Appendix B
Estimating Runoff

Introduction

The increased amount of erosion occurring with the conversion of rural land to urban areas depends on the amount of runoff that occurs as well as the amount of disturbance to natural vegetation and land forms. This section addresses what influences runoff and how the volume and rate of runoff is determined. The method and most of the material is reprinted from Urban Hydrology for Small Watersheds, TR—55, Soil Conservation Service, June 1986. The user is urged to obtain a copy of TR—55 and become familiar with the concepts and methods which it contains.

Factors Affecting Runoff

Rainfall: Precipitation, whether it occurs as rain or snow, is the potential source of water that may run off the surface of small watersheds. The extent of the storm and the distribution of rainfall during the storm are two major factors which affect the peak rate of runoff.

The storm distribution can be thought of as a measure of how the rate of rainfall (intensity) varies within a given time interval. For example, in a given 24—hour period, a certain amount of precipitation may have been measured, However, this precipitation may have occurred over the entire 24—hour period or in just one hour. These two situations represent two entirely different storm distributions.

The size of the storm is often described by the length of time over which precipitation occurs, the total amount of precipitation occurring and how often this same storm might be expected to occur (frequency). Thus a 10—year, 24—hour storm can be thought of as a storm producing the amount of rain in 24 hours with a 10% chance of occurrence in a year. One day (24 hour) rainfall tables are listed as Exhibit B—1 at the end of this section for 1, 2, 5, 10, 25, 50 and 100—year frequencies.

Antecedent Moisture Condition: The runoff from a given storm is affected by the existing soil moisture content resulting from the amount of precipitation occurring during the preceding five days (antecedent moisture condition).

Watershed Area: The watershed area or area draining water to the point of interest is usually determined from a topographic map or scaled aerial photograph accompanied by a field review locating manmade features that have diverted the flow of water.

Soils: In general, the higher the rate of infiltration, the lower the quantity of stormwater runoff. Fine—textured soils such as clay produce a higher rate of runoff than do coarse—textured soils such as sand. Sites having clay soils may require the construction of more elaborate drainage systems than sites having sandy soils. Exhibit B—2 contains a list of soils found in West Virginia and their respective hydrologic soil group.

Surface Cover: The type of cover and its condition affects runoff volume through its influence on the infiltration rate of the soil. Fallow land yields more runoff than forested or grass land for a given soil type.

The foliage and its litter maintain the soil's infiltration potential by preventing the sealing of the soil surface from the impact of the raindrops. Some of the raindrops are maintained on the surface of the foliage, increasing their chance of being evaporated back to the atmosphere. Some of the intercepted moisture takes a long time to drain from the plant down to the soil so that it is withheld from the initial period of runoff. Foliage also transpires moisture into the atmosphere thereby creating a moisture deficiency in the soil which must be replaced by rainfall before runoff occurs. Vegetation, including ground litter, forms numerous barriers along the path of the water flowing over the surface of the land which slows the water down and reduces its peak rate of runoff.

Covering areas with impervious material reduces surface storage and infiltration and thus increases the amount of runoff.

Time Parameters: Time is the parameter that is used to distribute the runoff into a hydrograph. The time is based on the velocities of flow through segments of the watershed. The slope of the land in the watershed is a major factor in determining the velocity. Two major parameters are time of concentration (T_c) and travel time of flow through the segments (T_t).

Storage in the Watershed: On very flat surfaces where ponding or swampy areas occur throughout the watershed, a considerable amount of the surface runoff may be retained in temporary storage, thus reducing the rate at which runoff will occur. Storage areas may be created to reduce the rate of runoff in an urbanizing area. These can be effective sediment traps as well as flood detention structures if permanently maintained in the watershed.

Methods of Determining Runoff

Many different methods of computing runoff have been developed. Some of the methods and limitations of each are listed below.

1. SCS National Engineering Handbook Section 4, Hydrology, may be used to develop hydrographs and peak discharge from any drainage area, including those larger than 20 square miles. The methods contained in this handbook are quite complex and should not be attempted by those who are untrained in hydrology.

2. Computer Program for Project Formulation—Hydrology, SCS—TR—20, utilizes hydrologic soil—cover complexes to determine runoff volumes and unit hydrographs to determine peak rates of discharge. Factors included in the method are 24—hour rainfall amount, a given rainfall distribution, runoff curve numbers, time of concentration, travel time, and drainage area. This procedure probably should not be used for drainage areas more than 20 square miles. It is very useful for large drainage basins, especially when there are a series of structures or several tributaries to be studied.

3. The SCS Engineering Field Handbook, Chapter 2, Procedures for Determining Peak Discharge, is valid for small rural

watersheds. The time of concentration for the non—urbanized area is estimated using a formula based on flow length, runoff curve number and average watershed slope. Chapter 2 procedures are applicable to drainage areas that range from 1 to 2000 acres. Tables, figures, exhibits, and worksheets are included for a quick and reliable way to estimate peak discharge and runoff for a range of rainfall amounts, soil types, land use and cover conditions.

4. The SCS—TR—55 tabular method is an approximation of the more detailed SCS—TR—20 method. The tabular method can be used for watersheds where hydrographs are needed to measure non—homogeneous runoff, i.e., the watershed is divided into subareas. It is especially applicable for measuring the effects of changed land use in a part of a watershed. It can also be used to determine the effects of structures and combinations of structures, including channel modifications, at different locations in a watershed. The tabular method should not be used when large changes in the curve number occur within subareas.

   For most watershed conditions, however, this procedure is adequate to determine the effects of urbanization on peak rates of discharge for subareas with "T_c" less than two hours.

5. The SCS—TR—55 Graphical Peak Discharge Method calculates peak discharge from hydrograph analyses using TR—20, Computer Program for Project Formulation. This method demonstrates a procedure for estimating depth and peak rates of runoff from small watersheds. The watershed must be hydrologically homogeneous, that is land use, soils, and cover are distributed uniformly throughout the watershed. The time of concentration for the watershed is estimated using the computed flow velocities for the sheet flow, shallow concentrated flow and channel flow. These values may range from 0.1 to 10 hours. This method was selected for inclusion in this manual to use in designing erosion and sediment control measures.

SCS Runoff Curve Number Method

The SCS Runoff Curve Number (CN) method is described in detail in National Engineering Handbook — Chapter 4 (NEH—4). The SCS runoff equation is

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \qquad \text{[Eq. B—1]}$$

where

Q = runoff (in),

P = rainfall (in),

S = potential maximum retention after runoff begins (in), and

I_a = initial abstraction (in).

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

$$I_a = 0.2S \qquad \text{[Eq. B—2]}$$

By removing I_a as an independent parameter, this approximation allows use of a combination of S and P to produce a unique runoff amount. Substituting equation B—2 into equation B—1 gives

$$Q = \frac{(P - 0.2S)^2}{(P+0.8S)} \qquad \text{[Eq. B—3]}$$

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

$$S = \frac{1000}{CN} - 10 \qquad \text{[Eq. B—4]}$$

Figure B—1 solves equation B—3 for a range of CN's and rainfall.

Factors Considered in Estimating Runoff Curve Numbers

The major factors that determine CN are the hydrologic soil group (HSG), cover type, treatment, hydrologic condition, and antecedent runoff condition (ARC). 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). Figure B—2 is provided to aid in selecting the appropriate figure or table for determining curve numbers.

CN's in Tables B—1, B—2 and B—3 represent average antecedent runoff condition for urban, cultivated agricultural and other agricultural uses. These tables assume impervious areas are directly connected. The following sections explain how to determine CN's and how to modify them for urban conditions.

Hydrologic Soil Groups: Infiltration rates of soils vary widely and are affected by subsurface permeability as well as surface intake rates. Soils are classified into four HSG's (A, B, C, and D) according to their minimum infiltration rate, which is obtained for bare soil after prolonged wetting. Exhibit B—2 defines the four groups and provides a list of the soils in West Virginia and their group classification. The soils in the area of interest may be identified from a county soil survey report, which can be obtained from local SCS offices or soil and water conservation district offices.

Most urban areas are only partially covered by impervious surfaces; 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 predominantly of silts and clays, which generally have low infiltration rates.

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, a method based on soil texture is given in Exhibit B—2 for determining the HSG classification for disturbed soils.

Cover Type: Tables B—1, B—2 and B—3 address most cover types such as vegetation, bare soil, and impervious surfaces. There are a number of methods for determining cover type. The most common are field reconnaissance, aerial photographs, and land use maps.

Treatment: Treatment is a cover type modifier (used only in Table B—2) to describe the management of cultivated agricultural lands. It includes mechanical practices, such as contouring and terracing, and management practices, such as crop rotations and reduced or no tillage.

Hydrologic Condition: Hydrologic condition indicates the effects of cover type and treatment on infiltration and runoff and is generally estimated from density of plant and residue cover on sample areas. Good hydrologic condition indicates that the soil usually has a low runoff potential for that specific hydrologic soil group, cover type and treatment. 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; (d) percent of residue cover; and (e) degree of surface roughness.

Antecedent Runoff Condition: The index of runoff potential before a storm event is the antecedent runoff condition (ARC). ARC is an attempt to account for the variation in CN at a site from storm to storm. CN for the average ARC at a site is the median value as taken from sample rainfall and runoff data. The CN's in Tables B—1, B—2 and B—3 are for the average ARC, which is primarily used for design applications. See the SCS NEH—4 for more detailed discussion of storm—to—storm variation and a demonstration of upper and lower enveloping curves.

Urban Impervious Area Modifications: Several factors, such as the percentage of impervious area and the means of conveying runoff from impervious areas to the drainage system, should be considered in computing 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?

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 a drainage system.

Urban CN's, Table B—1, 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 areas are shown in Table B—1.

If all of the impervious area is directly connected to the drainage system, but the impervious area percentages or the pervious land use assumptions in Table B—1 are not applicable, use Figure B—3 to compute a composite CN. For example, Table B—1 gives a CN of 70 for a 1/2—acre lot in hydrologic soil group B, with an 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 B—3 is 68. The CN difference between 70 and 68 reflects the difference in percent impervious area.

Unconnected Impervious Areas: Runoff from these areas is spread over a pervious area as sheet flow. To determine CN when all or part of the impervious area is not directly connected to the drainage system, (1) use Figure B—4 if total impervious area is less than 30 percent or (2) use Figure B—3 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 entering the right half of Figure B—4 with the percentage of total impervious area and the ratio of total unconnected impervious area to total impervious area. Then move left to the appropriate pervious CN and read down to find the composite CN. For example, for a 1/2—acre lot with 20 percent total impervious area (75 percent of which is unconnected) and a pervious CN of 61, the composite CN from Figure B—4 is 66. If all of the impervious area is connected, the resulting CN (from Figure B—3) would be 68.

Figure B-1 — Solution to Runoff Equation

(Reprinted from: 210-VI-TR-55, Second Ed., June 1986)

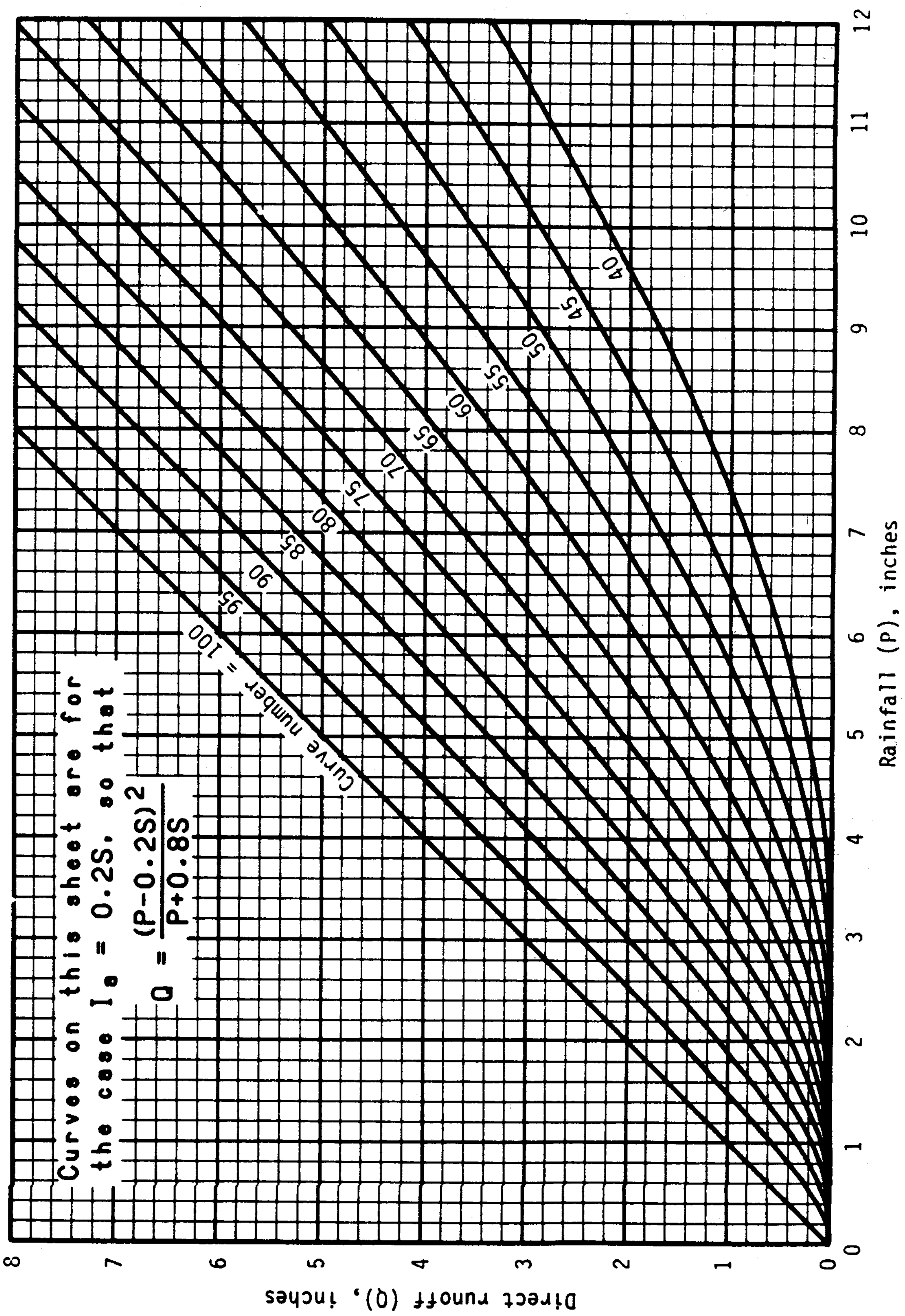


Figure B-2

Flow Chart for Selecting Appropriate Figure or Table for Determining Runoff Curve Numbers

(Reprinted from 210-VI-TR-55, Second Ed., June 1986)

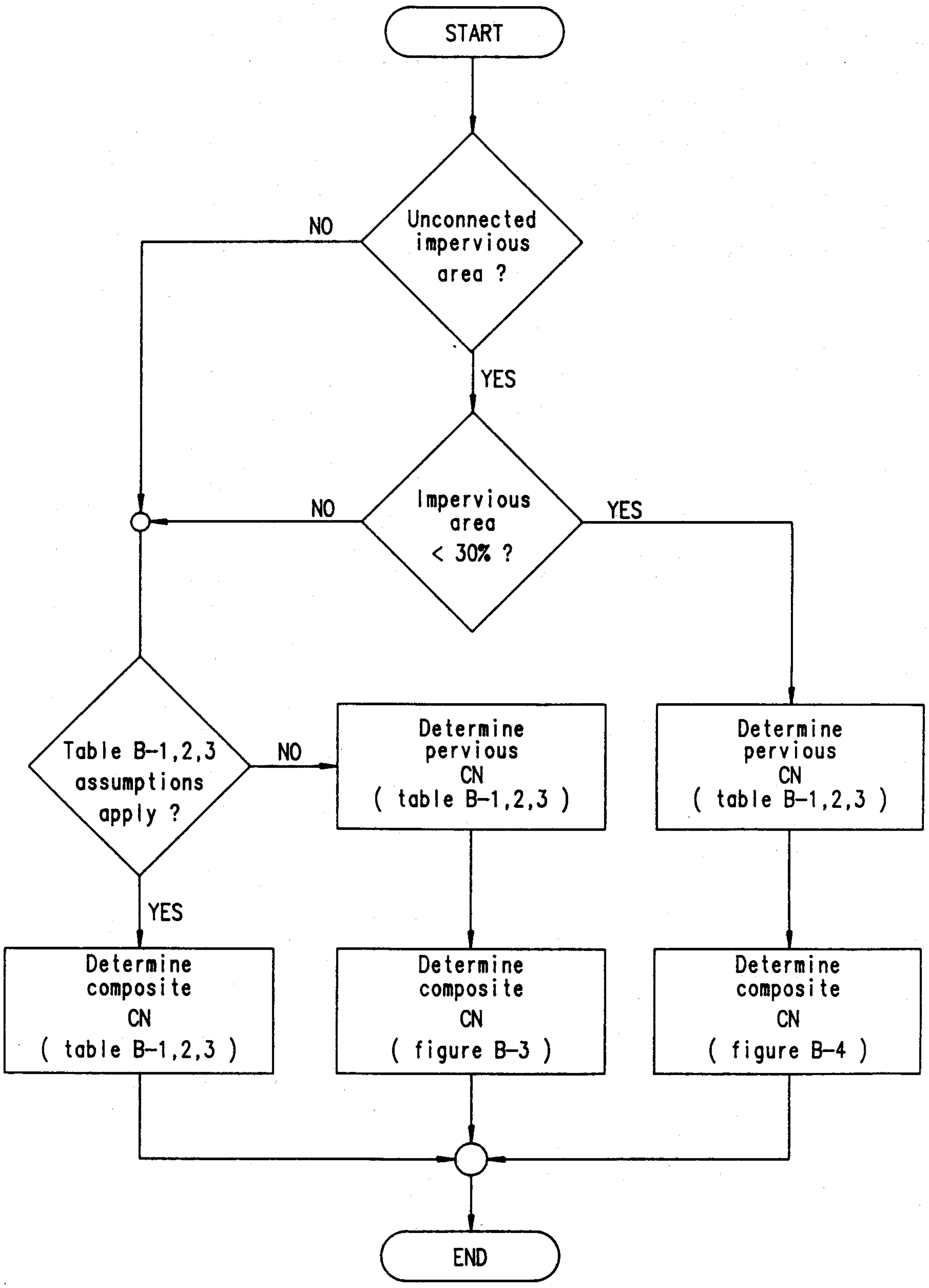


Table B-1 — Runoff Curve Numbers for Urban Areas [1]

(Reprinted from: 210-VI-TR-55, Second Ed., June 1986)

Cover Description		Curve numbers for hydrologic soil group			
Cover type and hydrologic condition	Average percent impervious area [2]	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	98
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
Natural desert landscape (pervious areas only) [4]		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with a 1 to 2 inch sand or gravel mulch and basin boarders)		96	96	96	96
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
Developing urban areas					
Newly graded areas (pervious areas only, no vegetation) [5]		77	86	91	94
Idle lands (CN's are determined using cover types similar to those in Table B-3)					

[1] Average runoff condition and $I_a = 0.2S$

[2] The average percent impervious area shown was used to develop 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 Figure B-3 or B-4.

[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 for natural desert landscaping should be computed using Figure E-3 or B-4 based on the impervious area percentage (CN = 98) and the pervious area CN. The pervious area CN's are assumed equivalent to desert shrub in poor hydrologic Condition.

[5] Composite CN's to use for the design of temporary measures during grading and construction should be computed using Figure B-3 or B 4 based on the degree of development (impervious area percentage) and the CN's for newly graded pervious areas.

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

(Reprinted from: 210-VI-TR-55, Second Ed., June 1986)

Cover description			Curve numbers 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	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

[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] Hydrologic condition is based on combination 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 in rotation, (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.

Table B-3 — Runoff Curve Numbers for Other Agricultural Lands [1]

(Reprinted from: 210-VI-TR-55, Second Ed., June 1986)

Cover description		Curve numbers for hydrologic soil group			
Cover type	Hydrologic condition	A	B	C	D
Pasture, grassland, or range-continous forage for grazing. [2]	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow-continous 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.

Figure B-3

Composite CN with Connected Impervious Area

(Reprinted from: 210-VI-TR-55, Second Ed., June 1986)

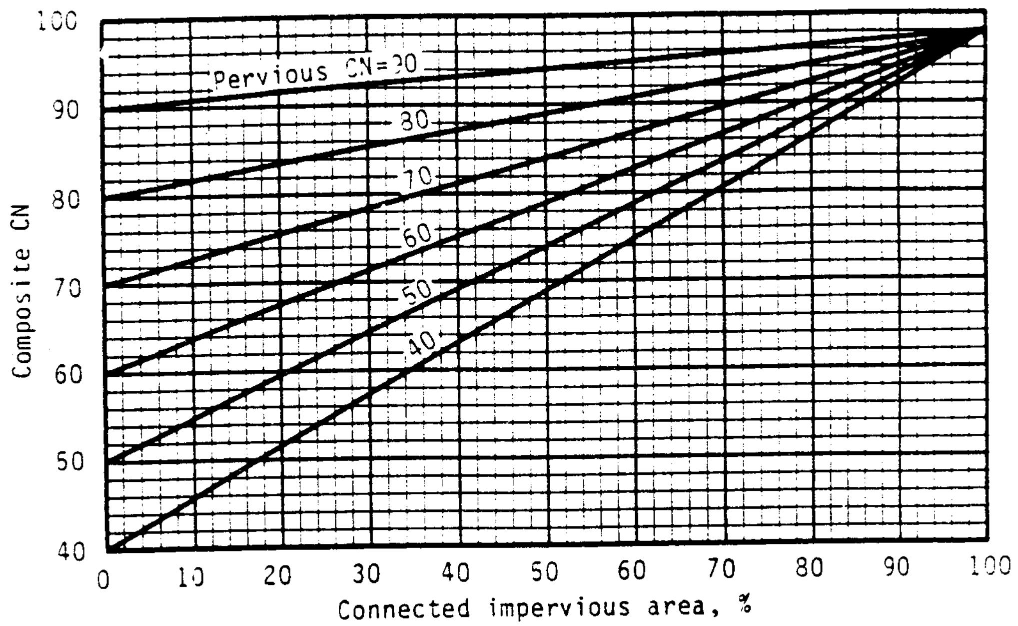
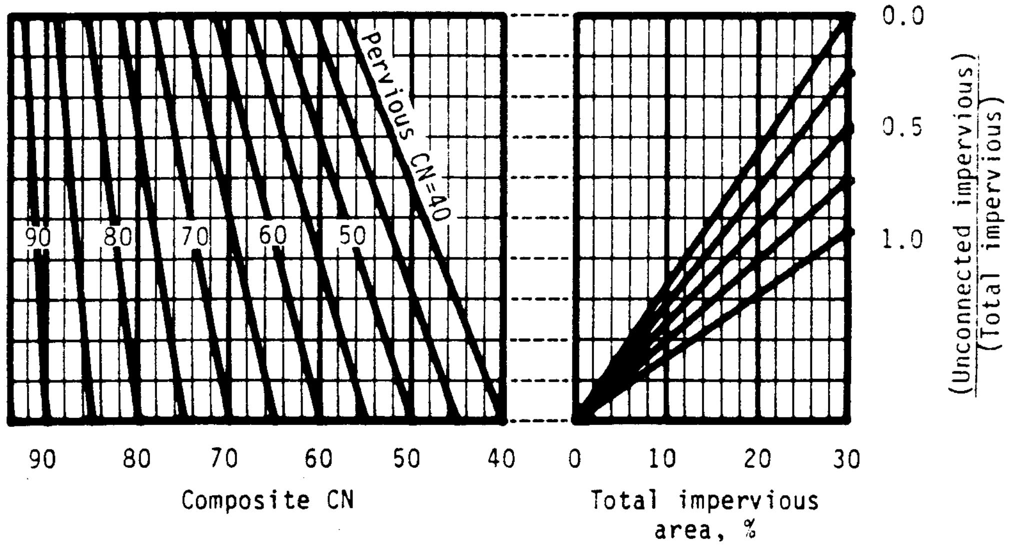


Figure B-4

Composite CN with Unconnected Impervious Areas and Total Impervious Areas less than 30%

(Reprinted from: 210-VI-TR-55, Second Ed., June 1986)



Runoff Determination

When CN and the amount of rainfall have been determined for the watershed, determine runoff by using Figure B—1.

Limitations: 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 recreating 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 user should understand the assumption reflected in the initial abstraction term (I_a) and should ascertain that the assumption applies to the situation. I_a, which consists of interception, initial infiltration, surface depression storage, evapotranspiration, and other factors, was generalized as 0.2S based on data from agricultural watersheds (S is the potential maximum retention after runoff begins). This approximation can be especially important in an urban application because the combination of impervious areas with pervious areas can imply a significant initial loss that may not take place. The opposite effect, a greater initial loss, can occur if the impervious areas have surface depressions that store some runoff. To use a relationship other than $I_a = 0.2S$, one must redevelop equation B—3, Figure B—1 and Tables B—1, B—2 and B—3 by using the original rainfall—runoff data to establish new S or CN relationships for each cover and hydrologic soil group.

Runoff from snowmelt or rain on frozen ground cannot be estimated using these procedures.

The CN procedure is less accurate when runoff is less than 0.5 inch. As a good check, use another procedure to determine runoff.

The SCS runoff 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 curve numbers. Good judgement and experience based on stream gage records are needed to adjust CN's as conditions warrant. When the weighted CN is less than 40, use another procedure to determine runoff.

Examples

Four examples illustrate the procedure for computing runoff curve number (CN) and runoff (Q) in inches. Worksheet 2, Figure B—5, is provided to assist users. Figures B—6 through Figure B—9 represent the use of Worksheet 2 for each example. All four examples are based on the same watershed and the same storm event.

The watershed covers 250 acres in Marion County, West Virginia. Seventy percent (175 acres) is a Gilpin soil, which is in hydrologic soil group C. Thirty percent (75 acres) is a Culleoka soil, which is in group B. The event is a 25—year frequency, 24—hour storm with a total rainfall of 4.63 inches.

Cover type and conditions in the watershed are different for each example. The examples, therefore, illustrate how to compute CN and Q for various situations of proposed, planned, or present development.

Example 1:
The present cover type is pasture in good hydrologic condition. See Figure B—6 for Worksheet 2 information.

Example 2:
Seventy percent (175 acres) of the watershed, consisting of all the Culleoka soil and 100 acres of the Gilpin soil, is 1/2—acre residential lots with lawns in good hydrologic condition. The rest of the watershed is scattered open space in good hydrologic condition. See Figure B—7.

Example 3:
This example is the same as Example 2, except that the 1/2—acre lots have a total impervious area of 35 percent. For these lots, the pervious area is lawns in good hydrologic condition. Since the impervious area percentage differs from the percentage assumed in Table B—1, use Figure B—3 to compute CN. See Figure B—8.

Example 4:
This example is also based on Example 2, except that 50 percent of the impervious area associated with the 1/2—acre lots on the Gilpin soil is "unconnected," that is, it is not directly connected to the drainage system. For these lots, the pervious area CN (lawn, good condition) is 74 and the impervious area is 25 percent. Use Figure B—4 to compute the CN for these lots. CN's for the 1/2—acre lots on Culleoka soil and the open space on Gilpin soil are the same as those in Example 2. See Figure B—9.