CHAPTER 3. DETERMINATION OF STORM WATER RUNOFF

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1.0 OVERVIEW

The intent of this chapter of the *Manual* is to provide reasonably dependable and consistent methods of approximating the characteristics of runoff in urban and nonurban areas within the City of Bella Vista, Arkansas. This chapter will guide the designer in how to choose the proper method for calculating runoff, based on the conditions present at a site as well as the necessary information/calculations the City requires for their review prior to development of the site.

This section of the *Manual* on the determination of storm water runoff was developed using several references including: Urban Storm Drainage Criteria Manual developed by Urban Drainage and Flood Control District in Denver, Colorado; *National Engineering Handbook*, Section 4 (NEH-4), 1985; NRCS Technical Paper No. 40, 1961; and NRCS Technical Release No. 55, 1986. Detailed information for all references used in this section can be found at the end of this chapter.

This chapter of the *Manual* should be utilized in conjunction with other universally accepted articles and engineering references and studies. NRCS Technical Release 55 is referenced extensively throughout this chapter as it is an excellent resource for urban hydrology design and methodology. It is important for the individual using this section of the manual to already have a firm understanding of the information provided in this document prior to implementing the recommendations outlined in this *Manual*.

1.1 Introduction

Determining the peak flow rate and volume of storm water runoff generated in a watershed for a given storm event is an essential step in evaluating drainage design. The size of rainfall event, type of flow condition, and flow rate of the runoff all play a major role in the sizing, configuration, and operation of storm drainage and flood control systems. Numerous methods for calculating runoff have been developed and studied as engineering design options but only a few are accepted by the City of Bella Vista, based on the climate and natural environment.

1.2 City of Bella Vista Drainage Methods

There are a number of different methods and procedures for computing runoff on which the design of storm drainage and flood control systems are based. The three methods the City accepts are:

1) The Rational Method;
2) The Soil Conservation Service Technical Release – 55 Synthetic Hydrograph Method (SCS method); or

3) USGS Regional Regression Equations. This third method will not be discussed in detail in this *Manual*, but can be examined and further studied in *Magnitude and Frequency of Floods in Arkansas* (USGS – WRIR 95-4224, 1995).

The two main drainage methods described in this *Manual* are: (1) the Rational Method and (2) SCS method. The Rational Method is generally used for smaller watersheds when only the peak flow rate or the total volume of runoff is needed at a design point or points (e.g., storm sewer sizing or simple detention basin sizing). The SCS method is used for larger watersheds and when a hydrograph of the storm event is needed (e.g., sizing large detention facilities). The watershed size limits and/or ranges for each analysis method are shown in Table RO-1.

Table RO-1: Watershed Size Applicability for Peak Runoff Calculations

Watershed Size (acres)	Applicable Drainage Method
0 to 30	Rational Method
30 to 2000	SCS Method
2000 +	Computer models (such as HEC-HMS, TR-20, or equivalent)

2.0 RATIONAL METHOD

For urban watersheds that are not complex and are generally 30 acres or less in size, it is acceptable that the design storm runoff be analyzed by the Rational Method. If properly understood and applied, the Rational Method can produce satisfactory results for the design of urban storm sewers and small on-site detention facilities.

2.1 Rational Formula

The Rational Method is based on the Rational Formula which is expressed as:

$$Q = k_i * C * I * A \qquad \textbf{(Equation RO-1)}$$

in which:

Q = peak rate of runoff in cfs. Q is actually in units of ac-in/hr, but conversion of the results to cfs differs by less than 1%. Since the difference is so small, the Q value calculated by the equation is accepted as cfs.

k_i = adjustment multiplier for design storm recurrence interval (see Table RO-4)

C = runoff coefficient - represented in the ratio of the amount of runoff to the amount of rainfall (see Section 2.5).

I = average intensity of rainfall (in/hr) for a period of time equal to the critical time of full contribution of the drainage area under consideration (see Section 2.6). This critical time for full contribution is commonly referred to as "time of concentration," t_c (see Section 2.8)

A = area in acres that contributes to runoff at the point of design or the point under consideration (see Section 2.7).

2.2 Rational Method Calculation Procedure

The general procedure for Rational Method calculations for a single watershed is as follows:

1) Delineate the watershed boundary and measure its area in acres.

2) Define the flow path from the hydraulically most distant point of the watershed to the design point. This flow path should be divided into reaches of similar flow type [i.e. overland flow (sheet flow), shallow concentrated flow (swales, shallow ditches, etc.)], and channelized flow (gutters, storm sewers, open channels, etc.). The length and slope of each reach should be measured.

3) Determine the time of concentration, t_c, for the watershed. Refer to Section 2.8 of this chapter for additional information on calculating t_c.

4) Find the rainfall intensity, I, for the design storm using the calculated t_c and the rainfall intensity-duration-frequency information (see Table RO-5). Use arithmetic interpolation to calculate rainfall intensity for t_c not displayed in the table.

5) Determine the runoff coefficient, C, (see Table RO-2 and/or Table RO-3) for the watershed boundary and its resulting subareas.

6) Calculate the peak flow rate from the watershed using Equation RO-1.

Calculations for the Rational Method shall be carried out using the spreadsheets or other software aides discussed in Section 4.0 of this chapter.

2.3 Assumptions

Basic assumptions associated with use of the Rational Method are as follows:

1) The computed peak rate of runoff to the design point is a function of the average rainfall rate during the time of concentration for the watershed.

2) The time of concentration is the critical value in determining the design rainfall intensity and is equal to the time required for water to flow from the hydraulically most distant point in the watershed to the point of design.

3) The runoff coefficient, C, is uniform during the entire duration of the storm event.

4) The rate of rainfall or rainfall intensity, I, is uniform for the entire duration of the storm event and is uniformly distributed over the entire watershed area.

5) The depth of rainfall used is that which occurs from the start of the storm to the time of concentration. The design rainfall depth during that time period is converted to the average rainfall intensity for that period in inches per hour (in/hr).

6) The maximum runoff rate occurs when the entire area is contributing flow. However, this assumption has to be modified when a more intensely developed portion of the watershed with a shorter time of concentration produces a higher rate of maximum runoff than the entire watershed with a longer time of concentration.

2.4 Limitations

The Rational Method is an adequate method for approximating the peak rate of runoff from a design rainstorm in a given watershed area. The greatest drawback to the Rational Method is that it normally provides only one point on the runoff hydrograph. When the areas become complex and where sub-watersheds come together, the Rational Method will tend to overestimate the actual flow, which results in over-sizing of drainage facilities. The Rational Method provides no direct information needed to route hydrographs through the drainage facilities. One reason the Rational Method is limited to small areas is that good design practice requires the routing of hydrographs for larger watersheds to achieve an economic design.

Another disadvantage of the Rational Method is that in the typical design procedure one normally assumes that all of the design flow is collected at the design point and that no water bypasses or runs overland to the next design point. However, this is not a limitation of the Rational Method but of the design procedure. The Rational Method must be modified, or another type of analysis used, when analyzing an existing system that is under-designed or when analyzing the effects of a major storm on a system designed for the minor storm.

2.5 Runoff Coefficient, *C*

The runoff coefficient, C, represents the integrated effects of infiltration, detention storage, evaporation, retention, flow routing, and interception, all of which affect the time of distribution and peak rate of runoff. The proportion of the total rainfall that runs off depends on the relative porosity or imperviousness of the ground surface, the surface slope, and the ponding character of the surface. Impervious surfaces, such as asphalt pavements and roofs of buildings, will be subject to nearly 100 percent runoff, regardless of the slope, after the surfaces have become thoroughly wet. On-site inspections and aerial photographs are valuable in determining the types of surfaces within the drainage area and are essential when assessing the runoff coefficient, C.

2.5.1 Soil Type

The runoff coefficient, *C*, in the Rational Formula is also dependent on the character of the surface soil. The type and condition of the soil determines its ability to absorb precipitation. The rate at which a soil absorbs rainfall typically decreases if the rainfall continues for an extended period of time. The soil absorption or infiltration rate during a rainfall event is also influenced by the degree of soil saturation before a rain (antecedent moisture condition), the rainfall intensity, the proximity of ground water, the degree of soil compaction, the porosity of the subsoil, vegetation, ground slopes, and surface topography (or relief). Detailed soil information is described in *Section 3.3.1 – Hydrologic Soil Group*.

2.5.2 Selection of Runoff Coefficients, *C*

The runoff coefficient, *C*, is the variable of the Rational Method which is least susceptible to precise determination. Proper selection requires judgment and experience on the part of the design engineer, and its use in the formula implies a fixed ratio for any given drainage area over the course of a rainfall event, which in reality is not the case. A reasonable runoff coefficient must be chosen in order to determine accurate volumes for runoff.

To standardize City design computations, Table RO-2 provides standard runoff coefficient values based on current zoning and land use designations. However, if the designer chooses, Table RO-3 provides runoff coefficient values for specific types of land/surface areas that can be used to evaluate a composite analysis that may provide a more accurate runoff coefficient value for an area.

Additionally, the values in Table RO-2 and Table RO-3 are typical for design storms with recurrence intervals of 1 to 10 years. For less frequent recurrence intervals (i.e., larger storm events), the runoff coefficient, *C*, must be adjusted upward using the correction factors shown in Table RO-4 due to saturated soil conditions that typically increase the runoff during larger storm events. Table RO-4 contains correction factors for the 1-, 5-, 10-, 25-, 50-, and 100-year events. To determine the appropriate runoff coefficient for these events, the runoff coefficient from either Table RO-2 or Table RO-3 shall be multiplied by the appropriate factor in Table RO-4.

Table RO-2: Runoff Coefficients, *C*, for Specific Zoning and Land Uses

Zoning	Description	Runoff Coefficient, *C*
P-1	Open Space	0.40
A-1	Agricultural	0.40
R-E	Residential Estate	0.45
R-1	Residential, Single Family	0.55
R-2	Residential, Two Family	0.65
R-3	Residential, Multi-Family	0.75
R-MH	Residential, Manufactured Home	0.70
C-1	Neighborhood Commercial District	0.90
C-2	Light Commercial District	0.90
C-3	Central Commercial District	0.90

C-4	Shopping Center District	0.90
I-1	Light Industrial	0.90
I-2	Heavy Industrial	0.90
Church		0.80
School		0.80
Park		0.40
Cemetery		0.40

Table RO-3: Runoff Coefficient, *C*, for Composite Land/Surface Areas

Character of Surface	Description	Runoff Coefficient, *C*
UNDEVELOPED AREAS	Historic Flow Analysis, Greenbelts, Agricultural, Natural Vegetation	
	Clay Soil	
	Flat, 2% slopes	0.30
	Average, 2 - 7% slopes	0.40
	Steep, 7% slopes	0.50
	Sandy Soil	
	Flat, 2% slopes	0.12
	Average, 2 - 7% slopes	0.20
	Steep, 7% slopes	0.30
STREETS	Paved	0.98
	Gravel	0.60
DRIVES & WALKS		0.98
ROOFS		0.98
LAWNS	Clay Soil	
	Flat, 2% slopes	0.18
	Average, 2 - 7% slopes	0.22
	Steep, 7% slopes	0.35
	Sandy Soil	
	Flat, 2% slopes	0.10
	Average, 2 - 7% slopes	0.15
	Steep, 7% slopes	0.20

Table RO-4: Frequency Factor Multipliers for Runoff Coefficients
(Debo and Reese 2002)

Recurrence Interval (years)	**Adjustment Multiplier** (k_i)
1 to 10	1.0
25	1.1
50	1.2
100	1.25

2.6 Rainfall Intensity, I

Rainfall intensity, I, is the design rainfall rate in inches-per-hour (in/hr) for a particular drainage basin or sub-basin of a watershed. The rainfall intensity, I, is obtained from an intensity-duration-frequency (IDF) chart for a specified return period under the assumption that the duration is equal to the time of concentration for the watershed being evaluated. Once the time of concentration is known, the design intensity of rainfall may be interpolated from Table RO-5. The frequency of recurrence interval is a statistical variable which may be established by City standards or chosen by the design engineer as a design parameter.

Table RO-5: Rainfall Intensity-Duration-Frequency Chart

Duration (min)	1 Year (in/hr)	2 Year (in/hr)	5 Year (in/hr)	10 Year (in/hr)	25 Year (in/hr)	50 Year (in/hr)	100 Year (in/hr)
5	4.88	5.54	6.58	7.34	8.46	9.35	10.22
6	4.89	5.35	6.34	7.07	8.15	9.00	9.85
7	4.78	5.10	6.09	6.80	7.80	8.68	9.50
8	4.63	4.92	5.85	6.54	7.52	8.34	9.14
9	4.47	4.72	5.64	6.30	7.29	8.06	8.80
10	4.31	4.58	5.45	6.08	7.06	7.78	8.50
11	4.15	4.41	5.28	5.88	6.78	7.50	8.25
12	4.00	4.27	5.10	5.70	6.55	7.25	7.92
13	3.86	4.12	4.92	5.50	6.32	7.00	7.70
14	3.72	4.00	4.78	5.34	6.15	6.81	7.45
15	3.60	3.88	4.65	5.18	6.00	6.61	7.24
16	3.48	3.78	4.52	5.04	5.84	6.45	7.05
17	3.37	3.67	4.38	4.91	5.69	6.30	6.90
18	3.27	3.55	4.29	4.80	5.55	6.15	6.73
19	3.18	3.47	4.17	4.70	5.43	6.00	6.55
20	3.09	3.38	4.06	4.59	5.32	5.88	6.43
21	3.00	3.29	3.98	4.49	5.20	5.76	6.30
22	2.92	3.20	3.89	4.39	5.10	5.65	6.27
23	2.85	3.13	3.80	4.30	4.98	5.52	6.08
24	2.78	3.05	3.73	4.20	4.89	5.43	5.93
25	2.71	2.99	3.66	4.12	4.80	5.32	5.85
26	2.65	2.93	3.58	4.06	4.72	5.24	5.75
27	2.59	2.87	3.50	3.96	4.62	5.13	5.65
28	2.53	2.80	3.44	3.90	4.54	5.05	5.55
29	2.47	2.73	3.37	3.83	4.47	4.97	5.46
30	2.42	2.69	3.30	3.76	4.40	4.90	5.38
31	2.37	2.62	3.24	3.70	4.31	4.80	5.30
32	2.32	2.58	3.19	3.64	4.25	4.74	5.20
33	2.28	2.52	3.12	3.57	4.18	4.67	5.12
34	2.24	2.48	3.07	3.51	4.11	4.60	5.04
35	2.19	2.42	3.02	3.46	4.06	4.51	4.98
36	2.15	2.40	2.97	3.40	3.99	4.45	4.90
37	2.12	2.37	2.92	3.33	3.92	4.40	4.83
38	2.08	2.30	2.89	3.28	3.87	4.33	4.78
39	2.04	2.28	2.82	3.24	3.81	4.28	4.70
40	2.01	2.23	2.79	3.18	3.76	4.20	4.62
41	1.98	2.20	2.75	3.13	3.70	4.15	4.58
42	1.95	2.16	2.70	3.10	3.65	4.10	4.50
43	1.91	2.12	2.67	3.07	3.60	4.05	4.43
44	1.89	2.10	2.63	3.01	3.56	3.97	4.40
45	1.86	2.07	2.60	2.97	3.51	3.92	4.33
46	1.83	2.04	2.55	2.94	3.46	3.87	4.28
47	1.80	2.00	2.52	2.90	3.42	3.82	4.22
48	1.78	1.98	2.49	2.86	3.37	3.78	4.18

49	1.75	1.97	2.47	2.82	3.33	3.72	4.12
50	1.73	1.96	2.42	2.79	3.29	3.69	4.08
51	1.70	1.90	2.40	2.74	3.25	3.63	4.03
52	1.68	1.88	2.36	2.71	3.20	3.60	3.98
Duration (min)	**1 Year (in/hr)**	**2 Year (in/hr)**	**5 Year (in/hr)**	**10 Year (in/hr)**	**25 Year (in/hr)**	**50 Year (in/hr)**	**100 Year (in/hr)**
53	1.66	1.86	2.33	2.69	3.17	3.55	3.92
54	1.64	1.84	2.31	2.65	3.14	3.50	3.88
55	1.62	1.82	2.29	2.62	3.10	3.46	3.83
56	1.60	1.80	2.26	2.59	3.06	3.44	3.80
57	1.58	1.79	2.23	2.56	3.02	3.39	3.75
58	1.56	1.76	2.21	2.54	2.98	3.35	3.70
59	1.54	1.74	2.19	2.50	2.96	3.30	3.67
60	1.52	1.73	2.17	2.48	2.90	3.26	3.62
70	1.36	1.57	1.96	2.24	2.66	2.94	3.31
80	1.24	1.45	1.84	2.07	2.43	2.71	3.08
90	1.14	1.34	1.70	1.93	2.28	2.53	2.86
100	1.05	1.24	1.59	1.81	2.11	2.37	2.67
110	0.98	1.19	1.49	1.70	1.98	2.22	2.49
120	0.92	1.12	1.41	1.61	1.86	2.09	2.32
140	0.82	1.02	1.25	1.43	1.67	1.86	2.08
160	0.74	0.90	1.14	1.29	1.50	1.68	1.89
180	0.68	0.79	1.04	1.20	1.37	1.53	1.72
360	0.39	0.48	0.62	0.73	0.84	0.93	1.03
720	0.24	0.29	0.37	0.44	0.50	0.56	0.62
1,440	0.14	0.17	0.22	0.25	0.29	0.33	0.36

Source:

2-, 5-, 10-, 25-, 50-, 100-Year Design Storm

5-60 min. NOAA HYDRO-35
60-120 min. interpolated
120-1,440 min. Technical Paper No. 40

1-Year Design Storm

180-,360-,720-, and 1440-min. Technical Paper No. 40
5-160 min. calc'd from logarithmic trend line from 5,10,15,30,60,&120-min. T.P.-40

2.7 Drainage Area, *A*

The drainage area is measured in acres when using the Rational Method. Drainage areas should be calculated using planimetric topographic maps, supplemented by field surveys where topographic data has changed or where the contour interval is too great to distinguish the exact direction of overland flows. Field surveys are also useful for verifying flows through culverts or other drainage structures.

2.8 Time of Concentration, t_c

The time of concentration, t_c, is best defined as the time required for water to flow from the hydraulically most distant point of a watershed to the design point at which peak runoff is desired. The critical time of concentration is the time to the peak of the runoff hydrograph at the location of the design point. Runoff from a watershed usually reaches a peak at the time when the entire watershed area is contributing to flow. The critical time of concentration, therefore, is assumed to be the flow time measured from the most remote part of the watershed to the design point. A trial and error procedure should be used to select the most remote point of a watershed since type of flow, ground slopes, soil types, surface treatments and improved conveyances all affect flow velocity and time of flow.

Water moves through a watershed as overland flow (sheet flow), shallow concentrated flow (swales, shallow ditches, etc.), channelized flow (gutters, storm sewers, open channels, etc.) or some combination of these. The type that occurs is a function of the conveyance system and is best determined by field inspection.

The time of concentration, t_c, is represented by Equation RO-2 for both urban and non-urban areas:

$$t_c = t_o + t_s + t_t \qquad \textbf{(Equation RO-2)}$$

in which:

t_c = time of concentration (minutes)

t_o = overland flow time (minutes)

t_s = shallow concentrated flow time (minutes)

t_t = channelized flow time (minutes)

Urban areas are characterized as densely populated areas, where the collection of streets, parking lots, and rooftops in close proximity to one another create a situation where the collective runoff area is more impervious than not. Non-urban areas are characterized as less populated and more rural, where the majority of the area is farmland, open pastures, and woodlands. This combination of agricultural land creates the situation where the collective runoff area is more pervious than not.

2.8.1 Overland Flow Time, t_o

Overland flow occurs over planar surfaces. With overland flow, the effective roughness coefficient (Manning's *n* value) includes the effect of raindrop impact; drag over the surface; obstacles such as litter, crop ridges, and rocks; and erosion and transportation of sediment. Table RO-6 gives Manning's *n* values for sheet flow for various surface conditions. These *n* values are for overland flow depths of approximately 0.1 foot.

The overland flow time, t_o, may be calculated using Equation RO-3:

$$t_o = \frac{0.007(n*L)^{0.8}}{(P_2)^{0.5}*S^{0.4}} \qquad \textbf{(Equation RO-3)}$$

in which:

t_o = overland flow time (minutes)

n = Manning's roughness coefficient (Table RO-6)

L = length of overland flow in feet (300-ft maximum in non-urban areas; 100-ft maximum in urban areas)

P_2 = 2-year, 24-hour rainfall (inches) calculated from Table RO-5 (or obtained from Table RO-9)

S = average basin slope (feet-per-feet) expressed as a decimal

Equation RO-3 is a simplified form of the Manning's kinematic solution, taken from TR-55 (1986), and is based on the following assumptions:

1) shallow steady uniform flow
2) constant intensity of rainfall excess (that part of a rain event available for runoff)
3) rainfall duration of 24 hours, and
4) minor effect of infiltration on travel time

Rainfall depth can be calculated from Table RO-5 (and/or can be obtained directly from Table RO-9). Engineering judgment should be used when determining the maximum overland flow distance. For example, in non-urban, gently sloping areas, with ground cover in good condition a maximum overland flow distance of 300-feet can be used. But in urban areas, where more impervious areas exist and ground cover condition is poor a maximum length of 100-feet shall be used. The engineer needs to be aware under what conditions and in what areas overland flow transitions to shallow concentrated or channelized flow when determining the overland flow distance. If the overland flow time is calculated to be in excess of 20 minutes, the designer should check to be sure that the time is reasonable considering the projected ultimate development of the area.

Table RO-6: Roughness Coefficients (Manning's *n*) for Overland Flow (USDA NRCS – TR-55 1986)

Surface Description	n[1]
Smooth surfaces (concrete, asphalt,	
gravel, or bare soil)	0.011
Fallow (no residue)	0.05
Cultivated Soils:	
Residue cover ≤ 20%	0.06
Residue cover > 20%	0.17
Grass:	
Short grass prairie	0.15
Dense grasses [2]	0.24
Bermuda grass	0.41
Range (natural)	0.13
Woods: [3]	
Light underbrush	0.40
Dense underbrush	0.80

[1] The *n* values are a composite of information compiled by Engman (1986).
[2] Includes species such as weeping lovegrass, bluegrass, buffalo grass, blue grama grass, and native grass mixtures.
[3] When selecting *n*, consider cover to a height of about 0.1 ft. This is the only part of the plant cover that will obstruct sheet flow.

2.8.2 Shallow Concentrated Flow Time, t_s

After a maximum of 300- or 100-feet (depending on non-urban or urban conditions), overland flow usually becomes shallow concentrated flow. The shallow concentrated flow time, t_s, may be calculated using Equation RO-4.

Travel time (t_s) within a watershed is the ratio of flow length to flow velocity:

$$t_s = \frac{L}{60 * V} \qquad \textbf{(Equation RO-4)}$$

in which:

t_s= travel time (minutes) for shallow concentrated flow

L = flow length (feet)

V = average velocity (feet per second)

60 = conversion factor from seconds to minutes.

The average velocity for shallow concentrated flow can be determined from Equation RO-5 and Equation RO-6 for paved and unpaved areas, respectively. The average velocity can then be substituted into Equation RO-4 to calculate t_s.

$$V = 20.3282 * S^{1/2}$$ (Paved Areas) **(Equation RO-5)**

and

$$V = 16.1345 * S^{1/2}$$ (Unpaved Areas) **(Equation RO-6)**

The velocity equations presented above are based on the solution of the Manning's Equation (Equation RO-8) with different assumptions for n and R for paved and unpaved areas. For unpaved areas, n is 0.05 and R is 0.4; for paved areas, n is 0.025 and R is 0.2 (USDA NRCS – TR-55 1986).

2.8.3 Channelized Flow Time, t_t

Channelized flow is that part of the flow path which is neither overland sheet flow, nor shallow concentrated flow. Channelized flow paths may consist of storm sewers, gutters, swales, ditches, or natural drainageways in any combination. The channelized flow time, t_t, may be calculated using Equation RO-7.

$$t_t = \frac{L}{60 * V}$$ **(Equation RO-7)**

in which:

t_t = travel time (minutes) for channelized flow

L = flow length (feet)

V = average velocity (feet per second). Refer to Equation RO-8

60 = conversion factor from seconds to minutes.

And where:

$$V = \frac{1.49}{n} * R^{2/3} * S^{1/2}$$ (Manning's Equation) **(Equation RO-8)**

in which:

V = average velocity (feet per second)

n = Manning's roughness coefficient

R = hydraulic radius (feet) and is equal to A/P_w

A = cross-sectional flow area (square-feet)

P_w = wetted perimeter (feet)

S = average channel slope (feet-per-feet) expressed as a decimal

Manning's *n* values for open channel flow can be obtained from Table RO-7. After average velocity is computed using Equation RO-8, t_t for the channel segment can be estimated from Equation RO-7.

Table RO-7: Manning's Values of Roughness Coefficient *n* for Open Channels (Bedient and Huber 2002)

Type of Channel and Description	Minimum	Normal	Maximum
Lined or built-up channels			
Concrete, float finish	0.013	0.015	0.016
Concrete, concrete bottom	0.020	0.030	0.035
Gravel bottom with riprap	0.023	0.033	0.036
Brick, glazed	0.011	0.013	0.015
Excavated or dredged canal			
Earth, straight and uniform - short grass	0.022	0.027	0.033
Earth, winding, sluggish - dense weeds	0.030	0.035	0.040
Rock cuts, jagged and irregular	0.035	0.040	0.050
Channels not maintained, weeds and brush uncut	0.050	0.080	0.120
Natural Streams			
Clean, straight, full stage	0.025	0.030	0.033
Clean, winding, some pools and shoals	0.033	0.040	0.045
Sluggish reaches, weedy, deep pools	0.050	0.070	0.080
Mountain stream steep banks; gravel and cobbles	0.030	0.040	0.050
Mountain stream steep banks; cobbles with large boulders	0.040	0.050	0.070
Floodplains			
Pasture, no brush, high grass	0.030	0.035	0.050
Brush, scattered brush, heavy weeds	0.035	0.050	0.070
Brush, medium to dense brush in summer	0.070	0.100	0.160
Trees, dense willows, summer, straight	0.110	0.150	0.200
Trees, heavy stand of timber	0.080	0.100	0.120

2.8.4 Minimum Time of Concentration

In non-urban watersheds, should the calculations result in a t_c of less than 10-minutes, a minimum value of 10-minutes shall be used. In urban watersheds, the minimum t_c shall not be less than 5-minutes; if calculations indicate a lesser value, use 5-minutes instead.

2.8.5 Common Errors in Calculating Time of Concentration

A common error is to not check the runoff peak resulting from only part of the watershed. In some cases, a lower portion of the watershed or a localized highly impervious area may produce a larger peak flow rate than the entire watershed. In such a case, the time of concentration should be calculated for the smaller area that produces the higher peak flow rate. Failing to recognize this condition will result in calculating a longer time of concentration than is appropriate which results in a lower rainfall intensity value. This error is most often encountered when the watershed is long (and narrow presumably) or the upper portion contains rural parkland areas and the lower portion is developed urban land. Such an error can result in the under-sizing of stormwater infrastructure.

3.0 SCS CURVE NUMBER METHOD

The *Soil Conservation Service Technical Release – 55 Synthetic Hydrograph Method* (SCS method) is a synthetic hydrograph method developed specifically for use in urbanized and urbanizing areas. This method is useful in analyzing watersheds involving several subareas with complex runoff patterns. The method is most useful in analyzing changes in runoff volume due to development and in the evaluation and design of runoff control measures. The SCS method as described herein shall be used in all cases where the watershed being developed is characterized by complex runoff patterns and site conditions and/or is larger than 30 acres and less than 2000 acres. Complex runoff patterns and site conditions are characterized as areas with continually transitioning surface types, a collection of different flow types, numerous obstructions interfering with the runoff's direction and flow type, etc. When a watershed is observed to contain two or more distinct interacting sub-basins consistent with the conditions as dictated above then the watershed is considered complex. This method is similar to the Rational Method in that runoff is directly related to rainfall amounts through use of runoff curve numbers (CNs). The SCS method is explained in greater detail in the *National Engineering Handbook*, Section 4 (NEH-4), "Hydrology" (SCS 1985).

3.1 SCS Method Formula

Runoff, Q, for the SCS method is represented by Equation RO-9:

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S}$$ **(Equation RO-9)**

in which:

Q = runoff (inches)

P = rainfall depth for design storm (inches)

S = potential maximum retention after runoff begins (inches)

I_a = initial abstraction (inches)

Initial abstraction, I_a , is all losses before runoff begins. It includes water retained in surface depressions, water intercepted by vegetation, evaporation, and infiltration. I_a is highly variable but generally is correlated ith soil and cover parameters. A relationship between I_a and S was developed by USDA NRCS through studies of many small agricultural watersheds. The empirical relationship used in the SCS runoff formula is:

$$I_a = 0.2 * S \qquad \textbf{(Equation RO-10)}$$

Substituting Equation RO-10 into Equation RO-9 gives:

$$Q = \frac{(P - 0.2 * S)^2}{(P + 0.8 * S)} \qquad \textbf{(Equation RO-11)}$$

S is related to the soil and cover conditions of the watershed through the CN. CN has a range of 0 to 100, and S is related to CN by:

$$S = \frac{1000}{CN} - 10 \qquad \textbf{(Equation RO-12)}$$

Figure RO-1 and Table RO-8 solve Equation RO-11 and Equation RO-12 for a range of CNs and rainfall. Refer to Section 3.3 for explanations and direction in determining proper CNs for use in Equation RO-12.

Figure RO-1: Solution of Runoff Equation (USDA NRCS – TR-55 1986)

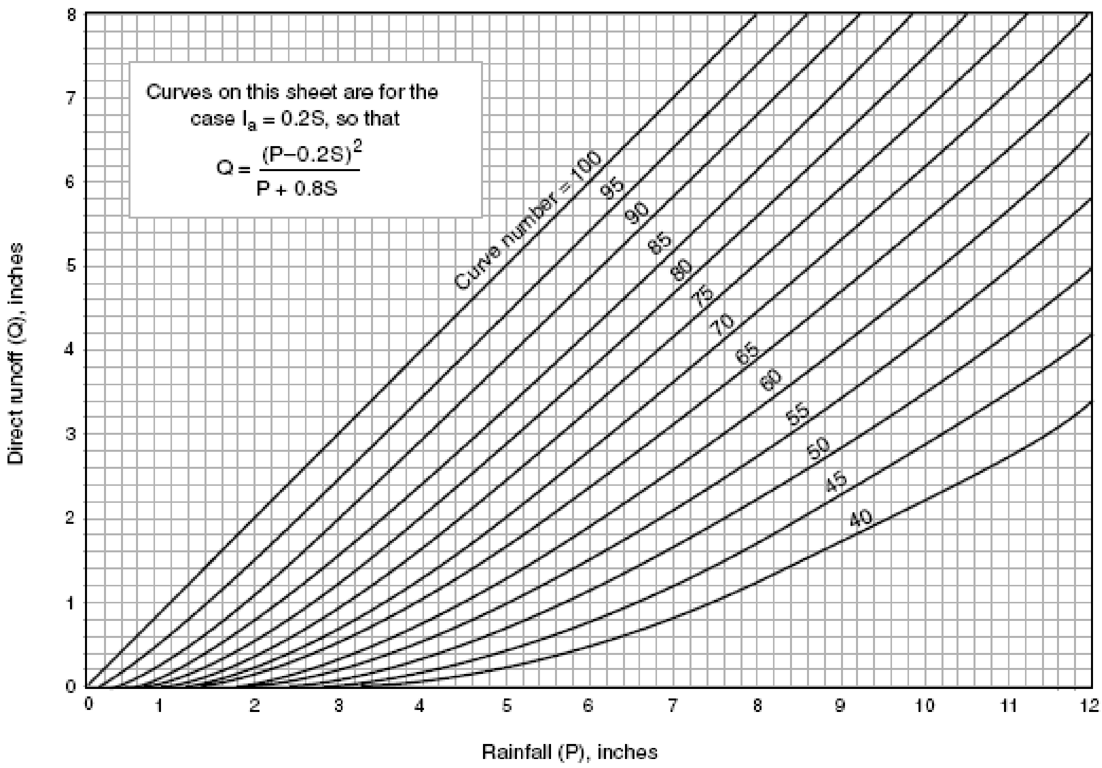


Table RO-8: Runoff Depths for Selected CNs and Rainfall Amounts
(USDA NRCS – TR-55 1986)

Rainfall (P) (inches)	Curve Number (CN [1])												
	40	45	50	55	60	65	70	75	80	85	90	95	98
	Inches												
1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.08	0.17	0.32	0.56	0.79
1.2	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.07	0.15	0.27	0.46	0.74	0.99
1.4	0.00	0.00	0.00	0.00	0.00	0.02	0.06	0.13	0.24	0.39	0.61	0.92	1.18
1.6	0.00	0.00	0.00	0.00	0.01	0.05	0.11	0.20	0.34	0.52	0.76	1.11	1.38
1.8	0.00	0.00	0.00	0.00	0.03	0.09	0.17	0.29	0.44	0.65	0.93	1.29	1.58
2.0	0.00	0.00	0.00	0.02	0.06	0.14	0.24	0.38	0.56	0.80	1.09	1.48	1.77
2.5	0.00	0.00	0.02	0.08	0.17	0.30	0.46	0.65	0.89	1.18	1.53	1.96	2.27
3.0	0.00	0.02	0.09	0.19	0.33	0.51	0.71	0.96	1.25	1.59	1.98	2.45	2.77
3.5	0.02	0.08	0.20	0.35	0.53	0.75	1.01	1.30	1.64	2.02	2.45	2.94	3.27
4.0	0.06	0.18	0.33	0.53	0.76	1.03	1.33	1.67	2.04	2.46	2.92	3.43	3.77
4.5	0.14	0.30	0.50	0.74	1.02	1.33	1.67	2.05	2.46	2.91	3.40	3.92	4.26
5.0	0.24	0.44	0.69	0.98	1.30	1.65	2.04	2.45	2.89	3.37	3.88	4.42	4.76
6.0	0.50	0.80	1.14	1.52	1.92	2.35	2.81	3.28	3.78	4.30	4.85	5.41	5.76
7.0	0.84	1.24	1.68	2.12	2.60	3.10	3.62	4.15	4.69	5.25	5.82	6.41	6.76
8.0	1.25	1.74	2.25	2.78	3.33	3.89	4.47	5.04	5.63	6.21	6.81	7.40	7.76
9.0	1.71	2.29	2.88	3.49	4.10	4.72	5.33	5.95	6.57	7.18	7.79	8.40	8.76
10.0	2.23	2.89	3.56	4.23	4.90	5.56	6.22	6.88	7.52	8.16	8.78	9.40	9.76
11.0	2.78	3.52	4.26	5.00	5.72	6.43	7.13	7.81	8.48	9.13	9.77	10.39	10.76
12.0	3.38	4.19	5.00	5.79	6.56	7.32	8.05	8.76	9.45	10.11	10.76	11.39	11.76
13.0	4.00	4.89	5.76	6.61	7.42	8.21	8.98	9.71	10.42	11.10	11.76	12.39	12.76
14.0	4.65	5.62	6.55	7.44	8.30	9.12	9.91	10.67	11.39	12.08	12.75	13.39	13.76
15.0	5.33	6.36	7.35	8.29	9.19	10.04	10.85	11.63	12.37	13.07	13.74	14.39	14.76

[1] To obtain runoff depths for CNs and other rainfall amounts not shown in this Table, use arithmetic interpolation.

3.2 Design Storm Data

The SCS method is based on 24-hour rainfall amounts for various design storm recurrence intervals (e.g., 1-year, 10-year, or 100-year storm events). These rainfall amounts are taken from the U.S. Weather Bureau Technical Paper No. 40 and are as follows for Bella Vista: 3.32 inches for the 1-year frequency rainfall; 4.08 inches for the 2-year frequency rainfall; 5.28 inches for the 5-year frequency rainfall; 6.00 inches for the 10-year frequency rainfall; 6.96 inches for the 25-year frequency; 7.92 inches for the 50-year frequency; and 8.64 inches for the 100-year frequency. Table RO-9 provides rainfall data derived from several sources for storm durations other than the 24-hour event and for a range of storm return frequencies, if needed for further detailed analysis.

Table RO-9: Rainfall Depth-Duration-Frequency Chart (Inches)

Duration (min)	1 Year (in)	2 Year (in)	5 Year (in)	10 Year (in)	25 Year (in)	50 Year (in)	100 Year (in)
5	0.41	0.46	0.55	0.61	0.71	0.78	0.85
6	0.49	0.54	0.63	0.71	0.82	0.90	0.99
7	0.56	0.60	0.71	0.79	0.91	1.01	1.11
8	0.62	0.66	0.78	0.87	1.00	1.11	1.22
9	0.67	0.71	0.85	0.95	1.09	1.21	1.32
10	0.72	0.76	0.91	1.01	1.18	1.30	1.42
11	0.76	0.81	0.97	1.08	1.24	1.38	1.51
12	0.80	0.85	1.02	1.14	1.31	1.45	1.58
13	0.84	0.89	1.07	1.19	1.37	1.52	1.67
14	0.87	0.93	1.12	1.25	1.44	1.59	1.74
15	0.90	0.97	1.16	1.30	1.50	1.65	1.81
16	0.93	1.01	1.21	1.34	1.56	1.72	1.88
17	0.96	1.04	1.24	1.39	1.61	1.79	1.96
18	0.98	1.07	1.29	1.44	1.67	1.85	2.02
19	1.01	1.10	1.32	1.49	1.72	1.90	2.07
20	1.03	1.13	1.35	1.53	1.77	1.96	2.14
21	1.05	1.15	1.39	1.57	1.82	2.02	2.21
22	1.07	1.17	1.43	1.61	1.87	2.07	2.30
23	1.09	1.20	1.46	1.65	1.91	2.12	2.33
24	1.11	1.22	1.49	1.68	1.96	2.17	2.37
25	1.13	1.25	1.53	1.72	2.00	2.22	2.44
26	1.15	1.27	1.55	1.76	2.05	2.27	2.49
27	1.16	1.29	1.58	1.78	2.08	2.31	2.54
28	1.18	1.31	1.61	1.82	2.12	2.36	2.59
29	1.20	1.32	1.63	1.85	2.16	2.40	2.64
30	1.21	1.35	1.65	1.88	2.20	2.45	2.69
31	1.23	1.35	1.67	1.91	2.23	2.48	2.74
32	1.24	1.38	1.70	1.94	2.27	2.53	2.77
33	1.25	1.39	1.72	1.96	2.30	2.57	2.82
34	1.27	1.41	1.74	1.99	2.33	2.61	2.86
35	1.28	1.41	1.76	2.02	2.37	2.63	2.91
36	1.29	1.44	1.78	2.04	2.39	2.67	2.94
37	1.30	1.46	1.80	2.05	2.42	2.71	2.98

Duration (min)	1 Year (in)	2 Year (in)	5 Year (in)	10 Year (in)	25 Year (in)	50 Year (in)	100 Year (in)
38	1.32	1.46	1.83	2.08	2.45	2.74	3.03
39	1.33	1.48	1.83	2.11	2.48	2.78	3.06
40	1.34	1.49	1.86	2.12	2.51	2.80	3.08
41	1.35	1.50	1.88	2.14	2.53	2.84	3.13
42	1.36	1.51	1.89	2.17	2.56	2.87	3.15
43	1.37	1.52	1.91	2.20	2.58	2.90	3.17
44	1.38	1.54	1.93	2.21	2.61	2.91	3.23
45	1.39	1.55	1.95	2.23	2.63	2.94	3.25
46	1.40	1.56	1.96	2.25	2.65	2.97	3.28
47	1.41	1.57	1.97	2.27	2.68	2.99	3.31
48	1.42	1.58	1.99	2.29	2.70	3.02	3.34
49	1.43	1.61	2.02	2.30	2.72	3.04	3.36
50	1.44	1.63	2.02	2.33	2.74	3.08	3.40
51	1.45	1.62	2.04	2.33	2.76	3.09	3.43
52	1.46	1.63	2.05	2.35	2.77	3.12	3.45
53	1.47	1.64	2.06	2.38	2.80	3.14	3.46
54	1.47	1.66	2.08	2.39	2.83	3.15	3.49
55	1.48	1.67	2.10	2.40	2.84	3.17	3.51
56	1.49	1.68	2.11	2.42	2.86	3.21	3.55
57	1.50	1.70	2.12	2.43	2.87	3.22	3.56
58	1.51	1.70	2.14	2.46	2.88	3.24	3.58
59	1.51	1.71	2.15	2.46	2.91	3.25	3.61
60	1.52	1.73	2.17	2.48	2.90	3.26	3.62
70	1.59	1.83	2.29	2.61	3.10	3.43	3.86
80	1.65	1.93	2.45	2.76	3.24	3.61	4.11
90	1.70	2.01	2.55	2.90	3.42	3.80	4.29
100	1.75	2.07	2.65	3.02	3.52	3.95	4.45
110	1.79	2.18	2.73	3.12	3.63	4.07	4.57
120	1.83	2.24	2.82	3.22	3.72	4.18	4.64
140	1.90	2.38	2.92	3.34	3.90	4.34	4.85
160	1.96	2.40	3.04	3.44	4.00	4.48	5.04
180	2.05	2.37	3.12	3.60	4.11	4.59	5.16
360	2.36	2.88	3.72	4.38	5.04	5.58	6.18
720	2.83	3.48	4.44	5.28	6.00	6.72	7.44
1,440	3.32	4.08	5.28	6.00	6.96	7.92	8.64

Source: 2-, 5-, 10-, 25-, 50-, 100-Year Design Storm
5-60 min. NOAA HYDRO-35
60-120 min. interpolated
120-1,440 min. Technical Paper No. 40
Source: 1-Year Design Storm
180-, 360-, 720-, 1440-min. Technical Paper No. 40
5-60 min. calculated from logarithmic trend line from 5, 10, 15, 30, 60, & 120-min. T.P.-40

3.3 Determination of Runoff Curve Number (CN)

The runoff curve number (CN) determines the amount of runoff that will occur given a specified rainfall amount. The determination of the CN value for a watershed is a function of the hydrologic soil group (HSG), cover type and hydrologic condition, and antecedent moisture condition (AMC). Another factor considered is whether impervious areas outlet directly to the drainage system (connected) or whether the flow spreads over pervious areas before entering the drainage system (unconnected).

CN values in Table RO-10 and Table RO-11 represent average antecedent moisture conditions for undeveloped and developed lands. For watersheds with multiple soil types or land uses, an area-weighted CN should be calculated. When significant differences in land use or natural control points exist, the watershed shall be broken into smaller drainage areas for modeling purposes. Curve Numbers presented in Table RO-10 and Table RO-11 are based on the assumption that impervious areas are directly connected. The following sections provide details on the factors governing the determination of CN values and their relationship to runoff.

3.3.1 Hydrologic Soil Group

Soils are classified as one of four (A, B, C, or D) hydrologic soil groups (HSG). A soil's HSG indicates the minimum rate of infiltration obtained for bare soil after prolonged wetting. Group A soils have the highest infiltration rates while Group D soils have the lowest. The infiltration rate is the rate at which water enters the soil at the soil surface and is controlled by the surface's cover type. The four HSGs are defined in TR-55 (USDA NRCS – TR-55 1986) as follows:

- **Group A –** (Sand, loamy sand, or sandy loam) 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).
- **Group B –** (Silt loam or loam) 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 (0.15-0.30 in/hr).
- **Group C –** (Sandy clay loam) 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 (0.05-0.15 in/hr).
- **Group D –** (Clay loam, silty clay loam, sandy clay, silty clay, or clay) 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 (0-0.05 in/hr).

It should be noted that any disturbance of a soil profile can significantly change its infiltration characteristics. With urbanization, native soil profiles may be mixed or removed or fill material from other areas may be introduced. Therefore, for areas where the soil profile has been disturbed, the HSG shall be adjusted up one level (i.e., from A to B, B to C, or C to D) unless it can be shown to the City's satisfaction that the predevelopment soil profile has been reestablished.

The predominant HSG in the City of Bella Vista is Group C. However, the soils in the area of interest for any project should be identified from a soil survey report, which can be obtained from local SCS offices, soil and water conservation district offices, or online resources such as the "Web Soil Survey" provided by USDA NRCS (http://websoilsurvey.nrcs.usda.gov).

3.3.2 Cover Type and Hydrologic Condition

Table RO-10 and Table RO-11 address most cover types, such as vegetation, bare soil, and impervious surfaces. There are several methods for determining cover type, but the most common are field reconnaissance, aerial photographs, and land use maps. It should be noted that anticipated cover types shall also be considered in runoff analysis based on the City's current zoning and future land use plan for the area of interest being analyzed.

Hydrologic condition indicates the effects of cover type on infiltration and runoff for a particular HSG and is generally estimated from plant density on sample areas, with higher plant density resulting in higher rates of infiltration. "*Good*" hydrologic condition indicates that the soil usually has a low runoff potential for that specific HSG and cover type. Some factors to consider in estimating the effect of cover on infiltration and runoff are (a) canopy or density of lawns, crops, or other vegetative areas; (b) amount of year-round cover; (c) amount of grass or close-seeded legumes in rotations; and (d) degree of surface roughness.

3.3.3 Antecedent Moisture Condition

Antecedent moisture condition (AMC) is the index of runoff potential before a storm event. The AMC accounts for the existing degree of soil saturation at the beginning of a rainfall, therefore adjusting the CN to reflect more accurate runoff conditions. All values given in Table RO-10 and Table RO-11 represent AMC II (median moisture conditions) and shall be used for design. Adjustments for AMC I (dry conditions) and AMC III (wet conditions) can be made if appropriate (refer to USDA NRCS – NEH-4 1985), but will need to be approved by the City prior to their use.

3.3.4 Impervious Area Drainage Paths – Connected or Unconnected

When determining CN values it is important to consider how runoff from impervious areas is conveyed to the drainage system. For example, do the impervious areas connect directly to the drainage system, or are they disconnected and flow onto lawns or other pervious areas where infiltration can occur?

3.3.4.1 Connected impervious areas

An impervious area is considered connected if runoff from the area flows directly into the drainage system. It is also considered connected if runoff from the area occurs as concentrated shallow flow that runs over an impervious area and then into the drainage system.

Urban Area CNs (Table RO-10) were developed for typical land use relationships based on specific assumed percentages of impervious area. These CN values were developed on the assumptions that (a) pervious urban areas are equivalent to pasture in good hydrologic condition and (b) impervious areas have a CN of 98 and are directly connected to the drainage system. Some assumed percentages of impervious area are shown in Table RO-10.

If all of the impervious area at a site is directly connected to the drainage system, but the impervious area percentages or the pervious land use assumptions in Table RO-10 are not applicable, use Figure RO-2 to compute a composite CN. For example, Table RO-10 gives a CN of 70 for a 1/2-acre lot in HSG B, with assumed impervious area of 25 percent. However, if the lot has 20 percent impervious area and a pervious area CN of 61, the composite CN obtained from Figure RO-2 is 68. The CN difference between 70 and 68 reflects the difference in percent impervious area. If composite values are used, their calculation shall be supplied in the Drainage Report.

3.3.4.2 Unconnected impervious areas

Runoff from unconnected impervious areas is spread over a pervious area as sheet flow. To determine the CN when all or part of the impervious area is not directly connected to the drainage system, (1) use Figure RO-3 if total impervious area is less than 30 percent, or (2) use Figure RO-2 if the total impervious area is equal to or greater than 30 percent, because the absorptive capacity of the remaining pervious areas will not significantly affect runoff.

When impervious area is less than 30 percent, obtain the composite CN by referring to the right half of Figure RO-3 and identifying the intersection point of the horizontal axis value (percentage of total impervious area) with the vertical axis value (ratio of total unconnected impervious area to total impervious area). From that intersection point, refer to the left portion of Figure RO-3 to the appropriate pervious CN and read down to find the composite CN. For example, for a 1/2-acre lot with 20 percent total impervious area (75 percent of which is unconnected) and pervious CN of 61, the composite CN from Figure RO-3 is 66. If all of the impervious area is connected, the resulting CN (from Figure RO-2) would be 68.

Table RO-10: Runoff Curve Numbers (*CN*) for Urban Areas (Antecedent Moisture Condition II, and $I_a = 0.2*S$) (USDA NRCS – TR-55 1986)

COVER DESCRIPTION		*CN* FOR HYDROLOGIC SOIL GROUP			
COVER TYPE	**AVERAGE % IMPERVIOUS AREA [3]**	**A**	**B**	**C**	**D**
Open Spaces (lawns, parks, golf courses, cemeteries, etc.)					
Poor Condition (grass cover <50%)	-	68	79	86	89
Fair condition: grass cover on 50% to 75% of the area .	-	49	69	79	84
Good condition: grass cover on 75% or more of the area [1]	-	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 R.O.W)	-	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: [2]					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Developing Urban Areas					
Newly Graded Areas (pervious areas only, no vegetation) . .	-	77	86	91	94

[1] Good cover is protected from grazing and litter and brush cover soil.
[2] Curve numbers are computed assuming that the runoff from the house and driveway is directed toward the street with a minimum of roof water directed to lawns where additional infiltration could occur.
[3] The remaining pervious areas (lawn) are considered to be in good pasture condition for these curve numbers.

Table RO-11: Runoff Curve Numbers (*CN*) for Non-Urban Areas (Antecedent Moisture Condition II, and $I_a = 0.2*S$) (USDA NRCS – TR-55 1986)

COVER DESCRIPTION		*CN* FOR HYDROLOGIC SOIL GROUP			
COVER TYPE AND HYDROLOGIC CONDITION		**A**	**B**	**C**	**D**
Idle Lands (not yet developed)					
Pasture, Grassland, or Range ---- continuous forage for grazing. [1]	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. [2]	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	30 [3]	48	65	73
Woods ---- grass combination (orchard or tree farm). [4]	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods [5]	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	30 [3]	55	70	77
Farmsteads ---- buildings, lanes, driveways, and surrounding lots.	----	59	74	82	86

[1] *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.

[2] *Poor*: <50% ground cover.
Fair: 50 to 75% ground cover.
Good: >75% ground cover.

[3] If actual CN is less than 30; use CN = 30 for runoff calculations

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

[5] *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.

Figure RO-2: Composite CN with Connected Impervious Area (USDA NRCS – TR-55 1986)

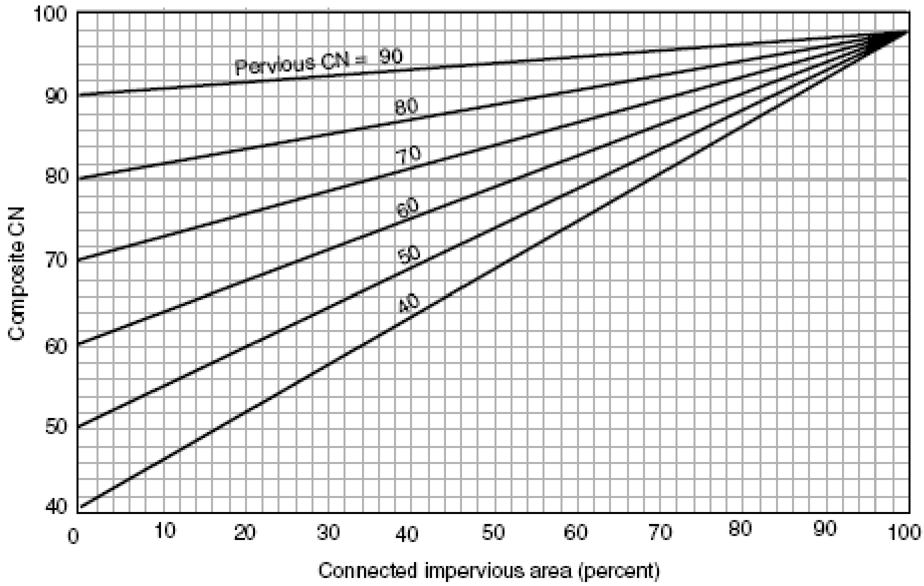
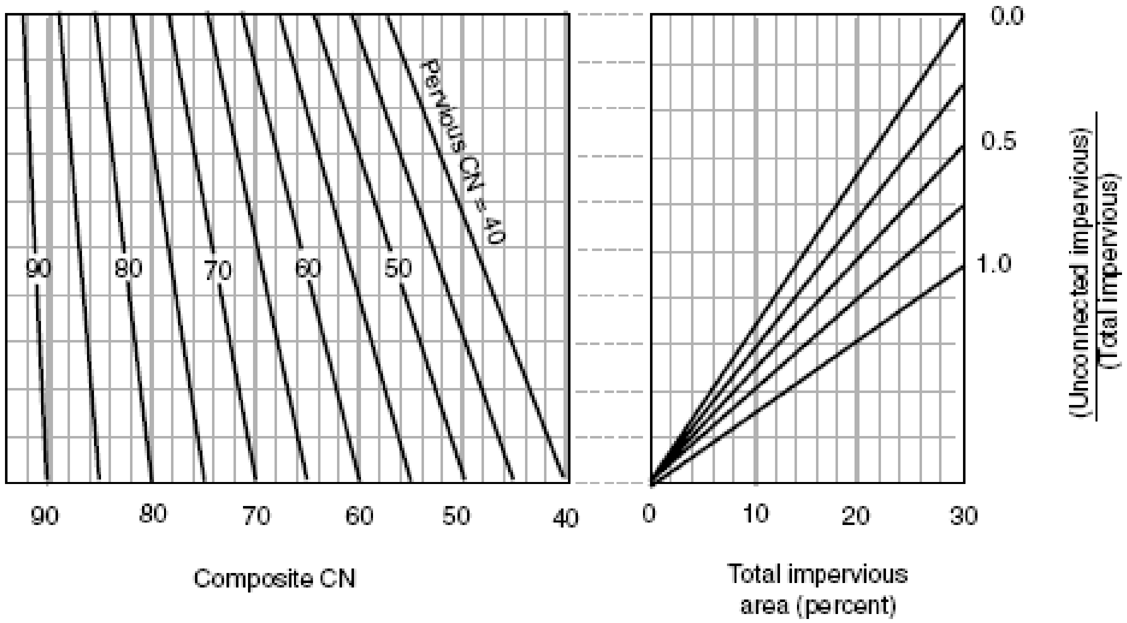


Figure RO-3: Composite CN with Unconnected Impervious Areas and Total Impervious Areas Less than 30% (USDA NRCS – TR-55 1986)



3.4 Limitations on Use of SCS Method

- Do not use the SCS method when large changes in CN values occur among watershed subareas and when runoff volumes are less than about 1-1/2 -inches for CN values less than 60.

- The CN procedure is less accurate when runoff is less than 1/2-inch. As a check, use another procedure to determine runoff when this occurs.
- Do not use the SCS method for watersheds that have several subareas with times of concentration that are less than 6 minutes. In these cases, subareas should be combined to produce a time of concentration of at least 6 minutes (0.10 hours) for the combined areas.
- Curve numbers describe average conditions that are useful for design purposes. If the rainfall event used is a historical storm, the modeling accuracy decreases.
- Use the runoff curve number equation with caution when re-creating specific features of an actual storm. The equation does not contain an expression for time and, therefore, does not account for rainfall duration or intensity.
- The initial abstraction relationship, $I_a = 0.2*S$ (which consists of interception, initial infiltration, surface depression storage, evapo-transpiration, and other factors) is based on data obtained by the USDA NRCS from agricultural watersheds (where S is the potential maximum retention after runoff begins). In reality not all watersheds (urban conditions and non-urban conditions) share the same I_a because of differing combinations of impervious and pervious areas along with differing storage features. However, for this Manual I_a will be related the same for all watershed conditions.
- Runoff from snowmelt or rain on frozen ground cannot be estimated using these procedures.
- The SCS method procedures apply only to direct surface runoff. Do not overlook large sources of subsurface flow or high ground water levels that contribute to runoff. These conditions are often related to HSG A soils and forest areas that have been assigned relatively low CNs in Table RO-10 and Table RO-11. Good judgment and experience based on stream gage records are needed to adjust CNs as conditions warrant.
- When the weighted CN is less than 40, use another procedure to determine runoff.

3.5 Computer Modeling

Due to the large number of computations involved in runoff calculations and routing, use of modern computer models by experienced engineers is allowed by the City for the drainage calculations/methods outlined above. The U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Center (HEC) has developed computer programs that can be downloaded online at the USACE hydrologic website (http://www.hec.usace.army.mil/) that can be applied to some of the drainage methods. HEC-HMS is one such program available from USACE.   Additionally, versions of TR-20 and TR-55 are available through the NRCS, which allow user input of rainfall distributions and perform acceptable detention and channel routing routines. The HEC-HMS, TR-55, and TR-20 models are available free of charge from the agencies that developed them. Table RO-12 provides additional information on the computer models as well as a link for downloading the available software.

Commercial software, such as StormCAD, StormNET, etc., is also an acceptable method for evaluating the drainage methods mentioned in this chapter. It is the responsibility of the design engineer to understand the methods employed within the commercial software used and ensure that the software's results will match and correspond with the methodology outlined in this chapter of the *Manual*.

Table RO-12: Computer Modeling Software

Available Computer Models	Computer model is useful in calculating …	Link to Download Computer Program
HEC-HMS	SCS method	**HEC-HMS Download Link**
TR-55	SCS method, T_c	**TR-55 Download Link**
TR-20	SCS method, T_c	**TR-20 Download Link**

If computer modeling is used for calculating the date provided in the development's submitted Drainage Report, the software used and which version shall be stated in the report prior to any of the calculation tables or data.

4.0 REFERENCES

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