas due to the need for homogeneous subwatersheds.

2.2 Symbols And Definitions

To provide consistency within this chapter, as well as throughout this manual, the following symbols will be used. These symbols were selected because of their wide use in hydrologic publications.

Table 2-2 Symbols And Definitions

Symbol	Definition	Units
A	Drainage area	acres or mi^2
C	Runoff coefficient	-
C_f	Frequency factor	-
CN	SCS-runoff curve number	-
d	Time interval	hours
F	Pond and swamp adjustment factor	-
I	Rainfall intensity	in./hr
IA	Percentage of impervious area	%
I_a	Initial abstraction from total rainfall	in.
NRCS	Natural Resources Conservation Service	-
n	Manning's roughness coefficient	-
P	Accumulated rainfall	in.
Q	Rate of runoff	cfs
q	Storm runoff during a time interval	in.
R	Hydraulic radius	ft
S or Y	Ground slope	ft/ft or %
S	Potential maximum retention storage	in.
SCS	Soil Conservation Service	-
SL	Main channel slope	ft/ft
S_L	Standard deviation of the logarithms of the peak annual floods	-
T_B	Time base of unit hydrograph	hours
t_c or T_c	Time of concentration	min or hours
T_L	Lag time	hours
V	Velocity	ft/s

2.3 Concept Definitions

A good understanding of the following concepts will be important in any hydrologic analysis. These concepts will be used throughout the remainder of this chapter in dealing with different aspects of hydrologic studies.

Antecedent Moisture Conditions

Antecedent moisture conditions are the soil moisture conditions of the watershed at the beginning of a storm. These conditions affect the volume of runoff generated by a particular storm event. Notably they affect the peak discharge in the lower range of flood magnitudes — say below about the 15-year event threshold. As floods become more rare, antecedent moisture has a rapidly decreasing influence on runoff.

Depression Storage

Depression storage is the water stored in natural depressions within a watershed. Generally, after the depression storage is filled, runoff will commence.

Frequency

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The frequency with which a given flood can be expected to occur is the reciprocal of the probability or chance that the flood will be equaled or exceeded in a given year. If a flood has a 20 percent chance of being equaled or exceeded each year, over a long period of time, the flood will be equaled or exceeded on an average of once every five years. This is also referred to as the recurrence interval or return period.

Hydraulic Roughness

Hydraulic roughness is a measure of the physical characteristics which impede the flow of water across the earth's surface, whether natural or channelized. It affects both the time response of a watershed and drainage channel as well as the channel storage characteristics.

Hydrograph

A hydrograph is a graph of the time distribution of runoff (expressed as a flow rate) from a watershed.

Hyetographs

The hyetograph is a graph of the time distribution of rainfall (usually expressed as an intensity) over a watershed.

Infiltration

Infiltration is the complex process whereby water penetrates the ground surface and is either stored in the soil pore spaces or flows to lower layers. An infiltration curve is a graph of the time distribution at which this occurs.

Interception

Storage of rainfall on foliage and other intercepting surfaces during a rainfall event is called interception storage.

Lag Time

Lag time is defined as the time from the centroid of the excess rainfall to the peak of the hydrograph.

Peak Discharge

The peak discharge, sometimes called peak flow, is the maximum rate of flow of water passing a given point during or after a rainfall event or snowmelt.

Rainfall Excess

The rainfall excess is the water available to runoff after interception, depression storage and infiltration are satisfied.

Recurrence Interval

The time interval in which an event will occur once on the average. (i.e. a 10-year storm is expected to occur once every 10 years, on the average)

Stage

The stage of a river or other water body is the elevation of the water surface above some elevation datum.

Time Of Concentration

The time of concentration is the time it takes a drop of water falling on the hydraulically most remote point in the watershed to travel through the watershed to the outlet or design point.

<u>Unit Hydrograph</u>

A unit hydrograph is the storm hydrograph resulting from a rainfall event which has a specific temporal and spatial distribution, which lasts for a specific duration and has unit volume (or results from a unit depth of runoff). The ordinates of the unit hydrograph are such that the volume of runoff represented by the area under the hydrograph is equal to one inch of runoff from the drainage area. When a unit hydrograph is shown with units of cubic feet per second, it is implied that the ordinates are cubic feet per second per inch of direct runoff.

2.4 Design Frequency

2.4.1 Overview

Since it is not economically feasible to design a structure for the maximum runoff a watershed is capable of producing, a design frequency must be established. The designer should note that the 5-year flood is not one that will necessarily be equaled or exceeded every five years. There is a 20 percent chance that the flood will be equaled or exceeded in any year; therefore, the 5-year flood could conceivably occur in several consecutive years. The same reasoning applies to floods with other return periods.

2.4.2 Frequency Design Criteria

<u>Cross Drainage</u>: Cross drainage facilities transport storm runoff under roadways. The cross drainage facilities shall be designed to convey (at a minimum) the 50-year runoff event without overtopping the roadway. The flow rate shall be based on upstream ultimate buildout land-use conditions. In addition, the 100-year frequency storm shall be routed through all culverts to be sure structures are not flooded or increased damage does not occur to the roadway or adjacent property for this design event.

<u>Storm drains</u>: A storm drain shall be designed to accommodate a 5-year storm in residential areas and a 10-year storm in commercial developments, downtown areas and in industrial developments. The design shall be such that the storm runoff does not: increase the flood hazard significantly on adjacent property; encroach onto the street or highway so as to cause a safety hazard by impeding traffic, emerging vehicles, or pedestrian movements to an unreasonable extent.

Based on these criteria, a design involving temporary street or road inundation is acceptable practice for flood events greater than the design event but not for floods that are equal to or less than the design event. Thus, if a storm drainage system crosses under a roadway, the design flood must be routed through the system to show that the roadway will not be overtopped by this event. The excess storm runoff from events larger than the design storm may be allowed to inundate the roadway or may be stored in areas other than on the roadway until the drainage system can accommodate the additional runoff.

<u>Inlets</u>: Inlets shall be designed for a 5-year storm in residential areas and small commercial developments and a 10-year storm in downtown areas industrial developments, and arterial roads.

<u>Detention and retention storage facilities</u>: All storage facilities shall be designed to provide sufficient storage and release rates to accommodate the 2-, 10-, and 100-year design storm events such that the post-development peak discharges do not exceed the pre-development rates. The design shall be such that the storm runoff does not increase the flood hazard significantly for adjacent, upstream, or downstream property or cause safety hazards associated with the facility. An emergency spillway shall be provided. For storage facilities, outlet designs that provide some control for flood events below the 2-year storm (e.g., v-notch weirs) are preferred over outlets that do not provide this control (e.g., pipes). In addition, the final design shall be checked to ensure that flood peaks at the downstream property line have not increased.

2.5 Rational Method

2.5.1 Introduction

The rational method can be used to estimate the design peak discharge for areas as large as 150 acres. This method, while first introduced in 1889, is still used in many engineering offices in the United States. Even though it has frequently come under criticism for its simplistic approach, no other drainage design method has received such widespread use.

2.5.2 Concept and Equation

The rational formula estimates the peak rate of runoff at any location in a watershed as a function of the drainage area, runoff coefficient, and mean rainfall intensity for a duration equal to the time of concentration (the time required for water to flow from the hydraulically most remote point of the basin to the location being analyzed). The rational formula is expressed as follows:

$$Q = CIA \qquad (2.1)$$

where: Q = peak rate of runoff, cfs
C = runoff coefficient representing a ratio of runoff to rainfall for future land-use conditions
I = average rainfall intensity for a duration equal to the time of concentration, for a selected return period in./hr (see Figure 2-3)
A = drainage area tributary to the design location, acres

2.5.3 Application

Peak discharges estimated using the rational formula are very sensitive to the parameters that are used. The designer must use good engineering judgment in assigning values to these parameters. Each of the parameters used in the rational method is discussed below.

2.5.3.1 Time Of Concentration

The time of concentration (t_c) is the time required for water to flow from the hydraulically most remote point of the drainage area to the point under investigation. Use of the rational formula requires the time of concentration (t_c) for each design point within the drainage basin. The duration of rainfall is then set equal to the time of concentration and is used to estimate the rainfall intensity (I). For a storm drain system, the time of concentration consists of an inlet time plus the time of flow in a closed conduit or open channel to the design point. Inlet time is the time required for runoff to flow over the surface to the nearest inlet and is primarily a function of the length of overland flow, the slope of the land and surface cover. Pipe or open channel flow time can be estimated from the hydraulic properties of the conduit or channel. One way to estimate overland flow time is to use Figure 2-1 to estimate overland flow velocity and divide the velocity into the overland travel distance.

For design situations that do not involve complex drainage conditions, Figure 2-2 can be used to estimate inlet time. For each drainage area, the distance is determined from the inlet to the most remote point in the tributary area. From a topographic map, the average slope is determined for the same distance. The Coefficient of Runoff, C is determined by the procedure described in a subsequent section of this chapter.

To obtain the total time of concentration, the pipe or open channel flow time must be calculated and added to the inlet time. After first determining the average flow velocity in the pipe or channel, the travel time is obtained by dividing velocity into the pipe or channel length. Manning's equation can be used to determine velocity. See Chapter 5 - Open Channel Hydraulics - for a discussion of Manning's equation.

Time of concentration is an important variable in most hydrologic methods. Several methods are available for estimating t_c. Appendix 2-C (Travel Time Estimation) at the end of this chapter describes the method from the SCS Technical Release No. 55 (2nd Edition). Figure 2-2 shows the velocities used for estimating time of concentration for various land use conditions. For inlet design the minimum t_c recommended should not be less than 8 minutes.

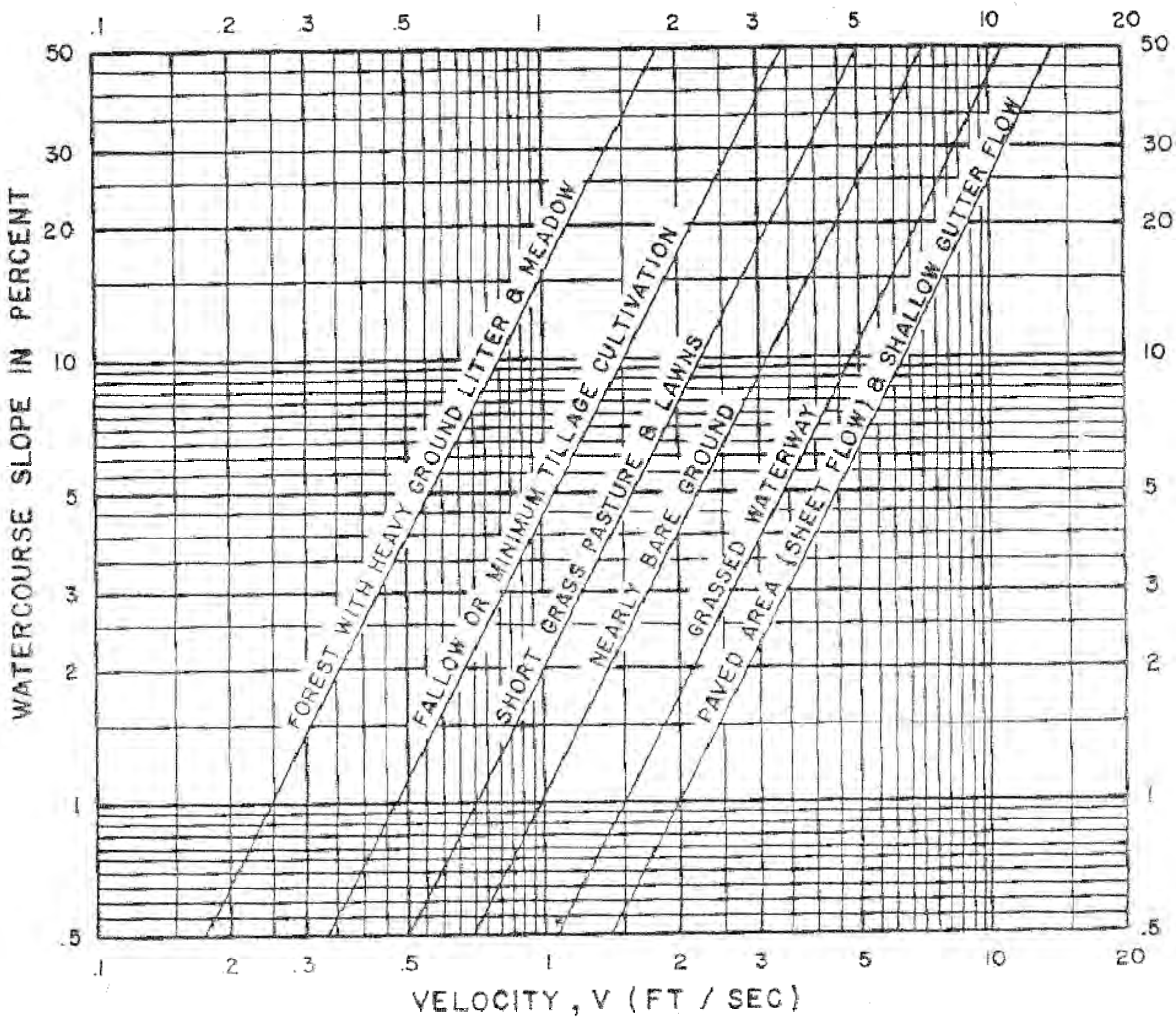

Figure 2-1 Velocities For Estimating Time Of Concentration

Source: HEC No. 19, FHWA

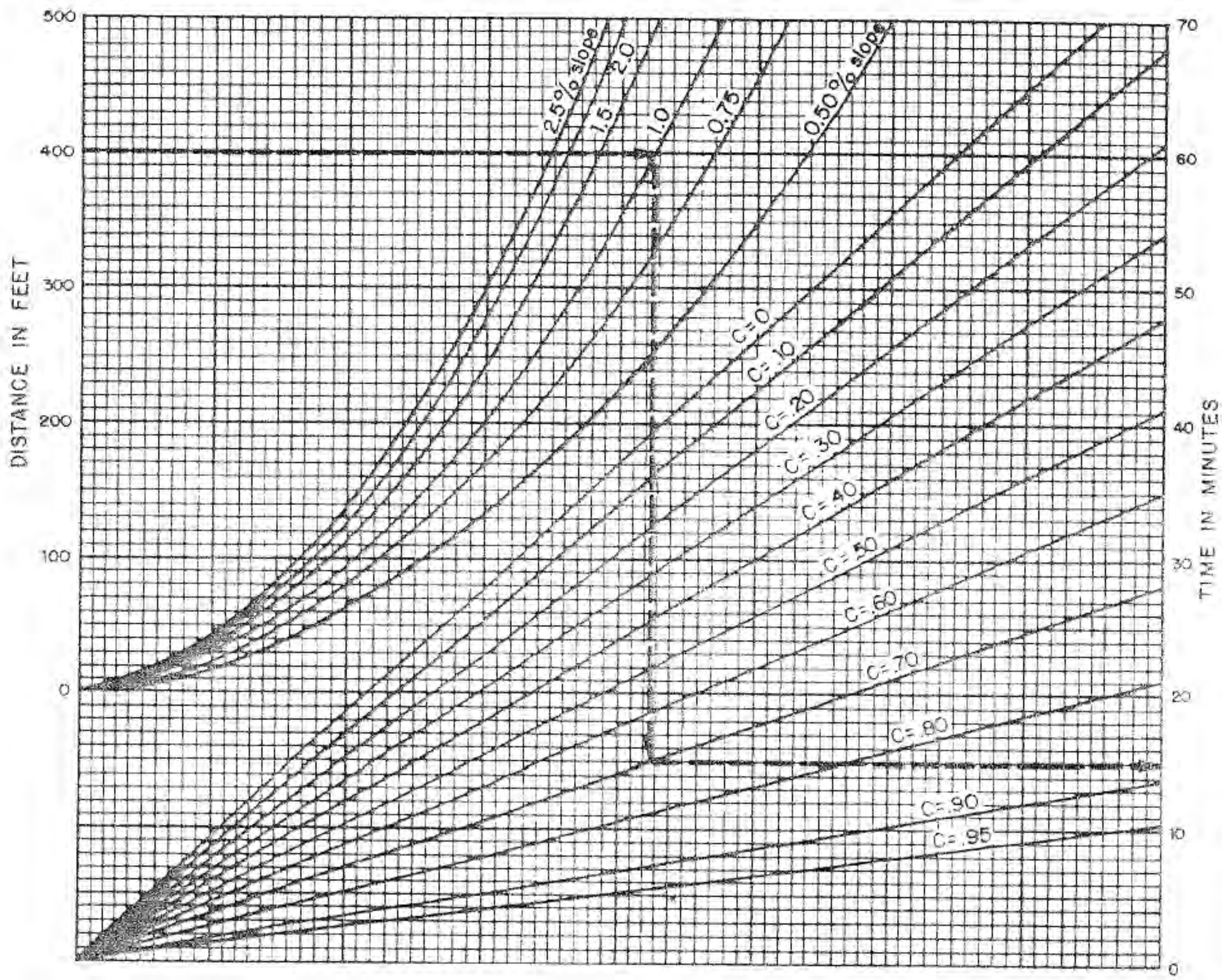

Figure 2-2 Overland Time Of Flow

Source: Airport Drainage, Federal Aviation Administration, 1965

2.5.3.1.1 Common Errors

Two common errors should be avoided when calculating t_c. First, in some cases runoff from a portion of the drainage area which is highly impervious may result in a greater peak discharge than would occur if the entire area were considered. In these cases, adjustments can be made to the drainage area by disregarding those areas where flow time is too slow to add to the peak discharge. Sometimes it is necessary to estimate several different times of concentration to determine the design flow that is critical for a particular application.

Second, when designing a drainage system, the overland flow path is not necessarily perpendicular to the contours shown on available mapping. Often the land will be graded and swales will intercept the natural contour and conduct the water to the streets, which reduces the time of concentration. Care should be exercised in selecting sheet flow paths in excess of 100 ft in urban areas and 300 ft in rural areas. Sheet flow conditions are not likely to be sustained for greater lengths and the estimated T_c will be too large.

2.5.3.2 Rainfall Intensity

The rainfall intensity (I) is the average rainfall rate (in./hr) for a duration equal to the time of concentration for a selected return period. Once a particular return period has been selected for design and a time of concentration calculated for the drainage area, the rainfall intensity can be determined from Intensity-Duration-Frequency (IDF) curves. The data from the IDF curve for the City of Lincoln are given in Figure 2-3.

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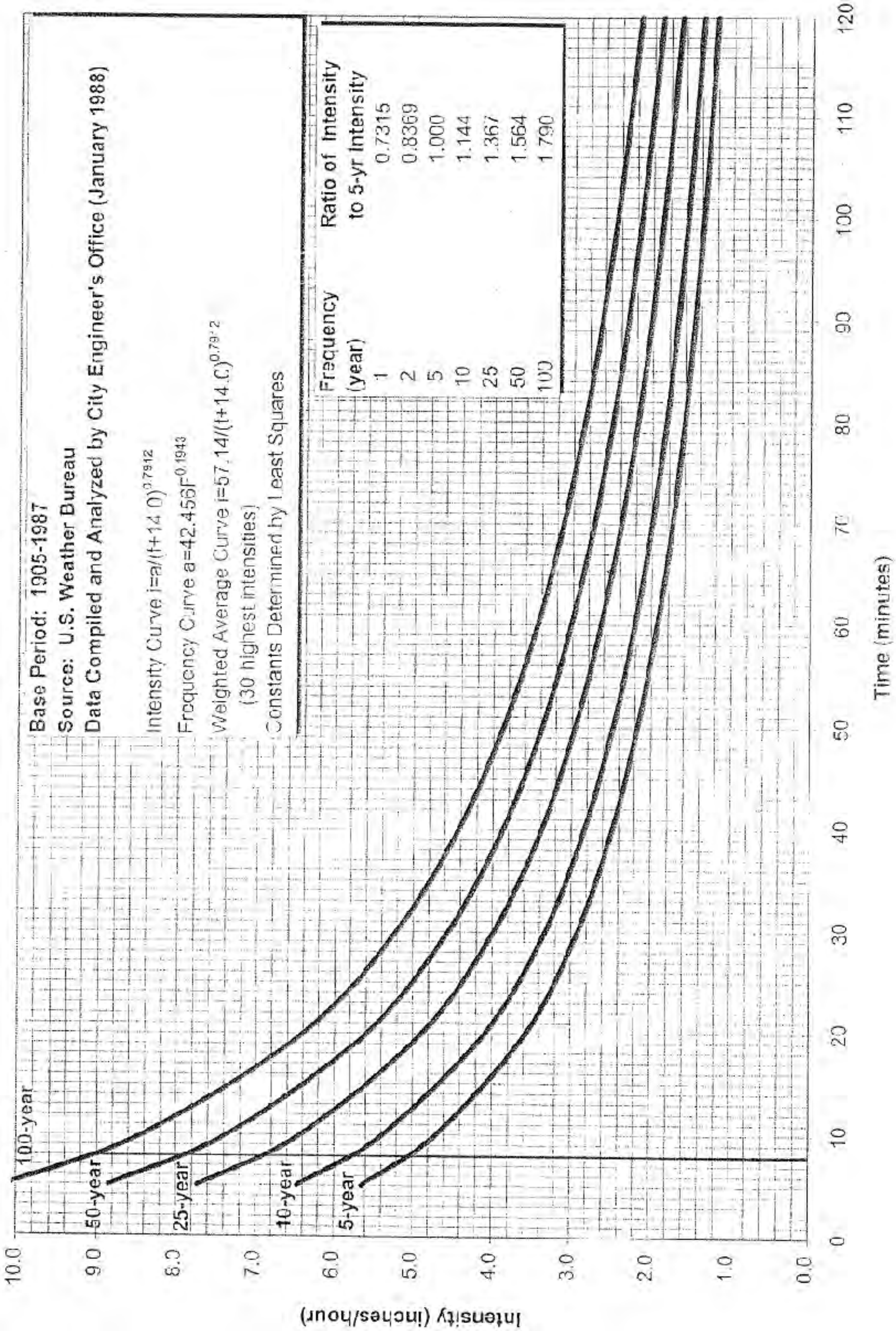

Figure 2-3 Intensity-Duration-Frequency Curves
Lincoln, Nebraska

Source: Lincoln Public Works and Utilities Department

2.5.3.3 Runoff Coefficient

The runoff coefficient (C) is the variable of the rational method least susceptible to precise determination and requires judgment and understanding on the part of the designer. Engineering judgment will always be required in the selection of runoff coefficients since a typical coefficient represents the integrated effects of many drainage basin parameters. The following discussion considers only the effects of soil groups, land use and average land slope.

The method for determining the runoff coefficient (C) is based on land use, soil groups and land slope. Table 2-4 in Manual gives the recommended coefficient C of runoff for pervious surfaces by selected hydrologic soil groupings and slope ranges. *The value of C shall be based on fully built-out land use conditions. The minimum runoff coefficient shall be 0.4 , unless owner can clearly demonstrate that the value less then 0.4 is adequate.*

Table 2-4 gives the recommended coefficient C of runoff for pervious surfaces by selected hydrologic soil groupings and slope ranges. From this table the C values for non-urban areas such as forest land, agricultural land, and open space can be determined. Soil properties influence the relationship between runoff and rainfall since soils have differing rates of infiltration. Infiltration is the movement of water through the soil surface into the soil. Based on infiltration rates, the Soil Conservation Service (SCS) has divided soils into four hydrologic soil groups as follows:

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

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

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

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

A list of soils for the City of Lincoln and their hydrologic classification is presented in the Lancaster County Soil Survey.

As the slope of the drainage basin increases, the selected C value should also increase. This is caused by the fact that as the slope of the drainage area increases, the velocity of overland and channel flow will increase, allowing less opportunity for water to infiltrate. Thus, more of the rainfall will become runoff from the drainage area.

It is often desirable to develop a composite runoff coefficient based on the percentage of different types of surface in the drainage area. Composites can be made with Tables 2-3 and 2-4. The composite procedure can be applied to an entire drainage area or to typical "sample" blocks as a guide to selection of reasonable values of the coefficient for an entire area.

Table 2-3 Recommended Coefficient Of Runoff Values For Various Selected Land Uses

Description of Area	Runoff Coefficients
Business: Downtown areas	0.70-0.95
Neighborhood areas	0.50-0.70
Residential: Single-family areas	0.30-0.50
Multi units, detached	0.40-0.60
Multi units, attached	0.60-0.75
Suburban	0.25-0.40
Residential (1 acre lots or larger)	0.30-0.45
Apartment dwelling areas	0.50-0.70
Industrial: Light areas	0.50-0.80
Heavy areas	0.60-0.90
Parks, cemeteries	0.10-0.25
Playgrounds	0.20-0.40
Railroad yard areas	0.20-0.40
Unimproved areas	0.04-0.38 (see Table 2-4)

Source: Hydrology, Federal Highway Administration, HEC No. 19, 1984

Table 2-4 Recommended Coefficient Of Runoff For Pervious Surfaces (Unimproved Areas) By Selected Hydrologic Soil Groupings And Slope Ranges

Slope	A	B	C	D
Flat (0 - 1%)	0.04-0.09	0.07-0.12	0.11-0.16	0.15-0.20
Average (2 - 6%)	0.09-0.14	0.12-0.17	0.16-0.21	0.20-0.25
Steep (Over 6%)	0.13-0.18	0.18-0.24	0.23-0.31	0.28-0.38

Source: Storm Drainage Design Manual, Erie and Niagara Counties Regional Planning Board.

2.5.3.3.1 Infrequent Storm

The coefficients given in Tables 2-3 and 2-4 are applicable for storms of 5-year to 10-year frequencies. Less frequent, higher intensity storms will require modification of the coefficient because infiltration and other losses have a proportionally smaller effect on runoff (Wright-McLaughlin, 1969). The adjustment of the rational method for use with major storms can be made by multiplying the right side of the rational formula by a frequency factor C_f. The rational formula now becomes:

$$Q = C_f CIA \tag{2.1}$$

C_f values are listed in Table 2-5. The product of C_f times C shall not exceed 1.0.

Table 2-5 Frequency Factors For Rational Formula

Recurrence Interval (years)	C_f
25	1.1
50	1.2
100	1.25

2.5.4 Limitations

Some precautions should be considered when applying the rational method.

- The first step in applying the rational method is to obtain a good topographic map and define the boundaries of the drainage area in question. A field inspection of the area should also be made to determine if the natural drainage divides have been altered.
- In determining the runoff coefficient (C) value for the drainage area, thought should be given to future changes in land use that might occur during the service life of the proposed facility that could result in an inadequate drainage system. Also, the effects of permanent upstream detention facilities may be taken into account.
- Restrictions to the natural flow such as highway crossings and dams that exist in the drainage area should be investigated to see how they affect the design flows.
- The charts, graphs and tables included in this section are not intended to replace reasonable and prudent engineering judgment which should permeate each step in the design process.

Characteristics of the rational method which limit its use to 150 acres include:

(1) The rate of runoff resulting from any rainfall intensity is a maximum when the rainfall intensity lasts as long or longer than the time of concentration. That is, the entire drainage area does not contribute to the peak discharge until the time of concentration has elapsed.

This assumption limits the size of the drainage basin that can be evaluated by the rational method. For large drainage areas, the time of concentration can be so large that constant rainfall intensities for such long periods do not occur and shorter, more intense rainfalls can produce larger peak flows.

(2) The frequency of peak discharges is the same as that of the rainfall intensity for the given time of concentration.

Frequencies of peak discharges depend on rainfall frequencies, antecedent moisture conditions in the watershed, and the response characteristics of the drainage system. For small and largely impervious areas, rainfall frequency is the dominant factor. For larger drainage basins and undeveloped drainage basins, the response characteristics control the frequencies of peak discharges. For drainage areas with few impervious surfaces (less urban development), antecedent moisture conditions usually govern, especially for rainfall events with a return period of 10 years or less.

(3) The fraction of rainfall that becomes runoff (C) is independent of rainfall intensity or volume.

This assumption is reasonable for impervious areas, such as streets, rooftops and parking lots. For pervious areas, the fraction of runoff varies with rainfall intensity and the accumulated volume of rainfall. Thus, the "art" necessary for application of the rational method involves the selection of a coefficient that is appropriate for the storm, soil and land use conditions. Many guidelines and tables have been established, but seldom, if ever, have they been supported with empirical evidence.

(4) The rational method provides estimates of only peak discharge rates of runoff. It does not provide information on the volume of runoff.

Modern drainage practice often includes detention of urban storm runoff to reduce the peak rate of runoff downstream. With only the peak rate of runoff, the rational method severely limits the evaluation of design alternatives available in urban and in some instances, rural drainage design.

Thus, the rational formula is best suited for small, highly impervious areas and least suitable for large drainage areas or drainage areas in natural or undeveloped conditions.

2.5.5 Example Problem - Rational Method

The following example problem illustrates the application of the rational method to estimate peak discharges. Preliminary estimates of the maximum rate of runoff are needed at the inlet to a culvert for a 10-year and 100-year return period.

<u>Site Data</u>

From a topographic map and field survey, the area of the drainage basin upstream from the culvert found to be 18 acres. In addition the following data were measured:

Length of overland flow = 50 ft
Average overland slope = 2.0%
Length of main basin channel = 1300 ft
Slope of channel = 0.018 ft/ft = 1.8%
Hydraulic radius = 1.97 ft
Estimated roughness coefficient (n) of channel = 0.090

Land Use And Soil Data

From existing land use maps, land use for the drainage basin was estimated to be:

Residential (single family)	80%
Undeveloped (2% slope)	20%

For the undeveloped area, the soil group was determined from a SCS map to be:

Group B	100%

From existing land use maps, the land use for the overland flow area at the head of the basin was estimated to be:

Undeveloped (Soil Group B, 2.0% slope)	100%

Overland Flow

A runoff coefficient (C) for the overland flow area was determined to be 0.12 from Table 2-4.

Time Of Concentration

From Figure 2-2, with an overland flow length of 50 ft, slope of 2.0%, and a C of 0.12, the inlet time is 10 min. Channel flow velocity is determined from Manning's formula to be 3.5 ft/s (n = 0.090, R = 1.97 ft and S = 0.018 ft/ft). Therefore,

Flow Time = (1300 ft)/(3.5 ft/s)(60 s/min) = 6.2 min
and t_c = 10 + 6.2 = 16.2 min - say 16 min

Rainfall Intensity

From Figure 2-3 with duration equal to 16 min,

I_{10} (10-year return period) = 4.50 in./hr

I_{100} (100-year return period) = 7.05 in./hr

Runoff Coefficient

A weighted runoff coefficient C for the total drainage area is determined in Table 2-6 by utilizing the values from Tables 2-3 and 2-5.

Table 2-6 Weighted Runoff Coefficient, C

Land Use	(1) Percent of Total Land Area	(2) Weighted Runoff Coefficient	(3) Runoff Coefficient*
Residential (single family)	0.80	0.40	0.32
Undeveloped (Soil Group B)	0.20	0.12	0.02
Total Weighted Runoff Coefficient			0.34

* Column 3 equals column 1 multiplied by column 2.

Peak Runoff

From the rational equation:

Q_{10} = CIA = 0.34 × 4.50 × 18 = 28 cfs

Q_{100} = C_fCIA = 1.25 × 0.34 × 7.05 × 18 = 54 cfs From Table 2.5

These are the estimates of peak runoff for a 10-year and 100-year design storm for the given basin.

2.6 SCS Unit Hydrograph Method

2.6.1 Introduction

Techniques developed by the U. S. Soil Conservation Service for calculating rates of runoff require the same basic data as the rational method: drainage area, a runoff factor, time of concentration and rainfall. The SCS approach, however, is more sophisticated in that it considers also the time distribution of the rainfall, the initial rainfall losses to interception and depression, storage and an infiltration rate that decreases during the course of a storm. With the SCS method, the direct runoff can be calculated for any storm, either real or fabricated, by subtracting infiltration and other losses from the rainfall to obtain the precipitation excess (runoff volume). Details of the methodology can be found in the SCS National Engineering Handbook, Section 4.

Two types of hydrographs are used in the SCS procedure, unit hydrographs and dimensionless hydrographs. A unit hydrograph represents the time distribution of flow resulting from one inch of direct runoff occurring over the watershed in a specified time. A dimensionless hydrograph represents the composite of many unit hydrographs. The dimensionless unit hydrograph is plotted in nondimensional units of time divided by time to peak and discharge divided by peak discharge.

Characteristics of the dimensionless hydrograph vary with the size, shape and slope of the tributary drainage area. The most significant characteristics affecting the dimensionless hydrograph shape are the basin lag and the peak discharge for a given rainfall. Basin lag is the time from the center of mass of rainfall excess to the hydrograph peak. Steep slopes, compact shape and an efficient drainage network tend to make lag time short and peaks high; flat slopes, elongated shape and an inefficient drainage network tend to make lag time long and peaks low.

2.6.2 Concepts and Equations

The following discussion outlines the basic concepts and equations utilized in the SCS method.

2.6.2.1 Rainfall-Runoff

Rainfall-Runoff Equation - A relationship between accumulated rainfall and accumulated runoff was derived by SCS from experimental plots for numerous soils and vegetative cover conditions. Data for land-treatment measures, such as contouring and terracing, from experimental watersheds were included. The equation was developed mainly for small watersheds from which only daily rainfall and watershed data are ordinarily available. It was developed from recorded storm data that included the total amount of rainfall in a calendar day but not its distribution with respect to time. The SCS runoff equation is therefore a method of estimating direct runoff from 24-hr or 1-day storm rainfall. The equation is:

$$\mathbf{Q = (P - I_a)^2 \ / \ (P - I_a) + S} \qquad \textbf{(2.2)}$$

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

The relationship between I_a and S was developed from experimental watershed data. It eliminates the need for estimating I_a for common usage. The empirical relationship used in the SCS runoff equation is:

$$I_a = 0.2S \qquad (2.3)$$

By substituting 0.2S for I_a in equation 2.3, the SCS rainfall-runoff equation becomes:

$$Q = (P - 0.2S)^2 / (P + 0.8S) \qquad (2.4)$$

S is related to the soil and cover conditions of the watershed through the curve number (CN) or runoff factor (See Section 2.6.3.1). CN has a range of 0 to 100, and S is related to CN by:

$$S = (1000 / CN) - 10 \qquad (2.5)$$

Figure 2-4 is a graphical solution of equation 2.4 which enables the precipitation excess (runoff depth) from a storm to be obtained if the total rainfall and watershed curve number are known.

Drainage Area - The drainage area of a watershed is determined from topographic maps and field surveys. For large drainage areas it might be necessary to divide the area into sub-drainage areas to account for major land use changes, to obtain analysis results at different points within the drainage area, or to locate stormwater drainage facilities and assess their effects on the flood flows. Also a field inspection of existing or proposed drainage systems should be made to determine if the natural drainage divides have been altered. These alterations could make significant changes in the size and slope of the subdrainage areas.

Rainfall - The SCS method is based on a 24-hr storm event with various time distributions, depending on the watershed location. The Type II storm distribution is a "typical" time distribution which the SCS has prepared from rainfall records and can be used in Lincoln, Nebraska. Figure 2-5 shows this distribution. To use this distribution it is necessary for the user to obtain the 24-hr duration rainfall value for the frequency of the design storm desired from the Table 2-7.

Table 2-7 City Of Lincoln 24-Hour Design Rainfall

Frequency	24-hour Rainfall	Frequency	24-hour Rainfall
2-year	3.00 in.	25-year	5.37 in.
5-year	3.93 in.	50-year	6.00 in.
10-year	4.69 in.	100-year	6.68 in.

Source: National Weather Service, Tech. Paper 40, “Rainfall Frequency Atlas of the U.S.”, May 1961.

2.6.2.2 Time Of Concentration

The average slope within the watershed together with the overall length and retardance of overland flow are the major factors affecting the runoff rate through the watershed. In the SCS method, time of concentration (t_c) is defined to be the time required for water to travel from the most hydraulically distant point in a watershed to its outlet. Lag (L) can be considered as a weighted time of concentration and is related to the physical properties of a watershed, such as area, length and slope. The SCS derived the following empirical relationship between lag and time of concentration:

$$L = 0.6\, t_c \qquad (2.6)$$

See Appendix 2-C for information on the derivation of t_c.

In small urban areas (less than 2000 acres), a curve number method can be used to estimate the time of concentration from watershed lag. In this method the lag for the runoff from an increment of excess rainfall can be considered as the time between the center of mass of the excess rainfall increment and the peak of its incremental outflow hydrograph. The equation developed by SCS to estimate lag is:

$$\mathbf{L = (l^{0.8} (S + 1)^{0.7}) / (1900\ Y^{0.5})} \qquad \mathbf{(2.7)}$$

Where:
- L = lag, hrs
- l = length of mainstream to farthest divide, ft
- Y = average slope of watershed, %
- S = (1000/CN) - 10
- CN = SCS curve number

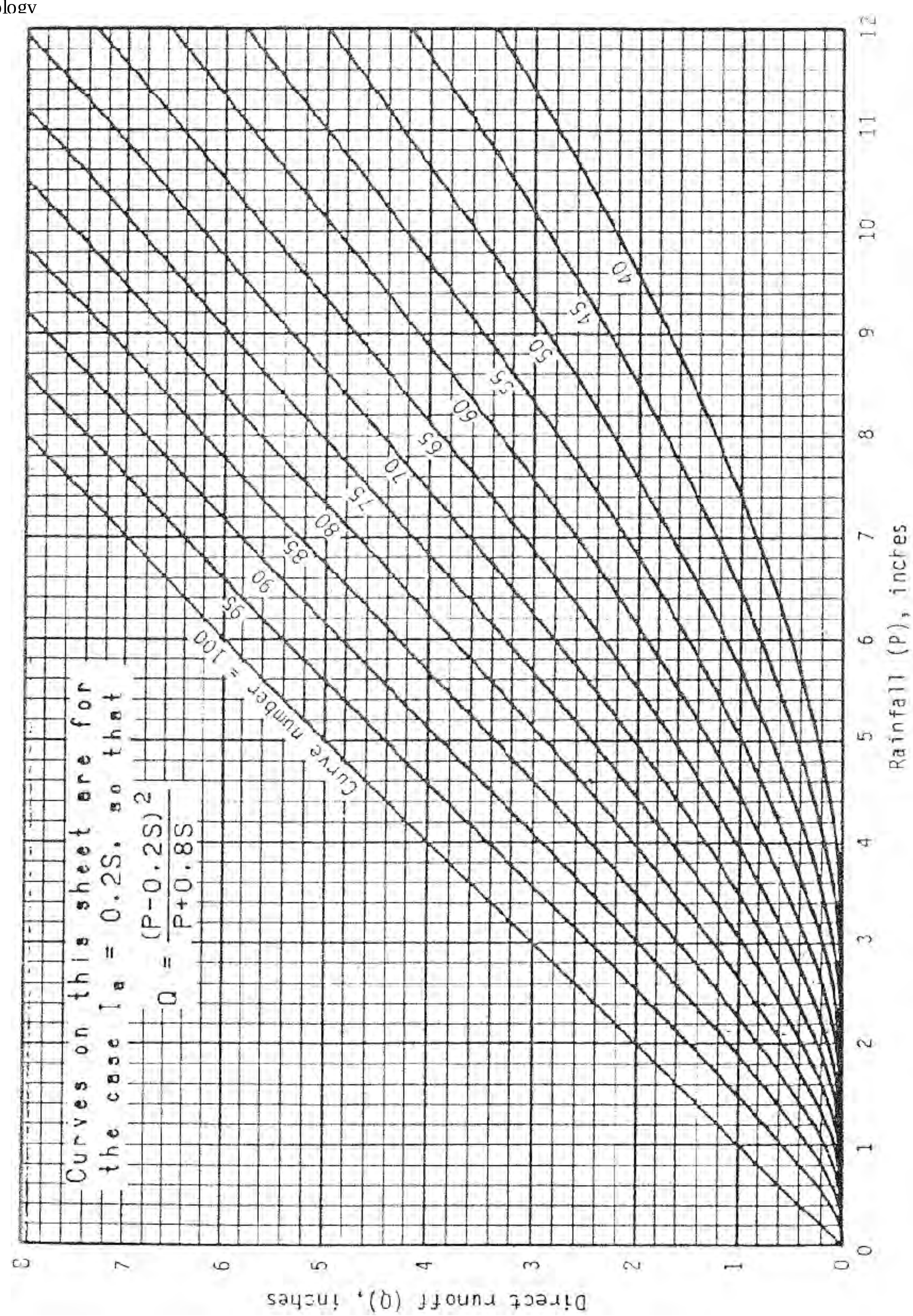

Figure 2-4 SCS Relation Between Direct Runoff, Curve Number And Precipitation

Source: HEC 19

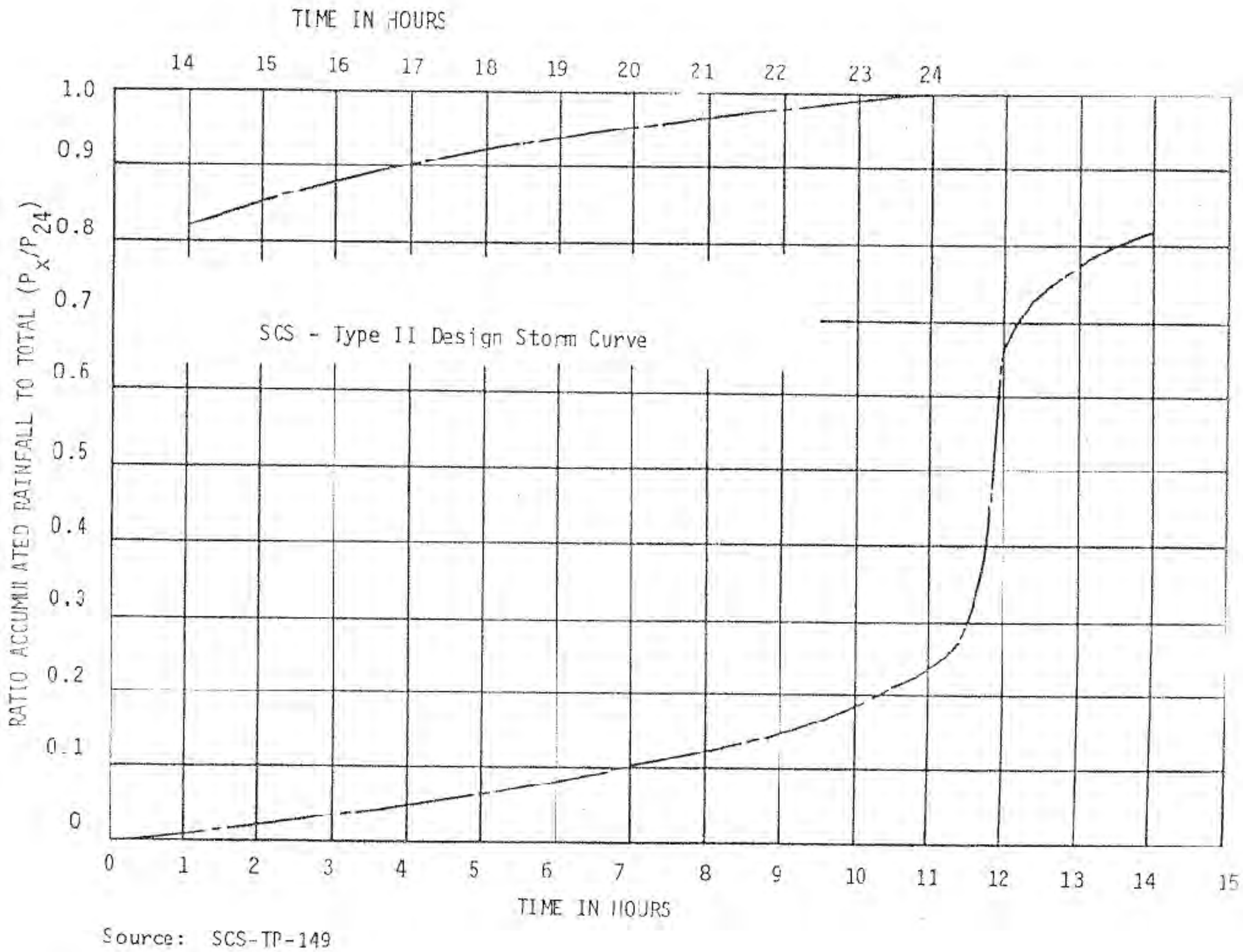

Figure 2-5 Type II Design Storm Curve

The lag time can be corrected for the effects of urbanization by using Figures 2-6 and 2-7. The amount of modifications to the hydraulic flow length usually must be determined from topographic maps or aerial photographs following a field inspection of the area. The modification to the hydraulic flow length not only includes pipes and channels but also the length of flow in streets and driveways.

After the lag time is adjusted for the effects of urbanization, the above equation that relates lag time and time of concentration can be used to calculate the time of concentration for use in the SCS method. Appendix 2-c presents an alternate procedure for travel time and time of concentration estimation.

2.6.2.3 Triangular Hydrograph Equation

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

$$q_p = (484\ A\ (q / (d/2 + L))) \qquad \textbf{(2.8)}$$

Where: q_p = peak rate of discharge, cfs
A = area, mi^2
q = storm runoff during time interval, in.
d = time interval, hrs
L = watershed lag, hrs

This equation can be used to estimate the peak discharge for the unit hydrograph which can then be used to estimate the peak discharge and hydrograph from the entire watershed.

The constant 484, or peak rate factor, is valid for the SCS dimensionless unit hydrograph. Any change in the dimensionless unit hydrograph reflecting a change in the percent of volume under the rising side would cause a corresponding change in the shape factor associated with the triangular hydrograph and therefore a change in the constant 484. This constant has been known to vary from about 600 in steep terrain to 300 in very flat, swampy country.

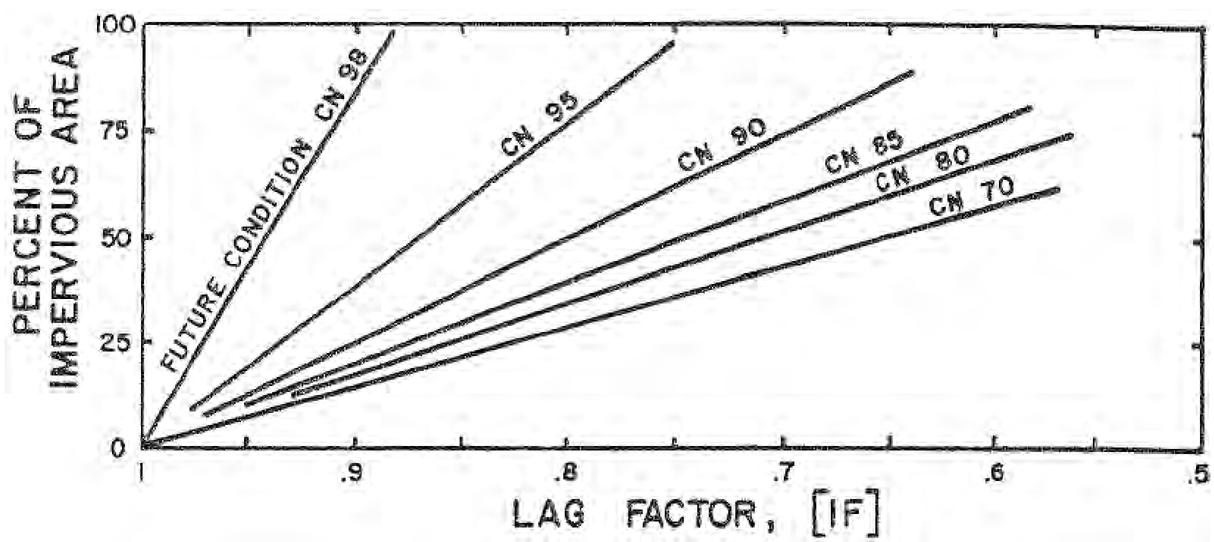

Figure 2-6 Factors For Adjusting Lag When Impervious Areas Occur In Watershed

Source: HEC-19

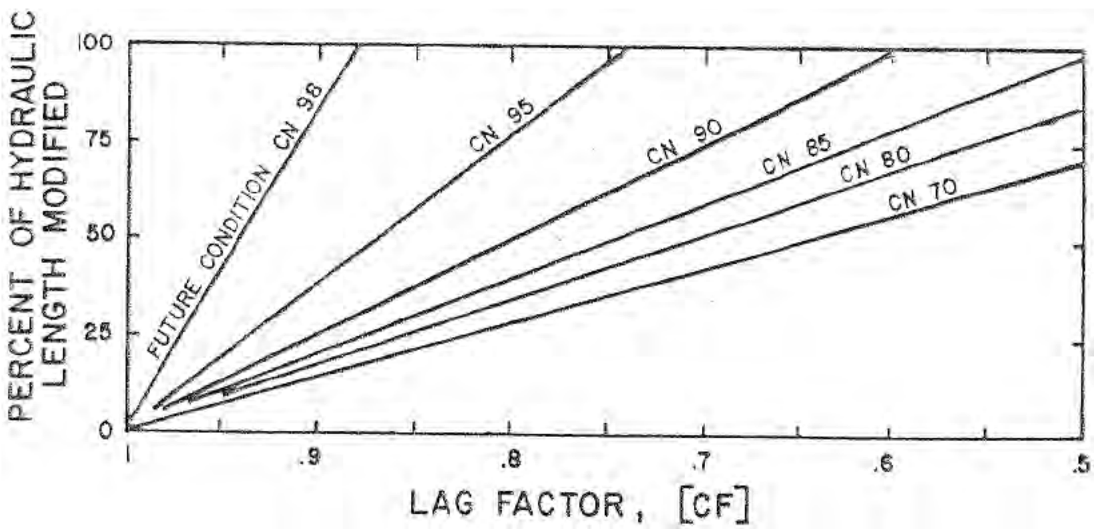

Figure 2-7 Factors For Adjusting Lag When The Main Channel Has Been Hydraulically Improved

Source: HEC 19

2.6.3 Application

The following discussion describes the procedures used in the SCS unit hydrograph method along with recommended design aids.

2.6.3.1 Runoff Factor

In hydrograph applications, runoff is often referred to as rainfall excess or effective rainfall — all defined as the amount by which rainfall exceeds the capability of the land to infiltrate or otherwise retain the rainfall. The principal physical watershed characteristics affecting the relationship between rainfall and runoff are land use, land treatment, soil types and land slope.

Land use is the watershed cover, and it includes both agricultural and nonagricultural uses. Items such as type of vegetation, water surfaces, roads, roofs, etc. are all part of the land use. Land treatment applies mainly to agricultural land use, and it includes mechanical practices such as contouring or terracing and management practices such as rotation of crops.

The SCS uses a combination of soil conditions and land-use (ground cover) to assign a runoff factor to an area. These runoff factors, called runoff curve numbers (CN), indicate the runoff potential of an area when the soil is not frozen. The higher the CN, the higher is the runoff potential.

Soil properties influence the relationship between rainfall and runoff by affecting the rate of infiltration. The SCS has divided soils into four hydrologic soil groups based on infiltration rates (Groups A, B, C and D). These groups were previously described for the rational method. Refer to Lancaster County Soil Survey.

Consideration should be given to the effects of urbanization on the natural hydrologic soil group. If heavy equipment can be expected to compact the soil during construction or if grading will mix the surface and subsurface soils, appropriate changes should be made in the soil group selected. Also, runoff curve numbers vary with the antecedent soil moisture conditions, defined as the amount of rainfall occurring in a selected period preceding a given storm. In general, the greater the antecedent rainfall, the more direct runoff there is from a given storm. A 5-day period is used as the minimum for estimating antecedent moisture conditions.

The following pages give a series of tables related to runoff factors. The first tables (Tables 2-8 - 2-10) give curve numbers for various land uses. These tables are based on an average antecedent moisture condition, i.e., soils that are neither very wet nor very dry when the design storm begins. Curve numbers should be selected only after a field inspection of the watershed and a review of zoning and soil maps. Table 2-11 gives conversion factors to convert average curve numbers to wet and dry curve numbers. Table 2-12 gives the antecedent conditions for the three classifications.

Table 2-8 Runoff Curve Numbers - Urban Areas[1]

Cover type and hydrologic condition	Average percent impervious area[2]		A	B	C	D
			Curve numbers for hydrologic soil groups			
Fully developed urban areas (vegetation established)						
Open space (lawns, parks, golf courses, cemeteries, etc.)[3]						
Poor condition (grass cover <50%)			68	79	86	89
Fair condition (grass cover 50% to 75%)			49	69	79	84
Good condition (grass cover > 75%)			39	61	74	80
Impervious areas:						
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)			98	98	98	98
Streets and roads:						
Paved; curbs and storm drains (excluding right-of-way)			98	98	98	98
Paved; open ditches (including right-of-way)			83	89	92	93
Gravel (including right-of-way)			76	85	89	91
Dirt (including right-of-way)			72	82	87	89
Urban districts:						
Commercial and business	85%		89	92	94	95
Industrial	72%	81	88	91	93	
Residential districts by average lot size:						
1/8 acre or less (town houses)	65%	77	85	90	92	
1/4 acre	38%		61	75	83	87
1/3 acre	30%		57	72	81	86
½ acre	25%		54	70	80	85
1 acre	20%		51	68	79	84
2 acres	12%		46	65	77	82
Developing urban areas						
Newly graded areas (pervious areas only, no vegetation)			77	86	91	94
Idle lands (CNs are determined using cover types similar to those in Table 2-10).						

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

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

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

Source: TR-55

Table 2-9 Cultivated Agricultural Land[1]

Cover description			Curve numbers for hydrologic soil group			
Cover type	Treatment[2]	Hydrologic condition[3]	A	B	C	D
Fallow	Bare soil	-	77	86	91	94
	Crop residue	Poor	76	85	90	93
	cover (CR)	Good	74	83	88	90
Row	Straight row (SR)	Poor	72	81	88	91
Crops		Good	67	78	85	89
	SR + CR	Poor	71	80	87	90
		Good	64	75	82	85
	Contoured (C)	Poor	70	79	84	88
		Good	65	75	82	86
	C + CR	Poor	69	78	83	87
		Good	64	74	81	85
	Contoured &	Poor	66	74	80	82
	terraced (C&T)	Good	62	71	78	81
	C&T + CR	Poor	65	73	79	81
		Good	61	70	77	80
	Small grain SR	Poor	65	76	84	88
		Good	63	75	83	87
	SR + CR	Poor	64	75	83	86
		Good	60	72	80	84
	C	Poor	63	74	82	85
		Good	61	73	81	84
	C + CR	Poor	62	73	81	84
		Good	60	72	80	83
	C&T	Poor	61	72	79	82
		Good	59	70	78	81
	C&T + CR	Poor	60	71	78	81
		Good	58	69	77	80
	Close-seeded SR	Poor	66	77	85	89
	or broadcast	Good	58	72	81	85
	Legumes or C	Poor	64	75	83	85
	Rotation	Good	55	69	78	83
	Meadow C&T	Poor	63	73	80	83
		Good	51	67	76	80

[1] Average runoff condition, and $I_a = 0.2S$.

[2] Crop residue cover applies only if residue is on at least 5% of the surface throughout the year.

[3]Hydrologic condition is based on a combination of factors that affect infiltration and runoff, including (a) density and canopy of vegetative areas, (b) amount of year-round cover, (c) amount of grass or closed-seeded legumes in rotations, (d) percent of residue cover on the land surface (good > 20%) and (e) degree of roughness.

Poor: Factors impair infiltration and tend to increase runoff.

Good: Factors encourage average and better than average infiltration and tend to decrease runoff.

Source: TR-55

Table 2-10 Other Agricultural Lands[1]

Cover description		Curve numbers for hydrologic soil group			
Cover type	Hydrologic condition	A	B	C	D
Pasture, grassland, or range-continuous forage for grazing[2]	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow—continuous grass, —protected from grazing and generally mowed for hay		30	58	71	78
Brush—brush-weed-grass mixture with brush the major element[3]	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	[4]30	48	65	73
Woods—grass combination (orchard or tree farm)[5]	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods[6]	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	[4]30	55	70	77
Farmsteads—buildings, lanes, driveways and surrounding lots	—	59	74	82	86

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

[2] Poor: < 50% ground cover or heavily grazed with no mulch
Fair: 50 to 75% ground cover and not heavily grazed
Good: > 75% ground cover and lightly or only occasionally grazed

[3] Poor: < 50% ground cover
Fair: 50 to 75% ground cover
Good: > 75% ground cover

[4] Actual curve number is less than 30; use CN = 30 for runoff computations.

[5] CNs shown were computed for areas with 50% grass (pasture) cover. Other combinations of conditions may be computed from CNs for woods and pasture.

[6] Poor: Forest litter, small trees and brush are destroyed by heavy grazing or regular burning.
Fair: Woods grazed but not burned, and some forest litter covers the soil.
Good: Woods protected from grazing, litter and brush adequately cover soil.

Source: TR-55

Table 2-11 Conversion From Average Antecedent Moisture Conditions To Dry And Wet Conditions

CN For Average Conditions	Corresponding CNs For Dry	Corresponding CNs For Wet
100	100	100
95	87	98
90	78	96
85	70	94
80	63	91
75	57	88
70	51	85
65	45	82
60	40	78
55	35	74
50	31	70
45	26	65
40	22	60
35	18	55
30	15	50
25	12	43
15	6	30
5	2	13

Source: USDA Soil Conservation Service TP-149 (SCS-TP-149), "A Method for Estimating Volume and Rate of Runoff in Small Watersheds," revised April 1973.

Table 2-12 Rainfall Groups For Antecedent Soil Moisture Conditions During Growing And Dormant Seasons

Antecedent Condition	Conditions Description	Growing Season 5-day Antecedent Rainfall	Dormant Season 5-day Antecedent Rainfall
Dry	An optimum condition of watershed soils, where soils are dry but not to the wilting point and when satisfactory plowing or cultivation takes place	Less than 1.4 in.	Less than 0.5 in.
Average	The average case for annual floods	1.4 - 2.1 in.	0.5 - 1.1 in.
Wet	When a heavy rainfall, or light rainfall and low temperatures, have occurred during the five days previous to a given storm	Over 2.1 in.	Over 1.1 in.

Source: Soil Conservation Service

2.6.4 Limitations

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

The curve number values given in Table 2-8 are based on directly connected impervious area. An impervious area is considered directly connected if runoff from it flows directly into the drainage system. It is also considered directly connected if runoff from it occurs as concentrated shallow flow that runs over a pervious area and then into a drainage system. It is possible that curve number values from urban areas could be reduced by not directly connecting impervious surfaces to the drainage system. For a discussion of impervious areas and their effect on curve number values, see Appendix 2-B at the end of this chapter.

2.7 Simplified SCS Method

2.7.1 Introduction

The following SCS procedures were taken from the SCS Technical Release 55 (TR-55) which presents simplified procedures to calculate storm runoff volume, peak rate of discharges and hydrographs. These procedures allow manual calculation of hydrologic parameters. HEC-HMS performs the same calculations when the SCS methodology is selected within the software package. These procedures are applicable to small drainage areas and include provisions to account for urbanization. The following procedures outline the use of the SCS-TR 55 method.

2.7.2 Concepts and Equations - Peak Discharge Method

The SCS peak discharge method is applicable for estimating the peak run-off rate from watersheds with homogeneous land uses. The following method is based on the results of computer analyses performed using TR-20, "Computer Program for Project Formulation - Hydrology" (SCS 1983).

The peak discharge equation is:

$$\mathbf{Q_p = q_u A Q F_p} \quad \textbf{(2.9)}$$

Where:

Q_p = peak discharge (cfs)
q_u = unit peak discharge (cfs/mi^2/in.)
A = drainage area (mi^2)
Q = runoff (in.)
F_p = pond and swamp adjustment factor

The input requirements for this method are as follows:

1. Time of concentration, T_c (hours)
2. Drainage area (mi^2)
3. Type II rainfall distribution
4. 24-hour design rainfall
5. CN value
6. Pond and swamp adjustment factor (If pond and swamp areas are spread throughout the watershed and are not considered in the T_c computation, an adjustment is needed.)

Computations for the peak discharge method proceed as follows:

1. The 24-hour rainfall depth is determined from Table 2-7.

2. The runoff curve number, CN, is estimated from Table 2-8 through 2-10 and direct runoff, Q, is calculated using equation 2.4.

3. The CN value is used to determine the initial abstraction, I_a, from Table 2-13, and the ratio I_a/P is then computed. (P = accumulated rainfall or potential maximum runoff.)

4. The watershed time of concentration is computed using the procedures in Section 2.6.2.2 and is used with the ratio I_a/P to obtain the unit peak discharge, q_u, from Figure 2-8 or the method given in Appendix 2-C. If the ratio I_a/P lies outside the range shown in Figure 2-8, either the limiting values or another peak discharge method should be used.

5. The pond and swamp adjustment factor, F_p, is estimated from the following information:

Pond & Swamp Areas (%)	F_p	Pond & Swamp Areas (%)	F_p
0	1.00	3.0	0.75
0.2	0.97	5.0	0.72
1.0	0.87		

6. The peak runoff rate is computed using equation 2.9.

Table 2-13 I_a Values For Runoff Curve Numbers

Curve Number	I_a (in)	Curve Number	I_a (in)
40	3.000	70	.857
41	2.878	71	.817
42	2.762	72	.778
43	2.651	73	.740
44	2.545	74	.703
45	2.444	75	.667
46	2.348	76	.632
47	2.255	77	.597
48	2.167	78	.564
49	2.082	79	.532
50	2.000	80	.500
51	1.922	81	.469
52	1.846	82	.439
53	1.774	83	.410
54	1.704	84	.381
55	1.636	85	.353
56	1.571	86	.326
57	1.509	87	.299
58	1.448	88	.273
59	1.390	89	.247
60	1.333	90	.222
61	1.279	91	.198
62	1.226	92	.174
63	1.175	93	.151
64	1.125	94	.128
65	1.077	95	.105
66	1.030	96	.083
67	.985	97	.062
68	.941	98	.041
69	.899		

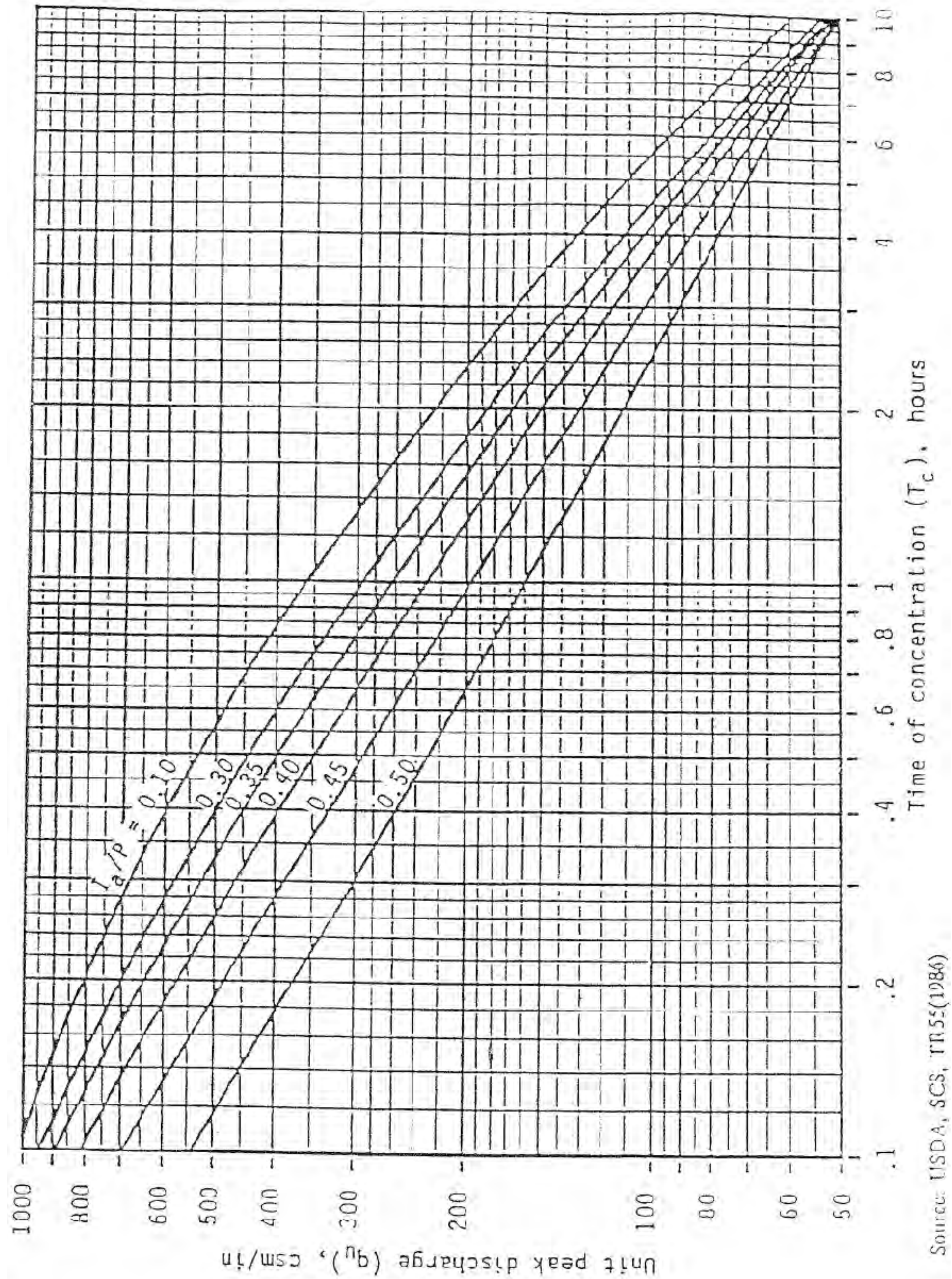

Figure 2-8 SCS Type II Unit Peak Discharge Graph

2.7.3 Limitations

The accuracy of the peak discharge method is subject to specific limitations, including the following.

1. The watershed must be hydrologically homogeneous and describable by a single/composite CN value.

2. The watershed may have only one main stream, or if more than one, the individual branches must have nearly equal time of concentrations.

3. Hydrologic routing cannot be considered.

4. The pond and swamp adjustment factor, F_p, applies only to areas located away from the main flow path.

5. Accuracy is reduced if the ratio I_a/P is outside the range given in Figure 2-7.

6. The weighted CN value must be greater than or equal to 40 and less than or equal to 98.

7. The same procedure should be used to estimate pre- and post-development time of concentration when computing pre- and post-development peak discharge.

8. The watershed time of concentration must be between 0.1 and 10 hours.

2.7.4 Example Problem

Compute the 25-year peak discharge for a 50-acre wooded watershed which will be developed as follows:

1. Forest land - good cover (hydrologic soil group B) = 10 ac.
2. Forest land - good cover (hydrologic soil group C) = 10 ac.
3. Town house residential (hydrologic soil group B) = 20 ac.
4. Industrial development (hydrological soil group C) = 10 ac.

Other data include:

percentage of pond and swamp area = 0.

The hydrologic flow path for this watershed = 1,920 ft.

Segment	Type of Flow	Length	Slope (%)
1	Overland (n = .45)	70 ft.	2.0 %
2	Shallow channel	750 ft.	1.7 %
3	Main channel*	1100 ft.	0.20 %

* For the main channel, n = .025, width = 10 feet, depth = 2 feet, rectangular channel.

Computations

1. Calculate rainfall excess:

The 25-year, 24-hour rainfall for Lincoln, Nebraska is 5.37 inches (see Table 2-7).

Composite weighted runoff coefficient is:

Dev. #	Area	% Total	CN	Composite CN
1	10 ac.	.20	55	11.0
2	10 ac.	.20	70	14.0
3	20 ac.	.40	85	34.0
4	10 ac.	.20	91	18.2
Total	50 ac.	1.00		77.2 use 77

2. Calculate time of concentration (Note: use the method outlined in Appendix 2-C.)

Segment 1 - Travel time from equation 2.C.3 with P_2 = 3.00 in.

$T_t = [0.42\ (0.45 \times 70)^{0.8}] / [(3.00)^{0.5}\ (.02)^{0.4}]$
T_t = 18.3 minutes

Segment 2 - Travel time from equation 2.C.5 and equation 2.C.1

V = 2.7 ft/sec (equation 2.C.5)

T_t = 750 / 60 (2.7) = 4.6 minutes

Segment 3 - Using equation 2.C.6 and equation 2.C.1

$V = (1.49/.025)\ (1.43)^{0.67}\ (.002)^{0.5}$ = 3.4 ft/sec
T_t = 1100 / 60 (3.4) = 5.4 minutes

T_c = 18.3 + 4.6 + 5.4 = 28.3 minutes (.47 hours)

3. Calculate I_a/P

For CN = 77, I_a = .597 (Table 2-13)

I_a/P = (.597 /5.37) = .111
(Note: Use I_a/P = .10 to facilitate use of Figure 2-8.

4. Estimate unit discharge q_u from Figure 2-8 = 550 cfs/mi^2/in

5. Calculate peak discharge with F_p = 1 using equation 2.9

From Figure 2-4 (or equation 2.4), Q = 2.9 inches
Q_{25} = 550 (50/640) (2.9) (1) = 125 cfs.

2.7.5 Hydrograph Generation

In addition to estimating the peak discharge, the SCS method can be used to estimate the entire hydrograph. The Soil Conservation Service has developed a tabular hydrograph procedure which can be used to generate the hydrograph for small drainage areas. The tabular hydrograph procedure uses unit discharge hydrographs which have been generated for a series of times of concentrations.

The tables in Appendix 2-A at the end of this chapter give the unit discharges (csm/in) for different times of concentration which are applicable to the City of Lincoln. The values that should be used are those with a travel time equal to zero. The other travel times indicate the unit hydrographs which would result if the hydrographs were routed through a channel system for a length of time equal to the travel time. Thus, using these unit hydrographs would account for the effects of channel routing. Straight line interpolation can be used for time of concentrations and travel times between the values given in the appendix.

2.7.6 Composite Hydrograph

The procedures given in this chapter are for generation of a hydrograph from a homogeneous developed drainage area. For drainage areas which are not homogeneous, hydrographs need to be generated from sub-areas and then routed and combined at a point downstream. To accomplish this, engineers should refer to the procedures outlined by the SCS in the 1986 version of TR-55 available from the National Technical Information Service in Springfield, Virginia or www.usda.nrcs.gov. The catalog number for TR-55, "Urban Hydrology for Small Watersheds," is PB87-101580.

2.7.7 Hydrograph Computation

For the example problem in 2.7.4, calculate the entire hydrograph from the 50 acre development.

Using the chart in Appendix 2-A with a time of concentration of 0.47 hours and $I_a/P = 0.10$, the following hydrograph can be generated (using straight line interpolation between time of concentration of .4 and .5 hours).

The values given in the charts are in csm/in or cubic feet per second per square mile per inch of runoff. Thus, for this example all values from the chart must be multiplied by 0.078 (50 acres/640 acres per square mile), 2.9 inches of runoff, and 1 for the ponding factor - (50/640)(2.9)(1) = 0.23

As an example, from the chart in Appendix 2-A with $T_c = 0.47$ hours and $I_a/P = 0.10$, the unit discharge at time 12.1 hours is 200 csm/in. Thus, the ordinate on the hydrograph for this example would be 200(.23) = 46 cfs. This calculation must be done for all hydrograph values. The results for selected time values are given in Table 2-14.

Table 2-14 Hydrograph Calculation Results for Selected Time Values

*Hydrograph Time (hours)	Unit Discharge (csm/in)	Hydrograph (cfs)
11.0	17	4
11.3	23	5
11.6	33	8
11.9	63	14
12.0	108	25
12.1	200	46
12.2	359	83
12.3	505	116
12.4	544	125
12.5	484	111
12.6	371	85
12.7	273	63
12.8	207	48
13.0	129	30
13.2	91	21
13.4	71	16
13.6	59	14
13.8	52	12
14.0	46	11
14.3	40	9
14.6	36	8
15.0	32	7
15.5	29	7
16.0	26	6

* Note skips in time increments.

2.8 Hydrologic Computer Modeling

2.8.1 Introduction

Hydrologic computer models are in widespread use. They are becoming more "user-friendly", more capable and flexible, and usually provide "report-ready" output. However, a model's real utility is in monitoring changes in the watershed or asking "what if" questions. For example, what happens to the 10-year peak discharge as a portion of the watershed becomes urbanized? Or, alternatively, can the peak discharge be reduced substantially with a strategically placed detention pond? Many hydrologic models will allow one to:

- quantify urban runoff (peaks, volumes, and in some cases, water quality),
- obtain design information (channels, pipes, reservoirs, etc.),
- determine the effects of control options (infiltration devices, retention ponds, etc.),
- perform frequency analysis, and
- provide input to economic models.

HEC-HMS (a nonproprietary model written by the U.S. Army Corps of Engineers) has been selected for use in Lincoln by the Public Works & Utility Department and the Lower Platte South NRD.

As you begin to use hydrologic computer models, keep in mind the memorable cliché: “Computers are fast, accurate, and stupid. People are slow, inaccurate, and brilliant. The combination is an opportunity beyond imagination.” However, one needs to remain “brilliant” by studying the underlying algorithms these models use. If one knows their limitations, he or she can use computer models wisely.

2.8.2 Concepts and Equations

Modern hydrologic models generally require the user to assemble watershed elements on the computer screen in a link-node structure. That is, nodes represent sub-basins (sub-watersheds), confluences (junctions, manholes, etc.), channels/pipes, and reservoirs. These nodes are "linked" together in an arrangement that depicts how runoff passes through the watershed.

Mathematical algorithms are associated with each node. For example, a sub-basin node will require certain information from the user in order to generate a runoff hydrograph. Rainfall is a necessary input. The user will also be required to input items like area, curve number, slope, etc. With this information, the model uses internal algorithms to compute a runoff hydrograph and sends it to the next downstream element. If this element is a channel/pipe node, other data will be required to route the hydrograph to the next element. Reservoir nodes also perform routing computations. A confluence node combines two or more hydrographs from upstream sub-basins, channels/pipes, and/or reservoirs. The hydrograph(s) continue to move downstream through all of the watershed elements.

SCS procedures are embedded in most hydrologic models. HEC-HMS allow the user to model watersheds with SCS methodology. Therefore, the concepts and equations mentioned previously in this chapter are still appropriate. These include the 24-hour storm, SCS rainfall distributions (like the Type II appropriate for Lincoln), the curve number method for allocating rainfall losses, and the SCS unit hydrograph procedure.

2.8.3 Application

The application of a good hydrologic model is not complicated, particularly if you have a good background in hydrology and a basic understanding of the underlying algorithms used by the model. The step-by-step modeling procedure listed below is typical of most modern hydrologic models. Of course, the sequence of steps taken and the particular data requested are dependent upon the model used and the solution methodology (algorithms) chosen.

The step-by-step modeling procedure is likely to progress as follows:

- Launch the model and name your new file.
- Choose a system of units, give the project a title, and insert project comments.
- Build a watershed schematic (link/node) using the elements provided on the "tool palette.”
- Choose a solution methodology (e.g., SCS) for individual watershed elements.
- Input requested data (e.g., rainfall, curve number, etc.) for each watershed element.
- Add any remaining general data (e.g., time step) and run the model.
- Interrogate individual elements from the watershed schematic for output (e.g., hydrographs).
- Evaluate the output data based on sound engineering judgement.
- Use the conclusions to determine estimates to the model for reliable output.

2.8.4 Limitations

Hydrologic models are subject to the same limitations as their underlying algorithms. For example, if SCS modeling procedures are utilized, the precautions and limitations mentioned in section 2.6.4 still apply. The major limitations of the SCS methodology are listed below.

- Curve numbers describe average conditions, particularly with regard to antecedent moisture conditions. Since a watershed or sub-watershed is described by one CN value, it should be delineated (to the extent feasible) such that it is hydrologically homogeneous. (See section 2.7.4 on weighted curve numbers.)
- Initial abstractions are assumed to be 20% of a basin’s potential losses.
- Runoff from snowfall or frozen ground cannot be accounted for using SCS procedures.
- SCS procedures account for surface runoff only, not interflow or groundwater contribution.

Since many hydrologic procedures contain empirical parameters, the processes of calibration and verification can be very useful in improving model accuracy. These processes require measured rainfall and runoff data from historical events. Calibration requires that a watershed be modeled using rainfall information from a number of historical storms. Certain empirical parameters are adjusted in the process so that the modeled output matches the measured output. Verification follows calibration. Using completely different historical rainfall information (not the same storms used for calibration), the model is run again with the adjusted empirical parameters to determine the accuracy of the results. If the modeled runoff from these new storms closely matches the measured runoff, the model is assumed to be "verified." The process of calibration and verification is highly desirable and increases confidence in the results of a hydrologic model.

References

AASHTO Highway Drainage Guidelines, Volume II.

Agency's Regression Equation Study.

Debo, T.N. and A.J. Reese. Municipal Storm Water Management. Boca Raton, Ann Arbor, London, Tokyo: Lewis Publishers. 1994

Erie and Niagra Counties Regional Planning Board. Storm Drainage Design Manual.

Federal Highway Administration. HYDRAIN Documentation. 1990.

Newton, D.W., and Herin, Janet C. Assessment of Commonly Used Methods of Estimating Flood Frequency. Transportation Research Board. National Academy of Sciences, Record Number 896. 1982

Overton, D.E. and M.E. Meadows. Storm Water Modeling. Academic Press. New York, N.Y. pp. 58-88. 1976.

Potter, W.D. Upper and Lower Frequency Curves for Peak Rates of Runoff. Transactions, American Geophysical Union, Vol. 39, No. 1, pp. 100-105. February 1985.

R.M. Regan. A Nomograph Based on Kinematic Wave Theory for Determining Time of Concentration for Overland Flow. Report Number 44. Civil Engineering Department, University of Maryland at College Park. 1971

Sauer, V.B., Thomas, W.O., Stricker, V.A., and Wilson, K.V. Flood Characteristics of Urban Watersheds in the United States — Techniques for Estimating Magnitude and Frequency of Urban Floods. U. S. Geological Survey Water-Supply Paper 2207. 1983.

U.S. Department of Agriculture, Soil Conservation Service. A Method for Estimating Volume and Rate of Runoff in Small Watersheds, Technical Paper 149. April 1973.

U.S. Department of Agriculture, Soil Conservation Service. National Engineering Handbook, Section 4.

U.S. Department of Agriculture, Soil Conservation Service. Soil Survey of Lancaster County, Nebraska. May 1980.

U.S. Department of Agriculture, Soil Conservation Service. Urban Hydrology for Small Watersheds, Technical Release 55. June 1986.

U.S. Department of Transportation, Federal Highway Administration. Hydrology. Hydraulic Engineering Circular No. 19. 1984.

Wahl, Kenneth L. Determining Stream Flow Characteristics Based on Channel Cross Section Properties. Transportation Research Board. National Academy of Sciences, Record Number 922. 1983.

Water Resources Council Bulletin 17B. Guidelines for Determining Flood Flow Frequency. 1981.

Urban Drainage and Flood Control District, RED. ED. (1984). Urban Storm Drainage Criteria Manual, Denver Regional Council of Governments, Denver, Colorado.

Appendix 2-A
SCS Unit Discharge Hydrographs

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

IA/P = 0.10 * * * TC = 0.1 HR * * * IA/P = 0.10

TRVL TIME (hr)	11.0	11.3	11.6	11.9	11.0	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	13.0	14.3	14.6	15.0	13.5	15.0	15.5	16.0	17.5	16.0	19.0	20.0	22.0	26.0
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	33	34	31	28	25	22	21	19	18	16	14	12	0
.30	17	23	33	56	92	174	337	582	662	545	389	269	190	109	79	65	56	50	45	39	35	32	29	25	22	21	20	19	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	33	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	720	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	23	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	15	19	25	39	75	142	262	308	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 = 0.10 * * * TC = 0.1 HR * * * IA/P = 0.10

TRVL TIME (hr)	11.0	11.3	11.6	11.9	11.0	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	13.0	14.3	14.6	15.0	13.5	15.0	15.5	16.0	17.5	16.0	19.0	20.0	22.0	26.0
0.0	0	0	0	154	568	536	924	217	172	149	126	107	97	85	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	95	84	74	6d	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	23	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	3e1	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 = 0.10 * * * TC = 0.1 HR * * * IA/P = 0.10

TRVL TIME (hr)	11.0	11.3	11.6	11.9	11.0	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	13.0	14.3	14.6	15.0	13.5	15.0	15.5	16.0	17.5	16.0	19.0	20.0	22.0	26.0
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	178	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	59	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: Tabular hydrograph unit discharges (csm/in) for type II rainfall distribution—continued

TRVL TIME (hr) — HYDROGRAPH TIME (HOURS)

TRVL TIME (hr)	11.0	11.3	11.6	11.9	11.0	12.1	12.2	12.3	12.4	12.5	12.6	12.7	12.8	13.C	13.2	13.4	13.6	13.8	13.0	14.3	14.6	15.0	13.5	15.0	15.5	16.0	17.5	16.0	19.0	20.0	22.0	26.0
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	208	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	258	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																																
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																																
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	188	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: Tabular hydrograph unit discharges (csm/in) for type II rainfall distribution—continued

HYDROGRAPH TIME (HOURS)

TRVL TIME (hr)	11.0	11.3	11.6	11.9	11.0	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	13.0	14.3	14.6	15.0	13.5	15.0	15.5	16.0	17.5	16.0	19.0	20.0	22.0	26.0
IA/P = 0.10													* * * TC = 0.3 HR * * *																IA/P = 0.10			
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	69	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	358	259	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			
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			
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

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

HYDROGRAPH TIME (HOURS)

TRVL TIME (hr)	11.0	11.3	11.6	11.9	11.0	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	13.0	14.3	14.6	15.0	13.5	15.0	15.5	16.0	17.5	16.0	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	375	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	55	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	23	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	95	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	195	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	293	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	135	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	18
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	105	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	125	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	25	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	73	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	53	57	48	42	34	27

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

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

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	225	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	55	123	202	297	280	161	88	52	39	33	29	26	21	15	14	10
2.5	2	3	4	5	5	6	6	7	7	8	9	9	10	12	15	18	24	36	66	150	244	270	171	87	52	39	33	29	25	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	85	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	97	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	255	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	24	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	109	192	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	152	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	163	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	164	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	180	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	15	50	97	135	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
3.3	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: Tabular hydrograph unit discharges (csm/in) for type II rainfall distribution—continued

HYDROGRAPH TIME (HOURS)

TRVL TIME (hr)	11.0	11.3	11.6	11.9	11.0	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	13.0	14.3	14.6	15.0	13.5	15.0	15.5	16.0	17.5	16.0	19.0	20.0	22.0	26.0
IA/P = 0.10											* * * TC = 0.75 HR * * *																					
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 * * *																					
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	3	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 * * *																					
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	133	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: Tabular hydrograph unit discharges (csm/in) for type II rainfall distribution—continued

TRVL TIME (hr)	11.0	11.3	11.6	11.9	11.0	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	13.0	14.3	14.6	15.0	13.5	15.0	15.5	16.0	17.5	16.0	19.0	20.0	22.0	26.0
IA/P = 0.10														* * * TC = 1.0 HR * * *																		
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	15	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	93	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 * * *																		
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 * * *																		
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: Tabular hydrograph unit discharges (csm/in) for type II rainfall distribution —continued

HYDROGRAPH TIME(HOURS)

IA/P = 0.10 * * * TC = 1.25 HR * * *

TRVL TIME (hr)	11.0	9.3	9.6	9.9	10.0	10.1	10.2	10.3	10.4	10.5	10.6	10.7	10.8	11.0	11.2	11.4	11.6	11.8	12.0	12.3	12.6	13.0	13.5	14.0	14.5	15.0	15.5	16.0	17.0	18.0	20.0	24.0
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	286	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	414	197	226	163	102	65	46	36	25	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 * * *

TRVL TIME (hr)	11.0	9.3	9.6	9.9	10.0	10.1	10.2	10.3	10.4	10.5	10.6	10.7	10.8	11.0	11.2	11.4	11.6	11.8	12.0	12.3	12.6	13.0	13.5	14.0	14.5	15.0	15.5	16.0	17.0	18.0	20.0	24.0
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 * * *

TRVL TIME (hr)	11.0	9.3	9.6	9.9	10.0	10.1	10.2	10.3	10.4	10.5	10.6	10.7	10.8	11.0	11.2	11.4	11.6	11.8	12.0	12.3	12.6	13.0	13.5	14.0	14.5	15.0	15.5	16.0	17.0	18.0	20.0	24.0
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: Tabular hydrograph unit discharges (csm/in) for type II rainfall distribution—continued

TRVL TIME (hr)	11.0	9.3	9.6	9.9	10.0	10.1	10.2	10.3	10.4	10.5	10.6	10.7	10.8	11.0	11.2	11.4	11.6	11.8	12.0	12.3	12.6	13.0	13.5	14.0	14.5	15.0	15.5	16.0	17.0	18.0	20.0	24.0
IA/P = 0.10													* * * TC = 1.5 HR * * *																IA/P = 0.10			
0.0	9	11	15	21	25	31	41	50	82	112	147	184	216	255	275	236	198	159	129	98	76	57	43	35	30	25	23	21	18	16	12	1
.15	9	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	37	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	136	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	158	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	130	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	95	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	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: Tabular hydrograph unit discharges (csm/in) for type II rainfall distribution—continued

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.
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	59	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	88	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

Appendix 2-B
Impervious Area Calculations

2.B.1 Urban Modifications

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

The curve number values given in Table 2-8 are based on directly connected impervious area. An impervious area is considered directly connected if runoff from it flows directly into the drainage system. It is also considered directly connected if runoff from it occurs as concentrated shallow flow that runs over pervious areas and then into a drainage system. It is possible that curve number values from urban areas could be reduced by not directly connecting impervious surfaces to the drainage system. The following discussion will give some guidance for adjusting curve numbers for different types of impervious areas.

Connected Impervious Areas

Urban CNs given in Table 2-8 were developed for typical land use relationships based on specific assumed percentages of impervious area. These CN values were developed on the assumptions that:

(a) pervious urban areas are equivalent to pasture in good hydrologic condition, and

(b) impervious areas have a CN of 98 and are directly connected to the drainage system.

Some assumed percentages of impervious area are shown in Table 2-8.

If all of the impervious area is directly connected to the drainage system, but the impervious area percentages or the pervious land use assumptions in Table 2-8 are not applicable, use Figure 2-B-1 to compute a composite CN. For example, Table 2-8 gives a CN of 70 for a ½-acre lot in hydrologic soil group B, with an assumed impervious area of 25 percent. However, if the lot has 20 percent impervious area and a pervious area CN of 61, the composite CN obtained from Figure 2-B-1 is 68. The CN difference between 70 and 68 reflects the difference in percent impervious area.

Unconnected Impervious Areas

Runoff from these areas is spread over a pervious area as sheet flow. To determine CN when all or part of the impervious area is not directly connected to the drainage system, (1) use Figure 2-B-2 if total impervious area is less then 30 percent or (2) use Figure 2-B-1 if the total impervious area is equal to or greater than 30 percent, because the absorptive capacity of the remaining pervious areas will not significantly affect runoff.

When impervious area is less than 30 percent, obtain the composite CN by entering the right half of Figure 2-B-2 with the percentage of total impervious area and the ratio of total unconnected impervious area to total impervious area. Then move left to the appropriate pervious CN and read down to find the composite CN. For example, for a ½-acre lot with 20 percent total impervious area (75 percent of which is unconnected) and pervious CN of 61, the composite CN from Figure 2-B-2 is 66. If all of the impervious area is connected, the resulting CN (from Figure 2-B-1) would be 68.

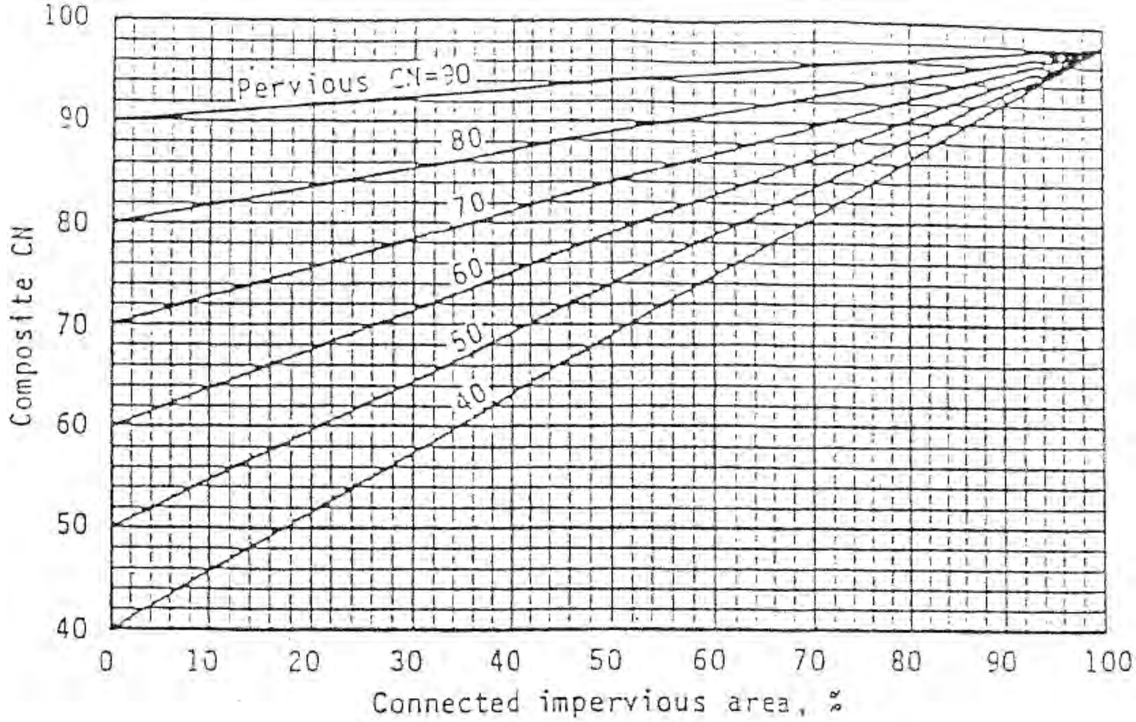

Figure 2-B-1 Composite CN With Connected Impervious Areas

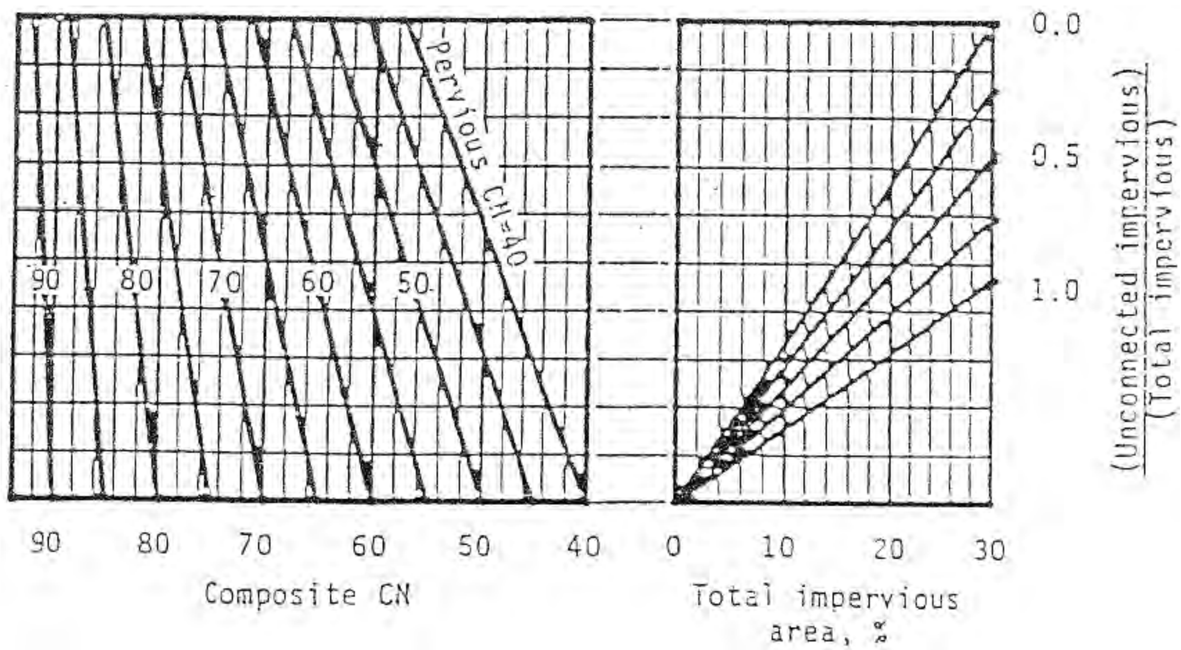

Figure 2-B-2 Composite CN With Unconnected Impervious Areas
(Total Impervious Area Less Than 30%)

2.B.2 Composite Curve Numbers

When a drainage area has more than one land use, a composite curve number can be calculated and used in the analysis. It should be noted that when composite curve numbers are used, the analysis does not take into account the location of the specific land uses but sees the drainage area as a uniform land use represented by the composite curve number.

Composite curve numbers for a drainage area can be calculated by entering the required data into a table such as Table 2-B-1.

Table 2-B-1 Composite Curve Number Calculations

(1) Land Use	(2) Curve Number	(3) Area	(4) % of Total Area	(5) Composite Curve No. (Col 2 X Col 4)

The composite curve number for the total drainage area is then the sum of the composite curve numbers from column 5.

The different land uses within the basin should represent a uniform hydrologic group represented by a single curve number. Any number of land uses can be included, but if their spatial distribution is important to the hydrologic analysis, then sub-basins should be developed and separate hydrographs developed and routed to the study point.

Appendix 2-C
Travel Time Estimation

2.C.1 Introduction

Travel time (T_t) is the time it takes water to travel from one location to another in a watershed. T_t is a component of time of concentration (T_c), which is the time for runoff to travel from the hydraulically most distant point of the watershed to a point of interest within the watershed. T_c is computed by summing all the travel times for consecutive components of the drainage conveyance system.

Procedures and equations for calculating travel time and time of concentration are discussed in the following sections.

2.C.2 Travel Time

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

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

$$\mathbf{T_t = L/(3600V)} \qquad \textbf{(2.C.1)}$$

Where:
- T_t = travel time, hr
- L = flow length, ft
- V = average velocity, ft/s
- 3600 = conversion factor from sec to hrs

2.C.3 Time Of Concentration

The time of concentration is the sum of T_t values for the various consecutive flow segments:

$$\mathbf{T_c = T_{t1} + T_{t2} + ... T_{tm}} \qquad \textbf{(2.C.2)}$$

Where:
- T_c = time of concentration, hr
- m = number of flow segments

2.C.4 Sheet Flow

Sheet flow is flow over plane surfaces. It usually occurs in the headwater of watersheds. With sheet flow, the friction value (Manning's n) is an effective roughness coefficient that includes the effect of raindrop impact; drag over the plane surface; obstacles such as litter, crop ridges and rocks; and erosion and transportation of sediment. These n values are for very shallow flow depths of about 0.1 ft or so. Table 2-C-1 gives Manning's n values for sheet flow for various surface conditions.

Sheet flow conditions are unlikely for length in excess of 300 ft. In urban residential development, sheet flow conditions may occur in rear yards and other open areas but generally ease when flow occurs between buildings. For sheet flow use Manning's kinematic solution (Overton and Meadows 1976) to compute T_t:

$$\mathbf{T_t = [0.42\ (nL)^{0.8} / (P_2)^{0.5} s^{0.4}]} \qquad \textbf{(2.C.3)}$$

Where:
- T_t = travel time, min
- n = Manning's roughness coefficient (Table 2-C-1)
- L = flow length, ft
- P_2 = 2-year, 24-hr rainfall, in. (3.0 inches in Lincoln)
- s = slope of hydraulic grade line (land slope), ft/ft

Table 2-C-1
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
Grasses:	
Short grass prairie	0.15
Dense grasses[2]	0.24
Bermuda grass	0.41
Range (natural)	0.13
Woods:[3]	
Light underbrush	0.40
Dense underbrush	0.80

[1] The n values are a composite of information complied 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.

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

1. shallow steady uniform flow,
2. constant intensity of rainfall excess (rain available for runoff),
3. rainfall duration of 24 hrs, and
4. minor effect of infiltration on travel time.

Another approach is to use the kinematic wave equation. For details on using this equation consult the publication by R. M. Regan, "A Nomograph Based on Kinematic Wave Theory for Determining Time of Concentration for Overland Flow," Report Number 44, Civil Engineering Department, University of Maryland at College Park, 1971.

2.C.5 Shallow Concentrated Flow

After a maximum of 300 ft, sheet flow usually becomes shallow concentrated flow. The average velocity for this flow can be determined from equations 2.C.4 and 2.C.5, in which average velocity is a function of watercourse slope and type of channel.

Unpaved $$V = 16.1345(s)^{0.5} \quad \textbf{(2.C.4)}$$
Paved $$V = 20.3282(s)^{0.5} \quad \textbf{(2.C.5)}$$

Where: V = average velocity, ft/s
s = slope of hydraulic grade line (watercourse slope), ft/ft

These two equations are based on the solution of Manning's equation with different assumptions for n (Manning's roughness coefficient) and r (hydraulic radius, feet). For unpaved areas, n is 0.05 and r is 0.4 ft; for paved areas, n is 0.025 and r is 0.2 ft.

After determining average velocity, use equation 2.C.1 to estimate travel time for the shallow concentrated flow segment.

2.C.6 Open Channels

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

$$\mathbf{V = (1.49\, r^{2/3}\, s^{1/2})/n} \qquad \textbf{(2.C.6)}$$

where:
- V = average velocity, ft/s
- r = hydraulic radius, ft (equal to a/p_w)
- a = cross sectional flow area, ft^2
- p_w = wetted perimeter, ft
- s = slope of the hydraulic grade line, ft/ft
- n = Manning's roughness coefficient

After average velocity is computed using equation 2.C.6, T_t for the channel segment can be estimated using equation 2.C.1.

2.C.7 Reservoir Or Lake

Sometimes it is necessary to compute a T_c for a watershed which has a relatively large body of water in the flow path. This travel time is normally very small and can be assumed as zero.

One must not overlook the fact that this does not account for the travel time involved with the passage of the inflow hydrograph through spillway storage and the reservoir or lake outlet. This time is generally much longer and is added to the travel time across the lake. The travel time through lake storage and its outlet can be determined by the storage routing procedures in Chapter 6.

2.C.8 Limitations

- Manning's kinematic solution should not be used for sheet flow longer than 300 ft. Equation 2.C.3 was developed for use with the four standard SCS rainfall intensity-duration relationships. (i.e., Type II)
- In watersheds with storm drains, carefully identify the appropriate hydraulic flow path to estimate T_c. Storm drains generally handle only a small portion of a large event. The rest of the peak flow travels by streets, lawns, and so on, to the outlet. Consult Chapter 3 to determine average velocity in pipes for either pressure or nonpressure flow.
- A culvert or bridge can act as a reservoir outlet if there is significant storage behind it. Detailed storage routing procedures should be used to determine the outflow through the culvert.