Runoff and Peak Flow

A. Introduction

Determining the volume and peak rate of runoff from a site is critical in designing and signing stormwater infrastructure including storm sewer, ditches, culverts, and detention basins. The common methods used to evaluate stormwater runoff include the Rational method for determination of peak flow and SCS methods for determination of both peak flow and runoff volume.

B. Rational Method

The Rational equation is commonly used for design in developed urban areas. The Rational equation is given as:

$$Q_T = Ci_TA$$ **Equation 2B-4.01**

where:

Q_T = estimate of the peak rate of runoff (cfs) for some recurrence interval, T
C = runoff coefficient; fraction of runoff, expressed as a dimensionless decimal fraction, that appears as surface runoff from the contributing drainage area.
i_T = average rainfall intensity (in/hr) for some recurrence interval, T, during that period of time equal to the T_c.
A = the contributing drainage area (acres) to the point of design that produces the maximum peak rate of runoff.
T_c = Time of concentration, minutes.

1. Rational Method Characteristics:

a. When using the Rational formula, an assumption is made that the maximum rate of flow is produced by a constant rainfall, which is maintained for a time equal to the time of concentration, which is the time required for the surface runoff from the most remote part of the drainage basin to reach the point being considered. There are other assumptions used in the Rational method, and thus the designer or engineer should consider how exceptions or other unusual circumstances might affect those results.
   1) The rainfall is uniform in space over the drainage area being considered.
   2) The rainfall intensity remains constant during the time period equal to the time of concentration.
   3) The runoff frequency curve is parallel to the rainfall frequency curve. This implies that the same value of the runoff coefficient is used for all recurrence intervals. In practice, the runoff coefficient is adjusted with a frequency coefficient (Cf) for the 25 year through 100 year recurrence intervals.
   4) The drainage area is the total area tributary to the point of design.

b. The following are additional factors that might not normally be considered, yet could prove important:
   1) The storm duration gives the length of time over which the average rainfall intensity (i_T) persists. Neither the storm duration, nor i_T, says anything about how the intensity varies during the storm, nor do they consider how much rain fell before the period in question.
   2) A 20% increase or decrease in the value of C has a similar effect as changing a 5 year recurrence interval to a 15 year or a 2 year interval, respectively.
   3) The chance of all design assumptions being satisfied simultaneously is less than the chance that the rainfall rate used in the design will actually occur. This, in effect, creates a built-in factor of safety.
   4) In an irregularly-shaped drainage area, a part of the area that has a short time of concentration (T_c) may cause a greater runoff rate (Q) at the intake or other design point) than the runoff rate calculated for the entire area. This is because parts of the area with long concentration times are far less susceptible to high-intensity rainfall. Thus, they skew the calculation.
   5) A portion of a drainage area that has a value of C much higher than the rest of the area may produce a greater amount of runoff at a design point than that calculated for the entire area. This effect is similar to that described above. In the design of storm sewers for small subbasin areas such as a cul-de-sac in a subdivision, the designer should be aware that an extremely short time of concentration will result in a high estimate of the rainfall intensity and the peak rate of runoff. The time of concentration estimates should be checked to make sure they are reasonable. For most applications, a minimum T_c of 15 minutes may be assumed.
   6) 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 was considered. In these cases, adjustments can be made to the drainage area by disregarding those areas where flow time is too slow to add to the peak discharge. Sometimes it is necessary to estimate several different times of concentration to determine the design flow that is critical for a particular application.
   7) When designing a drainage system, the overland flow path is not necessarily the same before and after development and grading operations have been completed. Selecting overland flow paths in excess of 100 feet in urban areas and 300 feet in rural areas should be done only after careful consideration.

2. Rational Method Limitations: The use of the rational formula is subject to several limitations and procedural issues in its use.

a. The most important limitation is that the only output from the method is a peak discharge (the method provides only an estimate of a single point on the runoff hydrograph).

b. The average rainfall intensities used in the formula have no time sequence relation to the actual rainfall pattern during the storm.

c. The computation of T_c should include the overland flow time, plus the time of flow in open and/or closed channels to the point of design.

d. The runoff coefficient, C, is usually estimated from a table of values (see Table 2B-4.01). The user must use good judgment when evaluating the land use in the drainage area under consideration. Note in Table 2B-4.01, that the value of C will vary with the return frequency.

e. Many users assume the entire drainage area is the value to be entered in the Rational method equation. In some cases, the runoff from the only interconnected impervious area yields the larger peak flow rate.

f. Studies and experience have shown that the Rational method tends to underestimate runoff rates for large drainage areas. This is due, in part, to the fact that a difference can exist between intense point rainfall (rainfall over a small area) and mean catchment area rainfall (average rainfall). For these reasons, use of the Rational method should be limited to drainage areas 40 acres or less.

3. Use of the Rational Method:

a. Runoff Coefficient: The runoff coefficient (C) represents the integrated effects of infiltration, evaporation, retention, flow routing, and interception; all of which affect the time distribution and peak rate of runoff. The runoff coefficient is the variable of the Rational method that requires the most judgment and understanding on the part of the designer. While engineering judgment will always be required in the selection of runoff coefficients, a typical coefficient represents the integrated effects of many drainage basin parameters. The Engineer should realize the C values shown in Table 2B-4.01 are typical values, and may have to be adjusted if the site deviates from typical conditions such as an increase or decrease in percent impervious.

The values are presented for different surface characteristics, as well as for different aggregate land uses. The coefficient for various surface areas can be used to develop a composite value for a different land use. The runoff values for business, residential, industrial, schools, and railroad yard areas are an average of all surfaces typically found in the particular land use.

The hydrologic soil groups used in Table 2B-4.01 are discussed in detail later in this section.

Table 2B-4.01: Runoff Coefficients for the Rational Method

Cover Type and Hydrologic Condition		Runoff Coefficients for Hydrologic Soil Group											
		A			*B*			*C*			*D*		
	Recurrence Interval	***5***	***10***	***100***	***5***	***10***	***100***	***5***	***10***	***100***	***5***	***10***	***100***
Open Space (lawns, parks, golf courses, cemeteries, etc.)													
Poor condition (grass cover < 50%)		.25	.30	.50	.45	.55	.65	.65	.70	.80	.70	.75	.85
Fair condition (grass cover 50% to 75%)		.10	.10	.15	.25	.30	.50	.45	.55	.65	.60	.65	.75
Good condition (grass cover >75%)		.05	.05	.10	.15	.20	.35	.35	.40	.55	.50	.55	.65
Impervious Areas													
Parking lots, roofs, driveways, etc. (excluding ROW)		.95	.95	.98	.95	.95	.98	.95	.95	.98	.95	.95	.98
Streets and roads:													
Paved; curbs & storm sewers (excluding ROW)		.95	.95	.98	.95	.95	.98	.95	.95	.98	.95	.95	.98
Paved; open ditches (including ROW)		---	---	---	.70	.75	.85	.80	.85	.90	.80	.85	.90
Gravel (including ROW)		---	---	---	.60	.65	.75	.70	.75	.85	.75	.80	.85
Dirt (including ROW)		---	---	---	.55	.60	.70	.65	.70	.80	.70	.75	.85
Urban Districts (excluding ROW)													
Commercial and business (85% impervious)		---	---	---	---	---	---	.85	.85	.90	.90	.90	.95
Industrial (72% impervious)		---	---	---	---	---	---	.80	.80	.85	.80	.85	.90
Residential Districts by Average Lot Size (excluding ROW)[1]													
1/8 acre (36% impervious)		---	---	---	---	---	---	.55	.60	.70	.65	.70	.75
1/4 acre (36% impervious)		---	---	---	---	---	---	.55	.60	.70	.65	.70	.75
1/3 acre (33% impervious)		---	---	---	---	---	---	.55	.60	.70	.65	.70	.75
1/2 acre (20% impervious)		---	---	---	---	---	---	.45	.50	.65	.60	.65	.70
1 acre (11% impervious)		---	---	---	---	---	---	.40	.45	.60	.55	.60	.65
2 acres (11% impervious)		---	---	---	---	---	---	.40	.45	.60	.55	.60	.65
Newly Graded Areas (pervious areas only, no vegetation)													
Agricultural and Undeveloped													
Meadow - protected from grazing (pre-settlement)		.10	.10	.25	.10	.15	.30	.30	.35	.55	.45	.50	.65
Straight Row Crops													
Straight Row (SR)	*Poor Condition*	.33	.39	.55	.52	.58	.71	.70	.74	.84	.78	.81	.89
	Good Condition	.24	.30	.46	.45	.51	.66	.62	.67	.78	.73	.76	.86
SR + Crop Residue (CR)	*Poor Condition*	.31	.37	.54	.50	.56	.70	.67	.72	.82	.75	.79	.87
	Good Condition	.19	.25	.41	.38	.45	.61	.55	.60	.73	.62	.67	.78
Contoured (C).............................	*Poor Condition*	.29	.35	.52	.47	.53	.70	.60	.65	.77	.70	.74	.84
	Good Condition	.21	.26	.43	.38	.45	.61	.55	.60	.73	.65	.69	.80
C+CR...	*Poor Condition*	.27	.33	.50	.45	.51	.66	.57	.63	.75	.67	.72	.82
	Good Condition	.19	.25	.41	.36	.43	.59	.52	.58	.71	.62	.67	.78
Contoured & Terraced (C&T)	*Poor Condition*	.22	.28	.45	.36	.43	.59	.50	.56	.70	.55	.60	.73
	Good Condition	.16	.22	.38	.31	.37	.54	.45	.51	.66	.52	.58	.71
C&T + CR	*Poor Condition*	.13	.19	.35	.31	.37	.54	.45	.51	.66	.52	.58	.71
	Good Condition	.10	.16	.32	.27	.33	.50	.43	.49	.65	.50	.56	.70

[1] The average percent impervious area shown was used to develop composite coefficients.

Note: Rational coefficients were derived from SCS CN method

b. Composite Runoff Analysis: Care should be taken not to average runoff coefficients for large segments that have multiple land uses of a wide variety (i.e., business to agriculture). However, within similar land uses, it is often desirable to develop a composite runoff coefficient based on the percentage of different types of surface in the drainage area. 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.

c. Rainfall Intensity: The intensity (i_T) is the average rainfall rate in inches per hour for the period of maximum rainfall of a given frequency, with duration equal to the time of concentration. The method(s) for determining time of concentration are presented in Section 2B-3.

From a practical standpoint, using a T_c of less than 15 minutes may yield unreasonably high flow rates. For most applications, a minimum T_c of 15 minutes may be used.

After the T_c has been determined, the rainfall intensity should be obtained. For the Rational method, the design rainfall intensity is that which occurs for the design year storm whose duration equals the time of concentration. Tables 2B-2.02 through 2B-2.10 in Section 2B-2 provide the Iowa rainfall data from Bulletin 71 to allow determination of rainfall intensity based on duration equaling the time of concentration.

d. Area: The area (A) of the basin in acres. A map showing the limits of the drainage basin used in design should be provided with design data and will be superimposed on the grading plan showing subbasins. As mentioned earlier, the configuration of the contributing area with respect to pervious and impervious sub-areas and the flow path should be considered when deciding whether to use all or a portion of the total area.

C. SCS Methods

Several methods of determining total runoff and peak runoff have been developed by the SCS (now known as the NRCS). The two methods described below include the SCS Runoff Curve Number method for determining the total runoff depth and the SCS Peak flow method, which utilizes the runoff depth and site conditions to determine the peak rate of runoff from a drainage area.

These methods are described in full detail in the NRCS Technical Release 55: Urban Hydrology for Small Watersheds. This document is also the basis for the publicly available computer program WIN-TR55. This section also includes information from the NRCS National Engineering Handbook, Part 630.

1. SCS Curve Number: The SCS methods classify the land use and soil type by a single parameter called the Curve Number (CN). The CN can be used to represent the drainage properties for any sized homogeneous watershed with a known percentage of imperviousness.

The major factors that determine CN are the hydrologic soil group, cover type, treatment, hydrologic condition, and antecedent runoff condition. Tables 2B-4.03 through 2B-4.05 include typical CN values for urban and agricultural areas respectively.

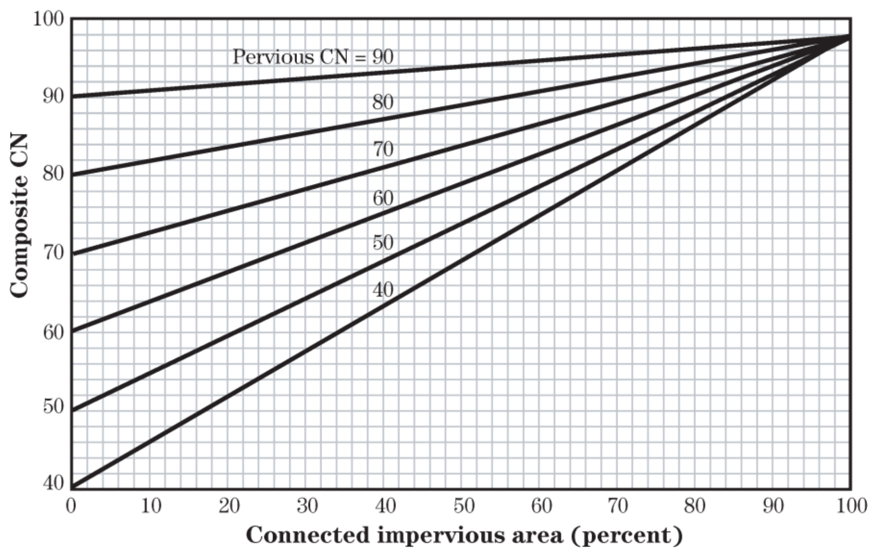
Several factors, such as the percentage of impervious area and the means of conveying runoff from the impervious areas to the drainage system, should be considered in computing the CN for urban areas. For example, do the impervious areas connect directly to the drainage system, or do they outlet onto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

The urban CN values (Table 2B-4.03) were developed for typical land use relationships based upon specific assumed percentages of impervious area. These CN values were developed on the assumptions that (a) the pervious urban areas are equivalent to pasture in good hydrologic condition, (b) impervious areas have a CN of 98 and are directly connected to the drainage system, and (c) the CN values for urban and residential districts assume an average percent impervious as shown in Table 2B-4.03.

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

If all of the impervious area is directly connected to the drainage system, but the impervious area percentages in Table 2B-4.02, or the pervious land use assumptions are not applicable, use Figure 2B-4.01 or Equation 2B-4.02 to compute a composite CN.

Figure 2B-4.01: Composite CN with Connected Impervious Area



Source: NRCS National Engineering Handbook, Part 630, Chapter 9

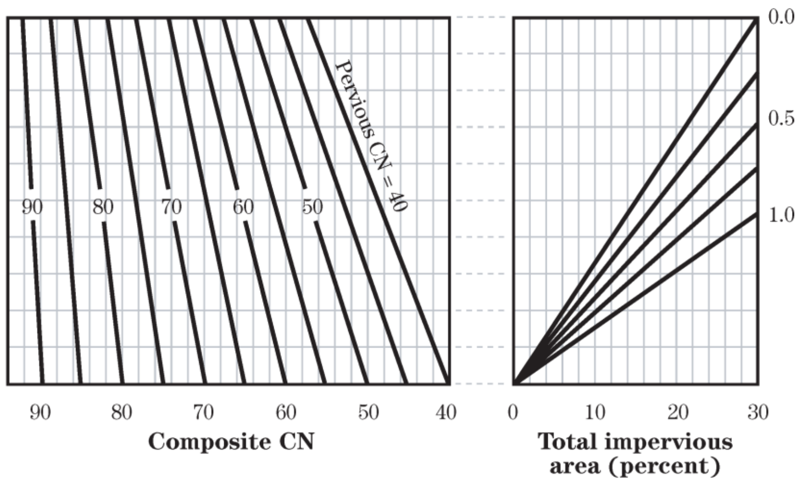
$$CN_c = CN_p + \left(\frac{P_{imp}}{100}\right)(98 - CN_p)$$ **Equation 2B-4.02**

where:

CN_c = composite runoff curve number
CN_p = pervious runoff curve number
P_{imp} = percent imperviousness

b. Unconnected Impervious Areas: If runoff from impervious areas occurs over a pervious area as sheet flow prior to entering the drainage system, the impervious area is unconnected. To determine the CN when all or part of the impervious area is not directly connected to the drainage system use Figure 2B-4.02 or Equation 2B-4.03 if the total impervious area is less than 30% of the total area. If the total impervious area is equal to or greater than 30% of the total area, utilize Figure 2B-4.02 or Equation 2B-4.02 because the absorptive capacity of the remaining pervious area will not significantly affect runoff.

Figure 2B-4.02: Composite CN with Unconnected Impervious Areas and Total Impervious Areas Less Than 30%



When the impervious area is less than 30%, obtain the composite CN by entering the right half of the figure with the percentage of total unconnected impervious area to total impervious area. Then move left to the appropriate CN and read down to find the composite CN.

Source: NRCS National Engineering Handbook, Part 630, Chapter 9

$$CN_c = CN_p + \left(\frac{P_{imp}}{100}\right)(98 - CN_p)(1 - 0.5R)$$ **Equation 2B-4.03**

where:

CN_c = composite runoff curve number
CN_p = pervious runoff curve number
P_{imp} = percent imperviousness
R = ratio of unconnected impervious area to total impervious area.

c. Hydrologic Soil Groups: Most urban areas are only partially covered by impervious surfaces and the soil remains an important factor in runoff estimates. Urbanization has a greater effect on runoff in watersheds with soils having high infiltration rates (sands and gravels) than in watersheds with low infiltration rates (silts and clays) since undeveloped runoff volumes are already elevated.

Infiltration rates of soils vary widely and are affected by subsurface permeability as well as surface intake rates. Soils are classified into hydrologic soil groups (HSG's) to indicate the minimum rate of infiltration obtained for bare soil after prolonged wetting. The HSG's, which are A, B, C, and D, are one element used in determining runoff curve numbers. The soil classification may be obtained from NRCS soil survey publications and can be obtained from the local NRCS offices for use in estimating soil types. Exhibit A of TR-55 includes a list of soils of the United States and the hydrologic soils group associated with each soil type.

The infiltration rate is the rate at which water enters the soil at the soil surface. It is controlled by surface conditions. HSG also indicates the transmission rate - the rate at which the water moves within the soil. This rate is controlled by the soil profile. The four groups are defined by SCS soil scientists as follows:

1) **Group A:** Group A soils have low runoff potential and high infiltration rates even when thoroughly wetted. They consist chiefly of deep, well to excessively drained sand or gravel and have a high rate of water transmission (greater than 0.30 in/hr).
2) **Group B:** Group B soils have moderate infiltration rates when thoroughly wetted and consist chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission (0.15 to 0.30 in/hr).
3) **Group C:** Group C soils have low infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes downward movement of water and soils with moderately fine to fine texture. These soils have a low rate of water transmission (0.05 to 0.15 in/hr).
4) **Group D:** Group D soils have high runoff potential. They have very low infiltration rates when thoroughly wetted and consist chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very low rate of water transmission (0 to 0.05 in/hr).
5) **Disturbed Soil Profiles:** Consideration should be given to the effects of urbanization on the natural hydrologic soil group. If heavy equipment can be expected to compact the soil during construction, or if grading will mix the surface and subsurface soils, appropriate changes should be made in the soil group selected. As a result of urbanization, the soil profile may be considerably altered and the listed group classification may no longer apply. In these circumstances, use the following to determine the hydrologic soil group according to the texture of the new surface soil (provided that significant compaction has not occurred).

Table 2B-4.02: Hydrologic Soil Group for Disturbed Soils

HSG	Soil Texture
A	Sand, loamy sand, or sandy loam
B	Silt loam or loam
C	Sandy clay loam
D	Clay loam, silty clay loam, sandy clay, silty clay, or clay

Source: NRCS TR-55

Table 2B-4.03: Runoff Curve Numbers for Urban Areas[1]

Cover Type and Hydrologic Condition	Average Percent Impervious Area[2]	CN's 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 homes)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Developing Urban Areas					
Newly graded areas (pervious areas only, no vegetation)[4]	-------------	77	86	91	94
Idle lands (CN's are determined using cover types similar to those in Table 2B-4.01)					

[1] Average runoff condition and I_a=0.2S

[2] The average percent impervious area shown was used to develop the composite CN's. 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. CN's for other combinations of conditions may be computed using Figures 2B-4.01 or 2B-4.02.

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

[4] Composite CN's to use for the design of temporary measures during grading and construction should be computed using Figures 2B-4.01 or 2B-4.02 based upon the degree of development (impervious area percentage) and the CN's for the newly graded pervious areas.

Source: NRCS National Engineering Handbook, Part 630, Chapter 9

Table 2B-4.04: Runoff Curve Numbers for Cultivated Agricultural Lands[1]

Cover Description			CN's for Hydrologic Soil Group			
Cover Type	***Treatment[2]***	***Hydrologic Condition[3]***	***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	Straight Row (SR)	Poor	65	76	84	88
		Good	63	75	83	87
	SR + CR	Poor	64	75	83	86
		Good	60	72	80	84
	Contoured (C)	Poor	63	74	82	85
		Good	61	73	81	84
	C + CR	Poor	62	73	81	84
		Good	60	72	80	83
	Contoured & terraced (C&T)	Poor	61	72	79	82
		Good	59	70	78	81
	C&T + CR	Poor	60	71	78	81
		Good	58	69	77	80
Close Seeded or Broadcast Legumes or Rotation Meadow	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

[1] Average runoff condition and I_a=0.2S
[2] Crop residue cover applies only if residue is on at least 5% of the surface throughout the year.
[3] Hydraulic condition is based on combination 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 roughness.

Poor: Factors impair infiltration and tend to increase runoff

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

Source: NRCS National Engineering Handbook, Part 630, Chapter 9

Table 2B-4.05: Runoff Curve Numbers for Other Agricultural Lands[1]

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

[1] Average runoff condition and I_a=0.2S.
[2] *Poor*: <50% ground cover or heavily grazed with no mulch.
Fair: 50 to 75% ground cover and not heavily grazed.
Good: >75% ground cover and lightly or only occasionally grazed.
[3] *Poor*: <50% ground cover.
Fair: 50 to 75% ground cover.
Good: >75% ground cover.
[4] Actual curve number is less than 30; use CN = 30 for runoff computations
[5] CN's shown were computed for areas with 50% woods and 50% grass (pasture) cover. Other combinations of conditions may be computed from the CN's for woods and pasture.
[6] *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. **SCS Depth of Runoff:** Depth of runoff may be calculated through the SCS Curve Number Method. This method separates total rainfall into direct runoff, retention, and initial abstraction to yield the following equation for rainfall runoff.

$$Q = \frac{(P-I_a)^2}{(P-I_a)+S}$$ **Equation 2B-4.04**

where:

Q = Depth of direct runoff, in
P = Depth of 24 hour precipitation, in. for design year storm (e.g. 10 year, 24 hour)
S = Potential maximum retention after runoff begins, in
I_a = Initial abstraction, in

The initial abstraction (I_a) is all losses before runoff begins. It includes water retained in surface depressions, water intercepted by vegetation, evaporation, and infiltration during the early part of the storm. Interception and surface depression storage may be estimated from cover and surface conditions, but infiltration during the early part of the storm is highly variable and dependent on such factors as rainfall intensity, soil crusting, and soil moisture. Establishing a relationship for I_a

is not easy. Therefore, I_a is assumed to be a function of the maximum potential retention, S. An empirical relationship between I_a and S is expressed as:

$$I_a = 0.2S$$ **Equation 2B-4.05**

Removing I_a and substituting Equation 2B-4.05 into Equation 2B-4.04 gives:

$$Q = \frac{(P-0.2S)^2}{(P+0.8S)}$$ **Equation 2B-4.06**

The potential maximum (S) is related to the soil cover and conditions of the watershed through the CN as follows:

$$S = \frac{1000}{CN} - 10$$ **Equation 2B-4.07**

After determining the CN and calculating the value for S, the total amount of rainfall, P, for the 24 hour storm with the selected return interval must be determined. Values for total rainfall depth by storm duration and return interval are listed in Section 2B-2. These values are inserted into Equation 2B-4.06 to calculate the total depth of runoff from the watershed.

3. **SCS Peak Runoff:** After the total runoff is determined, the SCS Peak Discharge Method may be utilized to determine the peak rate of discharge from the watershed. The equation for the peak discharge is given as:

$$q_p = q_u A_m Q F_p$$ **Equation 2B-4.08**

where:

q_p = peak discharge, cfs
q_u = unit peak discharge, $ft^3/s/mi^2/in$ (csm)
A_m = drainage area, mi^2
Q = runoff, in (from Equation 2B-4.04 above)
F_p = pond and swamp adjustment factor (Table 2B-4.05)

The unit peak flow is calculated with the following equation (graphical depictions are presented in TR-55):

$$q_u = 10^{[C_0+(C_1)(\log t_c)+(C_2)(\log t_c)^2]}$$ **Equation 2B-4.09**

where:

C_0, C_1, C_2 = Coefficients, listed in Table 2B-4.06. These are a function of the 24 hour rainfall distribution type and Ia/P.
t_c = time of concentration (refer to Section 2B-3)
I_a = Initial abstraction (refer to Equation 2B-4.05), in

Source: HEC-22, FHWA

Table 2B-4.06: Coefficients for SCS Peak Discharge Method

I_a/P	C_0	C_1	C_2
0.10	2.55323	-0.61512	-0.16403
0.30	2.46532	-0.62257	-0.11657
0.35	2.41896	-0.61594	-0.08820
0.40	2.36409	-0.59857	-0.05621
0.45	2.29238	-0.57005	-0.02281
0.50	2.20282	-0.51599	-0.01259

Note: Values are for Type II rain distribution, which applies to all of Iowa.

Source: TR-55, USDA

Table 2B-4.07: Adjustment Factor (F_p) for Pond and Swamp Areas that are Spread Throughout the Watershed

Percentage of pond and swamp area	F_p
0	1.00
0.2	0.97
1.0	0.87
3.0	0.75
5.0	0.72

Source: HEC-22, FHWA

4. **SCS Limitations:** The SCS methods presented herein are subject to the following limitations.

   a. These methods provide a determination of total runoff or peak flow only. If a hydrograph is needed or watershed subdivision is required the Tabular Hydrograph method (Section 2B-5) should be utilized.

   b. The watershed must be hydrologically homogenous, that is, describable by one of the CN. Land use, soils, and cover are distributed uniformly throughout the watershed.

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

   d. The method cannot perform valley or reservoir routing.
   e. The F_p factor can be applied only for ponds or swamps that are not in the t_c flow path.

   f. I_a/P values should be between 0.1 and 0.5.

   g. This method should only be used if the composite CN is greater than 40.

   h. The SCS methods are typically applicable for drainage areas between 0 and 2,000 acres.

D. References

U.S. Department of Transportation. *Urban Drainage Design Manual*. Hydraulic Engineering Circular, No. 22. Third Ed. 2009.

USDA Natural Resource Conservation Service. *National Engineering Handbook - Part 630. Chapter 9: Hydrologic Soil Cover Complexes*. 2004.