Chapter 3

HYDROLOGY

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3.1 INTRODUCTION

Hydrology involves the estimation of flow peaks, volumes and time distributions of stormwater runoff. The analysis of these parameters is fundamental to the design of stormwater management infrastructure, such as stormwater conveyance systems and stormwater control measures (SCM). During hydrologic analysis of a development/redevelopment site, there are several variable factors that affect the nature of stormwater runoff from the site. Some of the factors that need to be considered include:

- Rainfall amount and storm distribution
- Drainage area size, shape and orientation
- Ground cover and soil type
- Slopes of terrain and stream channel(s)
- Antecedent moisture condition
- Rainfall abstraction rates (initial and constant)
- Storage potential (e.g. floodplains, ponds, wetlands, reservoirs, channels, etc.)
- Watershed development potential
- Characteristics of the local drainage system

3.2 HYDROLOGIC DESIGN POLICIES

There are several hydrologic methods available to estimate runoff characteristics for a site or drainage sub-basin; however, the following methods have been selected to support hydrologic site analysis for the design methods and procedures included in this manual:

- Rational Method
- Modified Rational Method
- SCS (NRCS) Unit Hydrograph Method

These methods were selected based upon a verification of their accuracy in duplicating local hydrologic estimates for a range of design storms throughout the state, as well as the availability of equations, nomographs and computer programs to support the methods.

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, and the data available for the factors influencing the rainfall-runoff relationship is insufficient to expect exact solutions. It is up to the North Carolina licensed design professional, with concurrence from the City, to determine the most appropriate approach to performing the hydrologic analysis.

Table 3.2.a lists the hydrologic methods and the circumstances for their use in various analysis and design applications. **Table 3.2.b** provides some limitations on these methods.

TABLE 3.2.a APPLICATIONS OF THE RECOMMENDED HYDROLOGIC METHODS				
Design Application	*Manual Section*	*Rational Method*	*Modified Rational Method*	*SCS (NRCS) Unit Hydrograph Method*
Erosion Protection	5.1		✓	✓
Flood Mitigation	5.1		✓	✓
SCMs	5.4		✓	✓
Outlet Structures	4.7	✓	✓	✓
Gutter Flow and Inlets	4.3	✓		✓
Stormwater Conveyance Systems	4.2	✓		✓
Bridges/Culverts	4.6	✓		✓
Swales/Ditches/Open Channels	4.5	✓		✓

TABLE 3.2.b CONSTRAINTS ON USING RECOMMENDED HYDROLOGIC METHODS		
Method	*Size Limitations[1]*	*Comments*
Rational	0 – 100 acres	Method can be used for estimating peak flows and the design of stormwater conveyance systems
Modified Rational	0 – 100 acres	Method can be used for estimating runoff volumes for storage design
SCS (NRCS) Unit Hydrograph	Any Size	Method can be used for estimating peak flows and hydrographs for all design applications
[1]Size limitation refers to the drainage basin for the stormwater management facility (e.g. culvert, inlet, etc.)		

3.2.1 Fully Developed Conditions

All stormwater conveyances shall be designed based on fully developed land use conditions as shown on current City Land Use Plans and Zoning Maps or existing land use, whichever generates the higher runoff rate.

3.2.2 Drainage Area

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

3.2.3 Rainfall Data and Intensity

The rainfall intensity is the average rainfall rate in inches per hour for a duration equal to the time of concentration for a selected return period. Once a return period has been selected for design and a time of concentration calculated for the drainage area, the rainfall intensity can be determined from Rainfall-Intensity-Duration data given in NOAA Atlas 14 or from future rainfall intensity data adopted by the City, whichever is more conservative. The map location in the NOAA Atlas 14 hyperlink must be adjusted to the project specific location within the City in order to generate appropriate rainfall amounts. Precipitation data specific to the project site shall be included and shall show the selected region based on the project location. Data shall be obtained from NOAA Atlas 14 or equivalent future rainfall intensity data, whichever is more conservative, and the selected rainfall distribution shall consider the 24-hour rainfall event. The NOAA website works best when opened using Google Chrome or Firefox web browsers.

The following programs are acceptable to be used and submitted for hydrologic analysis:

- HEC-HMS
- WinTR-55
- HydroCAD
- PondPack
- XP SWMM
- EPA SWMM
- PC SWMM
- Infoworks ICM
- Civil Storm

Other programs not listed above may be requested on a case-by-case basis at the discretion of Stormwater Development Review staff; however, the Chainsaw Routing Method is not an accepted method for hydrologic analysis.

3.3 TIME OF CONCENTRATION

The time of concentration (t_c) is a concept used in hydrology to measure the response of a watershed to a storm event. It is defined as the time needed for water to flow from the most remote point in a watershed to the watershed outlet. Time of concentration is a function of topography, soil properties and land use within the watershed and varies depending on the slope. When the drainage area consists of several different surface types, t_c is calculated for each surface type, such as sheet flow, shallow concentrated and channelized, and then summed. The duration of rainfall is then set equal to the time of concentration and is used to estimate the design average rainfall intensity (i). Time of concentration is only applied to surface runoff and shall be no less than 5 minutes for hydrologic analysis.

3.3.1 SCS Method

The SCS Method of time of concentration is a valid method to use for either the Rational Method, Modified Rational Method or the SCS Unit Hydrograph Method.

3.3.1.1 Lag Time

Lag time is the delay between the time required for runoff to occur and the time required for runoff to reach its maximum peak. Lag time shall be used for SCS Unit Hydrograph calculations. Conceptually, lag time may be thought of as a weighted time of concentration and correlates to the unit hydrograph's time to peak. Programs, such as HEC-HMS, require a lag time input for calculations. The relationship between lag time and time of concentration is characterized by **Equation 3.3.1.1** below:

[EQ 3.3.1.1] $\boldsymbol{L = 0.6t_C}$

Where,

$L = lag\ time\ (min)$

$t_C = time\ of\ concentration\ (min)$

3.3.1.2 Travel Time

Water moves through a watershed as sheet flow, shallow concentrated flow, open channel 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:

[EQ 3.3.1.2.a] $\boldsymbol{T_t = \frac{L \times 0.0167}{V}}$

Where,

$T_t = travel\ time\ (min)$

$L = flow\ length\ (ft)$

$V = average\ velocity\ (fps)$

The time of concentration is the sum of T_t values for the various consecutive flow segments along the path extending from the hydraulically most distant point in the watershed to the point of interest.

[EQ 3.3.1.2.b] $\boldsymbol{t_c = T_{t1} + T_{t2} \ldots T_n}$

Where,

$t_c = time\ of\ concentration\ (min)$

$n = number\ of\ flow\ segments$

3.3.1.3 Sheet Flow

Sheet flow is flow over plane surfaces prior to channelization. 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 foot. When designing a drainage system, the sheet flow path is not necessarily the same before and after development and grading operations have been completed. Maximum sheet flow lengths are limited to 100 feet in undeveloped areas and 50 feet in developed areas.

[EQ 3.3.1.3]

$$T_t = \frac{0.007\,(n \times L)^{0.8}}{(P_2)^{0.5} \times (S)^{0.4}}$$

Where,

$T_t = travel\ time\ (min)$

$n = Manning's\ roughness\ coefficient\ (reference\ \textbf{Table 3.3.1.3})$

$L = flow\ length\ (ft)$

$P_2 = 2\text{-}yr, 24\text{-}hr\ rainfall$

$S = hydraulic\ grade\ line\ slope\ or\ land\ slope\ (ft/ft)$

TABLE 3.3.1.3

ROUGHNESS COEFFICIENTS (MANNING'S n)[1] FOR SHEET FLOW

Surface Description	*n Value*
Smooth surfaces (concrete, asphalt, gravel or bare soil)	0.011
Fallow (no residue)	0.05
Cultivated Soils	
Residue Cover < 20%	0.06
Residue Cover > 20%	0.17
Grass	
Short grass prairie	0.15
Dense grasses[2]	0.24
Bermuda grass	0.41
Range (natural)	0.13
Woods[3]	
Light underbrush	0.40
Dense underbrush	0.80

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

[2]Includes species, such as weeping love grass, bluegrass, buffalo grass, blue gamma grass and native grass mixture.

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

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

3.3.1.4 Shallow Concentrated Flow

After a maximum of 100 feet in undeveloped areas or 50 feet in developed areas, sheet flow becomes shallow concentrated flow. Average velocities for estimating travel time for shallow concentrated flow can be computed using the equations below. These equations can also be used for slopes less than 0.005 feet/feet.

[EQ 3.3.1.4.a] $$\boldsymbol{Unpaved \rightarrow V = 16.1345 \times (S)^{\frac{1}{2}}}$$

[EQ 3.3.1.4.b] $$\boldsymbol{Paved \rightarrow V = 20.3282 \times (S)^{\frac{1}{2}}}$$

$\boldsymbol{Where,}$

$V = average\ velocity\ (fps)$

$S = slope\ of\ hydraulic\ grade\ line\ (watercourse\ slope, ft/ft)$

After determining average velocity using **Equations 3.3.1.4.a or 3.3.1.4.b**, use **Equation 3.3.1.2.a** to estimate T_t for the shallow concentrated flow segment.

3.3.1.5 Channelized Flow

Open channel flow is 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 USGS 7.5-inch quadrangle sheets. Flow within pipes and culverts not under pressure is considered closed channel flow. Manning's Equation or water surface profile information can be used to estimate average flow velocity. Average flow velocity is usually determined for bankfull elevation. Manning's velocity for pipes assumes a full-flow condition.

[EQ 3.3.1.5] **Manning's Equation is** $$\boldsymbol{V = \frac{\left[1.49\ (r)^{\frac{2}{3}}\ (s)^{\frac{1}{2}}\right]}{n}}$$

$\boldsymbol{Where,}$

$V = average\ velocity\ (fps)$

$r = hydraulic\ radius\ (ft)\ and\ is\ equal\ to\ \frac{a}{p_w}$

$a = cross\text{-}sectional\ flow\ area\ (ft^2)$

$p_w = wetted\ perimeter\ (ft)$

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

$n = Manning's\ roughness\ coefficient\ for\ open\ channel\ flow$

After average velocity is computed using **Equation 3.3.1.5**, T_t for the channel segment can be estimated using **Equation 3.3.1.2.a**.

Velocity in channels shall be calculated from Manning's Equation. Cross sections from all channels to be used in the calculations shall be field verified.

3.3.2 Kirpich Equation

An alternate method for determining time of concentration is the Kirpich Equation (**Equation 3.3.2**) for use in the Rational Method; however, this methodology shall not be used with the Modified Rational Method or the SCS Unit Hydrograph Method.

[EQ 3.3.2] $$t_c = 0.0078 \times \frac{L^{0.77}}{S^{0.385}}$$

$$Where,$$

$$t_c = Time\ of\ concentration\ (min)$$

$$L = Longest\ hydraulic\ flow\ length\ (ft)$$

$$S = Surface\ slope\ (ft/ft)$$

This equation can be used to estimate the time of concentration for basins with well-defined channels; for overland flow on grassed, concrete or asphalt surfaces; and for concrete channels. Adjustments shall be made to the Kirpich Equation to compensate for channelization, as shown below in **Table 3.3.2.** For flow over multiple land cover types, the time of concentration will be the sum of the individually adjusted t_c calculations. Selecting overland flow paths in excess of 100 feet for undeveloped land use and 50 feet for developed land use is not allowed.

TABLE 3.3.2
ADJUSTMENTS TO THE KIRPICH EQUATION

Land Cover Type	*Time of Concentration Guidance*
Well-defined natural channels	t_C
Overland flow on grassy surfaces	$t_C * 2$
Overland flow on paved surfaces	$t_C * 0.4$
Concrete channels	$t_C * 0.2$

3.4 RATIONAL METHOD

When using the Rational Method, some precautions shall be considered:

- In determining the runoff coefficient (composite C) value (land use) for the drainage area, hydrologic analysis shall consider future land use changes. Stormwater infrastructure shall be designed for future land use conditions, as specified in the current City Land Use Plans and Zoning Maps (or existing land use, whichever generates the higher runoff rate). On-site composite C factors shall be calculated.
- Because the Rational Method uses a composite C value for the entire drainage area, the calculations shall show how the composite coefficient value was determined. Any assumptions shall be stated, and calculations shown.
- The charts, graphs and tables included in this section are provided to assist the engineer in applying the Rational Method. The engineer shall use good engineering judgment in

applying these design aids and shall make appropriate adjustments when specific site characteristics dictate that these adjustments are appropriate.

- The Kirpich Equation shall not be used to design SCMs where a comparison of pre-development and post-development hydrology is necessary.
- Two common errors shall be avoided when calculating time of concentration. First, in some cases, runoff from a portion of the drainage area that is highly impervious may result in a greater peak discharge than would occur if the entire area were considered. In that situation, it would be recommended to break up the drainage area into separate drainage areas for a more detailed analysis, rather than looking at the entire area as a whole. Second, when designing a drainage system, the overland flow path is not necessarily the same before and after development and grading operations have been completed.

3.4.1 Application of the Rational Method

The Rational Method can be used to estimate stormwater runoff peak flows for the design of gutter flows, drainage inlets, storm pipes, culverts and swales. It is most applicable to small, highly impervious areas. The maximum drainage area that shall be used with the Rational Method is no more than 100 acres. The Rational Method shall not be used for storage design or any other application where a more detailed routing procedure is required.

The Rational Method shall not be used for calculating peak flows downstream of bridges, culverts or stormwater conveyance systems that may act as restrictions causing storage, which impacts the peak rate of discharge**.**

3.4.2 Rational Method Runoff

The Rational Method estimates the peak rate of runoff at any location in a watershed as a function of the drainage area, runoff coefficient, frequency factor and mean rainfall intensity for a duration equal to the time of concentration (the time required for water to flow from the most remote point of the basin to the location being analyzed). The frequency factor (C_f) is applied to the equation as a safety factor to scale the maximum rate of runoff based on the design storm event. **Table 3.4.2** provides the frequency factors for different storm events to be used in the Rational Method. The Rational Method is expressed as follows:

[EQ 3.4.2] $$\boldsymbol{Q = C_f \times C \times i \times A}$$

$\boldsymbol{Where,}$

$Q = maximum\ rate\ of\ runoff\ (cfs)$

$C_f = frequency\ factor\ (reference\ \boldsymbol{Table\ 3.4.2})$

$C = runoff\ coefficient\ representing\ a\ ratio\ of\ runoff\ to\ rainfall$

$i = average\ rainfall\ intensity\ for\ a\ duration\ equal\ to\ the\ time\ of\ concentration\ or\ calculated\ travel\ time\ (in/hr)$

$$A = drainage\ area\ contributing\ to\ the\ design\ point\ location\ (ac)$$

The C_f values that can be used are listed in **Table 3.4.2**. The product of C_f multiplied by C shall not exceed 1.0.

TABLE 3.4.2 **FREQUENCY FACTORS FOR RATIONAL FORMULA**	
Recurrence Interval (yrs)	*C_f*
10 or less	1.0
25	1.1
50	1.2
100	1.25

3.4.3 Runoff Coefficient

The runoff coefficient is the variable of the Rational Method least susceptible to precise determination and requires judgment and understanding on the part of the engineer. While engineering judgment is always required in the selection of runoff coefficients, typical coefficients represent the integrated effects of many drainage basin parameters. **Table 3.4.3** provides the recommended runoff coefficients for the Rational Method.

TABLE 3.4.3
RECOMMENDED RUNOFF COEFFICIENT VALUES

Description of Area	Runoff Coefficient (C)
Woodlands	0.25
Parks, Cemeteries	0.25
Playgrounds	0.35
Lawns:	
Sandy Soil, Flat, 2%	0.10
Sandy Soil, Average, 2 – 7%	0.15
Sandy Soil, Steep, >7%	0.20
Clay Soil, Flat, 2%	0.17
Clay Soil, Average, 2 – 7%	0.22
Clay Soil, Steep, >7%	0.35
Graded or No Plant Cover:	
Sandy Soil, Flat, 0 – 5%	0.30
Sandy Soil, Average, 5 – 10%	0.40
Clay Soil, Flat, 0 – 5%	0.50
Clay Soil, Average, 5 – 10%	0.60
Residential:	
Single-Family (R – 4)	0.60
Single-Family (R – 6)	0.65
Multi-family (R – 10)	0.65
Multi-family (R – 20)	0.65
Multi-family (R – 30)	0.85
Business:	
O & I (I, II, III)	0.85
I1 & I2	0.95
Shopping Centers	0.95
Streets:	
Gravel Areas	0.50
Drives, Walks, and Roofs	0.95
Asphalt and Concrete	1.00

Note: The above runoff coefficients are valid for 2-year to 10-year storm frequencies only. Coefficients must be accompanied with a C_f factor when used for less frequent, higher-intensity storms.

(Sources: NRCS USDA Hydrology Training Series)

3.4.4 Composite Coefficients

It is often desirable to develop a composite runoff coefficient based on the percentage of different types of surfaces in the drainage areas. Composite runoff coefficients can be developed with the values from **Table 3.4.3** by using percentages of different land uses. 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. The Rational Method assumes that all land uses within a drainage area are uniformly distributed. If it is important to locate a specific land use within the drainage area, then another hydrologic method shall be used, where hydrographs can be generated and routed through the drainage area.

3.5 MODIFIED RATIONAL METHOD

For drainage areas of less than 100 acres, a modification of the Rational Method can be used for routing detention calculations utilizing pre- and post-development discharge. Pre-development discharge, based on existing site conditions, is calculated to determine allowable site discharge. Post-development site conditions are then considered, and a discharge is calculated based on changes to land cover and time of concentration. The difference between the two is the amount of discharge that must be detained and routed for the project as detailed in the design procedure in Section 3.5.1.

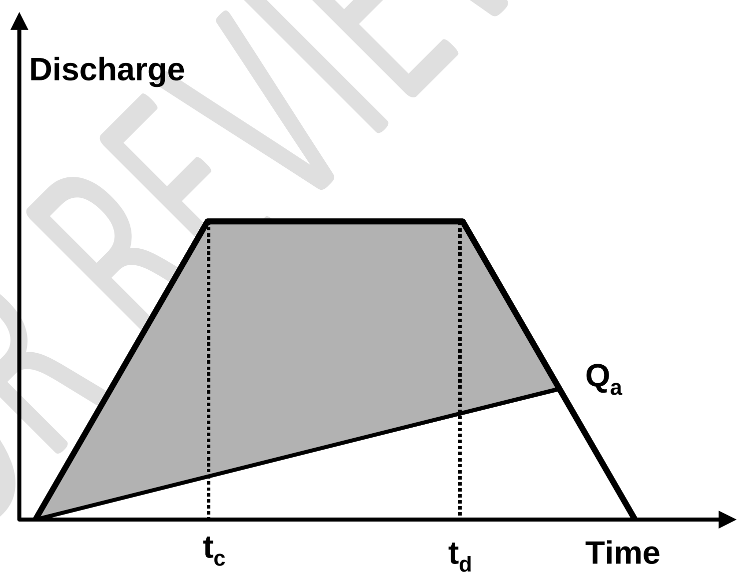

Figure 3.5 Modified Rational Routing Illustration

The Modified Rational Method uses the peak flow calculating capability of the Rational Method, paired with assumptions about the inflow and outflow hydrographs, to compute an approximation of storage volumes for simple detention calculations. There are many variations on the approach. **Figure 3.5** illustrates one application. The rising and falling limbs of the inflow hydrograph have a duration equal to the time of concentration (t_c). An allowable target outflow is set (Q_a) based on pre-development conditions. The storm duration (t_d) is varied until the storage volume (shaded gray area) is maximized. Downstream analysis is not possible with this method, as only approximate graphical routing takes place.

3.5.1 Design Procedure

The Modified Rational Method methodology utilizes an iterative approach to determine the critical duration at which the required storage volume is greatest. This is summarized in the steps below:

1. Calculate allowable site (pre-development) discharge based on the existing site conditions using **Equation 3.4.2** as shown in **Table 3.5.1.a**.
2. Calculate the proposed site (post-development) discharge based on the future site conditions using **Equation 3.4.2** as shown in **Table 3.5.1.a**. The C factor shall be adjusted to reflect proposed land use conditions for the site. Adjustments to time of concentration shall be made if the proposed land used altered the original time of concentration.
3. Identify a range of durations for the design storm recurrence interval and determine the corresponding intensities from NOAA Atlas 14 or future rainfall intensity data, whichever is more conservative. Calculate the inflow volume for post-development discharges by applying these varying intensity values in combination with the post-development runoff coefficient as shown in **Table 3.5.1.b**.

   [EQ 3.5.1.a] $$V_{inflow} = t_d \times Q \times 60$$

   Where,

   $$t_d = \text{Storm duration (min)}$$

   $$Q = \text{Post} - \text{development Discharge (cfs)}$$

4. Calculate the pre-development outflow volume for each of the preselected durations by adding the time duration (t_d) to the proposed condition t_c and then multiplying by the allowable site discharge from Step 1 as shown in **Table 3.5.1.b**.

   [EQ 3.5.1.b] $$V_{outflow} = 0.5 \times (t_d + t_c) \times Q \times 60$$

   Where,

   $$t_d = \text{Storm duration (min)}$$

   $$t_c = \text{Time of concentration (min)}$$

   $$Q = \text{Pre} - \text{development Discharge (cfs)}$$

5. Calculate the required storage volume for each of the selected storm durations by subtracting the proposed site outflow from the existing condition inflow as shown in **Table 3.5.1.b**.

[EQ 3.5.1.c] $V_{req} = V_{inflow} - V_{outflow}$

$Where,$

$V_{inflow} = Inflow\ volume\ (cf)$

$V_{outflow} = Outflow\ volume\ (cf)$

6. Determine the required volume as the maximum difference between inflow and outflow for the analyzed range of storm durations as shown in **Table 3.5.1.b**. If there is not a maximum peak in the volume, the range of storm durations will need to be increased.

TABLE 3.5.1.a

CALCULATION SETUP FOR THE ALLOWABLE SITE DISCHARGE AND THE PROPOSED SITE DISCHARGE

Steps	*Conditions*	*C_f*	*C*	*Design Frequency*	*t_c (min)*	*Intensity (in/hr)*	*A (ac)*	*Q Peak (cfs)*
1	Existing	1.25	0.25	100	10	7.28	10.00	22.75
2	Proposed	1.25	0.60	100	10	7.28	10.00	54.60

TABLE 3.5.1.b CALCULATION SETUP FOR THE REQUIRED VOLUME DETERMINATION										
	Step 3			*Step 3*			*Step 3*	*Step 4*	*Step 5*	*Step 6*
							Volume (ft^3)			*Volume (ac-ft)*
							Inflow	*Outflow*	*Req. Storage*	*Req. Volume*
Time Step	*t_d Duration (min)*	*C_f*	*C*	*I (in/hr)*	*A (ac)*	*Q peak (cfs)*	*t_d*Q*60*	*.5*(t_c+t_d)*Qo*60*	*Inflow - Outflow*	*Req. Storage / 43,560*
1	5	1.25	0.60	9.17	10.00	68.78	20,630	10,238	10,393	0.24
2	10	1.25	0.60	7.28	10.00	54.60	32,760	13,650	19,110	0.44
3	20	1.25	0.60	5.66	10.00	42.45	50,940	20,475	30,465	0.70
4	30	1.25	0.60	4.70	10.00	35.25	63,450	27,300	36,150	0.83
5	40	1.25	0.60	4.21	10.00	31.60	75,840	34,125	41,715	0.96
6	50	1.25	0.60	3.73	10.00	27.95	83,850	40,950	42,900	0.98
7	60	1.25	0.60	3.24	10.00	24.30	87,480	47,775	39,705	0.91

3.6 SCS (NRCS) UNIT HYDROGRAPH METHOD

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

3.6.1 Design Procedure

The SCS Unit Hydrograph Method utilizes the following approach to determine the critical duration at which the required storage volume is greatest:

1. Determine a composite curve number (CN) that represents and considers different land uses within the drainage area and state assumptions
2. Calculate the time of concentration to the design point location
3. Convert the time of concentration to lag time using **Equation 3.3.1.1**
4. Determine the total and excess rainfall amounts using the Type II rainfall distribution or the balanced storm distribution and peaking factor 484
5. Develop triangular and composite hydrographs for the drainage area using the unit hydrograph approach

3.6.2 Rainfall-Runoff Equation

NRCS derived a relationship between accumulated rainfall and accumulated runoff from experimental plots for numerous soils and vegetative cover conditions. The following NRCS runoff equation is used to estimate direct runoff from 24-hour storm rainfall:

[EQ 3.6.2.a]

$$\boldsymbol{Q} = \frac{(\boldsymbol{P}-\boldsymbol{I_a})^2}{[(\boldsymbol{P}-\boldsymbol{I_a})+\boldsymbol{S}]}$$

Where,

Q = *accumulated direct runoff (in)*

P = *accumulated rainfall or potential maximum runoff (in)*

I_a = *initial abstraction including surface storage, interception and infiltration prior to runoff (in)*

S = *potential maximum soil retention (in)*

The empirical relationship used in the NRCS runoff equation for estimating I_a is:

[EQ 3.6.2.b] $\boldsymbol{I_a = 0.2 \times S}$

Substituting 0.2S for I_a in **Equation 3.6.2.b**, the NRCS rainfall-runoff equation becomes:

[EQ 3.6.2.c]

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

Where,

$$S = \left(\frac{1{,}000}{CN}\right) - 10$$

$$CN = NRCS\ curve\ number\ (see\ \textbf{Table 3.6.3})$$

Figure 3.6.2 shows a graphical solution of this equation that enables the precipitation excess from a storm to be obtained if the total rainfall and watershed curve number are known.

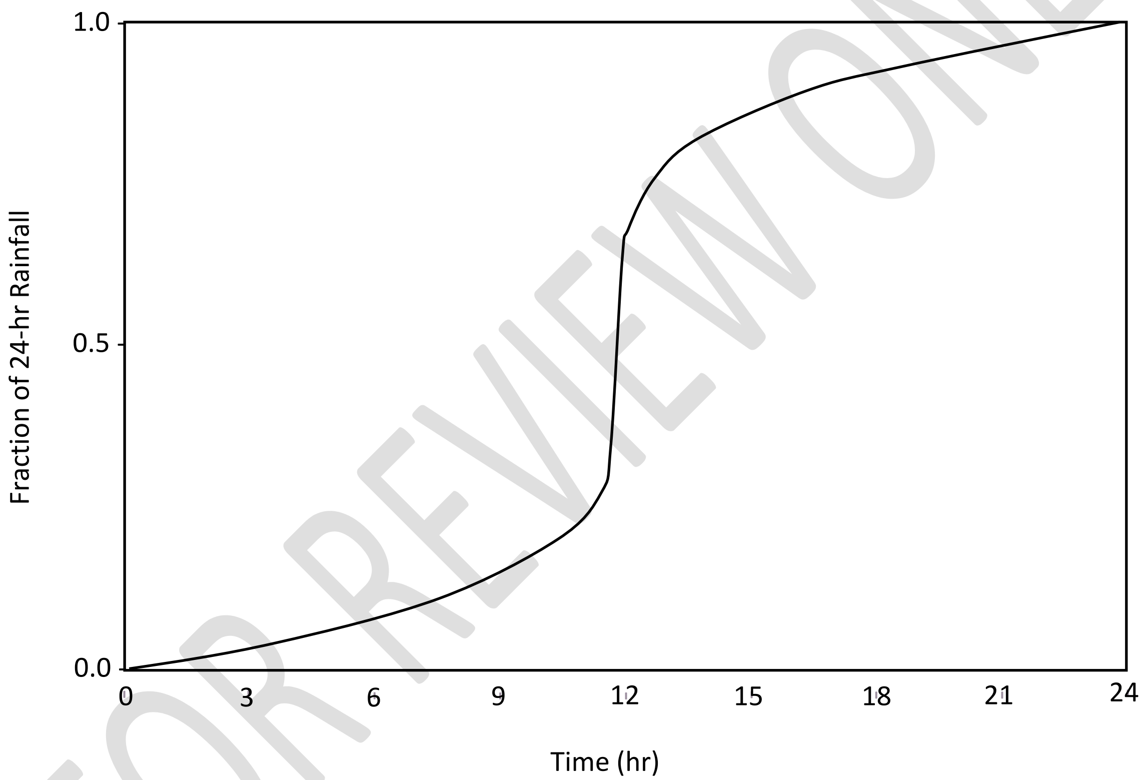

Figure 3.6.2 SCS(NRCS)Type II Rainfall Distribution

3.6.3 Runoff Factor

The physical watershed characteristics affecting the relationship between rainfall and runoff are land use, land cover and soil types. The NRCS uses a combination of soil conditions and land use (ground cover) to assign a runoff factor to an area. These runoff factors, CN, indicate the runoff potential of an area.

Soil properties influence the relationship between runoff and rainfall because soils have differing rates of infiltration. Based on infiltration rates, the NRCS 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 sand 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 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 of 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.

The most recent version of the Web Soil Survey Map or a geotechnical exploration report may be used to determine the hydrologic soil group classification. Soils assigned to a dual hydrologic group (A/D, B/D or C/D) shall be considered D soils. In these cases, the first letter categorizes drained areas and the second categorizes undrained areas. If a geotechnical exploration report is used to determine soil types, the least-permeable soil layer within six inches of the surface shall be used in runoff coefficient determinations. A legible map, clearly delineating and labeling the site boundary and soil types, shall be provided to substantiate the chosen classification. A reference table that describes the hydrologic soil group classification shall also be included.

Consideration shall be given to the effects of soil compaction due to development 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, suggested changes in the soil group selected shall be identified and explained. Also, runoff CNs vary with the antecedent soil moisture conditions. Average antecedent soil moisture conditions (AMC II) are recommended for all hydrologic analysis.

For determining the CN values, refer to **Table 3.6.3** or the NRCS Technical Release 55 (TR-55) Manual. When a drainage area has more than one land use, a composite CN can be calculated and used in the analysis. When composite CNs are used, the analysis does not consider the location of the specific land uses but sees the drainage area as a uniform land use represented by the composite CN. Calculations shall be provided to show how the composite runoff coefficient was determined. Providing a composite runoff coefficient without supporting documentation is not acceptable.

TABLE 3.6.3
RUNOFF CURVE NUMBERS

Cover description: Cover type and hydrologic condition	Average percent impervious area [2]	Curve numbers for hydrologic soil group: 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 (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
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Agricultural Lands					
Pasture, grassland or range (continuous for age for grazing)[4]					
Poor hydrologic condition		68	79	86	89
Fair hydrologic condition		49	69	79	84
Good hydrologic condition		39	61	74	80
Woods					
Poor hydrologic condition		45	66	77	83
Fair hydrologic condition		36	60	73	79
Good hydrologic condition		30	55	70	77
Developing urban areas					
Newly graded areas (pervious areas only, no vegetation)		77	86	91	94

1 Average runoff condition, and Ia = 0.2S.
2 The average percent impervious area shown was used to develop the composite CNs. Other assumptions are as follows: impervious areas 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 Poor: Forest litter, small trees and brush are 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.

Source: 210-VI-TR-55, Second Edition, June 1986

When calculating CN for developed areas, several factors, such as the percentage of impervious area and the means of conveying runoff from impervious areas to the drainage system, shall be considered. For example, consider whether the impervious areas connect directly to the drainage system or to lawns or other pervious areas where infiltration can occur.

The curve number values provided in **Table 3.6.3** are based on directly connected impervious areas. An impervious area is considered directly connected if runoff flows directly into the drainage system. It is also considered directly connected if runoff 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 developed areas could be reduced by not directly connecting impervious surfaces to the drainage system but allowing runoff to flow as sheet flow over significant pervious areas.

3.6.3.1 Connected Impervious Area

The CNs provided in **Table 3.6.3** for various land types were developed for typical land use relations based on specific assumed percentages of impervious area. This CN values were developed on the assumption that:

- Pervious urban areas are equivalent to pasture in good hydrologic condition
- Impervious areas have a CN of 98 and are directly connected to the drainage system

If all the impervious area is directly connected to the drainage system, but the impervious area percentages or the pervious land use assumptions in **Table 3.6.3** are not applicable, use **Figure 3.6.4.2.a** and **Figure 3.6.4.2.b** to compute composite CN. For example, **Table 3.6.3** gives a CN of 70 for a half-acre residential lot in hydrologic soil, group B, with an assumed impervious area of 25%. However, if the lot has 20% connected impervious area and a pervious area CN of 60, the composite CN obtained from **Figure 3.6.4.2.a** is 68. The CN difference between 70 and 68 reflects the difference in percent impervious area.

3.6.3.2 Unconnected Impervious Area

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, use **Figure 3.6.4.2.b** if total impervious area is less than 30% or **Figure 3.6.4.2.a** if the total impervious area is equal to or greater than 30%, because the absorptive capacity of the remaining pervious area will not significantly affect runoff.

When impervious area is less than 30%, obtain the composite CN by entering the right half of **Figure 3.6.4.2.b** 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 half-acre lot with 20% total impervious area (75% of which is unconnected) and pervious CN of 61, the composite CN from **Figure 3.6.3.b** is 66. If all of the impervious area is connected, the resulting CN (from **Figure 3.6.4.2.a**) is 68.

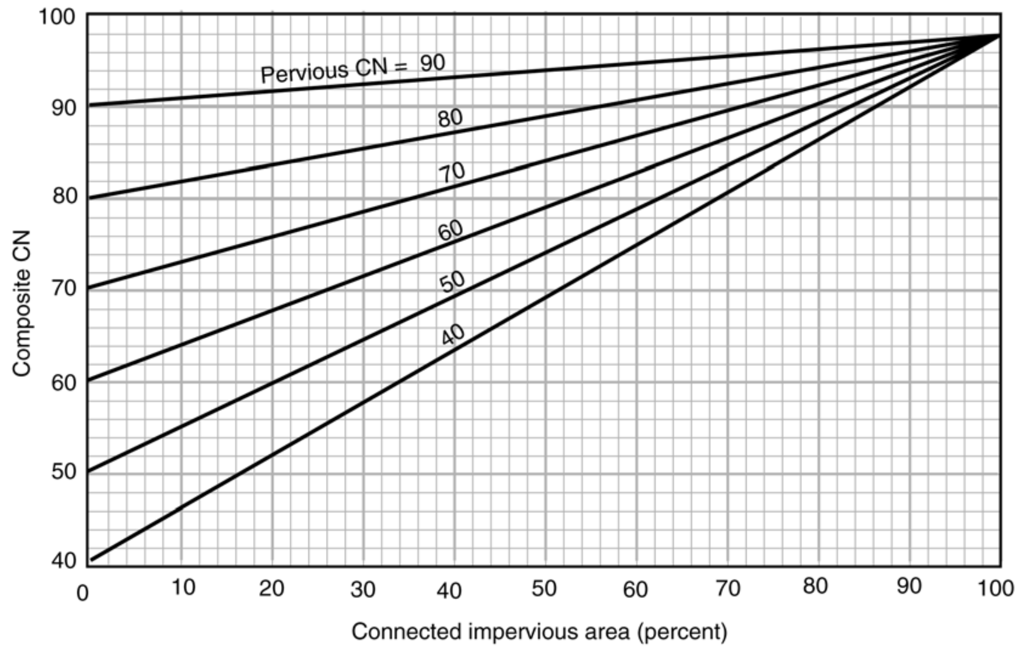

Figure 3.6.4.2.a Composite CN with Connected Impervious Area

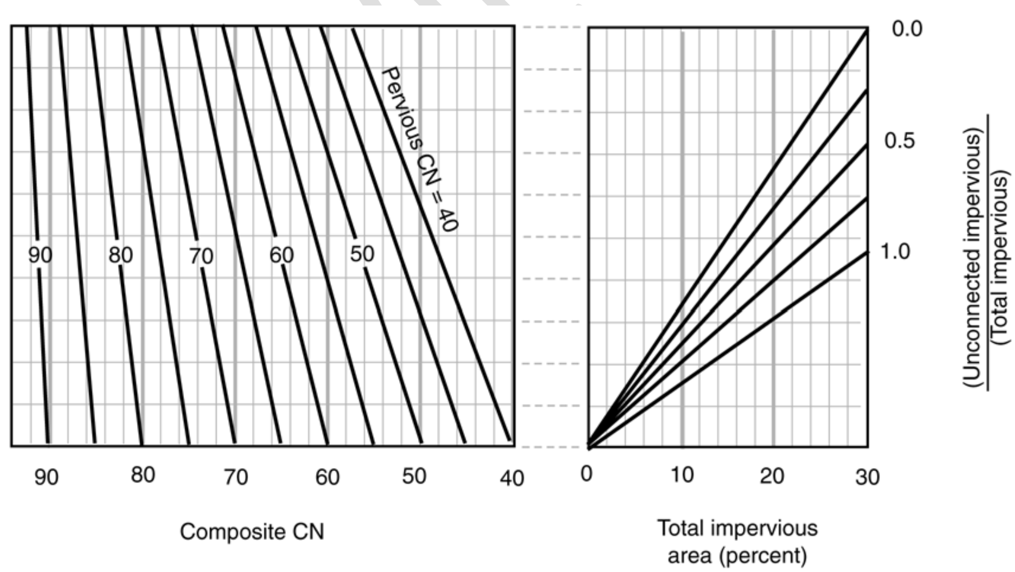

Figure 3.6.4.2.b Composite CN With Unconnected Impervious Area (Total Impervious Area Less than 30%)

3.6.3.3 Removal of Existing Impervious Area

In certain circumstances, impervious surface area may be removed and converted to pervious area to affect the runoff coefficient. In these circumstances, the areas of removed impervious surface must be clearly delineated and labeled on the site plan and construction drawings, with the following impervious-to-pervious conversion specifications included:

- Remove all impervious surfaces from the subject area.
- Till the area to a depth of 12 inches below the top of the compacted subgrade.
- Provide soil amendments, as needed, in accordance with soil tests. If lime and/or fertilizer are to be used, it shall be applied uniformly during seedbed preparation and mixed well in the top four to six inches of soil or applied as recommended in the planting specifications for proposed landscaping.