Chapter 5. HYDROLOGY

5.1 Introduction

The definition of hydrology is the scientific study of water and its properties, distribution, and effects on the earth's surface, in the soil and the atmosphere. Hydrology deals with estimating peak flow rates, volumes, and time distributions of stormwater runoff. Basic hydrology is fundamental in the design of stormwater management control facilities. This chapter addresses the movement of water over the land resulting directly from precipitation in the form of stormwater runoff.

Urbanization and land development changes a watershed's response to precipitation. The most common effects are reduced infiltration and decreased travel time, which have the potential to significantly increase peak discharges and runoff volumes. Total runoff volume is determined by the amount of precipitation and the receiving watershed's infiltration characteristics related to soil type, antecedent moisture conditions, cover type, impervious surfaces, and surface detention and/or retention.

The travel time, or time of concentration, of the watershed is directly related to the slope, flow path length, depth of flow, and roughness of the flow surfaces due to the type of ground cover. Peak discharge rates are based on the relationship of these parameters and on the total drainage area of the watershed, the location of the development, the effect of any flood controls or other manmade storage, and the time distribution of rainfall during a given storm event.

The primary purpose of this chapter is to define the minimum computational standards and methods required to comply with the regulatory requirements of the Greenville County Stormwater Management Permit. Any type of computer software program that utilizes the methods describe in this chapter shall be deemed as being an acceptable procedure.

5.2 Computational Standard Methods

This section describes the recommended procedures for calculating the runoff generated from a project site. Correct utilization of these procedures should result in the best available estimation of existing and projected runoff. Their use will also provide the consistency of results necessary when applied to project sites throughout Greenville County.

It is assumed that practicing design professionals involved with preparing drainage plans have adequate knowledge of the recommended procedures. Therefore, there is no attempt in this Design Manual to provide systematic calculation methodologies.

All hydrologic computational methods shall be accomplished using a volume hydrograph method acceptable by Greenville County. The storm duration for computational purposes for these methods shall be the 24-hour rainfall event, using the Soil Conservation Service (SCS) Type II rainfall distribution or new NRCS distribution (based on NOAA Atlas-14 data) with a 0.1 hour burst duration time increment.

In general the following guidelines should be followed when selecting hydrologic computation standards:

- If the contributing drainage area is 20 acres or less and if no storage design or runoff volume is required, the Rational Method or the SCS Method of runoff calculation shall be acceptable.

- If the contributing drainage area is greater than 20 acres, or if storage or runoff volume design is required, only the SCS Method or other County accepted runoff volume based calculation procedure shall be acceptable.

- Drainage channels may be designed by the Rational Method if the drainage area of the channel is 20 acres or less and no storage design is required, otherwise, the channel shall be designed using SCS runoff calculation methodology.

5.2.1 Rational Method

The Rational Method formula is utilized to determine peak flow rates in urban areas and small watersheds for the following situations:

- The total drainage area is 20 acres or less.
- No storage or volume design is required.
- Sizing individual gutters, storm drain inlets, storm drain pipes, culverts, and small ditches that do not have a total contributing drainage area greater than 20 acres.

The Rational Method shall not be used to do the following:

- Detailed storage design.
- Any application where detailed routing procedures are required.
- Calculating peak flows downstream of bridges, culverts, or storm sewers that may act as temporary storage and require routing calculations.

The Rational Method is recommended for small, highly impervious drainage areas such as parking lots and roadways draining into inlets and gutters as well as small rural watersheds. The Rational Method calculates peak discharge only (as opposed to developing a runoff hydrograph for an area). It makes a basic assumption that the design storm has a constant rainfall intensity for a time period equaling the project area time of concentration (T_c).

5.2.1.1. Rational Method Equation

The most common form of the Rational Method equation estimates the peak runoff at any location in a watershed or sub-basin as a function of drainage area, runoff coefficient, and mean rainfall intensity for a duration equal to the time of concentration, and is expressed as:

$$Q_p = CIA$$

Where Q_p is the peak runoff rate in ft^3/sec, C is a dimensionless runoff coefficient, I is the rainfall intensity in inches/hr, and A is the contributing area in acres.

The assumptions of the Rational Formula are as follows:

- Considers the entire drainage area as one unit.

- The peak flow occurs when the entire watershed is contributing to the runoff.

- The rainfall intensity is uniform over a duration of time equal to or greater than the time of concentration, T_c.

- The frequency of the peak flow is equal to the frequency of the rainfall intensity. For example, the 10-year rainfall intensity I, is assumed to produce the 10-year flood event.

5.2.1.2. Runoff Coefficient, C

The runoff coefficient, C, is taken to be a function of ground cover only and is considered independent of the intensity of rainfall. The coefficient C is a volumetric coefficient that relates peak discharge to the theoretical peak discharge equal to 100 percent runoff. Therefore, C is a function of infiltration and other hydrologic abstractions. Typical accepted values for C for 5- to 10-year frequency storm events are given in Tables 5-1 and 5-2 for urban and rural areas, respectively.

If the watershed contains varying amounts of different ground cover, an appropriate weighted C-Factor must be calculated based upon the percentages of the areas with different C-Factors. The general calculation to determine the weighted C value is:

$$\text{Weighted } C = \frac{C_1A_1 + C_2A_2 + \ldots + C_nA_n}{A_{Total}}$$

Table 5-1. Recommended Rational Method Runoff Coefficient (C) Values* for Urban Areas

Description of Area	Runoff Coefficient
Business	
Downtown areas	0.95
Neighborhood area	0.70
Residential	
Single-family areas	0.50
Multi-units, detached	0.60
Multi-units, attached	0.70
Suburban residential	0.40
Apartment dwelling areas	0.70
Industrial	
Light areas	0.70
Heavy Areas	0.80
Parks, cemeteries, golf courses	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
Railroad yard areas	0.40
Streets	
Asphalt and concrete	0.95
Brick	0.85
Drives, walks, roofs	0.95

Description of Area	Runoff Coefficient
Gravel areas	0.50
Unimproved areas	0.30
Graded with no plant cover	
Sandy soil, flat, < 2%	0.30
Sandy soil, average, 2-7%	0.40
Clay soil, flat, < 2%	0.50
Clay soil, average, 2-7%	0.60

* These recommended C values are applicable for 5- to 10-year frequency storms. Less frequent, higher intensity storms require the use of higher coefficients because infiltration and other losses have a proportionally smaller effect on the runoff.

Table 5-2. Recommended Rational Method Runoff Coefficient (C) Values* for Rural Areas

Description of Area	Runoff Coefficient For Hydrologic Soil Groups			
	HSG A	HSG B	HSG C	HSG D
Woodland				
Flat, 0-5% slope	0.10	0.10	0.30	0.40
Rolling, 5-10% slope	0.25	0.25	0.35	0.50
Hilly 10-30% slope	0.30	0.30	0.50	0.60
Pasture				
Flat, 0-5% slope	0.10	0.10	0.30	0.40
Rolling, 5-10% slope	0.16	0.16	0.36	0.55
Hilly 10-30% slope	0.22	0.22	0.42	0.60
Cultivated Bare Soil				
Flat, 0-5% slope	0.30	0.30	0.50	0.60
Rolling, 5-10% slope	0.40	0.40	0.60	0.70
Hilly 10-30% slope	0.52	0.52	0.72	0.82

* These recommended C values are applicable for 5- to 10-year frequency storms. Less frequent, higher intensity storms require the use of higher coefficients because infiltration and other losses have a proportionally smaller effect on the runoff.

5.2.1.3. Rainfall Intensity, I

The rainfall intensity factor, I, is presented in Appendix A.

5.2.1.4. Time of Concentration

The time of concentration (T_c) shall be determined by calculating the time for a particle of water to travel from the hydraulically most remote point of the project area to the point of interest. The time of concentration shall be calculated using the SCS TR-55 method procedure that is discussed in Section 5.2.3.

The storm duration for computational purposes for this method shall be equal to the time of concentration (T_c) of the contributing drainage area, with a minimum time of concentration equal to 0.1 hours (six minutes).

5.2.1.5. Infrequent Storms

The Ration Method runoff coefficients given in Tables 5-1 and 5-2 are applicable for 5- to 10-year frequency storm events. Less frequent, higher intensity storms require the use of higher coefficients because infiltration and other losses have a proportionally smaller effect on the runoff. The adjustment of the rational method for use with major storms can be made by multiplying the runoff coefficient by a frequency factor, C_f.

For infrequent storm events, the rational equation is then expressed as:

$$Q = C_f CIA$$

Where C_f is a frequency factor based on recurrence interval given in Table 5-3.

Table 5-3. Runoff Coefficient Frequency Factors

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

* The product of C_f times C shall not exceed 1.0.

5.2.2 Natural Resource Conservation Service (NRCS) Curve Number (CN) Method

The Natural Resource Conservation Service (NRCS) Curve Number (CN) Method, also known as the Soil Conservation Service (SCS) CN Method requires the following basic data that is similar to the Rational Method:

- Total drainage area of watershed or sub-basin.
- Runoff factor defined by a Curve Number (CN)
- Time of concentration (T_c).
- Rainfall data.

The SCS CN Method is more sophisticated than the Rational Method in that it also considers the following:

- Time of distribution of the rainfall.
- Initial rainfall losses due to interception and depression storage.
- Infiltration rates.

The SCS CN Method begins with a rainfall amount uniformly imposed on the watershed over a specified time distribution. Mass rainfall is converted to mass runoff by using a runoff CN that is based on soil type, plant cover, amount of impervious areas, interception, and surface storage. Runoff is then transformed into a hydrograph by using unit hydrograph theory and routing procedures that depend on runoff travel time through segments of the watershed.

The SCS Method shall be used to determine stormwater runoff peak flow rates, runoff volumes, and the generation of hydrographs for the routing of storm flows in urban areas and project sites where:

- The total drainage area is greater than 20 acres, the SCS CN Method must be used.
- The total drainage area is less than 20 acres, the SCS CN Method may be used.
- Runoff volume is required.
- Routing is required.
- The design of storage facilities and outlet structure is required.

When these project conditions exist, the design professional shall use the SCS Method in model form (any computer software program that utilizes TR-20, TR-55 or similar NRCS (or SCS) based runoff computations) or complete the calculations by hand using the various equations and charts listed in this section of the Design Manual.

5.2.2.1. Calculating Runoff Volume

The total runoff volume for a designated watershed or sub-basin for a particular storm event can be calculated using the SCS CN Method by using the following equation:

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

Where Q is the total runoff volume for the specified storm event in inches, P is the rainfall volume for the specified storm event in inches, k_a is a dimensionless coefficient approximated by 0.2, I_a is initial abstraction, and S is the maximum retention after runoff begins defined by the following equation.

$$S = k_s\left(\frac{1000}{CN} - 10\right)$$

Where k_s is the retention depth units conversion factor (1.0 for S in inches, and 25.4 for S in mm), and CN is the SCS CN for the designated watershed.

5.2.2.2. Initial Abstractions

Initial abstractions (I_a) are all losses in the watershed before runoff begins. These abstractions include water retained in surface depressions, water intercepted by vegetation, evaporation and infiltration. I_a is highly variable but generally is correlated with soil and cover parameters. Through the study of many small agricultural watersheds, I_a is approximated by the following empirical equation:

$$I_a = k_a S$$

5.2.2.3. Curve Number

The major factors that determine the SCS CN are cover type, treatment, hydrologic condition, hydrologic soil group (HSG) of the watershed soils, and antecedent moisture condition (AMC). Another factor of consideration is whether impervious areas are directly connected to the system or if the system is unconnected and flows from impervious areas spread over pervious areas before reaching the outfall point. The curve number is similar to the Rational Method C Factor in that it is based on the surface condition of the project site. Values of CN based on land use description can be found in 5-5 for the four Hydrologic Soil Groups (HSGs).

5.2.2.2.1. Hydrologic Soil Groups

Infiltration rates of soils vary widely and are affected by subsurface permeability as well as surface intake rates. Soils can be classified into the following four HSGs base on their minimum infiltration rate:

- HSG A- Soils with a low runoff potential due to high infiltration rates, primarily deep well-drained sands.
- HSG B- Soils with a moderate runoff potential due to moderate infiltration rates, primarily moderately deep to deep with coarse to moderately fine textures.
- HSG C- Soils having a moderately high runoff potential due to low infiltration rates, primarily moderately fine to fine textures.
- HSG D- Soils having a high runoff potential due to very low infiltration rates, predominantly clay soils or soils with high water tables.

5.2.2.2.2. Urban Impervious Area Modifications

Several factors, such as the percentage of impervious area and the means of conveying runoff from impervious areas to the drainage system, should be considered when computing the CN for urban areas.

- Connected Impervious Areas: An impervious area is considered connected if runoff from it flows directly into the storm drainage system. It is also considered connected if runoff from the area occurs as concentrated shallow flow that runs over a pervious area and then into a drainage system.

If all of the impervious area is directly connected to the drainage system, but the impervious area percentages or the pervious land use assumptions in Table 5-4 are not applicable, use **Figure 5-1** to compute a composite CN.

For example, Table 5-4 gives a CN of 70 for a ½-acre lot with HSG B soils, with an assumed impervious area of 25 percent. If the lot actually has 20 percent impervious area and a pervious area CN of 61, the composite CN obtained from **Figure 5-1** is 68. The decrease in the CN from 70 to 68 reflects the decrease in the percent impervious area.

- Unconnected Impervious Areas: Runoff from these areas is spread over a pervious area as sheet flow.

- Use **Figure 5-1** (Composite CN) if the total unconnected impervious area is less than 30 percent.

The composite CN can be computed by entering the right half of **Figure 5-1** with the percentage of total impervious area and the ratio of total unconnected impervious are to total impervious area. Then move left to the appropriate pervious CN and read down to find the composite CN.

For example, a ½-acre lot with 25 percent total impervious area (75 percent of that is unconnected) and a pervious CN of 61, the composite CN from **Figure 5-1** is 66.

- Use **Figure 5-1** (Connected Impervious Area) if the total unconnected impervious area is equal to or greater than 30 percent, because the absorptive capacity of the reaming pervious area will not significantly affect runoff.

5.2.2.2.3. Antecedent Moisture Conditions

The index of runoff potential before a storm event is termed the Antecedent Moisture Condition (AMC). The AMC is an attempt to account for the variation in CN at a particular site for various storm conditions. The CNs listed in Table 5-4 are for average AMC II, which are used primarily for design applications. The three AMC classifications are:

- **AMC I-** Little rain or drought conditions preceding rainfall event. The curve numbers for AMC I can be calculated using the following equation:

$$CN_{AMC\,I} = \frac{4.2 \cdot CN_{AMC\,II}}{10 - 0.058 \cdot CN_{AMC\,II}}$$

- **AMC II-** Standard CNs developed from rainfall and runoff data.

- **AMC III-** Considerable rainfall prior to rain event in question. The curve numbers for AMC III can be calculated using the following equation:

$$CN_{AMC\,III} = \frac{23 \cdot CN_{AMC\,II}}{10 - 0.13 \cdot CN_{AMC\,II}}$$

Table 5-4. Recommended Runoff Curve Number Values

Source: Soil Conservation Service (1986) **Land Use Description:**	Hydrologic Soil Group			
	A	**B**	**C**	**D**
Cultivated Land				
Without conservation treatment	72	81	88	91
With conservation treatment	62	71	78	81
Pasture or Range Land				
Poor condition: < 50% ground cover	68	79	86	89
Good condition: > 75% ground cover	39	61	74	80
Meadow of Continuous Grass Protected from Grazing	30	58	71	78

Wood or Forest Land				
Poor: forest litter, small trees, and brush are regularly cleared	45	66	77	83
Fair: grazed with some forest litter covering the soil	36	60	73	79
Good: no grazing, litter and brush adequately cover the soil	30	55	70	77
Open Spaces (lawns, parks, golf courses, and cemeteries)				
Poor: grass cover > 50%	68	79	86	89
Fair: grass cover from 50% to 75%	49	69	79	84
Good: grass cover > 75%	39	61	74	80
Impervious Areas				
Paved parking lots, roofs, and driveways	98	98	98	98
Streets and Roads				
Paved curb 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% average impervious area)	89	92	94	95
Industrial (72% average impervious area)	81	88	91	93
Residential Districts by Lot Size				
1/8 acre or less, townhomes (65% average impervious area)	77	85	90	92
¼ acre (38% average impervious area)	61	75	83	87
1/3 acre (30% average impervious area)	57	72	81	86
½ acre (25% average impervious area)	54	70	80	85
1 acre (20% average impervious area)	51	68	79	84
2 acres (12% average impervious area)	46	65	77	82
Developing Urban Areas, Newly Graded Areas with no Vegetation	77	86	91	94

* The average percent impervious areas shown were used to develop the composite CNs for the described land use. The impervious areas are assumed to be directly connected to the drainage system, with the impervious areas having a CN of 98 and the pervious areas being equivalent to open space in good hydrologic condition. If the impervious area is not connected, the SCS method has an adjustment to reduce the effect.

5.2.3 Time of Concentration

5.2.3.1. Definition

The time of concentration (T_c) is defined as being the time it takes runoff to travel from the hydraulically most distant or remote point of a watershed or sub-basin to the point of interest within the watershed or sub-basin. Therefore, the time of concentration is the time for water to travel through the watershed, which is not always the maximum distance of flow through the watershed to the outlet point. The time of concentration is computed by summing all the travel times for consecutive components of the watershed's drainage conveyance system. The time of concentration influences the shape and peak of the runoff hydrograph. Urbanization and land development usually decreases the T_c, thereby increasing the peak discharge.

5.2.3.2. Minimum Time of Concentration

The minimum time of concentration (T_c) used for the SCS CN Method and TR 55 application is 0.1 hours (six minutes).

5.2.3.3. Factors Affecting the Time of Concentration

One of the most significant effects of urbanization and land development on flow velocity is the reduction of the natural flow retardance produced by vegetation. Land development typically modifies undeveloped areas originally having shallow overland flow through vegetation. These modifications include adding roads, curb and gutters, and storm sewers that transport runoff downstream more rapidly than the existing pre-development conditions. Therefore, the T_c for the entire watershed is generally decreased due to the effects of urbanization and land development.

5.2.3.4. Calculating the Time of Concentration

Water will travel through a sub-basin
in one, or a combination of the following forms:

- Overland Sheet Flow
- Shallow Concentrated Flow
- Open Channel Flow

The type of flow that occurs at a particular point in the watershed is a function of land cover, flow depth, and the conveyance system present.

The total time of concentration is the sum of the various consecutive overland sheet, shallow concentrated, and open channel flow segments. The actual time of concentration shall be the longest travel time when all possible flow paths are considered.

$$T_c = T_{t,i} + T_{t,i+1} + \ldots + T_{t,n}$$

Where T_c is the time of concentration, and T_t is the travel time over segment i.

5.2.3.2.1 Overland Sheet Flow

Overland sheet flow is flow over plane surfaces. It usually occurs in the headwater area of stream watersheds, and in wooded and vegetated areas. When examining sheet flow, Manning's Roughness Coefficient for Sheet Flow is the major resistant factor that includes:

- Effects of raindrop impact,
- Drag over the plane surface,
- Obstacles such as litter, crop ridges, and rocks,
- Erosion,
- Sediment transport, and
- Very shallow sheet flow depths not much greater than 0.1-feet.

Manning's kinematic solution to compute the travel time for sheet flow is defined by the following equation:

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

Where "n" is Manning's Roughness Coefficient from Table 5-5, L is the flow length in feet (maximum 100 feet unless specific considerations are made), P_2 is the 2-yr, 24-hr rainfall depth in inches, and S is the slope of the hydraulic grade line (land slope) in ft/ft.

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

- The flow is shallow steady uniform flow,
- Constant intensity if rainfall excess (runoff),
- Maximum flow length of 100-feet,
- Rainfall duration of 24-hours; and,
- Minor effect of infiltration on the travel time for sheet flow.

Table 5-5. Manning's Roughness Coefficient for Sheet Flow

Surface Description: Source: Soil Conservation Service, (1986)		Manning's Sheet Flow "n"
Smooth Surfaces (concrete, asphalt, gravel, 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	0.24
	Bermuda Grass	0.41
Range (natural)		0.13
Woods	Light underbrush	0.40
	Medium underbrush	0.60
	Dense underbrush	0.80

5.2.3.2.2 Shallow Concentrated Flow

After a maximum of 300-feet of flow, sheet flow becomes shallow concentrated flow. The average velocity for this flow can be determined from **Figure 5-2**, in which the average velocity is a function of watercourse slope and type of channel. Flow may not always be directly down the watershed slope if tillage or contours run across the slope.

After the average velocity of the flow is determined from **Figure 5-2**, the following equation can be used to estimate the travel time for the shallow concentrated flow segment.

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

Where V is the average velocity (ft/sec) from **Figure 5-2**.

5.2.3.2.3 Open Channel Flow

Open channel flow occurs when shallow concentrated flows reach visible channels that have obtainable dimensions, depths and sizes. These channels may include, but are not limited to:

- Diversion,
- Swales,
- Paved gutters,
- Road side ditches,
- Intermittent streams,
- Perennial blue line streams that appear on USGS quadrangle sheets, and
- Storm sewer pipes

The average flow velocity in the open channels is calculated by using Manning's equation:

$$V = \frac{1.486}{n} R^{2/3} S^{1/2}$$

Where R is the hydraulic radius (ft) calculated as the cross-sectional area (A) over the wetted perimeter (P) of the channel. The wetted perimeter is the length of the perimeter of the cross section that is in contact with water.

Once the average flow velocity is calculated, the travel time for the open channel flow segment is then calculated in the same manner as the shallow concentrated flow.

5.3 Rainfall

One of the most important steps in hydrologic analysis of a watershed or sub-basin is estimating the amount of rainfall that will fall on the particular site for a given time period. The amount of rainfall can be defined by the following characteristics.

- Duration (hours): The length of time over which storm events occur.
- Depth (inches): The total amount of rainfall occurring during the storm duration.
- Intensity (inches per hour): The average rainfall rate.

The frequency of a rainfall event is the recurrence interval of storms having the same duration and volume. The frequency can be defined either in terms of exceedance probability or return period.

<u>Exceedance probability</u>- The probability that a storm event having the specified duration and volume will be exceeded in one given period, typically one year.

<u>Return period</u>- The average length of time between storm events that have the same duration and volume.

Therefore, if a storm event with a specified duration and volume has a 10 percent chance of occurring in any one year, then it has an exceedance probability of 0.1 and a return period of 10-years.

5.3.1 Rainfall Intensity

The rainfall intensity factor, I, is shown in Appendix A.

5.3.2 Rainfall Depth

The corresponding 24-hour rainfall depths (inches) for the 1, 2, 5, 10, 25, 50, and 100-year frequency storm events is provided in Appendix A.

5.4 Graphical Peak Discharge Method

5.4.1 Equation

This section presents the graphical peak discharge method for computing peak discharge rates using the SCS methodology. The graphical method was developed from the hydrograph analysis using TR-20, Computer Program for Project Formulation Hydrology (SCS 1983). This same methodology is available in current computer software programs, therefore TR-20 is not required to calculate the peak discharge. The peak discharge equation used is:

$$q_p = q_u AQF$$

Where $\mathbf{q_p}$ is the peak discharge in cfs, $\mathbf{q_u}$ is the unit peak discharge in CSM/in given in **Figure 5-3**, **A** is the drainage area in square miles, and **F** is the pond swamp adjustment factor given in Table 5-6.

The input requirements for the graphical method are as follows:

- Time of concentration (T_c hours)
- Drainage area (square miles)
- Appropriate rainfall distribution (Type II for Greenville County)
- Storm frequency 24-hour rainfall (inches)
- Drainage area applicable curve numbers

If pond and swamp areas are spread throughout the watershed and not considered in the time of concentration (T_c) computations, an adjustment for the pond and swamp factor must be included.

5.4.2 Calculating the Peak Discharge

The following items must be obtained to calculate peak discharges using the SCS methodology:

- **P:** For a selected rainfall frequency, the 24-hour rainfall (P in inches) should be read from Appendix A

- **Q:** The total runoff (Q in inches) for the watershed or sub-basin shall be calculated using the steps found in Section 5.2.2.1.

- **CN:** The curve number (CN) for the watershed or sub-basin shall be calculated using the steps found in Section 5.2.2.2.

- **I_a:** The initial abstractions (I_a) shall be calculated using the steps found in Section 5.2.2.2.

- **I_a/P:** The initial abstraction to rainfall ratio (I_a/P) shall be computed.

- **T_c:** Time of concentration (T_c) shall be calculated using the steps found in Section 5.2.3.

If the I_a/P ratio computed is outside the range of **Figure 5-3**, then the limiting value shall be used. If the I_a/P ratio falls between the limiting values of **Figure 5-3**, linear interpolation shall be used.

The peak discharge per square mile per inch of runoff q_u (unit peak discharge csm/in) is obtained from **Figure 5-3** by identifying the point where the I_a/P ratio and the T_c (hours) intersect.

If applicable, the pond and swamp adjustment factor shall be obtained from Table 5-6.

Table 5-6. Pond and Swamp Adjustment Factor

Watershed Percentage of Pond and Swamp	Adjustment Factor F_p
0.0	1.00
0.2	0.97
1.0	0.87
3.0	0.75
5.0	0.72

The peak discharge may then be calculated using the equation in Section 5.4.1.

5.4.3 Limitations and Assumptions of the Graphical Method

The graphical method has the following assumptions and limitations:

- The graphical method calculates peak discharge rate (cfs) only. If a hydrograph is needed, the tabular hydrograph method may be used or any approved hydrograph-based computer model may be used.
- The watershed or sub-basin is assumed to be hydrologically homogeneous.
- The weighted CN calculated for the watershed or sub-basin should be greater than 40.
- The watershed or sub-basin is assumed to have only one main stream or, if more than one, the branches must have similar times of concentration.
- The graphical method cannot perform reservoir routing calculations.
- The time of concentration used shall range from 0.1 to 10 hours.
- Accuracy of the peak discharge calculated will be reduced if values are used outside the range given in **Figure 5-3**. The limiting I_a/P values shall be used in these circumstances.

5.5 Unit Hydrograph Method

In addition to estimating runoff volumes and peak discharge rates, the SCS methodology can be used to estimate the entire hydrograph for a watershed or sub-basin. SCS has developed a tabular hydrograph procedure that can be used to generate hydrographs for small drainage areas less than 2,000 acres. The tabular hydrograph procedure uses the unit discharge hydrographs that have been generated for a series of time of concentrations. A unit hydrograph represents the time of flow resulting from one inch of direct runoff occurring over the watershed in a specified period of time. In addition, SCS has developed hydrograph procedures to be used to generate composite flood hydrographs. When hydrographs need to be generated from separate sub-basin areas and then routed and combined at a point downstream, the design professional is referred to the procedures by the SCS in the 1986 version of TR-55 or other current computer software that utilize the techniques used in TR-55.

The development of a runoff hydrograph from a watershed is a tedious, laborious process not normally performed by hand because of the simplicity of current computer model applications. For that reason, only an overview of the process is outlined in this Design Manual to assist the design professional in reviewing and understanding the input and output from typical computer hydrograph generation programs and models.

5.5.1 Basin Lag Time

Characteristics of the dimensionless hydrograph vary with size, shape, and slope of the tributary drainage area. The most significant characteristics affecting the dimensionless hydrograph shape are the basin lag and the peak discharge for a given rainfall. Basin lag in this application is defined as being the time from the center of mass of rainfall excess to hydrograph peak. The following equation is used to determine basin lag time:

$$T_L = 0.6 \cdot T_C$$

Where T_L is the basin lag time in hours (T_c also specified in hours).

5.5.2 Hydrograph Time to Peak

The time to peak is calculated from the basin lag time by:

$$T_p = (D/2) + T_L$$

Where T_p is the time to peak in hours, D is the duration of excess unit rainfall calculated as $0.4T_L$, where T_L is given in hours.

5.5.3 Peak Rate Factors

The unit hydrograph equations used in the SCS method for generating hydrographs includes a constant to account for the general land slope in the drainage basin. The constant is commonly referred to as the peak rate factor, and can be adjusted to match the characteristics of the basin. A default value of 484 for the peak rate factor represents rolling hills and a medium level of relief. SCS indicates that for mountainous terrain the peak rate factor can reach values as high as 600, and as low as 300 for flat and/or coastal areas.

For general calculations, the SCS unit hydrograph method can be used without modifications assuming a peak rate factor of 484.
The SCS method can be modified with a peak rate factor of 300 when watersheds are flat and have significant storage in the overbanks. These watersheds generally have the following characteristics:

- Mild slopes less than 2 percent.
- Significant surface storage throughout the watershed in the form of standing water during storm events or inefficient drainage systems.

Unit hydrograph time and discharge ratios are shown in Table 5-7 for peak discharge factors of 484 and 300. The SCS unit hydrograph method develops incremental hydrographs for small durations of the total design storm. These incremental hydrographs are then combined into a composite hydrograph for the drainage area.

For ease of spreadsheet development and calculations, the dimensionless unit hydrograph time and discharge ratios can be approximated by the following equation (Haan 1970):

$$\frac{q}{q_p} = \left[\frac{t}{T_p} e^{\left(1 - \frac{t}{T_p}\right)} \right]^k$$

Where q/q_p is the discharge ratio, t/T_P is the Time ratio, and K is a dimensionless parameter based on watershed characteristics and hydrograph shape.

K has the following approximate values:

- K = 3.77 for the dimensionless SCS unit hydrograph.
- K = 3.79 for a watershed having a peak rate factor of 484.
- K = 1.50 for a watershed having a peak rate factor of 300.

5.5.4 Peak Discharge and Unit Hydrograph Development

The peak discharge q_p is calculated from the following equation:

$$q_p = \frac{PRF \cdot A}{T_p}$$

Where PRF is the Peak Rate Factor (typ. 484 or 300), A is the drainage area in Square Miles, and T_p is the Time to Peak in hours.

To develop the actual unit hydrograph from the dimensionless unit hydrograph involves the following steps:

- Estimating rainfall from the 24-hour storm event,
- Estimating total rainfall excess by incorporating initial abstraction and curve numbers,
- Estimating the unit hydrograph time parameter ratios,
- Estimating the unit hydrograph peak flow rate (q_p),

- Multiplying each time ratio value (t/T_P) by the actual time to peak (T_P), and
- Multiplying each discharge ratio (q/q_p) by the peak flow rate (q_p).

Table 5-7 Dimensionless Unit Hydrographs

	484		300	
t/Tt	q/qu	Q/Qp	q/qu	Q/Qp
0.0	0.000	0.000	0.000	0.000
0.1	0.005	0.000	0.122	0.006
0.2	0.046	0.004	0.296	0.019
0.3	0.148	0.015	0.469	0.041
0.4	0.301	0.038	0.622	0.070
0.5	0.481	0.075	0.748	0.105
0.6	0.657	0.125	0.847	0.144
0.7	0.807	0.186	0.918	0.186
0.8	0.916	0.255	0.966	0.231
0.9	0.980	0.330	0.992	0.277
1.0	1.000	0.406	1.000	0.324
1.1	0.982	0.481	0.993	0.370
1.2	0.935	0.552	0.974	0.415
1.3	0.867	0.618	0.945	0.459
1.4	0.786	0.677	0.909	0.501
1.5	0.699	0.730	0.868	0.541
1.6	0.611	0.777	0.823	0.579
1.7	0.526	0.817	0.775	0.615
1.8	0.447	0.851	0.727	0.649
1.9	0.376	0.879	0.678	0.680
2.0	0.312	0.903	0.631	0.710
2.1	0.257	0.923	0.584	0.737
2.2	0.210	0.939	0.539	0.762
2.3	0.170	0.951	0.496	0.785
2.4	0.137	0.962	0.455	0.806
2.5	0.109	0.970	0.416	0.825
2.6	0.087	0.977	0.380	0.843
2.7	0.069	0.982	0.346	0.859
2.8	0.054	0.986	0.314	0.873
2.9	0.042	0.989	0.285	0.886
3.0	0.033	0.992	0.258	0.898
3.1	0.025	0.994	0.233	0.909
3.2	0.020	0.995	0.211	0.919
3.3	0.015	0.996	0.190	0.928
3.4	0.012	0.997	0.171	0.936
3.5	0.009	0.998	0.153	0.943

	484		300	
t/Tt	q/qu	Q/Qp	q/qu	Q/Qp
3.6	0.007	0.998	0.138	0.949
3.7	0.005	0.999	0.124	0.955
3.8	0.004	0.999	0.111	0.960
3.9	0.003	0.999	0.099	0.965
4.0	0.002	1.000	0.089	0.969
4.1			0.079	0.972
4.2			0.071	0.976
4.3			0.063	0.979
4.4			0.056	0.981
4.5			0.050	0.984
4.6			0.044	0.986
4.7			0.039	0.987
4.8			0.035	0.989
4.9			0.031	0.990
5.0			0.028	0.992
5.1			0.024	0.993
5.2			0.022	0.994
5.3			0.019	0.995
5.4			0.017	0.996
5.5			0.015	0.996
5.6			0.013	0.997
5.7			0.012	0.997
5.8			0.010	0.998
5.9			0.009	0.998
6.0			0.008	0.999
6.1			0.007	0.999
6.2			0.006	0.999
6.3			0.006	1.000

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