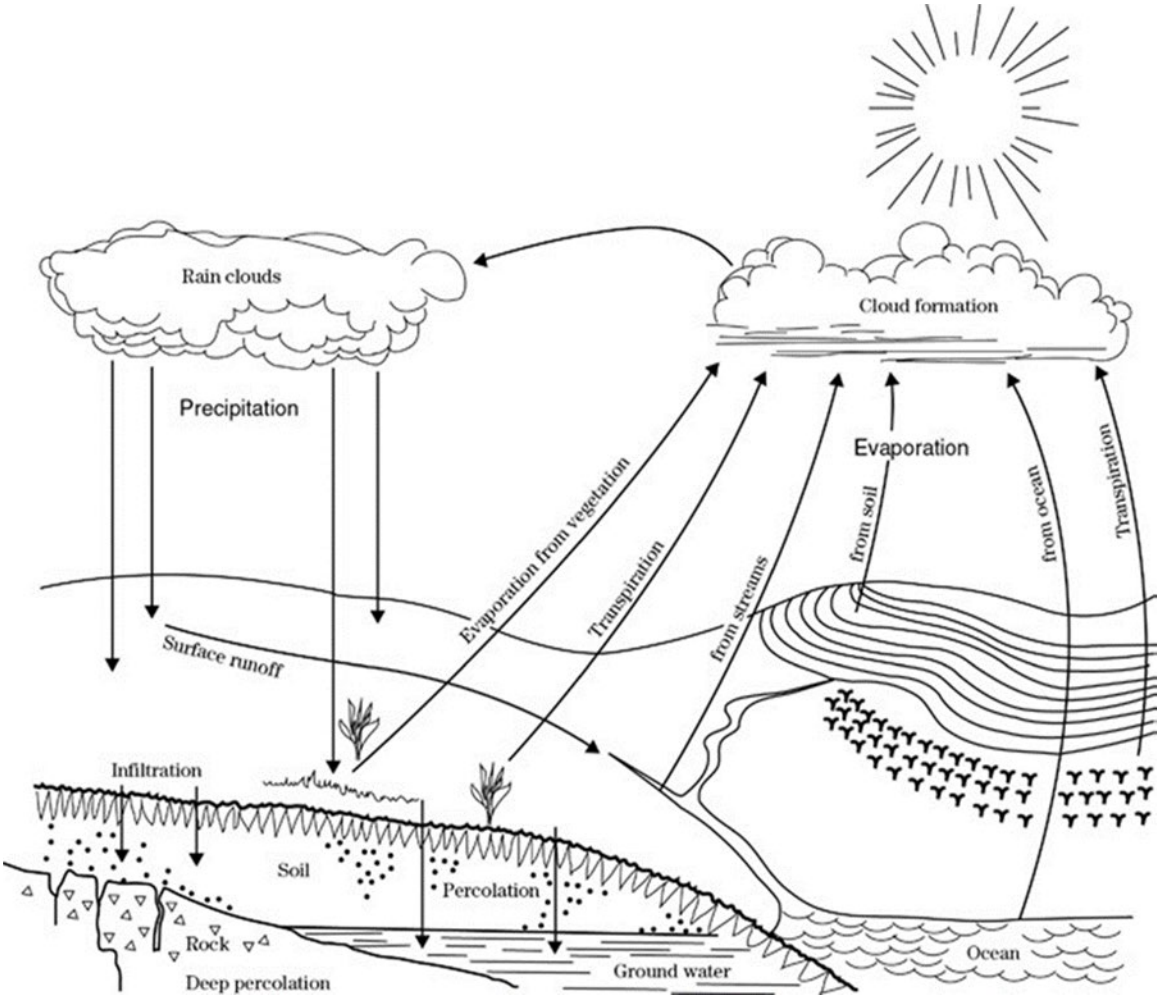
United States Department of Agriculture

Natural Resources Conservation Service

Part 650 Engineering Field Handbook
National Engineering Handbook

Chapter 2 Estimating Runoff Volume and Peak Discharge



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Part 650 – Engineering Field Handbook

Chapter 2 – Estimating Runoff Volume and Peak Discharge

650.0200 Introduction

A. This chapter presents procedures for estimating runoff volume and peak discharge from rainfall on small rural watersheds used in designing soil and water conservation measures, using the NRCS Runoff Curve Number (CN) Method. These procedures apply to drainage areas ranging in size from 1 to 2,000 acres in the United States, Puerto Rico, the U.S. Virgin Islands, and selected Pacific Islands.

B. This chapter includes figures and worksheets to estimate runoff volume and peak discharge using manual methods for a range of rainfall amounts, soil types, land use, and cover conditions.

C. The USDA NRCS developed the EFH-2 computer program to automate the computation procedures presented in this chapter. Past versions of EFH-2 utilized only the manual methods discussed in this chapter. Newer versions of EFH-2 utilize the computation procedures outlined in the NRCS Title 210- National Engineering Handbook (NEH), Part 630, “Hydrology” (210-NEH-630, “Hydrology”), and the TR-20 computational engine. The EFH-2 User’s Manual contains full instruction for the use of the EFH-2 computer program. The EFH-2 User’s Manual is included with the program download and install package, or as a stand-alone download through the EHF-2 web page hosted by the NRCS West National Technology Support Center (WNTSC): https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/water/manage/hydrology/?cid=stelprdb1042921

D. This chapter does not cover modeling runoff from snowmelt or rain on snow events. Modeling runoff from snow requires the use of special processes and procedures beyond the scope of this chapter. Nor does it cover methods used in a limited number of States for specific types of areas, such as the Cypress Creek Equations used for very flat coastal areas. For conditions beyond the limits of this chapter and for special situations and areas where procedures of this chapter may be considered too general to provide good estimates, use the procedures found in 210-NEH-630, the WinTR–55 computer program, “Small Watershed Hydrology”, or the WinTR–20 computer program “Project Formulation-Hydrology”, to estimate runoff volume and peak discharge, or consult State Supplements to this chapter for guidance on regions not covered by this chapter.

650.0201 Basic Hydrologic Concepts

A. Surface runoff is the volume of excess water that leaves a watershed, also referred to as runoff volume. The watershed retains some rainfall in the form of initial abstraction, interception, infiltration, and storage.

B. The runoff from a watershed is a volume, but often expressed as the average depth of water that would cover the entire watershed, usually expressed in inches. To convert inches of runoff to volume, multiply the inches of runoff by the drainage area. This volume is typically expressed in terms of acre-feet.

C. Initial abstraction is the amount of rain that falls before runoff begins. It consists mainly of interception, infiltration, and depression storage.

D. Interception is that portion of rainfall captured on plant and other surfaces in the watershed and does not run off. Interception occurs primarily during initial abstraction but does continue throughout the rainfall event. Most intercepted water evaporates back into the atmosphere following the rainfall event.

E. Infiltration is that part of the rainfall that soaks into the ground and does not run off. Some infiltration recharges groundwater. Plants take up some infiltration and transpire it back into the atmosphere. Infiltration occurs during initial abstraction and continues throughout the rainfall event.

F. Storage, or depression storage, is that part of the rainfall captured in depressions and does not run off. Depression storage starts during initial abstraction and continues throughout the rainfall event, until the depressions are full. Depressions that overflow contribute to runoff. Water held in depressions infiltrates or remains on the surface and evaporates back into the atmosphere. Frequently, interception is considered a part of storage.

G. Peak discharge is the peak rate of runoff (volume per unit time, typically cubic feet per second, cfs), from a drainage area for a given rainfall.

650.0202 Factors Affecting Runoff Volume

A. General

(1) Rainfall is the primary source of water that runs off the surface of small rural watersheds. The main factors affecting the volume of rainfall that runs off are soil type and land cover, including the type of vegetation, in the watershed. Factors that affect the rate at which water runs off are watershed topography and shape, along with land use and conservation practices on a watershed.

(2) Rainfall intensity affects peak discharge such that the greater the intensity, the higher the peak discharge. For small rural watersheds, the intensity of rainfall affects the peak discharge more than it does the volume of runoff. Intense rainfall that produces high peak discharges on small watersheds usually does not extend over a large area. Therefore, the same intense rainfall that causes flooding in a small tributary is unlikely to cause major flooding along a main stream that drains 100 or more square miles.

(3) In the intermountain and northern tier of the United States, in some years, the annual peak discharge results from rain falling on snow or from rapid snowmelt on frozen or saturated soils. This chapter considers only rainfall-generated runoff and not runoff generated from snowmelt. 210-NEH-630, Chapter 11, “Snowmelt" (210-NEH-630-11), presents procedures to use for estimating runoff from snow melt.

B. Rainfall Amount

(1) Originally, the Soil Conservation Service (SCS), now NRCS, primarily used precipitation-frequency data (rainfall amount by return period) as published in 1961 by the U.S. Department of Commerce, Weather Bureau, later the U.S. Department of Commerce, National Oceanic and Atmospheric Administration (NOAA), National Weather Service (NWS), in Technical Paper No. 40 (TP-40). SCS used Other publications for specific areas of the United States.

(2) In the early 2000s, the NWS started updating precipitation-frequency data to take advantage of a denser network of rain gages, to bring an additional 40 to 60 years of rainfall data into the precipitation-frequency estimates, and to use updated statistical methodologies. AS NWS updates regions of the country they publish these data as NOAA Atlas 14, with separate volumes covering specific regions of the United States. As of the publication of this document, the NWS has not published updated NOAA Atlas 14 precipitation-frequency estimates for Washington, Oregon, Idaho, Montana, and Wyoming.

(3) As the updated precipitation-frequency data come available, NRCS adopts the data for use in analysis and design for NRCS projects by policy as described in the NRCS Title 210 - National Engineering Manual (NEM), Part 530, Subpart A, 530.1. This policy requires use of the most current hydrometeorological data for planning, design, and operation of water-related structures and systems. The precipitation-frequency data found in NOAA Atlas 14, and the rainfall distributions derived from that data, represent the most current data.

(4) NRCS developed a rainfall database with rainfall values representative of individual counties (or portions thereof) for each county in the nation and incorporated these data into the NRCS hydrology computer programs. These data are also available in NRCS State Supplements to this chapter.

C. Rainfall Distribution

(1) General

(i) A rainfall distribution describes the amount of rainfall that falls in successive time increments over the duration of a storm event. The intensity of rainfall varies considerably during the storm period.

(ii) To avoid the use of a separate set of rainfall intensities for each drainage area, NRCS uses a set of synthetic rainfall distributions having nested rainfall intensities. This set of distributions maximizes the rainfall intensities by including short-duration intensities within those needed for longer duration.

(iii) The synthetic rainfall distributions do not represent individual actual storm events, but instead provide a time-tested representation of a rainfall event that is suitable for use in analysis and design of soil and water conservation practices.

(iv) NRCS chose a storm duration of 24 hours for the synthetic rainfall distributions, based on the watershed size for which NRCS typically provides assistance. The 24-hour storm, while longer than that needed to determine peak discharges, is suitable for determining runoff volumes. Thus, NRCS uses a single storm duration and associated synthetic rainfall distribution to estimate peak discharges for a wide range of watershed areas.

(2) NRCS Standard Rainfall Distributions

(i) Using the Weather Bureau's TP-40 and other reference data, SCS, now NRCS, in the 1960s and 1970s developed four 24-hour synthetic storm distributions Type I, Type IA, Type II, and Type III, associated with four broad climatic regions across the United States. NRCS refers these distributions as the NRCS Standard Rainfall Distributions. The term NRCS Standard Rainfall Distributions refers specifically to this set of four distributions. The updated rainfall distributions derived using the NOAA Atlas 14 data are generally referred to as the NRCS Updated Rainfall Distributions.

(ii) Figure 2-1 shows the approximate geographic boundaries for the four NRCS Standard Rainfall Distributions. State Supplement to this chapter may have more detailed guidance for selecting distributions.

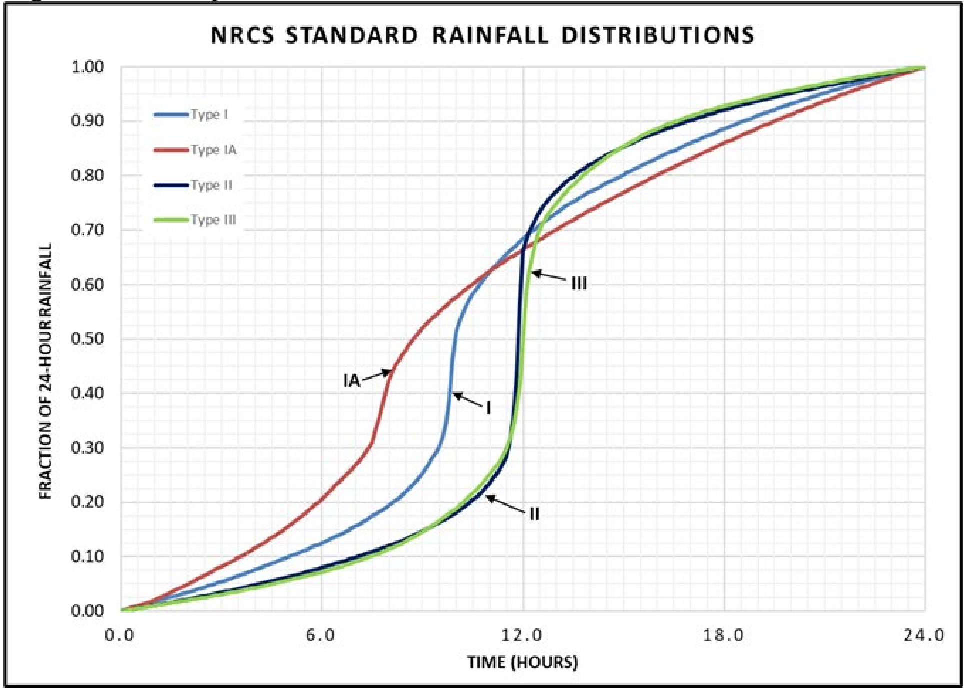
Figure 2-1: Approximate Geographic Boundaries for NRCS Standard Rainfall Distributions

(iii) Types IA and I storm distributions are typical of maritime climates in the Western United States where winters are wet, and summers are dry. The Type IA storm distribution is characteristic of the coastal side of the Cascade and Sierra Nevada Mountains in Oregon, Washington, and northern California. The Type I storm distribution is the characteristic storm distribution of the coastal side of the Sierra Nevada Mountains in southern California and for Hawaii and Alaska. The Type III storm distribution represents the Gulf of Mexico and the Atlantic coastal areas where tropical storms bring large 24-hour rainfalls. The Type II storm distribution is typical of the more intense storms that occur over the remainder of the United States, Puerto Rico, and the Virgin Islands.

(iv) Type IA maximum intensities are less than Type I; Type I intensities are less than Type III; and Type III intensities are less than Type II intensities.

(v) Figure 2-2 shows temporal plots of the of the NRCS Standard Rainfall Distribution illustrating the concepts described.

Figure 2-2: Temporal Plots of NRCS Standard Rainfall Distributions



(3) NRCS Updated Rainfall Distributions

(i) As the NWS updated precipitation-frequency data in NOAA Atlas 14, they published these data in volumes covering specific regions of the nation. NRCS developed updated rainfall distributions using these higher in quantity and quality NOAA Atlas 14 data for all the volumes currently available. By taking advantage of advancements in computer technology, NRCS developed many distributions to cover the nation.

(ii) The NRCS Updated Rainfall Distributions provide better definition, particularly in what was the Type II rainfall distribution geographic area, accounting for climatic conditions and orographic influences.

(iii) As an example, figure 2-3 shows the approximate geographic boundaries for NRCS-derived rainfall distributions from the NOAA Atlas 14, Volume 2, “Precipitation-Frequency Atlas of the United States, Ohio River Basin and Surrounding States”. A single map for the entire United States is not available. Due to the increased number of distributions, it is difficult to show all of them on a single map.

(iv) Figure 2-4 shows temporal plots of the NRCS Updated Rainfall Distributions for the Ohio River Basin and surrounding States. Distributions are available for all regions of the country currently covered by updated NOAA Atlas 14 volumes. Refer to the appropriate State Supplement to this chapter for more information.

(v) For those States not yet covered by updated NOAA Atlas 14 rainfall data, NRCS typically uses data from NOAA Atlas 2, “Precipitation-Frequency Atlas of the Western United States”, Volume 1, Montana (1973), Volume 2, Wyoming (1973, updated 2006), Volume 5, Idaho (1973), Volume 9, Washington (1973), and Volume 10, Oregon (1973). As NWS develops and publishes updated precipitation-frequency data, NRCS is developing updated rainfall distributions.

(vi) In those regions where NOAA Atlas 14 precipitation-frequency data are available, NRCS incorporated them and the NRCS Updated Rainfall Distributions into NRCS computer programs for estimating peak discharge.

Figure 2-3: NOAA Atlas 14, Volume 2 – Geographic Boundaries of NRCS Updated Rainfall Distributions for the Ohio River Basin and Surrounding States

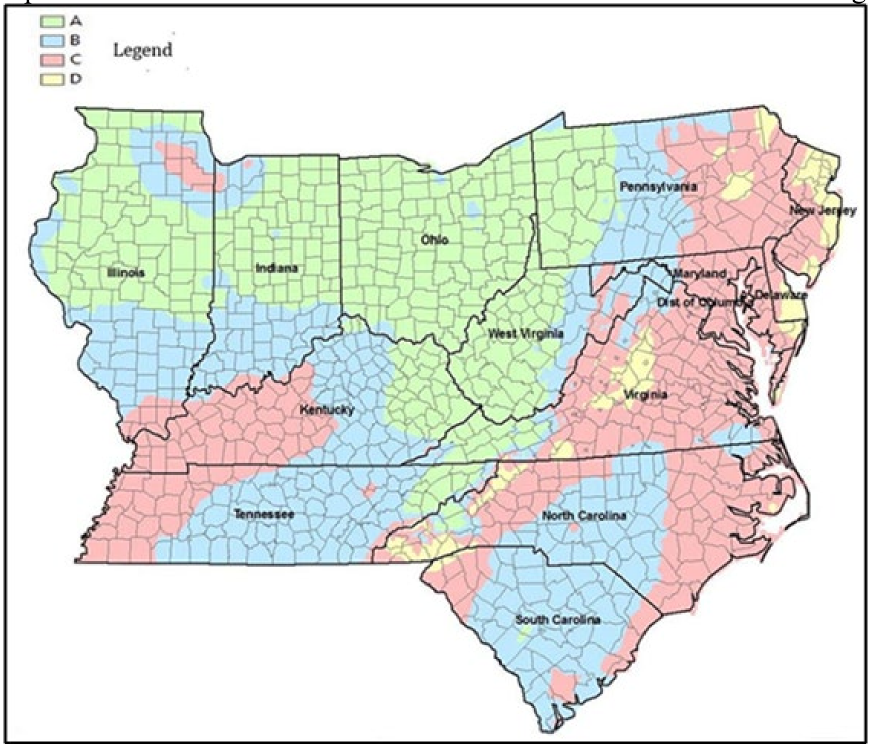
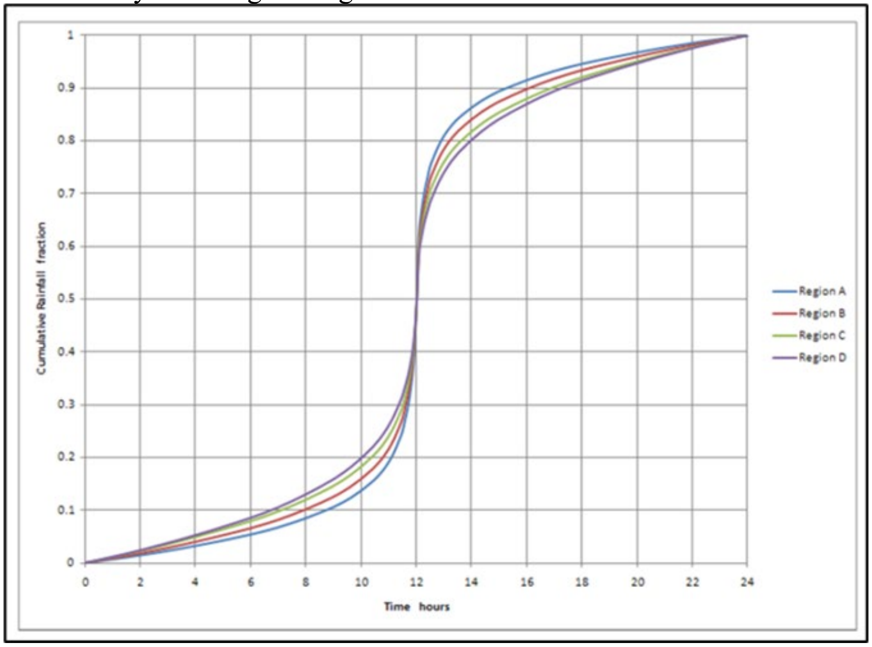


Figure 2-4: Temporal plots of the NRCS Updated Rainfall Distributions for the Ohio Valley and Neighboring States



D. Hydrologic Soil Groups

(1) The NRCS defines four hydrologic soil groups (HSGs) that, along with land use, management practices, and hydrologic conditions, determine a soil's associated runoff curve number (210-NEH-630-9, "Hydrologic Soil-Cover Complexes").

(2) In general, the definitions for the four HSGs are as follows:

  (i) Group A—Soils in this group have low runoff potential when thoroughly wet. Water transmits freely through the soil. Group A soils typically have less than 10 percent clay and more than 90 percent sand or gravel and have gravel or sand textures. Some soils having loamy sand, sandy loam, loam, or silt loam textures may be in this group if they are well aggregated, of low bulk density, or contain greater than 35 percent rock fragments.

  (ii) Group B—Soils in this group have moderately low runoff potential when thoroughly wet. Water transmission through the soil is unimpeded. Group B soils typically have between 10 percent and 20 percent clay and 50 percent to 90 percent sand and have loamy sand or sandy loam textures. Some soils having loam, silt loam, silt, or sandy clay loam textures may be in this group if they are well aggregated, of low bulk density, or contain greater than 35 percent rock fragments.

  (iii) Group C—Soils in this group have moderately high runoff potential when thoroughly wet. Water transmission through the soil is somewhat restricted. Group C soils typically have between 20 percent and 40 percent clay and less than 50 percent sand and have loam, silt loam, sandy clay loam, clay loam, and silty clay loam textures. Some soils having clay, silty clay, or sandy clay textures may be in this group if they are well aggregated, of low bulk density, or contain greater than 35 percent rock fragments.

  (iv) Group D—Soils in this group have high runoff potential when thoroughly wet. Water movement through the soil is restricted or very restricted. Group D soils typically have greater than 40 percent clay, less than 50 percent sand, and have clayey textures. In some areas, they also have high shrink-swell potential.

  (v) Some wet soils are in group D based on the presence of a water table and are classed A/D, B/D, or C/D if not adequately drained where the first letter applies to the drained condition and the second to the undrained condition. If the soil is adequately drained the soil is no longer in the D class and reverts to base soil group class A, B, or C. Careful field investigation is necessary to determine the appropriate HSG for dual classed soils.

(3) 210-NEH-630-7, "Hydrologic Soil Groups", provides complete definitions for each of the soil groups including the limits on the diagnostic physical characteristics of each group and assignment of soils to HSGs.

(4) The assigned groups can be found by consulting NRCS Web Soil Survey at https://websoilsurvey.sc.egov.usda.gov/.

E. Land Use and Cover Type

(1) NRCS' Title 180, National Planning Procedures Handbook (NPPH), Part 600, Subpart A, 600.2, "Definitions", defines land use as follows. Land Use - A term that includes categories of land cover and categories of land use. Land use is the purpose of human activity on the land; it is usually, but not always, related to land cover. NRCS developed the following land use designations to be used primarily by planners and modelers at the field and landscape level: crop, forest, range, pasture, farmstead, developed land, water, associated agricultural lands, and other. Further, NPPH 600.2 provides descriptions of the following land use modifiers to provide additional specificity and help denote what the land is managed for: irrigated, wildlife, grazed, drained, organic, water feature, protected, and hayed.

(2) According to 180-NPPH-600-A-600.2, land cover is the vegetation or other kind of material that covers the land surface. Cover type affects runoff in several ways. Foliage and its litter (ground cover) help to maintain the soil's infiltration potential by preventing the impact of the raindrops from sealing the soil surface. The foliage surface retains some raindrops, increasing their chance of evaporation back into the atmosphere. Some of the intercepted moisture never makes it to the soil or takes so long to drain to the soil that it is withheld from the initial period of runoff. Ground cover also allows soil moisture from previous rains to infiltrate where living vegetation takes it up. Depending upon the amount of soil moisture left from previous rains, there may be either a greater or lesser void in the soil to be filled the next time rain falls.

(3) Vegetation, including its ground litter, forms numerous barriers along the path of the water flowing over the surface of the land. This is often referred to as surface roughness. Surface roughness causes water to flow more slowly, increasing the time it takes water to reach the point of interest (time of concentration, T_c, described in section 650.0205) and reducing peak discharge.

(4) Watershed land use changes over time. This frequently occurs as the result of development in the watershed, but also occurs as a result of changes in management, vegetative type, or other factors. It is important to consider potential changes when making hydrologic analyses.

F. Land Treatment

(1) Land treatment, sometimes referred to as conservation practices, applies mainly to agricultural land uses and includes structural practices, such as contouring or terracing, and vegetative measures, or management practices, such as grazing control or crop rotation. Land treatment helps to maintain soil structure at the surface, which increases water infiltration and reduces runoff. However, this effect diminishes rapidly with increases in storm magnitude.

(2) Contouring and terracing decrease the amount of runoff by forming small reservoirs. Closed-end level terraces function as storage reservoirs without spillways. Areas with level terraces may be excluded from the drainage area above downstream measures if the terrace system has enough capacity to store the volume of runoff commensurate with the frequency of the runoff event under analysis. Gradient terraces with grassed waterway outlets increase the distance water must travel and thereby increase the T_c. Gradient terraces with underground outlets act as storage reservoirs with small spillways that prevent overland flow between the terrace and outlet, and slowly release the runoff reducing the peak flow.

G. Hydrologic Conditions

(1) Hydrologic condition of the site can affect runoff significantly. Hydrologic condition is based on 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 close-seeded legumes in rotations, (d) percent of residue cover on the land surface, and (e) degree of surface roughness. Good hydrologic condition indicates that these factors encourage average and better than average infiltration and tend to decrease runoff (site has a lower runoff potential). For example, crop residue tilled into the soil and the residual root system from grasses included in crop rotations produce a good hydrologic condition. Poor hydrologic condition indicates that these factors impair infiltration and tend to increase runoff. For example, such things as a lack of vegetative cover causing raindrop impact to seal the soil surface, or compaction of the soil surface by animal hooves, often result in a poor hydrologic condition.

(2) Hydrologic condition varies over time based on management, vegetative condition, or events, such as wildfire. It is important to document the date of hydrologic condition assessment. Independently assess hydrologic condition for runoff estimates rather than use historic assessments.

H. Topography

(1) Watershed slopes have a major effect on peak discharge at downstream points but little effect on runoff volume. As watershed slope increases, velocity increases, T_c decreases, and peak discharge increases.

(2) Watershed shape also affects peak discharge. An average small watershed is fan shaped (wide). As the watershed becomes elongated (long), the flow length increases and the peak discharge decreases.

(3) Potholes, small depressional wetland areas, may trap a small amount of rain, thus reducing the amount of expected runoff. If potholes and other wetland areas make up a third or less of the total watershed and do not intercept the drainage from the remaining two-thirds they may be excluded from the drainage area for estimating peak discharge. A careful assessment of the potholes is necessary before deciding to exclude them since they could potentially fill and overflow contributing to runoff, particularly for large rainfalls. If potholes make up than a third of the total drainage or if they intercept the drainage, use the procedures in 210-NEH-630 to estimate the peak discharge.

650.0203. Hydrographs

A. General

(1) A hydrograph is a graph of flow (rate versus time) at a point of interest in the path of concentrated flow, often a waterway or stream. The hydrograph shape is a function of watershed conditions and all the factors previously discussed.

(2) For most NRCS on-farm conservation work, it is necessary to know only the peak rate of runoff, or the peak of the hydrograph. Determining the peak rate of runoff requires developing a hydrograph

B. Types of Hydrographs

There are several useful types of hydrographs:

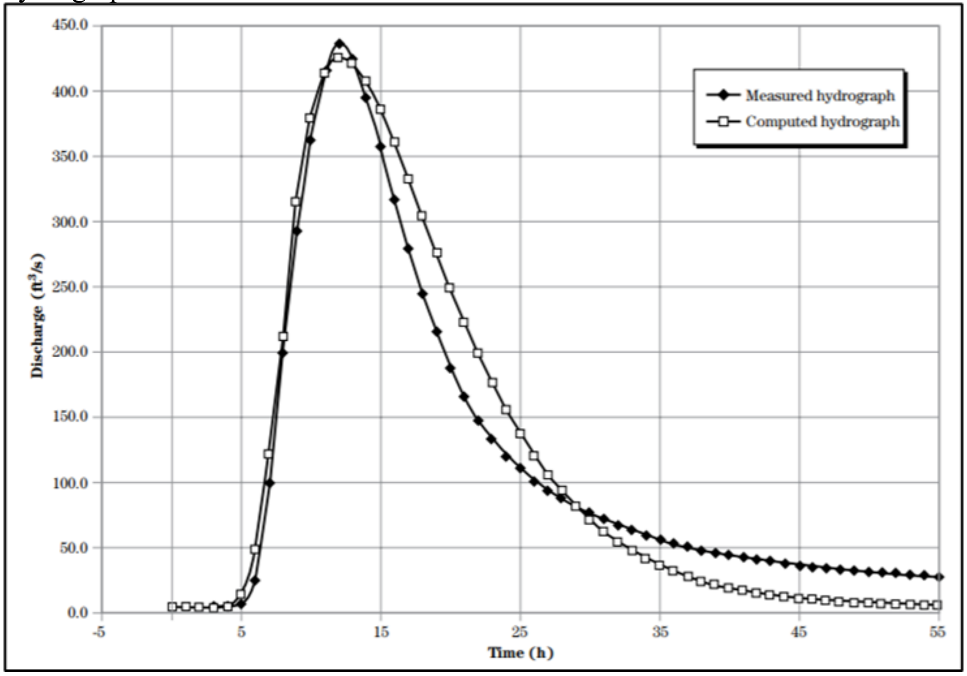
(i) Natural hydrographs, or measured hydrographs, obtained directly from the flow records of a gaged stream resulting from an actual rainfall event.

(ii) Synthetic (modeled) hydrographs computed using watershed parameters and storm characteristics to simulate a natural hydrograph. Figure 2-5 illustrates a natural hydrograph and a synthetic hydrograph for a small watershed.

(iii) Unit hydrographs, which represent 1 inch of direct runoff distributed uniformly over a watershed resulting from a rainfall of a specified duration. In the case of typical NRCS work, the storm duration is 24-hours.

(iv) Dimensionless unit hydrographs (DUHs), which represent several unit hydrographs plotted using the ratio of the basic units of time to peak and peak rate of discharge. DUHs describe the response rate or the rate at which water flows off the watershed to the point of interest.

Figure 2-5: Hydrograph plot illustrating a natural hydrograph and a synthetic hydrograph for the same watershed



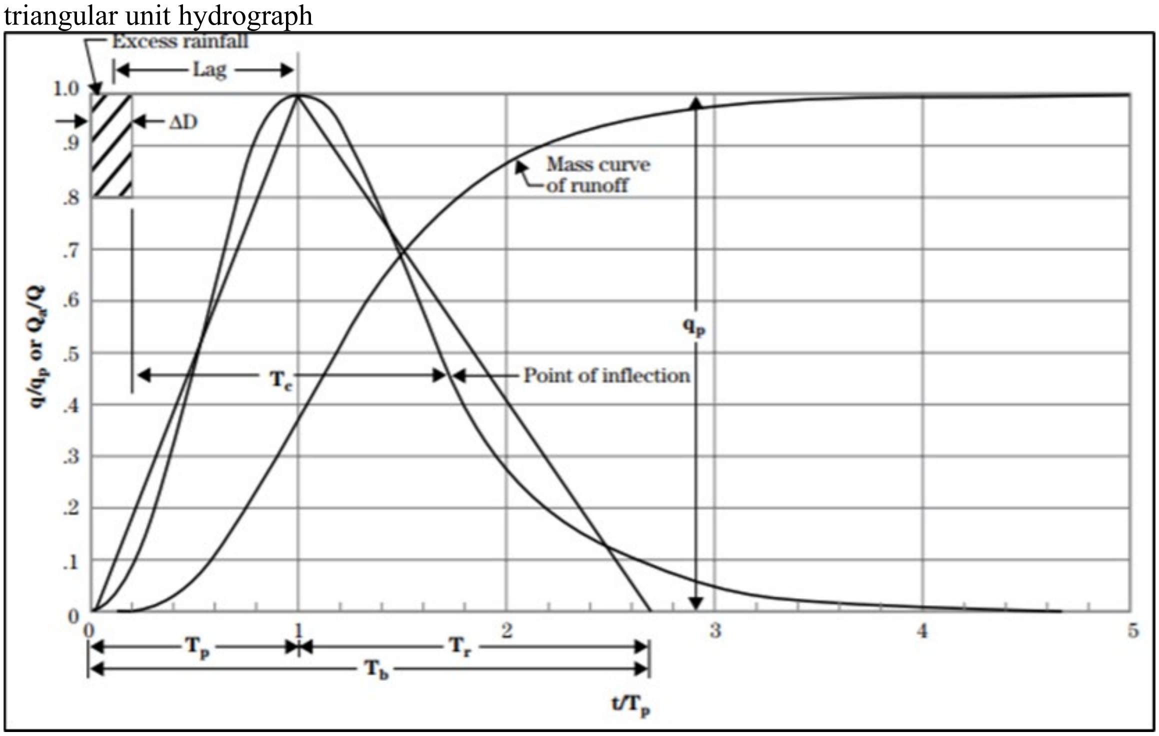
C. Dimensionless unit hydrograph peak rate factors

(1) DUHs define the shape of the synthetic hydrograph based on the proportion of runoff in the rising limb and receding limb of the hydrograph.

(2) The peak rate factor (PRF) describes the shape of a DUH since it is a measure of the percentages of runoff volume in the rising versus receding limbs of the hydrograph and are a function of watershed topography. The shape of the DUH affects peak discharge estimates. A high PRF corresponds to a high peak rate of runoff, while a low PRF corresponds to a low peak rate of runoff.

(3) NRCS typically uses a standard DUH with a PRF equal to 484, often referred to as a 484 DUH or a standard DUH, for the design of on-farm conservation practices. The 484 represents the type of runoff response seen throughout most of the United States and is typical of locations where the landscape is rolling and not very flat. The 484 DUH has 37.5% of the runoff volume in the rising limb of the hydrograph and 62.5% of the runoff volume in the receding limb of the hydrograph. Figure 2-6 illustrates the 484 DUH.

Figure 2-6: Dimensionless curvilinear unit hydrograph (PRF=484) and equivalent dimensionless triangular unit hydrograph



where: T_p = time from the beginning of the triangular hydrograph to its peak (see NEH Part 630, Chapter 16)
T_r = time from the peak to the end of the triangular hydrograph (see NEH Part 630, Chapter 16)
T_b = time from beginning to end of the triangular hydrograph = Tp+Tr (see NEH Part 630, Chapter 16)
ΔD = duration of unit excess rainfall, hours = 0.133 Tc (see NEH Part 630, Chapter 16)
Lag = watershed lag, hours (see NEH Part 630, Chapter 15)
T_c = watershed time of concentration, hours (see section 650.0205)
q = discharge at time t, cfs (see NEH Part 630, Chapter 16)
q_p = peak discharge, cfs (see Section 650.0206)
Q_a = accumulated runoff volume at time t, inches (represented by mass curve of runoff)
Q = total runoff volume, inches (see Section 650.0204)
t = selected time
Excess rainfall = rainfall that results in runoff, in

(4) Another frequently used DUH within NRCS work is the 286 DUH, derived through observations of runoff data on the Delaware-Maryland-Virginia peninsula. Thus it is often referred to as the DelMarVa unit hydrograph. The DelMarVa peninsula is in the Coastal Plain region along the East Coast of the United States, where land slopes are generally flat and peak rates of runoff are not as high as elsewhere in the nation. Consult State Supplements to this chapter for guidance regarding selection of appropriate DUHs.

(5) 210-NEH-630-16, “Hydrographs”, contains many other NRCS-developed DUHs with a range of PRFs.

650.0204 Runoff Volume

A. General

(1) As stated previously, runoff is the volume of excess water that leaves a drainage area.
(2) On a hydrograph plot, the area under the hydrograph represents the runoff volume.

B. NRCS Runoff Equation

(1) The NRCS runoff equation, also referred to as the NRCS CN Method, is a tool used to estimate runoff volume resulting from a storm event. For more information on the development and derivation of the runoff equation, see 210-NEH-630-9 and 210-NEH-630-10, "Estimation of Direct Runoff from Storm Rainfall".
(2) The NRCS runoff equation is:

$$Q = \frac{(P-I_a)^2}{(P-I_a)+S} \quad \textit{for } P > I_a \qquad \text{(eq. 2–1a)}$$

$$Q = 0 \quad \textit{for } P \leq I_a \qquad \text{(eq. 2-1b)}$$

where:
Q = runoff, in
P = rainfall, in
I_a = initial abstraction, in
S = potential maximum retention after runoff begins, in

(3) Initial abstraction (I_a) includes all losses (water retained on the landscape) before runoff begins. It includes water retained in surface depressions, water intercepted by vegetation and other cover, and water lost to evaporation and infiltration. I_a is highly variable but is generally correlated with soil and cover parameters. Through studies of many small agricultural watersheds, researchers found I_a to be approximated by:

$$I_a = 0.2S \qquad \text{(eq. 2–2)}$$

(4) Removing I_a as an independent parameter allows use of a combination of S and P to produce unique runoff volumes. Substituting equation 2–2 into equation 2–1 gives:

$$Q = \frac{(P-0.2S)^2}{(P+0.8S)} \quad \textit{for } P > I_a \qquad \text{(eq. 2–3a)}$$

$$Q = 0 \quad \textit{for } P \leq I_a \qquad \text{(eq. 2-3b)}$$

C. Runoff Curve Numbers

(1) The potential maximum retention, S, can range from zero on a smooth, impervious surface to infinity in deep gravel. Converting an S value to a CN using the following transformation provides for greater convenience:

$$CN = \frac{1{,}000}{10+S} \qquad \text{(eq. 2–4)}$$

(2) According to equation 2-4, the runoff curve number is 100 when S is zero, and approaches zero as S approaches infinity. Runoff curve numbers can be any value from zero to 100, but for practical applications fall within a limited range of about 40 to 98
(3) Researchers developed the runoff curve numbers in the tables in figures 2-7a through 2-7d by examining rainfall runoff data from small agricultural watersheds. The runoff curve number for a given soil-cover type is not a constant but varies from storm to storm, and even within the storm. The NRCS CN method assigns a representative runoff curve number for a given soil and cover type for design purposes.

(4) The index of runoff potential for a given storm is the antecedent runoff condition (ARC). ARC is an attempt to account for the variation in runoff curve number at a site from storm to storm. The runoff curve numbers in the tables in figures 2-7a through 2-7d are for an average antecedent condition (ARC=II) and represent runoff curve number values used for design. Because ARC in one location of the country may not reflect ARC in other locations some States developed tables to adjust runoff curve number values for their specific locations. It is important to consult State Supplements to this chapters for full information on any runoff curve number adjustments for those States.

(5) The Runoff Curve Number worksheet (see section 650.0211, Exhibit A) is available for use in estimating a representative runoff curve number for a watershed as illustrated in the Example – Estimating Weighted Runoff Curve Number (section 650.0208A).

D. Estimating Runoff Volume using the NRCS CN Method

(1) Use equation 2-1a to estimate runoff volume for a storm event using the watershed runoff curve number value and the rainfall amount for the storm.

(2) Alternatively, use figure 2-8 to estimate storm runoff volume by entering the figure from the bottom axis, Rainfall (P); reading up to the appropriate runoff curve number (CN) value; and then reading across to the left to the direct runoff volume (Q).

(3) Another alternative is to use a table as shown in figure 2-9 that summarizes runoff volume by runoff curve number for various rainfall amounts.

Figure 2-7: Runoff Curve Numbers
(a) Cultivated Agricultural Lands [1/]

Cover Description		**Hydrologic Condition [3/]**	**Runoff Curve Numbers for Hydrologic Soil Group**			
Cover Ttype	**Treatment [2/]**		**A**	**B**	**C**	**D**
Fallow	Bare soil	-----	77	86	91	94
	Crop residue cover (CR)	Poor	76	85	90	93
		Good	74	83	88	90
Row crops	Straight row	Poor	72	81	88	91
		Good	67	78	85	89
	Straight row + CR	Poor	71	80	87	90
		Good	64	75	82	85
	Contoured (C)	Poor	70	79	84	88
		Good	65	75	82	86
	Contoured + CR	Poor	69	78	83	87
		Good	64	74	81	85
	Contoured & terraced (C&T)	Poor	66	74	80	82
		Good	62	71	78	81
	C&T + CR	Poor	65	73	79	81
		Good	61	70	77	80
Small grain	Straight row	Poor	65	76	84	88
		Good	63	75	83	87
	Straight row + CR	Poor	64	75	83	86
		Good	60	72	80	84
	Contoured (C)	Poor	63	74	82	85
		Good	61	73	81	84
	Contoured + CR	Poor	62	73	81	84
		Good	60	72	80	83
	Contoured & terraced (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 or broadcast legumes or rotation meadow	Straight row	Poor	66	77	85	89
		Good	58	72	81	85
	Contoured (C)	Poor	64	75	83	85
		Good	55	69	78	83
	Contoured & terraced (C&T)	Poor	63	73	80	83
		Good	51	67	76	80

1/ Average runoff condition and I_a=0.2S
2/ CR applies only if residue is on at least 5% of the surface throughout the year
3/ Hydrologic condition is based on 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 close-seeded legumes in rotations, (d) percent of residue cover on the land surface (good > 20%), and (e) degree of surface roughness
Poor: Factors impair infiltration and tend to increase runoff
Good: Factors encourage average and better than average infiltration and tend to decrease runoff

For conservation tillage, poor hydrologic condition, 5 to 20 percent of the surface is covered with residue (less than 750 lb/acre for small grain

For conservation tillage, good hydrologic condition, more than 20 percent of the surface is covered with residue (greater than 750 lb/acre for row crops or 300 lb/acre for small grains)

Figure 2-7: Runoff Curve Numbers - continued
(b) Other Agricultural Lands [1]

Cover Description	Hydrologic Condition	Runoff Curve Numbers for Hydrologic Soil Group			
Cover Type		**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-forbs-grass mixture with brush the major element [3]	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	30 [4]	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	30 [4]	55	70	77
Farmsteads—buildings, lanes, driveways, and surrounding lots	-----	59	74	82	86

[1] Average runoff condition and Ia=0.2S

[2] Poor: < 50% ground cover or heavily grazed with no mulch
Fair: 50% to 75% ground cover or 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% woods and 50% grass (pasture) cover. Other combinations of conditions may be computed from the CNs for woods and pasture

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

Figure 2-7: Runoff Curve Numbers – continued
(c) Arid and Semiarid Rangelands [1/]

Cover Description	**Hydrologic Condition** [2/]	**Runoff Curve Numbers for Hydrologic Soil Group**			
Cover Type		**A** [3/]	**B**	**C**	**D**
Herbaceous – mixture of grass, weeds, and low-growing brush, with brush the minor element	Poor		80	87	93
	Fair		71	81	89
	Good		62	74	85
Oak-aspen – mountain brush mixture of oak brush, aspen, mountain mahogany, bitter brush, maple, and other brush	Poor		66	74	79
	Fair		48	57	63
	Good		30	41	48
Pinyon-juniper – pinyon, juniper, or both; grass understory	Poor		75	85	89
	Fair		58	73	80
	Good		41	61	71
Sagebrush with grass understory	Poor		67	80	85
	Fair		51	63	70
	Good		35	47	55
Desert shrub – major plants, include saltbush, greasewood, creosotebush, blackbrush, bursage, palo verde, mesquite, and cactus	Poor	63	77	85	88
	Fair	55	72	81	86
	Good	49	68	79	84

[1/] Average runoff condition and I_a=0.2S. or rangelands in humid regions, use table 2–1(b).

[2/] Poor: <30% ground cover (litter, grass, and brush overstory)
Fair: 30% to 70% ground cover
Good: >70% ground cover

[3/] Curve numbers for group A have been developed only for desert shrub.

Figure 2-7: Runoff Curve Numbers – continued
(d) Urban Areas [1]

Cover Description	**Average Percent Impervious Area** [2]	**Runoff Curve Numbers for Hydrologic Soil Group**			
Cover Type and Hydrologic Condition		**A**	**B**	**C**	**D**
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 sewers		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
Western desert urban areas:					
Natural desert landscaping (pervious areas only) [4]		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2- inch sand or gravel mulch and basin borders)		96	96	96	96
Urban district:					
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
1/2 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) [5]		77	86	91	94

[1] Average runoff condition and I_a=0.2S

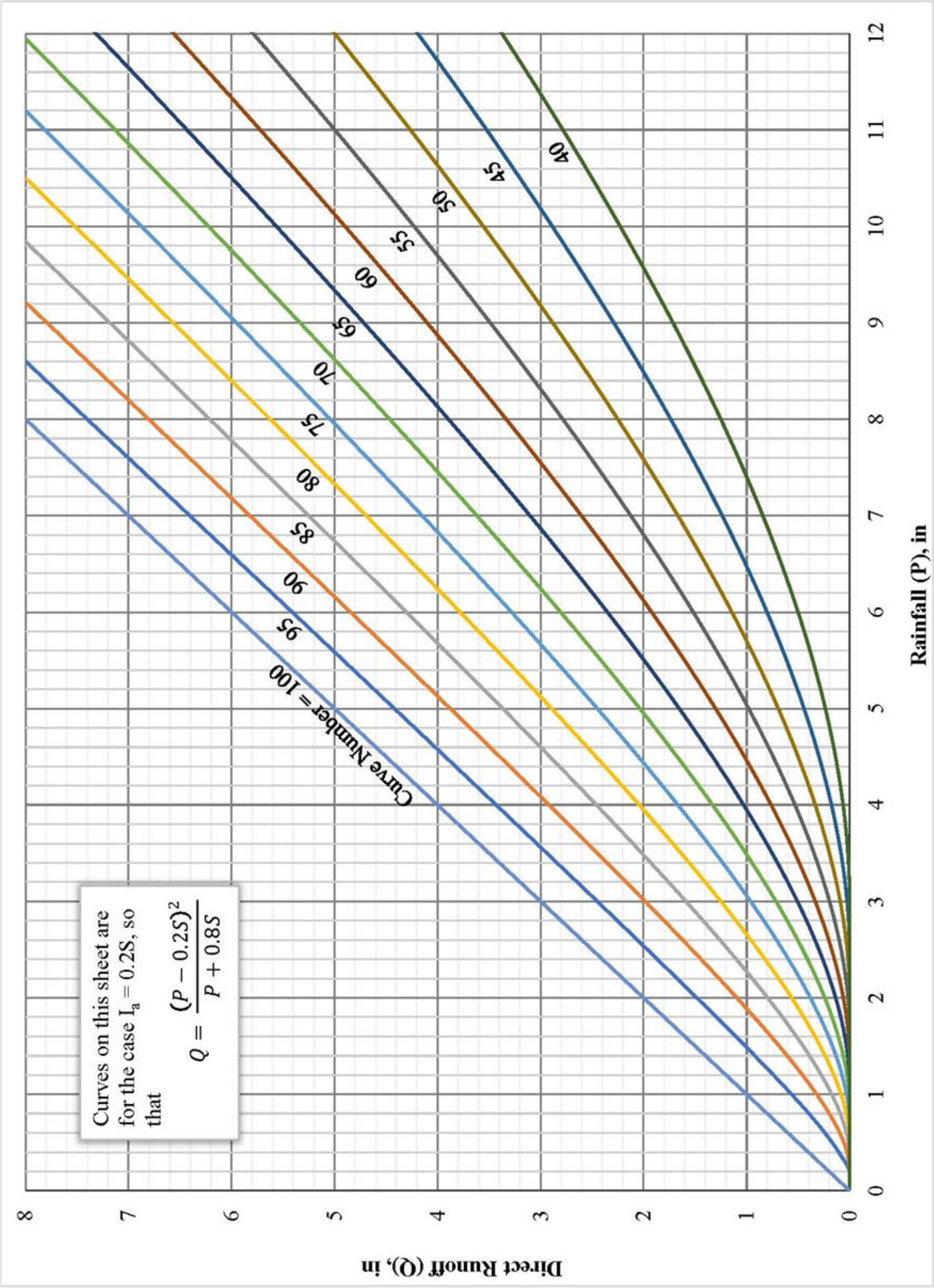
[2] The average percent impervious area shown was used to develop the composite CNs. Other assumptions are as follows: impervious areas are directly connected to the drainage system, impervious areas have a CN of 98, and pervious areas are considered equivalent to open space in good hydrologic condition.

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

[4] Composite CNs for natural desert landscaping should be computed based on the impervious area (CN=98) and the pervious area CN. The pervious area CNs are assumed equivalent to desert shrub in poor hydrologic condition.

[5] Composite CNs to use for the design of temporary measures during grading and construction should be computed using the degree of development (impervious area percentage) and the CNs for the newly graded pervious areas.

Figure 2-8: Solution to the NRCS Runoff Equation



Curves on this sheet are for the case $I_a = 0.2S$, so that

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S}$$

Figure 2-9: Runoff Depth for Selected CNs And Rainfall Amounts[1/]

Rainfall (in)	- - - - - - - - - -Runoff (Q) in inches for Runoff Curve Number of - - - - - - - - - - -										
	40	45	50	55	60	65	70	75	80	85	90	95
1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.08	0.17	0.32	0.56
1.2	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.07	0.15	0.27	0.46	0.74
1.4	0.00	0.00	0.00	0.00	0.00	0.02	0.06	0.13	0.24	0.39	0.61	0.92
1.6	0.00	0.00	0.00	0.00	0.01	0.05	0.11	0.20	0.34	0.52	0.76	1.11
1.8	0.00	0.00	0.00	0.00	0.03	0.09	0.17	0.29	0.44	0.65	0.93	1.29
2.0	0.00	0.00	0.00	0.02	0.06	0.14	0.24	0.38	0.56	0.80	1.09	1.48
2.5	0.00	0.00	0.02	0.08	0.17	0.30	0.46	0.65	0.89	1.18	1.53	1.96
3.0	0.00	0.02	0.09	0.19	0.33	0.51	0.71	0.96	1.25	1.59	1.98	2.45
3.5	0.02	0.08	0.20	0.35	0.53	0.75	1.01	1.30	1.64	2.02	2.45	2.94
4.0	0.06	0.18	0.33	0.53	0.76	1.03	1.33	1.67	2.04	2.46	2.92	3.43
4.5	0.14	0.30	0.50	0.74	1.02	1.33	1.67	2.05	2.46	2.91	3.40	3.92
5.0	0.24	0.44	0.69	0.98	1.30	1.65	2.04	2.45	2.89	3.37	3.88	4.42
6.0	0.50	0.80	1.14	1.52	1.92	2.35	2.81	3.28	3.78	4.30	4.85	5.41
7.0	0.84	1.24	1.67	2.12	2.60	3.10	3.62	4.15	4.69	5.25	5.82	6.41
8.0	1.25	1.74	2.25	2.78	3.33	3.89	4.46	5.04	5.63	6.21	6.81	7.40
9.0	1.71	2.29	2.88	3.49	4.10	4.72	5.33	5.95	6.57	7.18	7.79	8.40
10.0	2.23	2.89	3.56	4.23	4.90	5.56	6.22	6.88	7.52	8.16	8.78	9.40
11.0	2.78	3.52	4.26	5.00	5.72	6.43	7.13	7.81	8.48	9.13	9.77	10.39
12.0	3.38	4.19	5.00	5.79	6.56	7.32	8.05	8.76	9.45	10.11	10.76	11.39
13.0	4.00	4.89	5.76	6.61	7.42	8.21	8.98	9.71	10.42	11.10	11.76	12.39
14.0	4.65	5.62	6.55	7.44	8.30	9.12	9.91	10.67	11.39	12.08	12.75	13.39
15.0	5.33	6.36	7.35	8.29	9.19	10.04	10.85	11.63	12.37	13.07	13.74	14.39

[1/] Interpolate the values shown to obtain runoff depths for CNs or rainfall amounts not shown.

650.0205 Time of Concentration

A. General

(1) Time of concentration, T_c, is the time it takes for runoff to travel from the hydraulically most distant point of the watershed to the outlet. T_c influences the peak discharge. For the same size watershed, the shorter the T_c, the larger the peak discharge. This means that peak discharge has an inverse relationship with T_c.

(2) On a hydrograph, T_c is the time from the end of the excess rainfall (when the storm event ends) to the point of inflection on the receding limb of the hydrograph. Figure 2-6 shows this relationship between the end of the excess rainfall and T_c.

(3) An estimate of the T_c is necessary for developing a hydrograph to estimate the peak discharge from a watershed.

(4) There are numerous methods for computing T_c. This chapter contains information on using the NRCS Lag Equation.

B. The NRCS Lag Equation and Inputs

(1) NRCS Lag Equation

Estimate T_c for small rural watersheds using the following empirical relationship referred to as the lag equation:

$$T_c = \frac{l^{0.8}\left[\left(\frac{1,000}{CN}\right)-9\right]^{0.7}}{1140Y^{0.5}} \qquad \text{(eq. 2–5)}$$

where: T_c = time of concentration, hr
l = flow length, ft
CN = runoff curve number
Y = average watershed slope, %

(2) Average Watershed Slope

(i) The average watershed slope (Y) is the slope of the land and not the watercourse.

(ii) Y can be determined using several different methods:

- Measuring hillside slopes with a hand level, Locke level, or clinometer in the direction of overland flow; and averaging the individual land slope measurements.
- Measuring the lengths of the contours in the watershed, summing the contour lengths, multiplying by the contour intervals, and dividing by the drainage area as described in the following relationship:

$$Y = \frac{100CI}{A} \qquad \text{(eq. 2–6)}$$

where: Y = average watershed slope, %
C = total length of contours measured, ft
I = contour interval, ft
A = drainage area, ft^2

- Drawing a minimum of three random lines across the contour lines on a topographic map, determining the slope for each of the lines and averaging those slopes.
- Another process for determining Y is to transfer delineation of the watershed boundary to a soils map, tally the acres of each soil type, look up the average slopes for each soil type, and then average those slopes to determine Y for the entire watershed.
- GIS applications are also frequently used. Methodologies may vary among GIS applications.
- For small watersheds, using an average of the slopes may be sufficient, in other cases it may be desirable to weight the slopes based upon the percentage of area for each slope.

(3) Flow Length

(i) Flow length (l) is the hydraulically most distant flow path in the watershed from the watershed divide to the outlet. Generally, it is considered the longest flow path. But if it takes water a longer time to flow from the divide to the outlet along a shorter flow path than it takes water to flow along the longest flow path, the shorter flow path should be used. It is the total path water travels overland and in small channels on the way to the outlet. The flow length can be determined using a topographic maps, aerial photos, or field measurements.

(ii) Figures 2-10 and 2-11 provide a conceptual illustration of how flow lengths can differ between a natural watershed and the same watershed with a gradient terrace.

- In the case of the natural watershed, water flows overland and through a small channel (dashed blue line) from the watershed divide to the main stream (solid blue line) and from there to the watershed outlet.
- In the case of the watershed with a gradient terrace, water flows from the watershed divide to and along the terrace (dashed blue line) to the terrace outlet, or in this case, the main stream (solid blue line) and then along the main stream to the watershed outlet.
- The red line illustrates the total flow length along the flow path for each scenario.

(iii) For situations where a small detention structure lies within the flow path, the general assumption is that the length of the detention pool is zero.

Figure 2-10: Natural watershed

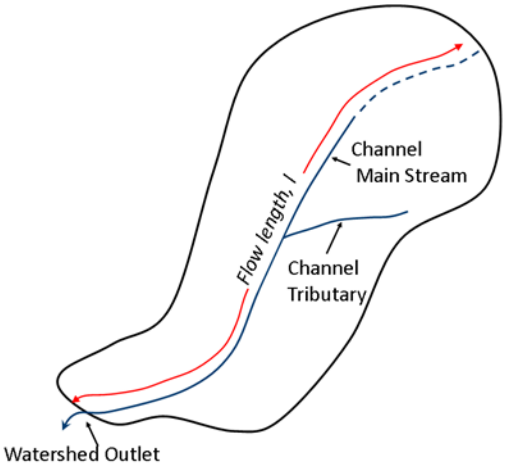
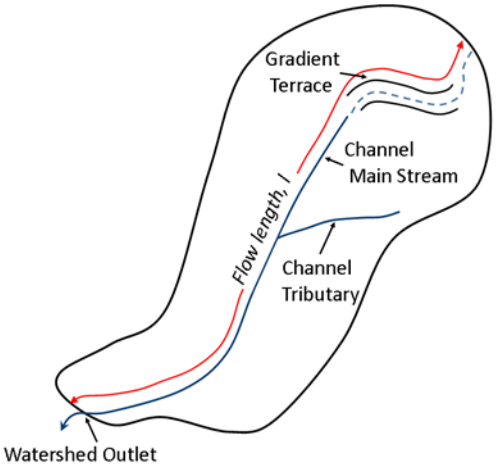


Figure 2-11: Watershed with Gradient Terrace



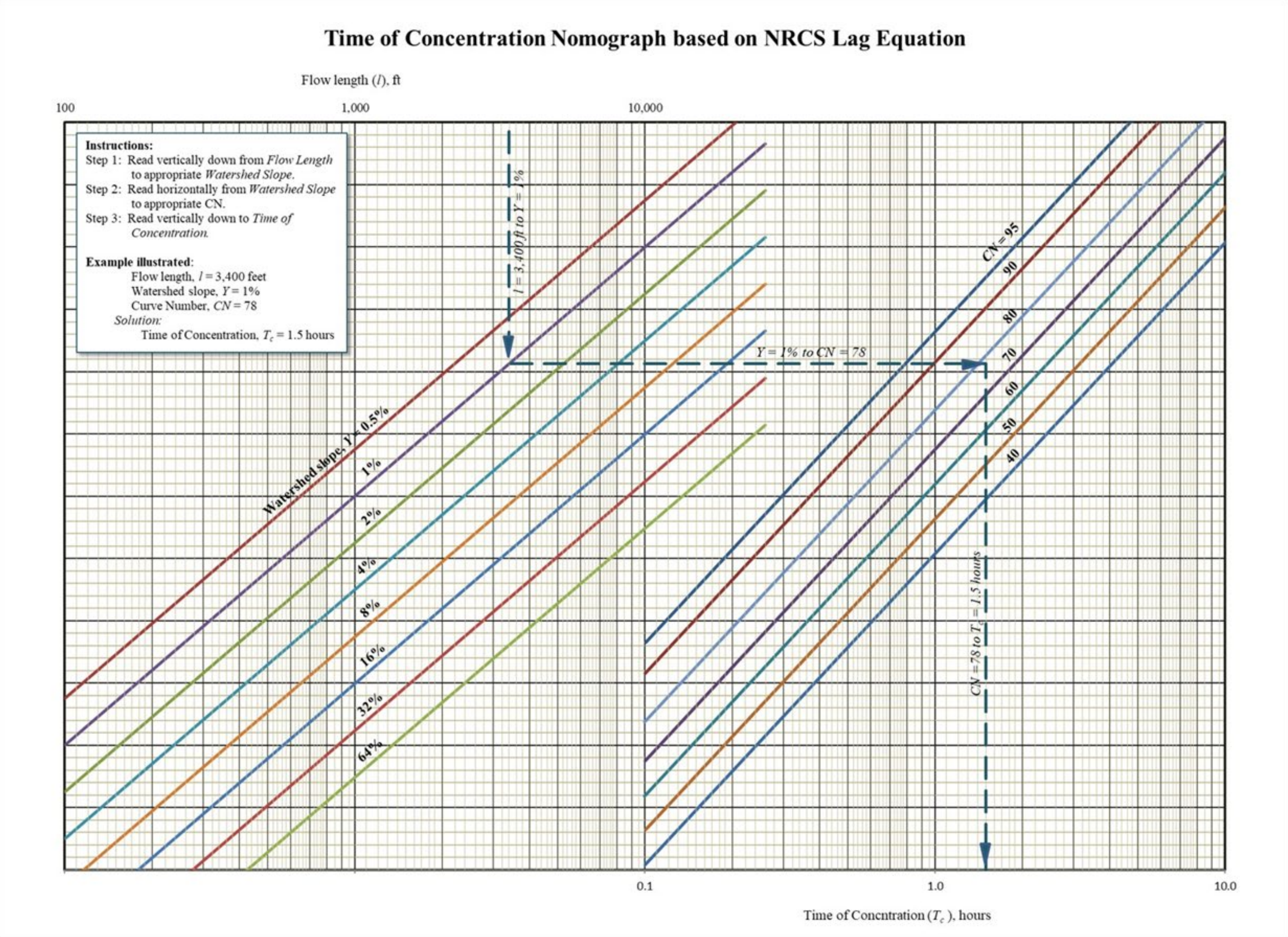
C. Estimating T_c Using the NRCS Lag Equation

Figure 2-12 is a nomograph for solving equation 2–5. Section 650.0211, Exhibit B is a worksheet for computing T_c. Example – Estimating Time of Concentration and Peak Discharge (section 650.0208) demonstrates this procedure.

D. Use of other T_c Methods

For watersheds where hydraulic conditions make it necessary to use velocities of water flow in different T_c flow path segments, for example watersheds where urban areas exceed approximately 10% of the total watershed area, estimate T_c using the velocity method or other methods described in 210-NEH-630-15, “Time of Concentration”.

Figure 2-12: Time of Concentration (T_c) Nomograph based on the NRCS Lag Equation



Time of Concentration Nomograph based on NRCS Lag Equation

Instructions:
Step 1: Read vertically down from *Flow Length* to appropriate *Watershed Slope*.
Step 2: Read horizontally from *Watershed Slope* to appropriate CN.
Step 3: Read vertically down to *Time of Concentration.*

Example illustrated:
Flow length, l = 3,400 feet
Watershed slope, Y = 1%
Curve Number, CN = 78
Solution:
Time of Concentration, T_c = 1.5 hours

650.0206 Peak Discharge

A. General

(1) For many NRCS on-farm conservation practice analyses and designs, the modeler only needs to know peak discharge. However, to compute the peak discharge requires estimation of the runoff volume.

(2) Estimating peak discharge can be done manually provided unit peak discharge curves are available. Software tools, such as the NRCS EFH-2 computer program, may also be used.

B. Estimating Peak Discharge Manually

(1) Unit peak discharge curves

(i) Unit peak discharge curves represent a combination of rainfall distribution and dimensionless unit hydrograph for use in specific locations. NRCS developed these curves as part of a generalized and simplified method of computing peak discharge for on-farm conservation practices. The long-hand computations for developing peak discharge detailed in 210-NEH-630-16, are complex requiring development of hydrographs manually for each individual practice. This is a long and tedious process unnecessary for common on-farm practices.

(ii) Unit peak discharge curves are sometimes referred to as rainfall type curves but combine a rainfall distribution and a dimensionless unit hydrograph.

(iii) Equations for the unit peak discharge curves are available for users to develop their own software tools. These equations are typically published in State Supplements to this chapter.

(iv) For locations where unit peak discharge (q_u) curves are available, peak discharge (q_p) can be estimated manually as the product of the q_u, drainage area (A), and runoff volume (Q):

$$q_p = q_u A Q \qquad \text{(eq. 2–7)}$$

where:
q_p = peak discharge (cfs)
q_u = unit peak discharge (cfs/ac/in)
A = watershed drainage area (ac)
Q = runoff volume (in)

(v) Time of concentration and the ratio of initial abstraction to precipitation (I_a/P) values are needed to obtain a value for q_u from the unit peak discharge curves (figures 2-14 through 2-17 or from the appropriate NRCS State supplement to this chapter).

(2) I_a/P ratio

(i) The I_a/P ratio is a parameter that indicates how much of the total rainfall is needed to satisfy the initial abstraction. The larger the I_a/P ratio, the lower the q_u for a given time of concentration. This indicates that if initial abstraction is a high portion of rainfall, the peak discharge will be lower. Thus, the I_a/P ratio is greater for small storms.

(ii) Use equations 2-4 and 2-2, or the table in figure 2-13, with the watershed runoff curve number to determine the initial abstraction.

(iii) If the computed I_a/P ratio is outside the range shown (0.1 to 0.50) in figures 2-14 through 2-17, then the limiting values should be used; i.e., use 0.1 if less than 0.1 and use 0.5 if greater than 0.5. If the ratio falls between the limiting values, use linear interpolation.

(3) Estimating Peak Discharge

(i) For the NRCS standard rainfall distributions (old distributions), obtain the unit peak discharge using the q_u curves illustrated in figures 2-14 through 2-17 for the appropriate rainfall type. Figure 2-1 shows the approximate geographic boundaries for the four NRCS Standard Rainfall Distributions.

(ii) For States with Updated NRCS Rainfall Distributions obtain unit peak discharge from the q_u curves available in the appropriate State Supplement to this chapter.

(iii) Section 650.0211, Exhibit B is a worksheet for use in determining peak discharge as illustrated in the example in section 650.0208 B.

Figure 2 13: Initial Abstraction Values for Runoff Curve Numbers

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

Figure 2-14: Unit Peak Discharge (q_u) for NRCS Rainfall Type I Rainfall Distribution

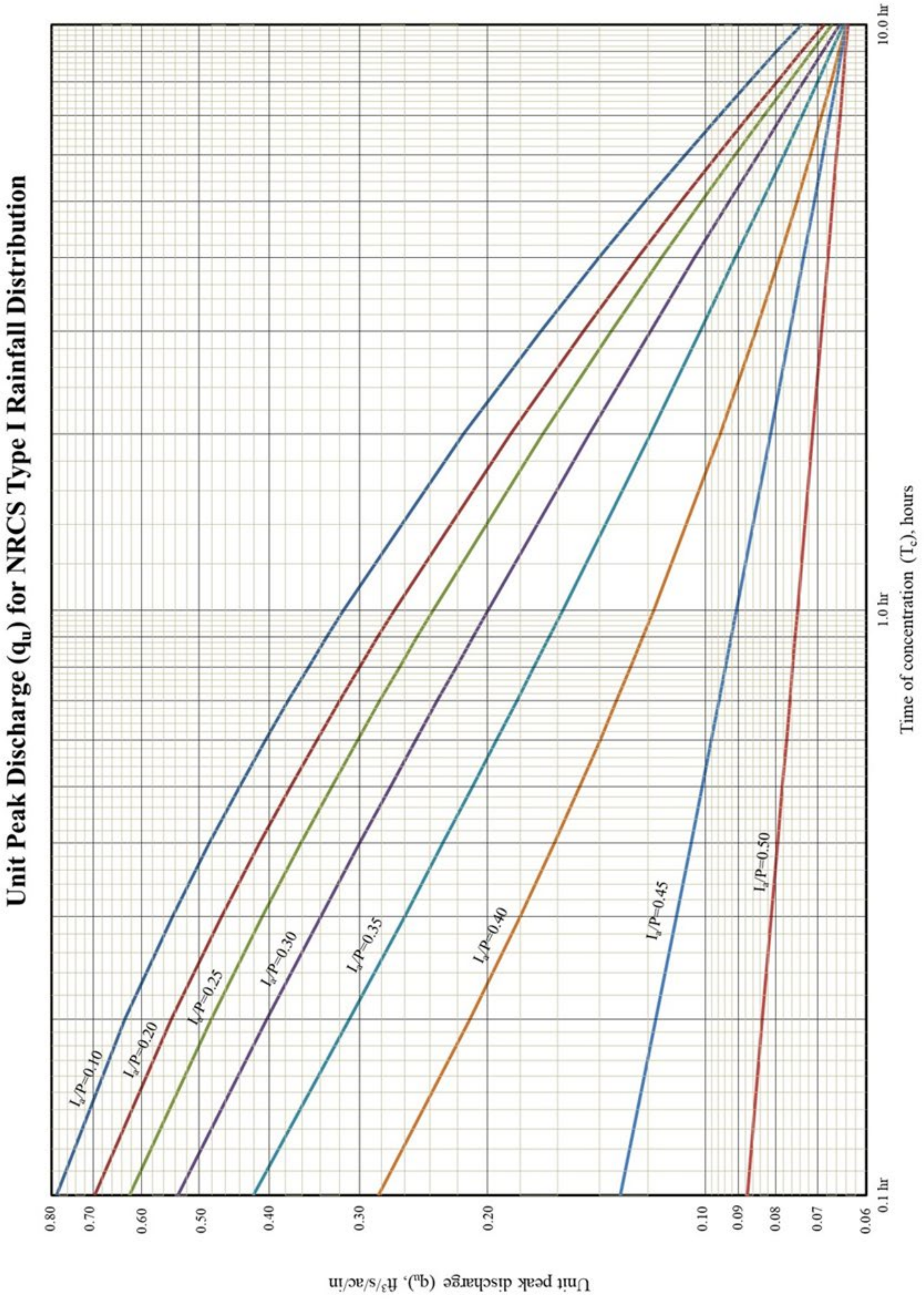


Figure 2-15: Unit Peak Discharge (q_u) for NRCS Rainfall Type IA Rainfall Distribution

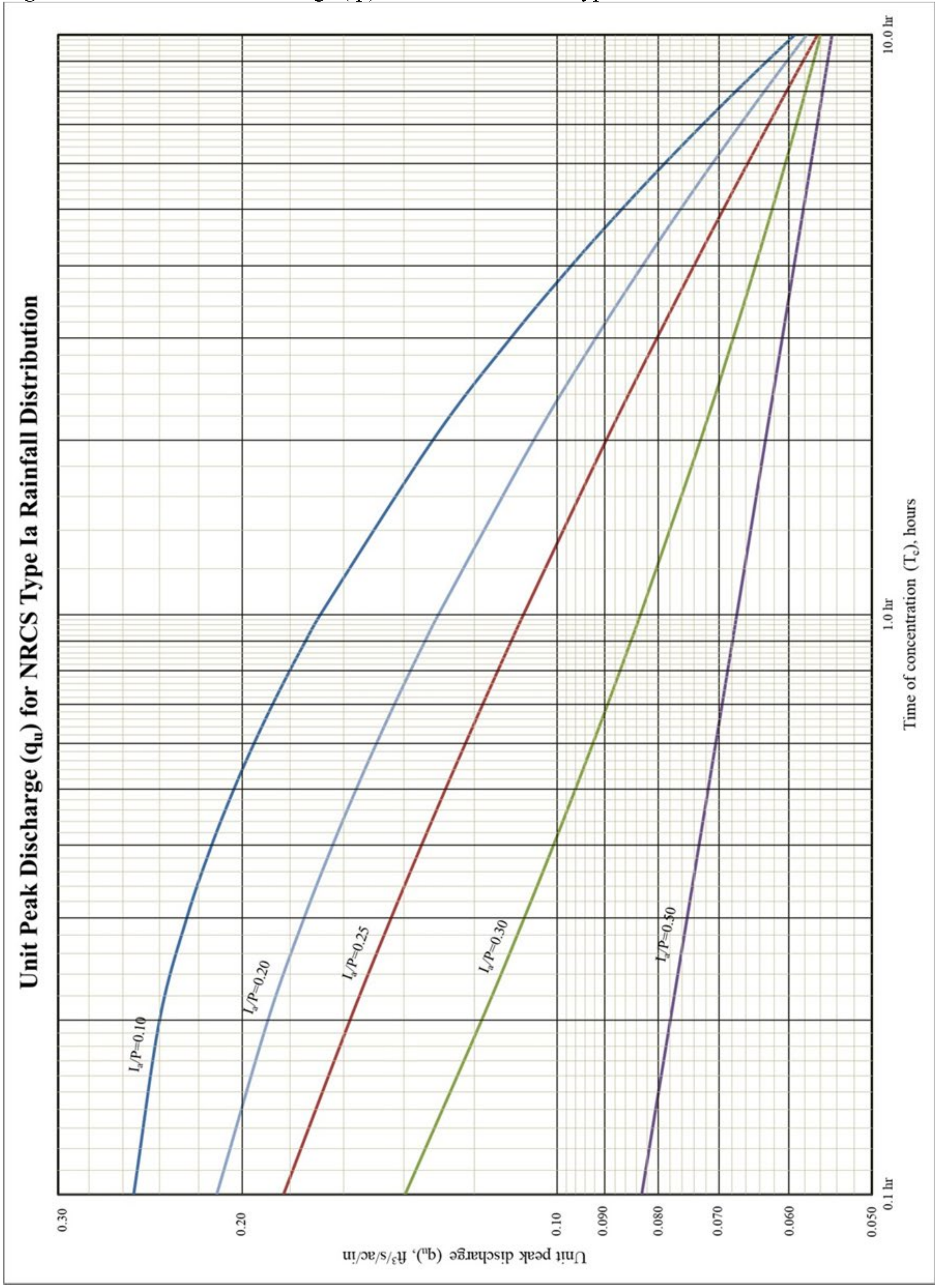


Figure 2-16: Unit Peak Discharge (q_u) for NRCS Rainfall Type II Rainfall Distribution

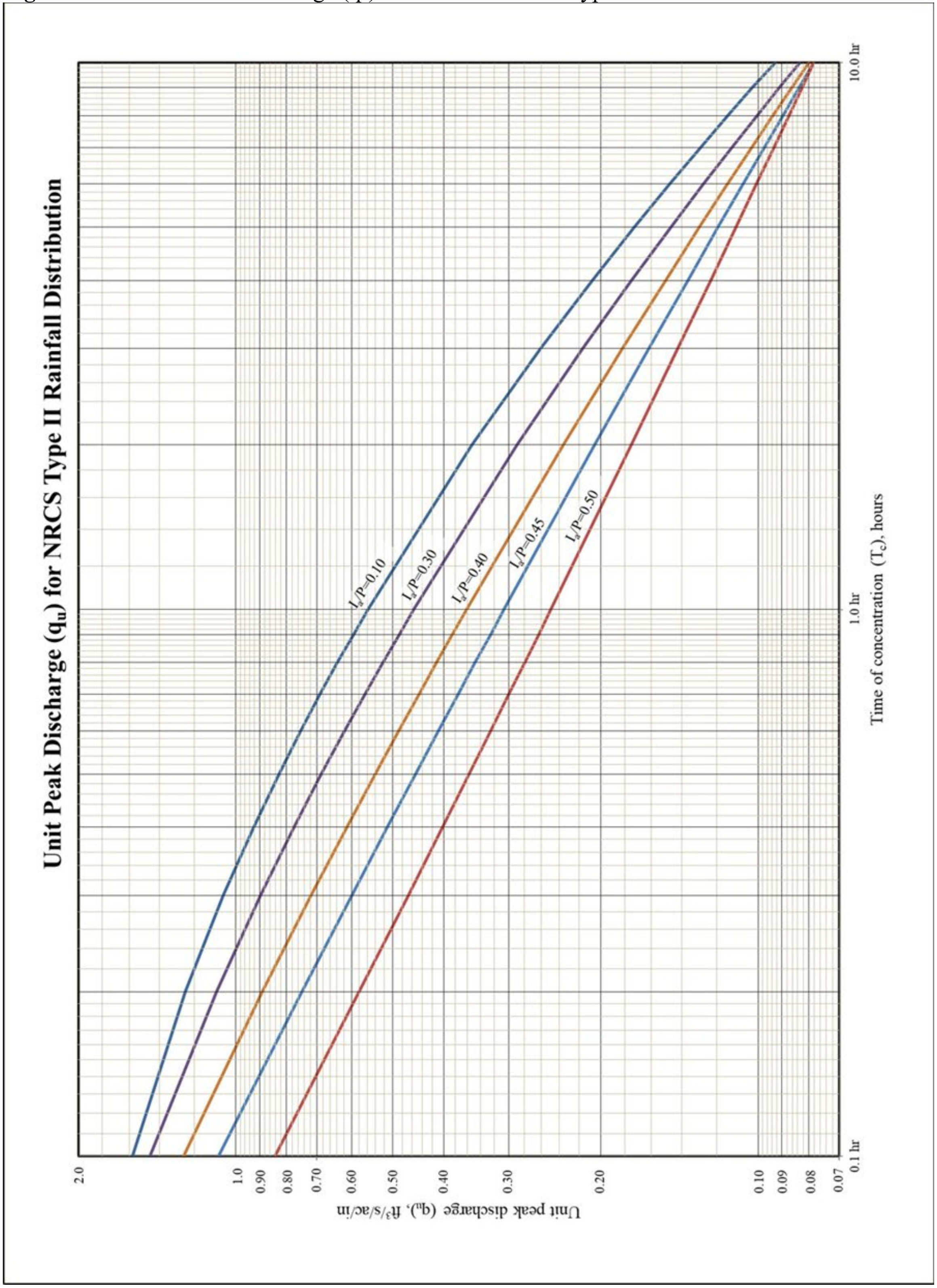
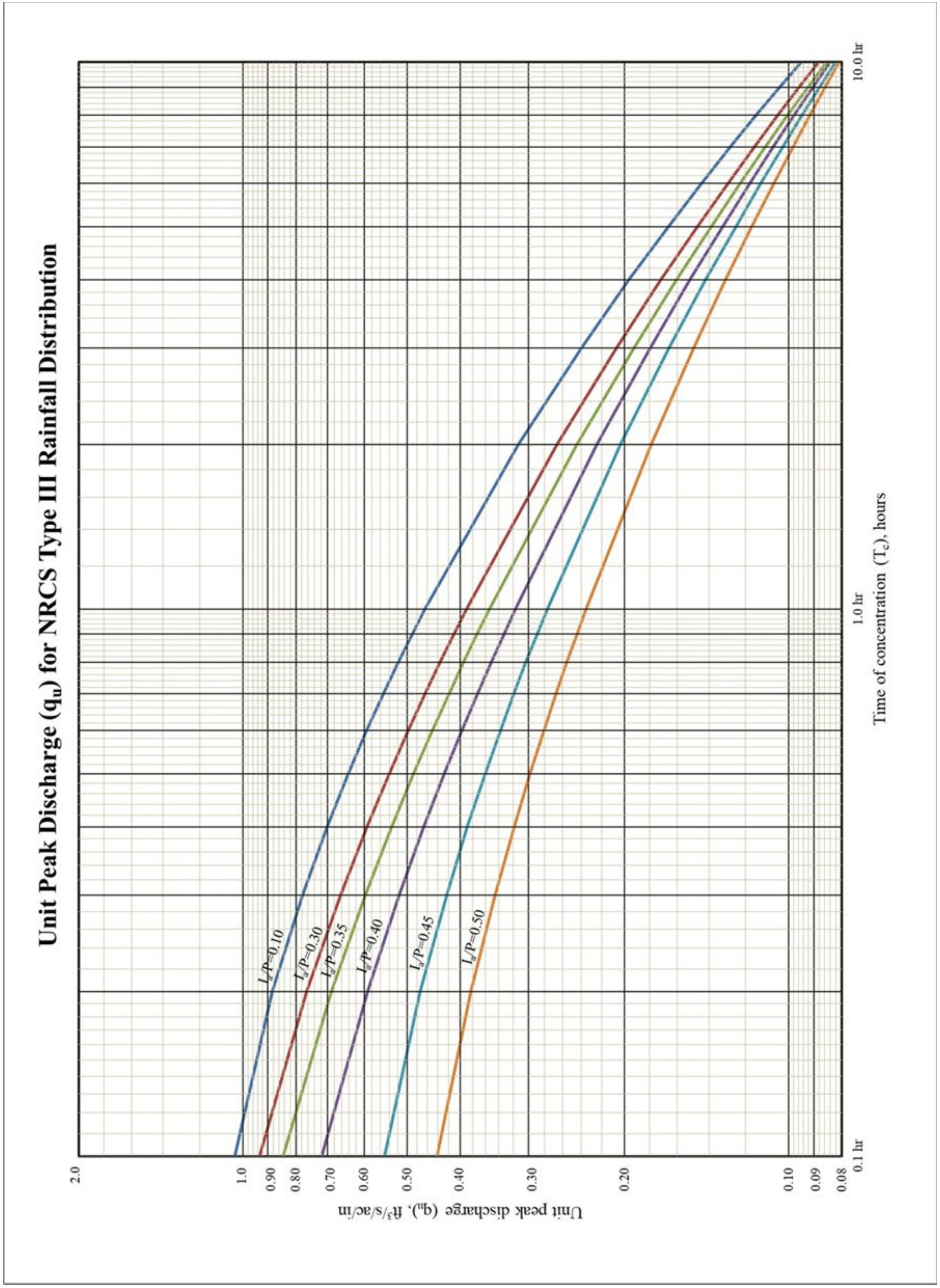


Figure 2-17: Unit Peak Discharge (q_u) for NRCS Rainfall Type III Rainfall Distribution



C. Estimating Peak Discharge Using the Computer Programs

(1) Several software packages and spreadsheets are available, both commercially and through NRCS, that automate estimation of runoff volume and peak discharge.
(2) Some of these tools utilize methods other than the NRCS CN Method to give just a peak discharge; some use the NRCS CN Method with the unit peak discharge methodology described in this chapter to give a runoff volume and a peak discharge, and others use the NRCS CN Method and procedures described in 210-NEH-630-16, to develop full hydrographs for the location of interest and provide an estimate of peak discharge.
(3) Regardless of which software is used, the user must typically identify watershed drainage area, land use within the watershed, T_c, and appropriate rainfall amounts. Depending upon the software used, the user may also need to identify an appropriate rainfall distribution and dimensionless unit hydrograph.
(4) The nationally supported EFH-2 computer program is most often used by NRCS for estimating runoff volume and peak discharge for small on-farm conservation practices.

650.0207 Limitations

A. The watershed drainage area must be greater than 1.0 acre and less than 2,000 acres. Use another procedure, such as those described in 210-NEH-630, to estimate peak discharge if the drainage area is outside these limits. The WinTR-55 and WinTR-20 computer programs automate these procedures.

B. The watershed should have only one main stream. If more than one exists, the branches must have nearly equal times of concentration.

C. The watershed must be hydrologically similar; i.e., represented by a single weighted runoff curve number. Land use, soils, and cover are distributed uniformly throughout the watershed. The land use must be primarily rural. If urban conditions are present and not uniformly distributed throughout the watershed, or if they represent more than 10 percent of the watershed, use other procedures such as those found in 210-NEH-630.

D. If using the unit peak discharge curves, the accuracy of peak discharge estimated by the method described in this chapter is reduced if I_a/P ratio used is outside the range of 0.1 to 0.5 as shown in figures 2-14 through 2-17.

E. When the average watershed slope is less than 0.5 percent, a different unit hydrograph shape, such as the DelMarVa (PRF=286), can be used.

F. If the computed T_c is less than 0.1 hour, use 0.1 hour. If the computed T_c is greater than 10 hours, estimate peak discharge using the procedures documented in 210-NEH-630.

G. When the flow length is less than 200 feet or greater than 26,000 feet, use another procedure, such as those documented in 210-NEH-630-15 to estimate T_c.

H. Do not estimate runoff and peak discharge from snowmelt or rain on frozen ground using these procedures. A procedure for estimating peak discharge in these situations is in 210-NEH-630-11, “Snowmelt”.

I. If potholes make up more than a third of the total drainage area or if they intercept the drainage, use the procedures in 210-NEH-630.

J. When the average watershed slope is greater than 64 percent or less than 0.5 percent, use another procedure to estimate T_c. 210-NEH-630-15 presents several other methods for computing T_c.

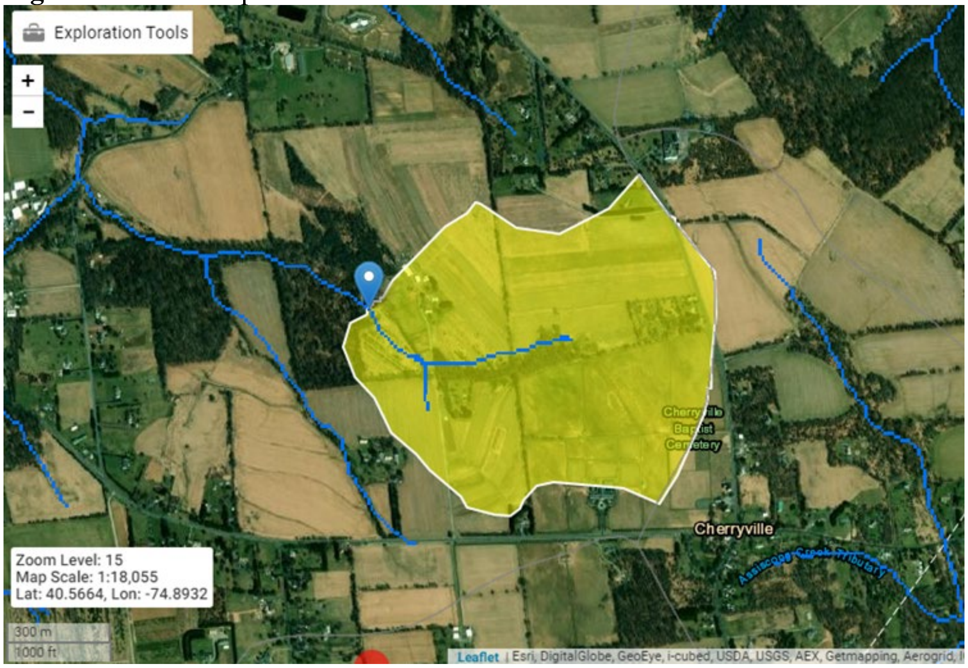
K. When the weighted runoff curve number is less than 40 or more than 98, use another procedure to estimate peak discharge.

650.0208 Examples

A. Example - Estimating Weighted Runoff Curve Number

(1) For the 192-acre watershed in Hunterdon County, New Jersey, as shown in figure 2-18, determine the weighted curve number for the drainage area above a proposed waterway.

Figure 2-18: Example Watershed



(i) The soils map obtained through NRCS' Web Soil Survey, shown in figure 2-19, shows that the soils and their associated HSG in the watershed are:

- BoyAT: Bowmansville silt loam, 0 to 2% slopes, frequently flooded: HSG B/D
- ChC: Chalfont silt loam, 2-6% slopes. HSG C
- CoxB: Croton silt loam, 2-6& slopes. HSG D
- QukB: Quakertown silt loam, 2-6% slopes. HSG C
- QukC2: Quakertown silt loam, 6-12% slopes, eroded. HSG C
- QukD: Quakertown silt loam, 12-18% slopes, eroded. HSG C

Figure 2-19: Soils Map for example watershed

(ii) Land use by HSG breaks down as shown in figure 2-20.

Figure 2-20: Land Use for Example Watershed

Land Use Description	HSG	Area (acres)
Woods – Good Condition	C	6
Pasture- Good Condition	C	28
Pasture- Fair Condition	C	10
Small Grain, Straight Row +CR- Good Condition	C	45
Farmstead	C	3
Row Crops, Straight Row + CR- Good Condition	C	42
Row Crops, Contoured + CR- Good Condition	C	50
Woods- Good Condition	D	2
Pasture- Good Condition	D	6

(2) Solution: Figure 2-21 shows the completed computations for estimating the weighted runoff curve number for this example. Section 650.0211, Exhibit A, at the end of this document is a blank worksheet for estimating weighted runoff curve number.

B. Example - Estimating Time of Concentration

(1) For the watershed in the Example – Estimating Weighted Runoff Curve Number, determine the time of concentration. The average watershed slope is 2.8%, and the flow length is 4,000 feet.

(2) Figure 2-22 shows the completed computation for estimating the time of concentration. The time of concentration computation in this example uses the weighted runoff curve number estimated in the previous example. Section 650.0211, Exhibit B at the end of this document is a blank worksheet for estimating time of concentration and peak discharge.

C. Example - Manual Estimation of Peak Discharge

(1) For the watershed in examples A and B, determine the peak discharges for the 2-, 5-, and 10-year events. The 2-year, 24-hour precipitation is 3.38 inches; the 5-year, 24-hour precipitation is 4.26 inches; and the 10-year, 24-hour precipitation is 5.0 inches. (Design of a grassed waterway requires the use of the 10-year, 24-hour precipitation).

(2) Figure 2-22 shows the completed computations for the peak discharge for this example. Section 650.0211, Exhibit B at the end of this document is a blank worksheet for estimating time of concentration and peak discharge.

(3) This example for the State of New Jersey is based on using updated NOAA Atlas 14 rainfall data, but still using the NRCS Standard Type III Rainfall Distribution within the unit peak discharge curves. The State of New Jersey has updated NOAA Atlas-14 rainfall data and distributions available and is using them. Results obtained using the New Jersey updated rainfall data and distributions will be different than those illustrated in this example. Consult appropriate State Supplements for updated rainfall data, distributions, unit peak discharge curves.

Figure 2-21: Solution to Example – Estimating Weighted Runoff Curve Number

Runoff Curve Number (CN)

Client: *Example A* By: *cch* Date: *12/07/2020*

County: *Hunterdon* State: *NJ* Checked: Date:

Practice: *Grassed Waterway*

Soil name and hydrologic soil group	Cover description (cover type, treatment, and hydrologic condition)	CN (figure 2-7)	Area (acres or %)	Product of CN x Area
C	*Woods – Good Condition*	*70*	*6*	*420*
C	*Pasture – Good Condition*	*74*	*28*	*2,072*
C	*Pasture – Fair Condition*	*79*	*10*	*790*
C	*Small Grain, SR+CR, Good Condition*	*80*	*45*	*3,600*
C	*Farmstead*	*82*	*3*	*246*
C	*Row Crops, SR+CR, Good Condition*	*81*	*50*	*4,050*
C	*Row Crops, Contoured+CR, Good Condition*	*81*	*50*	*4,050*
D	*Woods – Good Condition*	*77*	*2*	*154*
D	*Pasture – Good Condition*	*80*	*6*	*480*
		TOTALS:	*200*	*15,862*

$$\text{CN (weighted)} = \frac{\text{Product of CN} \times \text{Area}}{\text{Total Area}} = \frac{15{,}862}{200} = 79.3$$

USE CN = **79**

Figure 2-22: Solution to Example – Estimating Time of Concentration and Peak Discharge

Time of Concentration and Peak Discharge

Client: *Examples B and C* By: *cch* Date: *12/07/2020*
County: *Hunterdon* State: *NJ* Checked: ____ Date: ____
Practice: *Grassed Waterway*

Estimating time of concentration:

1. Data:

Rainfall distribution type.. *III*

From NRCS standard distribution type (I, IA, II, or III) OR Updated NRCS rainfall distribution type (from State Supplement to 210-NEH-650-2)

Drainage area...A = *192* acres
Runoff curve number..CN = *79*

From Runoff Curve Number worksheet.

Watershed slope..Y = *2.8* %
Flow length.. ℓ = *4,000* ft

2. T_c using ℓ, Y, CN, and figure 2-12..T_c = ____ hrs

OR using equation 2-5:

$$T_c = \frac{l^{0.8}\left(\frac{1,000}{CN} - 9\right)^{0.7}}{1,140Y^{0.5}} = \frac{(4,000)^{0.8}\left(\frac{1,000}{79} - 9\right)^{0.7}}{1,140(2.8)^{0.5}} = 0.99 \text{ hrs}$$

Estimating peak discharge:

		Storm #1	Storm #2	Storm #3
1. Frequency	yr	2	5	10
2. Rainfall, P (24-hour)........	in	3.38	4.26	5.0
3. Initial abstraction, I_a .... *(use CN with figure 2-13)*	in	0.532	0.532	0.532
4. Compute I_a/P ratio		0.16	0.12	0.11
5. Unit peak discharge, q_u*	cfs/ac/in	0.44	0.45	0.46
6. Runoff, Q	in	1.47	2.18	2.80
7. Peak discharge, q_p .... *(where $q_p = q_u A Q$)*	cfs	124	188	248

**(use T_c and I_a/P with figures 2-14 through 2-17 OR with appropriate unit peak discharge figures for updated NRCS rainfall distributions from State Supplements to 210-NEH-650-2)*

650.0209 References

A. United States Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS). Title 210-National Engineering Handbook (NEH), Part 630, "Hydrology".

(1) Chapter 7, "Hydrologic Soil Groups", 2009.
(2) Chapter 9, "Hydrologic Soil-Cover Complexes", 2004.
(3) Chapter 10, "Estimation of Direct Runoff from Storm Rainfall", 2004.
(4) Chapter 11, "Snowmelt", 2004.
(5) Chapter 15, "Time of Concentration", 2010.
(6) Chapter 16, "Hydrographs", 2007.

B. USDA-NRCS. Title 180 – Conservation Planning and Application, Part 600, "National Planning Procedures Handbook", Amendment 7, Subpart A – General, 600.2 Definitions. 2020.

C. United States Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service (NOAA-NWS). NOAA Atlas 14, "Precipitation-Frequency Atlas of the United States". https://www.weather.gov/owp/hdsc_publications

(1) Volume 1: Semiarid Southwest Arizona, Southeast California, Nevada, New Mexico, Utah, 2004, rev. 2011. (SE California superseded by NOAA Atlas 14, Volume 6).
(2) Volume 2: Ohio River Basin and Surrounding States (Delaware, District of Columbia, Illinois, Indiana, Kentucky, Maryland, New Jersey, North Carolina, Ohio, Pennsylvania, South Carolina, Tennessee, Virginia, West Virginia), 2004, rev. 2006.
(3) Volume 3: Puerto Rico and the U.S. Virgin Islands, 2006, rev. 2008.
(4) Volume 4: Hawaiian Islands, 2009, rev. 2011.
(5) Volume 5: Selected Pacific Islands, 2009, ver. 2011.
(6) Volume 6: California, 2011, rev. 2014.
(7) Volume 7: Alaska, 2012.
(8) Volume 8: Midwestern States (Colorado, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Oklahoma, South Dakota, Wisconsin), 2013.
(9) Volume 9: Southeastern States (Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi), 2013.
(10) Volume 10: Northeastern States (Connecticut, Maine, Massachusetts, New Hampshire, New York, Rhode Island, Vermont), 2015, rev. 2018.
(11) Volume 11: Texas, 2018.

D. United States Department of Commerce, NOAA-NWS. NOAA Atlas 2, "Precipitation-Frequency Atlas of the Western United States", volumes 1 - XI, 1973. https://www.weather.gov/owp/hdsc_publications

(1) Volume I: Montana, 1973.
(2) Volume II: Wyoming, 1973.
(3) Volume III: Colorado, 1973. (Superseded by NOAA Atlas 14, Volume 8.)
(4) Volume IV: New Mexico, 1973. (Superseded by NOAA Atlas 14, Volume 1.)
(5) Volume V: Idaho, 1973.
(6) Volume VI6: Utah, 1973. (Superseded by NOAA Atlas 14, Volume 1.)
(7) Volume VII: Nevada, 1973. (Superseded by NOAA Atlas 14, Volume 1.)
(8) Volume VIII: Arizona, 1973. (Superseded by NOAA Atlas 14, Volume 1.)
(9) Volume IX: Washington, 1973.
(10) Volume X. Oregon, 1973.
(11) Volume XI. California, 1973. (Superseded by NOAA Atlas 14, Volume 6.)

E. United States Department of Commerce, Weather Bureau. Technical Paper No. 40, “Rainfall Frequency Atlas of the United States for Durations from 30 Minutes to 24 Hours and Return Periods from 1 to 100 Years”. 1961, repaginated and reprinted 1963. (Superseded by NOAA Atlas 2 and NOAA Atlas 14.) https://www.weather.gov/owp/hdsc_publications

650.0210 Acknowledgements

A. **Kenneth M. Kent** (retired) and **Wendell A. Styner** (retired) originally prepared Chapter 2, “Estimating Runoff”, which appeared in the Soil Conservation Service (SCS, now Natural Resources Conservation Service, NRCS) in the SCS “Engineering Field Manual”, in 1971.

B. **Donald E. Woodward** (retired) directed updates to Chapter 2 in 1989 and 1990 and retitled the chapter “Estimating Runoff and Peak Discharge”. SCS published the 1990 version as Chapter 2, 210-NEH-650, “Engineering Field Handbook”.

C. This edition incorporates the following revisions to the 1990 edition:

(1) Updated Soil Conservation Service to the Natural Resources Conservation Service.
(2) Retitled the chapter “Estimating Runoff Volume and Peak Discharge” and published it as Chapter 2 in 210-NEH-650, “Engineering Field Handbook”, 2nd edition.
(3) Updated the chapter to the current required format for NRCS handbooks.
(4) Added a brief discussion on estimating peak discharge using computer programs.
(5) Added information on the use of updated precipitation-frequency data and rainfall distributions.
(6) Added a discussion of dual classification of hydrologic soil groups.
(7) Added a section on hydrographs, dimensionless unit hydrographs, and peak rate factors.

C. **Claudia Hoeft**, National Hydraulic Engineer, Conservation Engineering Division, NRCS, Washington, D.C. prepared the majority of the revisions with reviews and recommendations from **William Merkel** (retired), **Helen Fox Moody** (deceased), **Quan Quan**, Hydraulic Engineer, West National Technology Support Center, Beltsville, Maryland, and **Geoff Cerrelli** (retired).

D. Special thanks to the following individuals who provided additional review and comments on this chapter.

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(4) **Dave Jones**, State Conservation Engineer, NRCS, Minneapolis, Minnesota
(5) **David Lamm**, State Conservation Engineer, NRCS, Somerset, New Jersey
(6) **Mark McCurdy**, Civil Engineer, NRCS, Des Moines, Iowa
(7) **Tim Ridley**, Dam Safety Engineer, NRCS, Morgantown, West Virginia

D. **Lynn Owens** (retired), **Suzy Self** (retired), and **Wendy Pierce**, illustrator, National Geospatial Management Center, NRCS, Fort Worth, Texas assisted with early editing and illustrations.

650.0211 Exhibits

A, Runoff Curve Number Worksheet

B. Time of Concentration and Peak Discharge Worksheet

Runoff Curve Number (CN)

Client: ______________________ By: ______ Date: __________

County: ______________ State: ______ Checked: ______ Date: __________

Practice: ____

Soil name and hydrologic soil group	Cover description (cover type, treatment, and hydrologic condition)	CN (figure 2-7)	Area (acres or %)	Product of CN x Area
		TOTALS:		

$$\text{CN (weighted)} = \frac{\text{Product of CN} \times \text{Area}}{\text{Total Area}} = \underline{\qquad} =$$

USE CN = ☐

Time of Concentration and Peak Discharge

Client: ______________________ By: ______ Date: __________

County: ______________ State: ______ Checked: ______ Date: __________

Practice: ____

Estimating time of concentration:

1. Data:

Rainfall distribution type…………………………………… ________

From NRCS standard distribution type (I, IA, II, or III) OR Updated NRCS rainfall distribution type (from State Supplement to 210-NEH-650-2)

Drainage area…………………………………………………..A = ________ acres

Runoff curve number………………………………………CN = ________

From Runoff Curve Number worksheet.

Watershed slope……………………………………………..Y = ________ %

Flow length………………………………………………….. ℓ = ________ ft

2. T_c using ℓ, Y, CN, and figure 2-12………..…………………..T_c = ________ hrs

OR using equation 2-5:

$$T_c = \frac{\ell^{0.8}\left(\frac{1{,}000}{CN} - 9\right)^{0.7}}{1{,}140Y^{0.5}} = \frac{(\_\_\_\_\_\_)^{0.8}\left(\frac{1{,}000}{\_\_\_} - 9\right)^{0.7}}{1{,}140(\_\_\_)^{0.5}} = \_\_\_\_\_\_\_\_ \text{ hrs}$$

Estimating peak discharge:

		Storm #1	Storm #2	Storm #3
1. Frequency	yr			
2. Rainfall, P (24-hour).	in			
3. Initial abstraction, I_a . . . . *(use CN with figure 2-13)*	in			
4. Compute I_a/P ratio				
5. Unit peak discharge, q_u*	cfs/ac/in			
6. Runoff, Q	in			
7. Peak discharge, q_p . . . . *(where $q_p = q_u A Q$)*	cfs			

(use T_c and I_a/P with figures 2-14 through 2-17 OR with appropriate unit peak discharge figures for updated NRCS rainfall distributions from State Supplements to 210-NEH-650-2)