2. HYDROLOGY

2.1 Overview

Hydrology is the study of the movement and distribution of water. Runoff is the drainage that leaves an area as surface flow or pipeline flow. Hydrologic analysis is necessary to estimate the peak runoff rate and volume of runoff that a drainage structure will be required to convey or control. Methods for computing peak rates of runoff and criteria for determining design storm frequencies are included in this section. Because these methods only estimate runoff, stream gage or other historical flood data should be used by designers (when available) to calibrate or correlate calculated estimates of runoff.

2.1.1 Hydrologic Method Selection

Several hydrologic methods have been developed for estimating peak runoff quantities. This section presents the two methods recommended for computing peak runoff; the rational method and the Natural Resources Conservation Service (NRCS) unit hydrograph method. It is recommended that each of the two methods be limited to use within a given drainage basin size, as detailed below. If a drainage basin greater than the recommended size for the NRCS unit hydrograph method is encountered, NDOT regression equations are recommended for computing peak runoff per the most recent version of the NDOT Drainage Design and Erosion Control Manual.

The rational method can only be used to estimate the peak runoff of a drainage basin. This is its only use; the rational method cannot be used to derive a runoff hydrograph or for the design of a storage facility.

Table 2-1. Recommended Hydrologic Methods

Method	Size Limitations[1]	Comments
Rational	0 to 200 Acres	Method can be used for estimating peak flow only. Method shall not be used for the design of storage facilities (See NRCS Method below for storage facility design).
NRCS[2] Unit Hydrograph	200 Acres to 10 Square Miles	Method can be used for estimating peak flow and developing hydrographs. Method shall be used for the design of all storage facilities regardless of sub-basin size.
NDOT Regression Equations	Greater Than 10 Square Miles	Refer to the most recent version of the NDOT Drainage Design and Erosion Control Manual for all design criteria for regression equations.

[1] Size limitations refer to the sub-basin size to the point where the stormwater management facility (i.e., culvert, inlet) is located.

[2] The NRCS was previously called the Soil Conservation Service (SCS), and many of the methods detailed by the NRCS are still commonly referred to as SCS Methods. For the purposes of this manual, all methods will be referred to as NRCS methods.

2.1.2 Frequency Design Criteria

Since it generally is not economically feasible to design a structure for the maximum runoff a watershed is capable of producing, design frequency criteria must be established. The design frequency criteria for common stormwater management facilities is summarized in Table 2-2.

Table 2-2. Design Frequency Criteria

Stormwater Management Facility	Design Frequency
Pavement Drainage/Inlets/Storm Sewer	10 Year Commercial/Industrial, 5 Year Residential
Culverts/Pavement Cross Drainage (Major System)	50 Year
Culverts (Minor System[1])	10 Year
Open Channels (Major System)	100 Year
Open Channels (Minor System[1])	10 Year
Storage Facilities	2, 10 & 100 Year
Temporary Facilities[2]	2 Year

[1] Culverts and open channels for the minor system run parallel to the roadway and are used to drain the roadway in lieu of a storm sewer system. No culvert that crosses a public roadway is considered to be part of the minor system.

[2] These facilities shall remain in place no longer than two years.

In some cases, particularly in municipalities located in extremely flat terrain, the 10-year commercial/industrial and 5-year residential design frequency for storm sewer may be impractical to obtain. In these cases, consideration may be given for design frequencies as low as 2-years. City approval must be obtained in these cases.

2.2 Rational Method

The rational method is the most commonly used method to estimate the peak runoff of a drainage basin. It can be used to estimate the peak runoff for areas as large as 200 acres.

2.2.1 Concept and Equation

The rational method estimates the peak rate of runoff at any location in a watershed as a function of the drainage area, runoff coefficient, and mean rainfall intensity for a duration equal to the time of concentration. The rational method is based on the following formula:

$$Q = CIA$$

Where:

$Q = Discharge\ Occurring\ at\ the\ Time\ of\ Concentration, cfs$
$C = Runoff\ Coefficient$
$I = Average\ Rainfall\ Intesity\ for\ a\ Duration\ Equal\ to\ the\ Time\ of\ Concentration, in/hr$
$A = Drainage\ Area, acres$

2.2.2 Application

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

2.2.2.1 Time of Concentration

The time of concentration (Tc) is the time required for water to flow from the hydraulically most remote point of the drainage area to the design point. The duration of rainfall is set equal to the Tc and is used to estimate the rainfall intensity. In some cases, for a basin with highly impervious areas, several different Tc's must be calculated to determine the governing design flow. No matter how small a drainage area may be, the time of concentration shall not be shorter than five minutes. See Section 2.2.3 Common Errors and Limitations.

For a storm sewer system, the Tc consists of the inlet time plus the time of flow in a pipe or open channel to the design point. The velocity method from the NRCS is recommended for computing Tc.

The total Tc is:

$$Tc = T_i + T_p$$

Where:

$Tc = Time\ of\ Concentration$
$T_i = Inlet\ Time$
$(Sheet\ Flow\ Plus\ Shallow\ Concentrated\ Flow\ Times, See\ Below)$
$T_p = Time\ in\ Pipe\ or\ Channel$

2.2.2.1.1 Inlet Time

Inlet time is the time required for runoff to flow over the surface to the nearest inlet and is primarily a function of the length of overland flow, the slope of the land and surface cover. Overland flow includes sheet flow and shallow concentrated flow and the total inlet time can be estimated by summing these two components.

Sheet flow time is based on the following formula:

$$T_{sf} = \frac{0.42(nl)^{0.8}}{(P_2)^{0.5} S^{0.4}}$$

Where:

$T_{sf} = Sheet\ Flow\ Time, minutes$
$n = Manning's\ Roughness\ Coefficient$
$l = Sheet\ Flow\ Length, feet$
$P_2 = 2 - Year, 24 - Hour\ Rainfall, inches$
$S = Slope\ of\ Land\ Surface,\ ft/ft$

To avoid inaccurate estimations of sheet flow time, the sheet flow length should be limited according to the following formula, with a maximum sheet flow length of 300 feet. Maximum sheet flow lengths for common surfaces can be found in Table 2-3.

$$l = \frac{100\sqrt{S}}{n}$$

Where:

$l = Limiting\ Length\ of\ Flow, feet$
$n = Manning's\ Roughness\ Coefficient$
$S = Slope, ft/ft$

Table 2-3. Maximum Sheet Flow Lengths

Surface Description	n Value	Slope, ft/ft	Length, ft
Smooth Surface (Concrete, Asphalt, Gravel, Bare Soil)	0.011	0.01	300
Range	0.13	0.01	77
Dense Grass	0.24	0.01	42
Woods (Dense)	0.80	0.01	12.5
Smooth Surface (Concrete, Asphalt, Gravel, Bare Soil)	0.011	0.05	300
Range	0.13	0.05	172
Dense Grass	0.24	0.05	55
Woods (Dense)	0.80	0.05	28

Table 2-4. Manning's Roughness Coefficients for Sheet Flow

Surface Description	n Value
Smooth Surface (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[1]	0.24
Bermudagrass	0.41
Range (Natural)	0.13
Woods[2]	
Light Underbrush	0.40
Dense Underbrush	0.80

[1] Includes species such as weeping lovegrass, bluegrass, buffalo grass, blue grama grass, and native grass mixtures.

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

After a maximum of 300 feet, sheet flow usually becomes shallow concentrated flow with a depth of 0.1 feet to 0.5 feet. The average velocity for shallow concentrated flow can be estimated from the following formulas and shallow concentrated flow time can be determined by dividing the flow length by the average velocity.

Table 2-5. Velocity Equations for Shallow Concentrated Flow

Surface Description	Velocity Equation[1]
Pavement and Small Upland Gullies	$V = 20.328(S)^{0.5}$
Grassed Waterways	$V = 16.135(S)^{0.5}$
Nearly Bare and Untilled Soil	$V = 9.965(S)^{0.5}$
Cultivated Straight Row Crops	$V = 8.762(S)^{0.5}$
Short Grass Pasture	$V = 6.962(S)^{0.5}$
Minimum Tillage Cultivation, Contour or Strip-Cropped and Woodlands	$V = 5.032(S)^{0.5}$
Forest with Heavy Ground Litter and Hay Meadows	$V = 2.516(S)^{0.5}$

[1] $V = Average\ Velocity, ft/s$ $S = Slope\ of\ Land\ Surface, ft/ft$

2.2.2.1.2 Pipe and Open Channel Flow Time

The average velocity for pipe and open channel flow can be estimated from the hydraulic properties of the conduit or channel by using Manning's equation. Pipe and open channel flow time can be determined by dividing the flow length by the average velocity. See Chapters Three and Four for additional discussion on flow in pipes and open channels.

2.2.2.2 Rainfall Intensity

The rainfall intensity is the average rainfall rate (inches per hour) ***for a duration equal to the Tc*** for a selected return period. The rainfall intensity shall be determined from Intensity-Duration-Frequency (IDF) curves shown on Figure 2-1 or the tabular data in Table 2-6. All rainfall intensity data provided was obtained from the National Oceanic and Atmospheric Administration (NOAA) Atlas 14 Point Precipitation Frequency Estimates.

Figure 2-1. Intensity-Duration-Frequency Curves

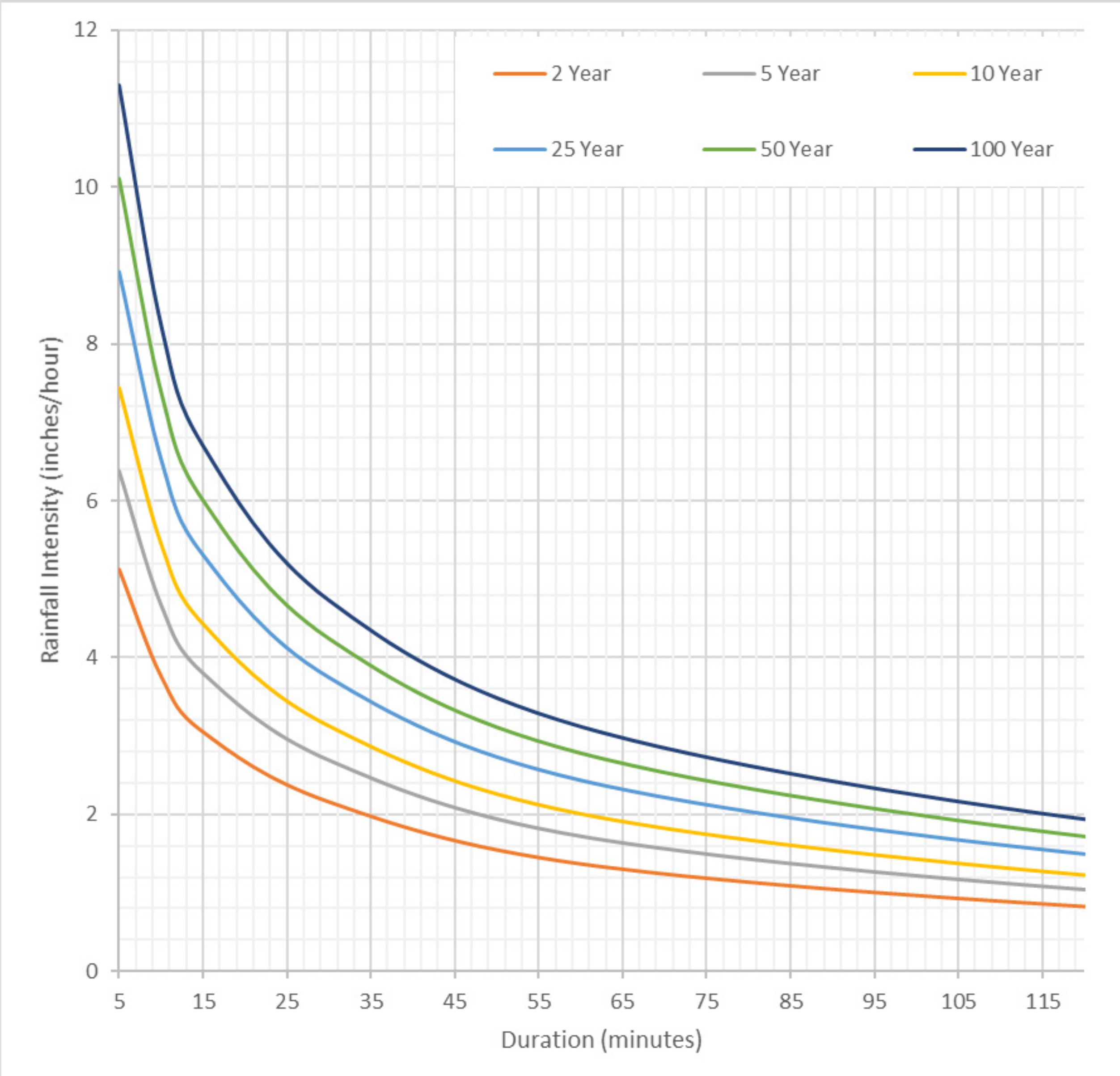


Table 2-6. Rainfall Intensity Tabular Data

Duration	2 Year	5 Year	10 Year	25 Year	50 Year	100 Year
5 Minutes	5.12	6.38	7.44	8.92	10.1	11.3
10 Minutes	3.76	4.67	5.45	6.53	7.38	8.24
15 Minutes	3.05	3.80	4.43	5.31	6.00	6.70
30 Minutes	2.16	2.69	3.13	3.75	4.24	4.73
60 Minutes	1.37	1.72	2.01	2.44	2.78	3.12
2 Hours	0.828	1.04	1.23	1.50	1.72	1.94
3 Hours	0.599	0.758	0.898	1.10	1.27	1.45
6 Hours	0.343	0.433	0.514	0.635	0.735	0.843
12 Hours	0.193	0.241	0.285	0.349	0.403	0.461
24 Hours	0.110	0.136	0.159	0.193	0.222	0.252

2.2.2.3 Runoff Coefficient

The runoff coefficient value in the rational formula is the fraction of rainfall intensity, expressed as a decimal, which contributes to the peak discharge, occurring at the time of concentration. It does not represent how much of the rain becomes runoff. Runoff coefficients vary based on land use, soil type, imperviousness, watershed slope and rainfall intensity/duration. Runoff coefficients should be selected from Table 2-7 or Table 2-8, depending on the land use. Where a drainage area consists of several land uses, a weighted runoff coefficient should be developed to represent the entire area.

Table 2-7. Runoff Coefficients for Developed Areas

Cover Description	Runoff Coefficients for Return Period					
	2	5	10	25	50	100
Asphalt	0.73	0.77	0.81	0.86	0.90	0.95
Concrete/Roof	0.75	0.80	0.83	0.88	0.92	0.97
Grass Areas (Lawns, Parks, etc.)						
Poor Condition (Grass Cover < 50%)						
Flat, 0-2%	0.32	0.34	0.37	0.40	0.44	0.47
Average, 2-7%	0.37	0.40	0.43	0.46	0.49	0.53
Steep, Over 7%	0.40	0.43	0.45	0.49	0.52	0.55
Fair Condition (Grass Cover 50% to 75%)						
Flat, 0-2%	0.25	0.28	0.30	0.34	0.37	0.41
Average, 2-7%	0.33	0.36	0.38	0.42	0.45	0.49
Steep, Over 7%	0.37	0.40	0.42	0.46	0.49	0.53
Good Condition (Grass Cover > 75%)						
Flat, 0-2%	0.21	0.23	0.25	0.29	0.32	0.36
Average, 2-7%	0.29	0.32	0.35	0.39	0.42	0.46
Steep, Over 7%	0.37	0.40	0.42	0.46	0.49	0.53

Cover Description	Runoff Coefficients for Return Period					
	2	5	10	25	50	100
Urban Districts:						
Commercial and Business (85% Impervious)[1]	0.68	0.73	0.76	0.81	0.85	0.89
Industrial (72% Impervious)[1]	0.62	0.67	0.70	0.74	0.78	0.83
Residential Districts by Average Lot Size:						
1/8 Acre or Less (Town Houses) (65% Impervious)[1]	0.59	0.63	0.66	0.71	0.75	0.79
1/4 Acre (38% Impervious)[1]	0.46	0.50	0.53	0.58	0.61	0.65
1/3 Acre (30% Impervious)[1]	0.43	0.46	0.49	0.54	0.57	0.61
1/2 Acre (25% Impervious)[1]	0.41	0.44	0.47	0.51	0.55	0.59
1 Acre (20% Impervious)[1]	0.38	0.42	0.45	0.49	0.52	0.56
2 Acres (12% Impervious)[1]	0.35	0.38	0.41	0.45	0.48	0.52

[1] The average percent impervious shown was used to develop the composite runoff coefficients. Other assumptions are as follows: impervious areas are directly connected to the drainage system, impervious areas are considered equivalent to concrete/roof, and pervious areas are considered equivalent to grass areas in good condition with an average slope.

Table 2-8. Runoff Coefficients for Undeveloped Areas

Cover Description	Runoff Coefficients for Return Period					
	2	5	10	25	50	100
Cultivated Land						
Flat, 0–2%	0.31	0.34	0.36	0.40	0.43	0.47
Average, 2–7%	0.35	0.38	0.41	0.44	0.48	0.51
Steep, Over 7%	0.39	0.42	0.44	0.48	0.51	0.54
Pasture/Range						
Flat, 0–2%	0.25	0.28	0.30	0.34	0.37	0.41
Average, 2–7%	0.33	0.36	0.38	0.42	0.45	0.49
Steep, Over 7%	0.37	0.40	0.42	0.46	0.49	0.53
Forest/Woodlands						
Flat, 0–2%	0.22	0.25	0.28	0.31	0.35	0.39
Average, 2–7%	0.31	0.34	0.36	0.40	0.43	0.47
Steep, Over 7%	0.35	0.39	0.41	0.45	0.48	0.52

2.2.3 Common Errors and Limitations

- In some cases runoff from a portion of the drainage area which is highly impervious may result in a greater peak discharge than would occur if the entire area were considered. In these cases, adjustments can be made to the drainage area by disregarding those areas where flow time is too slow to add to the peak discharge. Sometimes it is necessary to estimate several times of concentration to determine the design flow that is critical for an application.
- When designing a drainage system, the overland flow path is not necessarily perpendicular to the contours shown on available mapping. Often the land will be graded and swales will intercept the natural contour and conduct the water to the streets, which may reduce the time of concentration.
- The rational method only provides estimates of peak runoff. It does not provide information on the volume or timing of runoff. Modern drainage practices often include detention of urban storm runoff to reduce the peak rate of runoff downstream. The rational method is not appropriate for use in design of stormwater detention or storage facilities.

2.3 NRCS Unit Hydrograph Method

The NRCS method uses data similar to the rational method to determine peak discharge, such as drainage area, a runoff factor, time of concentration, and rainfall. However, the technique is more sophisticated in that it also considers the time distribution of the rainfall, the initial rainfall losses to interception and depression storage (initial abstraction), and an infiltration rate that decreases during the course of a storm. It can be used to estimate the peak runoff and runoff volumes for areas from 200 acres up to 10 square miles. The following discussion outlines the basic concepts and equations used in the NRCS method.

2.3.1 Concepts and Equations

The following discussion outlines the basic concepts and equations utilized in the NRCS method. Additional details not included in this manual can be found in the NRCS National Engineering Handbook Hydrology Chapters (Part 630).

2.3.1.1 Rainfall-Runoff

A relationship between accumulated rainfall and accumulated runoff was derived by the NRCS 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:

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

Where:

$Q = Depth\ of\ Direct\ Runoff, inches$
$P = Depth\ of\ Accumulated\ Rainfall$
$or\ Potential\ Maximum\ Runoff, inches$
$I_a = Initial\ Abstraction, inches$
$S = Maximum\ Potential\ Retention, inches$

I_a is highly variable but generally is correlated with soil and cover parameters. Through studies of many small agricultural watersheds, I_a was found to be approximated by the following empirical equation:

$$I_a = 0.2S$$

By substituting 0.2S for I_a, the NRCS runoff equation becomes:

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

S is related to the soil and cover conditions of the watershed through the runoff factor (curve number, see Section 2.3.1.3) by the following equation:

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

2.3.1.2 Rainfall

The NRCS method is based on a 24-hour storm event. Rainfall depths specific for this region to be used for the NRCS method should be selected from Table 2-7and should be used with a Type II rainfall distribution. All rainfall depth data provided was obtained from the National Oceanic and Atmospheric Administration (NOAA) Atlas 14 Point Precipitation Frequency Estimates.

Table 2-9. 24-Hour Accumulated Rainfall Total

Frequency	24-Hour Rainfall, inches
1 Year	2.28
2 Year	2.64
5 Year	3.26
10 Year	3.82
25 Year	4.64
50 Year	5.32
100 Year	6.04

2.3.1.3 Runoff Factor (Curve Number)

The principal physical watershed characteristics affecting the relationship between rainfall and runoff are land use, land treatment, soil types, and land slope. The NRCS method uses a combination of soil conditions and land uses (ground cover) to assign a runoff factor to an area. These runoff factors, called runoff curve numbers (CN), indicate the runoff potential of an area. The higher an area's CN, the higher that area's runoff potential will be. Soil properties influence the relationship between runoff and rainfall since soils have differing rates of infiltration. Based on infiltration rates, the NRCS has divided soils into four hydrologic soil groups (Groups A, B, C, and D), with Group A having the highest infiltration rate and Group D having the lowest infiltration rate. Hydrologic soil groups and other soil properties can be obtained online using the USDA/NRCS Web Soil Survey Tool.

Curve numbers should be selected from Table 2-10 or Table 2-11, depending on the land use. Where a drainage area consists of several land uses, a weighted curve number should be developed to represent the entire area. When land use is expected to change over time, the most conservative land use shall be selected.

Runoff curve numbers vary with antecedent moisture conditions (amount of soil moisture when rainfall occurs). Average antecedent soil moisture conditions (AMC II) are recommended for most hydrologic analysis. All curve numbers shown in this manual reflect an average antecedent soil moisture condition (AMC II).

Table 2-10. Curve Numbers for Developed Areas[1]

Cover Description	Average % Impervious[2]	CN 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
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
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
Developing Urban Areas:					
Newly Graded Areas (Pervious Areas Only, No Vegetation)		77	86	91	94

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

2 The average percent impervious 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 type.

Table 2-11. Curve Numbers for Undeveloped Areas[1]

Cover Description		Hydrologic Condition[3]	CN for Hydrologic Soil Group			
Cover Type	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 (SR)	Poor	72	81	88	91
		Good	67	78	85	89
	SR + CR	Poor	71	80	87	90
		Good	64	75	82	85
	Contoured (C)	Poor	70	79	84	88
		Good	65	75	82	86
	C + CR	Poor	69	78	83	87
		Good	64	74	81	85
	Contoured & 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	SR	Poor	65	76	84	88
		Good	63	75	83	87
	SR + CR	Poor	64	75	83	86
		Good	60	72	80	84
	C	Poor	63	74	82	85
		Good	61	73	81	84
	C + CR	Poor	62	73	81	84
		Good	60	72	80	83
	C&T	Poor	61	72	79	82
		Good	59	70	78	81
	C&T + CR	Poor	60	71	78	81
		Good	58	69	77	80
Close-Seeded or Broadcast Legumes or Rotation Meadow	SR	Poor	66	77	85	89
		Good	58	72	81	85
	C	Poor	64	75	83	85
		Good	55	69	78	83
	C&T	Poor	63	73	80	83
		Good	51	67	76	80
Pasture, Grassland or Range – Continuous Forage for Grazing[4]		Poor	68	79	86	89
		Fair	49	69	79	84
		Good	39	61	74	80

Cover Description		Hydrologic Condition[3]	CN for Hydrologic Soil Group			
Cover Type	Treatment[2]		A	B	C	D
Meadow – Continuous Grass, Protected from Grazing and Generally Mowed for Hay		Good	30	58	71	78
Brush-Forbs-Grass Mixture with Brush the Major Element[5]		Poor	48	67	77	83
		Fair	35	56	70	77
		Good	30[6]	48	65	73
Woods-Grass Combination (Orchard or Tree Farm)[7]		Poor	57	73	82	86
		Fair	43	65	76	82
		Good	32	58	72	79
Woods[8]		Poor	45	66	77	83
		Fair	36	60	73	79
		Good	30	55	70	77
Farmstead – Buildings, Lanes, Driveways and Surround Lots			59	74	82	86
Roads (Including Right-of-Way)	Dirt		72	82	87	89
	Gravel		76	85	89	91

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

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

3 Hydrologic condition is based on combinations 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, (d) percent of residue cover on the land surface (good >20%), and (e) degree of surface toughness.

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 pounds per acre for row crops or 300 pounds per acre for small grain).

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

4 Poor: < 50% ground cover or heavily grazed with no mulch.

Fair: 50 to 75% ground cover and not heavily grazed.

Good: > 75% ground cover and lightly or only occasionally grazed.

5 Poor: < 50% ground cover.
Fair: 50 to 75% ground cover.
Good: > 75% ground cover.

6 If actual curve number is less than 30, use CN = 30 for runoff computation.

7 CNs shown were computed for areas with 50 percent woods and 50 percent grass (pasture) cover. Other combinations of conditions may be computed from the CNs for woods and pasture.

8 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.

2.3.1.4 Time of Concentration

The time of concentration (Tc) is the time required for water to flow from the hydraulically most remote point of the drainage area to the design point. In some cases, for a basin with highly impervious areas several different Tc's must be calculated to determine the governing design flow. See Section 2.2.3 Common Errors and Limitations. For a storm drainage system, the Tc consists of the inlet time plus the time of flow in a pipe or open channel to the design point. The velocity method from the NRCS is recommended for computing Tc. See Section 2.2.2.1 for additional guidance on computing the Tc.

2.3.1.5 Lag Time

Lag time (L) can be considered as a weighted Tc and is related to the physical properties of a watershed, such as area, length, and slope. The NRCS derived the following empirical relationship between L and Tc.

$$L = 0.6Tc$$

Where:

$L = Lag\ Time$

$Tc = Time\ of\ Concentration$

In small urban areas (less than 2,000 acres), a curve number method can be used to estimate watershed lag time. In this method, the lag time for the runoff from an increment of excess rainfall can be considered as the time between the center of mass of the excess rainfall increment and the peak of its incremental outflow hydrograph. The equation developed by the NRCS to estimate lag time is:

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

Where:

$L = Lag\ Time, hours$

$l = Length\ of\ Mainstream\ Flow\ Path\ from$
$Farthest\ Drainage\ Divide\ to\ the\ Outlet$

$S = 1000/CN - 10$

$CN = NRCS\ Curve\ Number$

$Y = Average\ Slope\ of\ Watershed, Percent$

2.3.1.6 NRCS Peak Discharge Calculation

The following NRCS peak discharge equation can be used for estimating the peak runoff rate from a single watershed with homogeneous land use:

$$Q_p = q_u A Q F_p$$

Where:

$Q_p = Peak\ Discharge, cfs$

$q_u = Unit\ Peak\ Discharge, cfs/mi^2\ /in$

A= $Drainage\ Area, mi^2$

$Q = Depth\ of\ Direct\ Runoff, inches$

$F_p = Pond\ and\ Swamp\ Adjustment\ Factor$

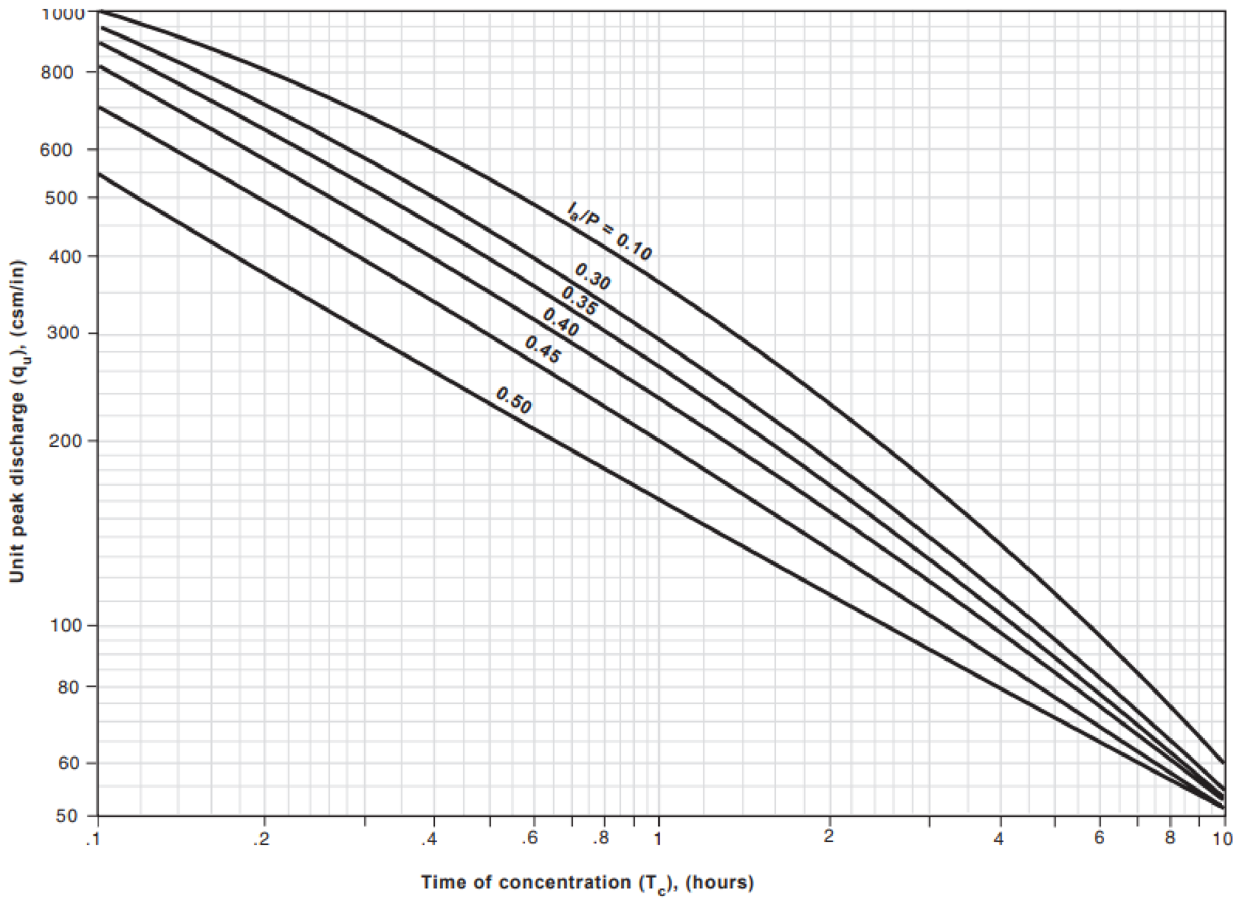
The input requirements are:

1. Time of concentration, Tc (hours)
2. Drainage area (mi^2)
3. 24-hr design rainfall
4. CN value
5. Pond and swamp adjustment factor (use 1.0, see below).

Computations for the peak discharge method proceed as follows:

1. The 24-hr rainfall depth, P, for the design storm is determined from Table 2-7.
2. The runoff curve number (CN) is estimated from Table 2-10 and Table 2-11, with weighted CNs calculated as needed.
3. Direct runoff, Q, is calculated by using the CN to solve for S and substituting into the direct runoff equation in Section 2.3.1.1.
4. CN and S are used to determine initial abstraction (I_a) from the equation given in Section 2.3.1.1.
5. Compute the ratio I_a/P for the return period of the design storm.
6. The drainage area's time of concentration (Tc) is computed using the procedures in Section 2.2.2.1.
7. The computed Tc and I_a/P is used to obtain the unit peak discharge, q_u, from Figure 2-2 below. If the ratio I_a/P lies outside the range shown, use the limiting values.
8. The pond and swamp adjustment factor, F_p, is assumed to be equal to 1.0 (no pond or swamp areas), in order to be conservative.
9. The peak discharge is computed using the equation at the beginning of this section.

Figure 2-2. Unit Peak Discharge, q_u



2.3.1.7 Hydrographs

The NRCS method can be used to estimate the entire hydrograph for a drainage area. From this hydrograph, discharge rates and volumes can be determined. The NRCS has developed a tabular hydrograph procedure that can be used to generate the hydrograph for small drainage areas. The tabular hydrograph procedure uses unit discharge hydrographs that have been generated for a series of times of concentrations. To use the tabular hydrograph procedure, designers should refer to the NRCS National Engineering Handbook Hydrology Chapters (Part 630).

2.4 References

- City of Brookings, South Dakota, 2006. *Storm Drainage Design and Technical Criteria Manual.*
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