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ON

SCS-CN METHOD

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SCS-METHOD

INTRODUCTION

The Soil Conservation Service Curve Number (SCS-CN) method was developed in 1954 and is documented in Section 4 of the National Engineering Handbook (NEH-4) published by the Soil Conservation Service (now called the Natural Resources Conservation Service), U.S. Department of Agriculture in 1956. The document has since been revised in 1964, 1965, 1971, 1972, 1985, and 1993. The SCS-CN method is the result of exhaustive field investigations carried out during the late 1930s and early 1940s and the works of several early investigators, including Mockus, Sherman, Andrews, and Ogrosky. The passage of Watershed Protection and Flood Prevention Act (Public Law 83-566) in August 1954 led to the recognition of the method at the Federal level and the method has since witnessed myriad applications all over the world. It is one of the most popular methods for computing the volume of surface runoff for a given rainfall event from small agricultural, forest, and urban watersheds. The method is simple, easy to understand and apply, stable, and useful for ungauged watersheds. The primary reason for its wide applicability and acceptability lies in the fact that it accounts for most runoff producing watershed characteristics: soil type, land use/treatment, surface condition, and antecedent moisture condition. This chapter describes the existing SCS-CN method, the concept of curve number and factors affecting it, the procedure for its application, sensitivity of its parameters, and its advantages and limitations.

SCS-CN METHOD

The SCS-CN method is based on the water balance equation and two fundamental hypotheses. The first hypothesis equates the ratio of the actual amount of direct surface runoff (Q) to the total rainfall (P) (or maximum potential surface runoff) to the ratio of the amount of actual infiltration (F) to the amount of the potential maximum retention (S). The second hypothesis relates the initial abstraction (I_a) to the potential maximum retention. Thus, the SCS-CN method consists of

(a) water balance equation:

$$P = I_a + F + Q \qquad (1)$$

(b) proportional equality hypothesis:

$$\frac{Q}{P - I_a} = \frac{F}{S} \qquad (2)$$

and (c) I_a-S hypothesis:

$$I_a = \lambda S \qquad (3)$$

where P = total rainfall; I_a = initial abstraction; F = cumulative infiltration excluding I_a; Q = direct runoff; and S = potential maximum retention or infiltration, also described as the potential post initial abstraction retention. All quantities in equations (1) through (3) are in depth or volumetric units.

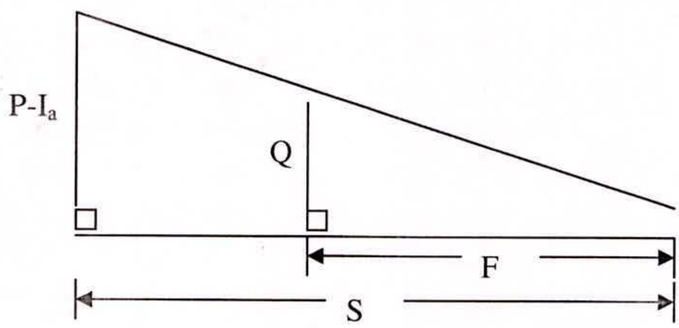

Figure 1. Proportionality concept

The fundamental hypothesis (equation (2)) is primarily a proportionality concept, as shown in Figure 1. Apparently, as $Q \rightarrow (P-I_a)$, $F \rightarrow S$. This proportionality enables partitioning (or dividing) $(P-I_a)$ into two surface water (Q) and subsurface water (F) for given watershed characteristics or S. This partitioning, however, undermines the saturated overland flow or source area concept that allows runoff generation from only saturated or wet portions of the watershed. Consequently, the statistical theory based on the runoff production from only saturated (independent or interacting) storage elements is negated. According to the SCS-CN method, the extent of runoff contribution of a storage element depends on its capacity or, alternatively, the magnitude of S and, therefore, the whole watershed should contribute to runoff, if S is taken to be a definite quantity. Thus, the ratio of the wet and total areas describing the contributing portion should be equal to one.

Parameter S of the SCS-CN method depends on the soil type, land use, hydrologic condition, and antecedent moisture condition (AMC). The initial abstraction accounts for the short-term losses, such as interception, surface storage, and infiltration. Parameter λ is frequently viewed as a regional parameter dependent on geologic and climatic factors. The existing SCS-CN method assumes λ to be equal to 0.2 for practical applications. Many other studies carried out in the United States and other countries report λ to vary in the range of (0, 0.3). The second hypothesis of the SCS-CN method (equation (3)) linearly relates the initial abstraction to the potential maximum retention. Combining equations (1) and (2), the popular form of the SCS-CN method is obtained as:

$$Q = \frac{(P - I_a)^2}{P - I_a + S} \tag{4}$$

Equation (4) is valid for $P \geq I_a$; $Q = 0$ otherwise. For $\lambda = 0.2$, equation (4) can be re-written as:

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \tag{5}$$

Thus, the existing SCS-CN method (equation (5)) is a one-parameter model for computing surface runoff from daily storm rainfall, for the method was originally developed using daily rainfall-runoff data of annual extreme flows. Since parameter S (equation (5)) can vary in the range of $0 \leq S \leq \infty$, it is mapped into a dimensionless curve number (CN), varying in a more appealing range $0 \leq CN \leq 100$, as follows:

$$S = \frac{1000}{CN} - 10 \tag{6}$$

The underlying difference between S and CN is that the former is a dimensional quantity [L] whereas the latter is a non-dimensional quantity. Although CN theoretically varies from 0 to 100, the practical design values validated by experience lie in the range (40, 98).

FACTORS AFFECTING CN

Major watershed characteristics that affect the SCS-CN parameter S or curve number, CN, are soil type, type of vegetation cover, land use/treatment, hydrologic condition, antecedent moisture condition, and climate of the watershed. The combination of soil type, vegetation cover, and land use/treatment is referred to as soil-vegetation-land use (SVL) complex. These characteristics primarily affect the infiltration potential of a watershed. For a given rainfall amount, the magnitude of Q depends on S (or CN) or the infiltration potential. NEH-4 presents CN-values for several typical vegetation cover or land use/treatment and its combinations, as given in Table 1. Apparently, the SVL combinations can broadly be classified into urban, agricultural, and woods and forest. A description of these factors affecting CN or infiltration follows.

Soil Type

Soils are broadly classified as sand, silt, and clay on the basis of the grain size, which decreases in their order. The size of grains affects the size of pores that, in turn, affects infiltration. Other major factors in this category include soil texture, structure, hydraulic conductivity, and initial moisture content that affect infiltration. A loose conductive sandy soil will exhibit larger infiltration rate than the tightly packed clay. A soil with good under-drainage system will exhibit larger infiltration than in the otherwise situation. A layered soil with different textural properties and the order of their arrangement will also affect the overall infiltration. A dry soil will show larger infiltration than will a wet soil.

The Soil Conservation Service identified four hydrologic groups of soils A, B, C, and D, based on their infiltration and transmission rates. Infiltration is defined as the rate at which the water enters the soil at its surface and is thus controlled by surface conditions. On the other hand, the transmission is defined as the rate at which water moves in the soil and is controlled by the soil horizon. The former refers to the infiltration capacity of the soil defined by various formulae whereas the latter refers to the hydraulic conductivity of the soil.

Table 1. Runoff curve numbers for hydrologic cover complexes
(for AMC II and $I_a = 0.2$ S)

Sl. No.	Land use Description/Treatment	Hydrologic Condition /% impervious area	Hydrologic Soil Groups			
			A	B	C	D
	Urban					
1	[1]Residential:					
	Average lot size- 1/8 acre or less	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 acre	12*	46	65	77	82
2	Paved parking lots, roofs, driveways, etc.[2] (excluding right-of-way)		98	98	98	98
3	Streets and roads :					
	Paved with curbs and storm sewers[2]		98	98	98	98

	(excluding right-of-way)					
	Paved, open ditches (including right-of-way)		82	89	92	93
	Gravel (including right-of-way)		76	85	89	91
	Dirt (including right-of-way)		72	82	87	89
4	Western desert areas:					
	Natural desert landscaping (pervious areas only)[3]		63	77	85	88
	Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)		96	96	96	96
5	Urban districts :					
	Commercial and business areas	85	89	92	94	95
	Industrial districts	72	81	88	91	93
6	Developing areas :					
	Newly graded areas (pervious areas only, no vegetation)[4]		77	86	91	94
	Idle lands					
7	Open spaces, lawns, parks, golf courses, cemeteries, etc.					
	Grass cover on 75% or more of the area	Good	39	61	74	80
	Grass cover on 50% to 75% of the area	Fair	49	69	79	84
	Agricultural					
	Cultivated lands :					
8	Fallow :					
	Bare soil Straight row	----	77	86	91	94
	Crop residue cover	Poor	76	85	90	93
		Good	74	83	88	90
9	Row crops :					
	Straight row	Poor	72	81	88	91
	Straight row	Good	67	78	85	89
	Crop residue cover Straight row	Poor	71	80	87	90
	Crop residue cover Straight row	Good	64	75	82	85
	Contoured	Poor	70	79	84	88
	Contoured	Good	65	75	82	86
	Crop residue cover Contoured	Poor	69	78	83	87
	Crop residue cover Contoured	Good	64	74	81	85
	Contoured & terraced	Poor	66	74	80	82

	Contoured & terraced	Good	62	71	78	81
	Crop residue cover Contoured & terraced	Poor	65	73	79	81
	Crop residue cover Contoured & terraced	Good	61	70	77	80
10	Small grain :					
	Straight row	Poor	65	76	84	88
	Straight row	Good	63	75	83	87
	Crop residue cover Straight row	Poor	64	75	83	86
	Crop residue cover Straight row	Good	60	72	80	84
	Contoured	Poor	63	74	82	85
	Contoured	Good	61	73	81	84
	Crop residue cover Contoured	Poor	62	73	81	84
	Crop residue cover Contoured	Good	60	72	80	83
	Contoured & terraced	Poor	61	72	79	82
	Contoured & terraced	Good	59	70	78	81
	Crop residue cover Contoured & terraced	Poor	60	71	78	81
	Crop residue cover Contoured & terraced	Good	58	69	77	80
11	Close-seeded legumes[5] or rotation meadow :					
	Straight row	Poor	66	77	85	89
	Straight row	Good	58	72	81	85
	Contoured	Poor	64	75	83	85
	Contoured	Good	55	69	78	83
	Contoured & terraced	Poor	63	73	80	83
	Contoured & terraced	Good	51	67	76	80
	Uncultivated lands :					
12	Pasture or range :	Poor	68	79	86	89
		Fair	49	69	79	84
		Good	39	61	74	80
	Contoured	Poor	47	67	81	88
	Contoured	Fair	25	59	75	83
	Contoured	Good	6	35	70	79
13	Meadow- continuous grass, protected from grazing, and generally mowed for hay	Good	30	58	71	78
	Brush-brush weed grass mixture with brush being the major element	Poor	48	67	77	83
		Fair	35	56	70	77
		Good	30	48	65	73
14	Farmsteads- buildings, lanes, driveways, and	----	59	74	82	86

	surrounding lots					
	Woods and forests					
	Humid rangelands or agricultural uncultivated lands :					
15	Woods or forest land	Poor	45	66	77	83
		Fair	36	60	73	79
		Good	25	55	70	77
16	Woods-grass combination (orchard or tree farm)	Poor	57	73	82	86
		Fair	43	65	76	82
		Good	32	58	72	79
	Arid and Semiarid rangelands[6] :					
17	Herbaceous	Poor		80	87	93
		Fair		71	81	89
		Good		62	74	85
18	Oak-aspen	Poor		66	74	79
		Fair		48	57	63
		Good		30	41	48
19	Pinyon-juniper	Poor		75	85	89
		Fair		58	73	80
		Good		41	61	71
20	Sagebrush with grass understory	Poor		67	80	85
		Fair		51	63	70
		Good		35	47	55
21	Desert shrub	Poor	63	77	85	88
		Fair	55	72	81	86
		Good	49	68	79	84

Notations:

[1]Curve numbers are computed assuming the runoff from the house and driveway is directed towards the street with a minimum of roof water directed to lawns where additional infiltration could occur.

[2]In some warmer climates of the country, a curve number of 95 may be used.

[3]Composite CNs should be computed based on % impervious area (CN=98) and the pervious area CN. The pervious area CNs are taken to be equivalent to desert shrub in poor hydrologic condition.

[4]Composite CNs for the design of temporary measures during grading and construction should be computed based on the degree of development (impervious area percentage) and the CNs for the newly graded pervious areas.

[5]Close-drilled or broadcast.

[6]Curve numbers for Group À have been developed only for desert shrub.

[*]The remaining pervious areas (lawns) are considered to be in good pasture condition.

Group A. The soils falling in Group A exhibit high infiltration rates even when they are thoroughly wetted, high rate of water transmission, and low runoff potential. Such soils include primarily deep, well to excessively drained sands or gravels.

Group B. These soils have moderate infiltration rates when thoroughly wetted and consist primarily of moderately deep to deep, moderately well to well drained soils with fine, moderately fine to moderately coarse textures, for example, shallow loess and sandy loam. These soils exhibit moderate rates of water transmission.

Group C. Soils in this group have low infiltration rates when thoroughly wetted. These soils primarily contain a layer that impedes downward movement of water. Such soils are of moderately fine to fine texture as, for example, clay loams, shallow sandy loam, and soils low in organic content. These soils exhibit a slow rate of water transmission.

Group D. The soils of this group exhibit very low rates of infiltration when they are thoroughly wetted. Such soils are primarily clay soils of 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 exhibit a very slow rate of water transmission. Table 2 shows the description of these hydrologic soil groups in terms of minimum infiltration rate.

Table 2. Description of hydrologic groups

Hydrologic Soil Group	Minimum infiltration rate (inch/hr)
A	0.30-0.45
B	0.15-0.30
C	0.05-0.15
D	0-0.05

Land Use

The land use characterizes the uppermost surface of the soil system and has a definite bearing on infiltration. It describes the watershed cover and includes every kind of vegetation, litter and mulch, and fallow as well as nonagricultural uses, such as water surfaces, roads, roofs, etc. A forest soil, rich in organic matter, allows greater infiltration than a paved one in urban areas. On an agricultural land or a land surface with loose soil whose particles are easily detached by the impact of rainfall, infiltration is affected by the process of rearrangement of these particles in the upper layers such that the pores are clogged and lead to reduction in the infiltration rate. A grassy or vegetated land will help reduce such a clogging and allow more infiltration. Land treatment applies mainly to agricultural land uses and includes mechanical practices, such as contouring and terracing and management practices, such as grazing control or rotation of crops. Classes refer to the combinations of use and treatment actually to be found on watersheds. The land use and treatment classes listed in Table 1 can be broadly classified into urban, cultivated land, and woods and forest.

Urban Lands

Urban lands refer to the areas of low or insignificant permeability. Table 1 lists curve numbers for residential; paved parking lots; streets and roads; western desert areas; commercial and industrial areas; developing areas; and open spaces, including lawns, parks, etc. Paved areas are assigned the curve number equal to 98. Most of these classifications are based on the amount of percent imperviousness of the area. The remaining pervious areas are assumed to be in a good pasture condition. Thus, the amount of imperviousness plays an important role in the rainfall-runoff process. The larger the impervious area, the higher will be the runoff potential of the watershed and vice versa.

The above described impervious areas include only directly connected impervious areas (DCIA). If runoff from an impervious area passes over a pervious area as sheet flow prior to being discharged, that impervious area is not considered directly connected, rather it is considered as part of the pervious area because it undergoes infiltration while passing over a pervious area as sheet flow. It is noted that infiltration occurs in the same manner as if the runoff originated from the pervious area. There may be significant differences between DCIA and the total impervious area of the watershed. For example, based on the calibration of the observed rainfall/runoff data in a residential watershed during storm events, Pandit and Regan found that while the total impervious area was 61%, DCIA was only 40% of the watershed area. This difference was mainly because portions of roofs and the driveway discharged water over lawns as sheet flow and were, therefore, not directly connected.

Cultivated Land

It is apparent from Table 1 that agricultural watersheds can also be classified as cultivated and uncultivated. The agricultural land uses are classified as fallow land, row crops, small grain crops, close-seeded legumes or rotation meadow, pasture or range, and meadow. Fallow refers to bare agricultural land use treatment having the highest runoff potential. A row crop implies any field crop (for example, maize, sorghum, soybean, sugar beat, tomato, tulip, etc.) planted in rows far apart so that most of the soil surface is exposed to the rainfall impact throughout the growing season. In the areas experiencing snowfall, growing seasons occur when soils are not frozen and there is no snow on the ground. At the planting time, it is tantamount to fallow land and may be so again after harvest. Row crops can be planted either in straight rows or on the contour and they can be in poor or good rotation.

Straight row fields are farmed in straight rows either up and down the hill or across the slope. Where land slopes are less than 2%, farming across the land slope in straight rows is equivalent to contouring. Contoured fields are farmed as nearly as possible along the contour. Contouring delays runoff to increase infiltration. As an example, from Table 1, row crops on soil A in poor hydrologic condition exhibit a CN-value of 72 whereas a CN-value of 70 on the same soil in the same hydrologic condition but on contoured rows.

Rotation refers to a planned sequence of crops to maintain soil fertility or reduce erosion or provide an annual moisture supply to a particular crop. Rotation can be poor, fair, or good depending on the allowance for density of vegetative cover in the rotation. Poor rotations are generally one-crop land uses, such as continuous corn (maize) or continuous wheat or combinations of row crops, small grains, and fallow. On the other hand, good rotations generally contain alfalfa or other close-seeded legume or grass to improve tilth and increase infiltration. Another terraced class of land use refers to the systems containing open-end level or graded terraces, grassed waterway outlets, and contour furrows between terraces. In furrows and terraces, a low infiltration land use, if replaced by grassed waterways, will increase opportunities for infiltration.

Small grain crops (for example, wheat, oat, barley, flax, etc.) are planted in rows close enough so that the soil surface is not exposed except during planting and shortly thereafter. Close-seeded legumes or rotation meadow (for example, alfalfa, sweet-clover, timothy, etc. and combinations) are either planted in close rows or broadcast. This cover may remain for more than a year to allow year-round protection to the soil from rainfall impact. Meadows represent fields on which grass is continuously grown. These are protected from grazing and are generally mowed for hay. If a wet meadow is drained, its soil group classification as well as its land use and treatment class may change. Contour furrows on native pasture or range last longer than on cultivated land. Their life span depends on the type of soil, intensity of grazing, and the density of cover. The CN-values in Table 1 are based on the data from contour grassland watersheds in central and southern Great Plains. Terraces are seldom used for grasslands. In the event of their use, the construction methods expose bare soils such that the terraced grassland acts hydrologically like a terraced cropland for the next 2-3 years. In other words, the runoff potential of the terraced grassland is the same as of the terraced cropland in the coming few years.

Woods and Forests

Woods and forests may fall under humid rangelands that are tantamount to uncultivated agricultural watersheds and arid and semiarid rangelands. Woods are usually small isolated grooves of trees raised for farm or ranch use. Based on the cover effectiveness (not on timber production), woods can be evaluated as shown in Table 3. The hydrologic condition, described in the following section, is estimated visually. Forests, on the other hand, generally cover a large part of the watershed. In humid forest regions of the United States, soil group, humus type, and humus depth are the major factors affecting CN. The undecomposed leaves or needles, twigs, bark, and other vegetative debris on the forest floor form litter, from which humus is derived. Humus is the organic layer immediately below the litter layer. Thus, litter protects humus from oxidation. Humus may consist of mull, an intimate mixture of organic matter and mineral soil or of mor which is practically pure organic matter indistinguishable from the original material lying on the forest floor. Humus increases with the age of forest and because of its porous nature, it increases infiltration. Good management practices refer to proper use, protection and improvement of humus content for increasing infiltration, whereas poor management practices allow burning, over-cutting or overgrazing, and thereby, reduce infiltration. Humus content is evaluated in terms of the degree of compaction: compact, moderately compact, and loose or friable. If mulls are firm and mors are felty, it is compact; otherwise, it is friable. The moderately compact situation represents the transition stage. Frost in compact humus acts like concrete and inhibits infiltration and in loose humus, the frost is granular and favors infiltration. Since frost and humus type are closely related, the effect of frost was not separately accounted for.

Table 3. Classification of woods

Sl. No.	Vegetation Condition	Hydrologic Condition
1	Heavily grazed or regularly burned. Litter, small trees, and brush are destroyed.	Poor
2	Grazed but not burned. Some litter exists, but these woods not protected.	Fair
3	Protected from grazing and litter and shrubs cover the soil.	Good

Hydrologic Condition

The hydrologic condition of an agricultural watershed is defined in terms of the percent area of grass-cover. The larger the area of grass cover in a watershed, the lesser will be the runoff potential of the watershed and more will be infiltration. Such a situation describes the watershed to be in a good hydrologic condition. It is good because it favors the protection of watershed from erosion for soil conservation purposes. Similarly, a watershed having lesser acreage of grass cover can be defined to be in a poor hydrologic condition. Alternatively, a good hydrologic condition allows more infiltration than does a poor hydrologic condition. Thus, the hydrologic condition of a forest area also represents its runoff-producing potential. The curve number will be the highest for poor, average for fair, and the lowest for good condition, leading to categorizing the hydrologic condition into three groups: good, fair, and poor, depending on the areal extent of grasslands or native pasture or range, as shown in Table 4. These conditions are based on cover effectiveness. It is emphasized that the cover effectiveness does not imply forage protection. The percent area covered and the intensity of grazing are estimated visually. Grazing on dry soils results in lowering of infiltration rates due to the compaction of the soil by hooves. Its effect may carry over for a year or more even without further grazing. Meadows representing fields on which grass is continuously grown, and are protected from grazing. Drained meadows (with low water table) have little or no surface runoff except during rainfalls of high intensity. Undrained meadows (with high water table) may be as much wet as water surfaces for which CN is equal to 100.

Table 4. Classification of native pasture or range

Sl. No.	Vegetation condition	Hydrologic Condition
1	Heavily grazed and no mulch or plant cover on less than 1/2 of the area	Poor
2	Not heavily grazed and plant cover on less than 1/2 to 3/4 of the area	Fair
3	Lightly grazed and plant cover on more than 3/4 of the area	Good

Agricultural Management Practices

Agricultural management systems involve different types of tillage, vegetation, and surface cover. Studies have illustrated the effects of tillage practices (moldboard plough, chisel plough, and no till) on infiltration. Brakensiek and Rawls reported that moldboard plough increases soil porosity from 10-20%, depending on the soil texture and, in turn, increases infiltration rates over non-tilled soils. It is found that an increase in organic matter in the soil lowers bulk density or increases porosity, and hence increases infiltration and, in turn, decreases the runoff potential. Rawls found the bare soil to decrease the hydraulic conductivity, K_h, between planting and midseason and then K_h was found to stay stable because of crusting. The residue maintains a high steady state rate until harvest while the canopy and canopy-residue combination increase K_h. Thus, the residue cover as such increases the soil porosity, n, and hence reduces the runoff potential.

Antecedent Moisture Condition

The antecedent moisture condition (AMC) refers to the wetness of the soil surface or the amount of moisture available in the soil profile, or alternatively the degree of saturation before the start of the storm. In the event that the soil is fully saturated, the whole amount of rainfall will directly convert to runoff without infiltration losses and if the soil is fully dry, it is possible that the whole rainfall amount is absorbed by the soil, leading to no surface runoff. Thus, the antecedent moisture condition affects the process of rainfall-runoff significantly. Laboratory infiltration data exhibited a significant impact of initial water content of the soil on infiltration rates. For completeness, a brief description of the antecedent moisture condition is in order.

A conceptual model like the existing SCS-CN method working with the mean values leaves room for some variability. Experience indicates that a set of curve numbers can exist for a given watershed. Ponce and Hawkins summarized the likely sources to lie in the spatial and temporal variability of rainfall, quality of measured rainfall-runoff data, and the variability of antecedent rainfall and the associated soil moisture amount. The last source of variability was recognized very early leading to the development of the concept of antecedent moisture condition. This concept is also referred to as the antecedent runoff condition (ARC), implying a departure of emphasis from soil moisture to runoff. In the plot of rainfall-runoff data, the scatter of the data points is usually interpreted as the measure of natural variability of soil moisture in the associated rainfall-runoff relation. There are three concepts generally used in hydrologic literature to identify the antecedent moisture condition (AMC) of the soil. These are the antecedent precipitation index (API), antecedent baseflow index (ABFI), and the soil-moisture-index (SMI).

API is based on the amount of antecedent rainfall. The term antecedent varies from previous 5 to 30 days (d). However, there is no explicit guideline available to vary the soil moisture with the antecedent rainfall of certain duration. The National Engineering Handbook uses the antecedent 5-d rainfall as API for AMC (Table 5) and it is generally used in practice. AMC is categorized into three levels: AMC I, AMC II, and AMC III. AMC I refers to the dry condition of a soil, AMC II to the normal or average, and AMC III to the wet condition of the watershed. Thus, the CN corresponding to AMC I refers to the dry CN or the lowest runoff potential; the CN corresponding to AMC III refers to the wet CN or the highest runoff potential, and the CN corresponding to AMC II stands for the average CN or the average runoff potential. In other words, higher the antecedent moisture or rainfall amount, higher the CN and higher the runoff potential of the watershed and vice versa. Table 6 is used for converting CN of AMC II to CNs of AMC I and AMC III.

Table 5. Antecedent soil moisture conditions (AMC)

AMC	Total 5-day antecedent rainfall (cm)	
	Dormant season	Growing season
I	Less than 1.3	Less than 3.6
II	1.3 to 2.8	3.6 to 5.3
III	More than 2.8	More than 5.3

The dry, wet, and normal situations are statistically found to correspond, respectively, to 90%, 10%, and 50% cumulative probability of exceedance of runoff depth for a given rainfall. Alternatively, AMC II represents the central tendency, whereas AMC I and AMC III account for dispersion in the data. Depending on the amount of antecedent 5-d rainfall, AMC is varied according to Table 5. The cases of 3-d antecedent rainfall have also been reported in literature. Soil Conservation Service also recommended for developing AMC criteria for individual watersheds using rainfall-runoff data. The advantage of the existing approach of API is that it is simple, easy to grasp, and easy to apply in field.

Table 6. Curve numbers for three antecedent moisture conditions

AMC II	AMC I	AMC III	AMC II	AMC I	AMC III
100	100	100	60	40	78
99	97	100	59	39	77
98	94	99	58	38	76
97	91	99	57	37	75
96	89	99	56	36	75
95	87	98	55	35	74
94	85	98	54	34	73
93	83	98	53	33	72
92	81	97	52	32	71
91	80	97	51	31	70
90	78	96	50	31	70
89	76	96	49	30	69
88	75	95	48	29	68
87	73	95	47	28	67
86	72	94	46	27	66
85	70	94	45	26	65
84	68	93	44	25	64
83	67	93	43	25	63
82	66	92	42	24	62
81	64	92	41	23	61
80	63	91	40	22	60
79	62	91	39	21	59
78	60	90	38	21	58
77	59	89	37	20	57
76	58	89	36	19	56
75	57	88	35	18	55
74	55	88	34	18	54

73	54	87	33	17	53
72	53	86	32	16	52
71	52	86	31	16	51
70	51	85	30	15	50
69	50	84			
68	48	84	25	12	43
67	47	83	20	9	37
66	46	82	15	6	30
65	45	82	10	4	22
64	44	81	5	2	13
63	43	80	0	0	0
62	42	79			
61	41	78			

DETERMINATION OF CURVE NUMBER

In most cases, the curve numbers were developed using daily rainfall-runoff records corresponding to the maximum annual flows derived from gauged watersheds for which information on their soils, cover, and hydrologic conditions was available. Rainfall (P)-runoff (Q) data were plotted on the arithmetic paper having a grid of plotted curve numbers, as shown in Figure 2. The curve number that represented the watershed was taken as the median curve number. Thus, the developed curve numbers represented the averages of median site values for soil groups, cover, and hydrologic conditions. The upper enveloping curve was taken to correspond to AMC III and the lower curve to AMC I. The average was later extended to imply the average soil moisture condition. It is worth mentioning that not all soils, cover types, and hydrologic conditions were represented by rainfall-runoff data, rather these were interpolated to complete the information contained in NEH-4.

To derive the average CN-values for AMC II mathematically from the rainfall-runoff data of a gauged watershed, Hawkins suggested S- (or CN-) computation using the following equation:

$$S = 5[P + 2Q - \sqrt{Q(4Q + 5P)}] \tag{7}$$

which can be derived from equation (5). For application of the SCS-CN method to ungauged watersheds, NEH-4 related the above three antecedent moisture conditions with the amount of antecedent 5-d rainfall and the crop season (Table 5).

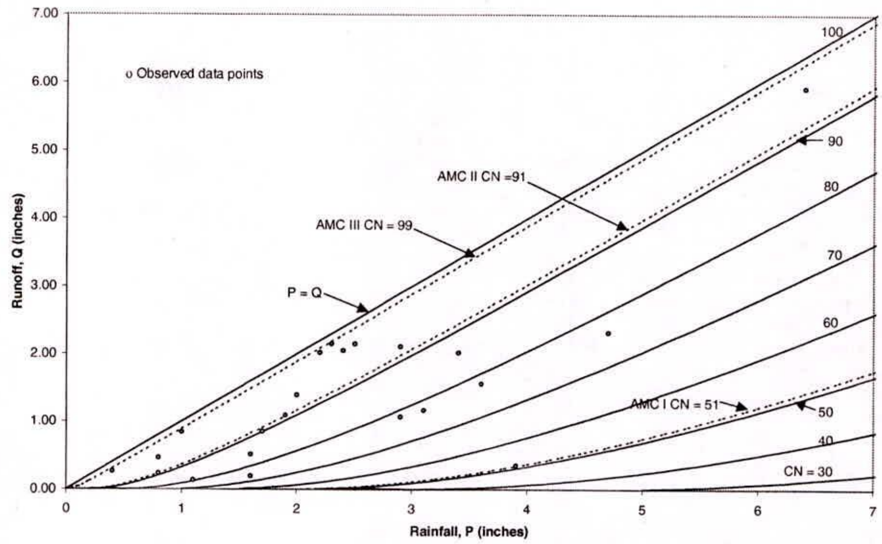

Figure 2. Determination of CN for AMC I through AMC III using existing SCS-CN method.

DEVELOPMENT OF CN FOR COMPLEXES

Since the NEH-4 table (Table 1) forms the key to the application of the existing SCS-CN method, it is necessary to mention a little about the development of this table or on the assignment of CN to the above described complexes. To this end, according to Mockus, data were searched for the watersheds in single cover complexes (one soil group and one cover). For most of the listed complexes, watersheds were available. As described above, an average CN for each watershed was obtained using rainfall-runoff data corresponding to annual extreme flows (storms). The selected watersheds were generally less than 1 square mile in size, the number of watersheds for a complex varied, and the storms were of 1 day or less duration. The CN values of the watersheds in the same complex were averaged, all CN-values for a cover were plotted as shown in Figure 2, a curve for each cover was drawn with greater weight given to the CN based on the data from more than one watershed, and each curve was extended as far as necessary to provide CN for ungauged watersheds. Except for arbitrary complexes (in Table 1:- Sl. No. 3 for "gravel and dirt"; and Sl. No. 14), the CN-values for all agricultural watersheds were derived in this fashion. For agricultural watersheds of complexes not listed in Table 1, CN is taken equal to 100, which is equivalent to a water body. For arbitrary complexes, the proportions of different covers were estimated and CN was computed from the previously derived CN.

USE OF NEH-4 TABLES FOR SCS-CN APPLICATION

For field applications, the procedure for using Tables 1, 2, 5, and 6 is as follows:

I. Subdivide large watersheds of different soils and land uses into subwatersheds or hydrological units. Each hydrological unit represents a drainage basin of a tributary joining the major river.

II. Identify the kind of land use, class of treatment, and the type of soils in the hydrological unit of the watershed. A soil can be classified according to Table 2 that is based on the minimum infiltration rates of soils.

III. Determine the percent acreage of each of the identified classes.

IV. Read CN-values for each of the classes from Table 1.

V. Multiply the CN-values by the respective percent areal coverage by each class to compute the weighted CN. This CN corresponds to AMC II.

VI. Sum the antecedent 5-d rainfall amounts and determine AMC from Table 5.

VII. Revise the weighted CN value of AMC II (step e) according to the identified AMC using Table 6.

VIII. Use the revised CN-value in equation (5) for computing the direct runoff volume from the watershed for a given amount of rainfall.

The above procedure is illustrated by the following examples.

Example 1: Determine the direct runoff for an average storm rainfall depth of 4.3 inches which occurred on a watershed having a cover of good pasture, soil type C, and antecedent moisture condition, AMC II.

Solution: In this example, 'good pasture' watershed implies that the watershed cover is of pasture and it is in good hydrologic condition. This SVL class is defined at Sl. No. 12 of Table 1. The curve number for soil type C for this SVL is equal to 74, which is for AMC II. For computing the direct runoff Q, the potential maximum retention, S, is determined as:

$$S = \frac{1000}{CN} - 10 = 1000/74 - 10 = 3.51 \text{ inch.}$$

Compute the amount of initial abstraction, I_a, as:

$I_a = 0.2 \text{ x } S = 0.2 \text{ x } 3.51 = 0.70$

which is less than the amount of rainfall, P = 4.3 inches. If P were less than I_a, Q would be equal to zero. Since $P > I_a$, Q is computed from equation (5) as:

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} = \frac{(4.3 - 0.2 \text{ x } 3.51)^2}{4.3 + 0.8 \text{ x } 3.51} = 1.82 \text{ inches}.$$

Example 2: Taking the same watershed as of Example 1, compute the amount of direct runoff for AMC I through III for the same rainfall amount and compare them.

Solution: For the given CN = 74 for AMC II, the CN values corresponding to AMC I and III (Table 6) are 55 and 88, respectively. Therefore, the potential maximum retention, S, for AMC I and AMC III, respectively, are:

S = 1000/55 –10 = 8.18 inches.

and

S = 1000/88 –10 = 1.36 inches.

Thus, the magnitudes of direct runoff for AMC I and AMC III are, respectively, computed using equation (5) as:

$$Q = \frac{(4.3 - 0.2 \times 8.18)^2}{4.3 + 0.8 \times 8.18} = 0.65 \text{ inch}$$

and

$$Q = \frac{(4.3 - 0.2 \times 1.36)^2}{4.3 + 0.8 \times 1.36} = 3.01 \text{ inches}$$

The former is 35.7 % (= 0.65 x 100/1.82) and the latter is 165.4 % (= 3.01 x 100/1.82) of the runoff amount for AMC II, viz., 1.82 inches.

Example 3: A watershed of soil group B is of 630 acres. Its 400 acres of area is under 'row crop, contoured, good rotation' and the remaining 230 acres is occupied by 'rotation meadow, contoured, and good rotation'. Compute the direct runoff for the rainfall amount of 5.1 inches when the watershed is in AMC II.

Solution: This example can be solved in two ways (a) by weighted-Q method and (b) by weighted-CN method.

(a) *Weighted-Q Method*

The computations are performed in Table 7. It is noted that good rotation implies good hydrologic condition. Good rotation infers the rotation of crops on agricultural fields in such a way that enhances infiltration. The computation of runoff is shown in Table 7. Col. 1 of this table shows the given SVL complex; col. 2 the area in acres; col. 3 the % area covered by each complex; col. 4 the CN values for each complex derived from Table 1; col. 5 the potential maximum retention, S, computed using equation (6); col. 6 the computed runoff using equation (5), and col. 7 computes the weighted-Q as the product of the Q (col. 6) and % area (col. 3) divided by 100. The sum of the weighted Qs represents the total direct runoff of the watershed for the given rainfall P = 5.1 inches.

Table 7. Computation of runoff using the weighted-Q method

SVL Complex	Area (acres)	% area	CN (for AMC II)	S (inches)	Q (inches)	Weighted Q (inches)
1	2	3	4	5	6	7
Row crop, contoured, good rotation	400	63.49	75	3.33	2.53	1.61
Rotation meadow, contoured, and good rotation	230	36.51	58	7.24	1.22	0.45
Sum	630					2.06

Table 8. Computation of runoff using the weighted-CN method

SVL Complex	Area (acres)	% area	CN (for AMC II)	Weighted CN	S (inches)	Q (inches)
1	2	3	4	5	6	7
Row crop, contoured, good rotation	400	63.49	75	48	---	----
Rotation meadow, contou-red, and good rotation	230	36.51	58	21		
Sum	630			69	4.49	2.03

(b) *Weighted-CN Method*

The computations for the direct runoff are shown in Table 8. In the weighted-CN method, the CN computed in col. 4 is areally weighted by multiplying the CN-value with the % area (col. 2) and divided by 100. The computed weighted CNs are summed up to obtain the corresponding S (col. 6). Using S = 4.49 inches, Q is computed as equal to 2.03 inches. It is noted that the computed Q (= 2.06 inches) by the weighted-Q method compares fairly well with the present Q = 2.03 inches. The small discrepancy is, however, attributed to the rounding off errors in computations.

It is worth mentioning here that the weighted-Q method is superior to the weighted-CN method, for the former is more rational than the latter for water balance reasons. However, the former method requires more computational effort than the latter. The weighted-CN is easier to work with the watershed having many complexes or with a series of storms. However, when there is a large difference in CN for various complexes in a watershed, the computed direct runoff by the weighted-CN method significantly deviates from that by the weighted-Q method, as shown in the following example.

Example 4: For an urban watershed with 20 acres of impervious area and 175 acres of lawn classed as good pasture on a B soil, compute the direct runoff, Q, values for rainfall values of 1, 2, 4, 8, 16, 32 inches. Based on the computed Q-values, compare the weighted–Q and weighted–CN methods. Assume CN = 100 for impervious area.

Solution: For the SVL complex defined by 'lawn, good pasture, and soil group B', CN = 61 (Table 1). As in Example 3, compute the Q values for the rainfall values of 1, 2, 4, 8, 16, 32 inches using the weighted Q and CN methods, as shown in Tables 9 and 10, respectively.

For comparison, the Q values computed by both the above methods (weighted-Q and weighted-CN methods) are listed in Table 11 along with the percent deviation of Qs computed using the weighted-CN method from those computed using the weighted-Q method. It is seen from this table that the weighted-Q method is preferable when the rainfall amount is small, for the % deviation is quite large. On the other hand, for high rainfalls, the weighted-CN computes Q values that deviate from those computed by weighted-Q method in the range from 7.85 to 8.67 %, which is an acceptable range.

Table 9. Computation of runoff using the weighted-Q method

SVL Complex	Area (acre)	% area	CN	S	Weighted-Q for rainfalls (inches):					
				(in)	1	2	4	8	16	32
Impervious area	20	10.26	100	0	0.10	0.21	0.41	0.82	1.64	3.28
Lawn, good pasture	175	89.74	61	6.39	0	0.07	0.81	3.45	10.26	25.43
Sum	195				0.10	0.28	1.22	4.27	11.90	28.71

Table 10. Computation of runoff using the weighted-CN method

SVL Complex	Area (acre)	% area	CN	[a]CN	S	Direct runoff for rainfalls (inches):					
					(in)	1	2	4	8	16	32
Impervious area	20	10.26	100	10							
Lawn, good pasture	175	89.74	61	55							
Sum	195			65	5.38	0	0.14	1.03	3.90	10.97	26.3

[a]Weighted CN

Table 11. Comparison of the weighted-Q and –CN methods

Storm rainfall →	1	2	4	8	16	32
Weighted-Q method	0.12	0.28	1.22	4.27	11.90	28.71
Weighted-CN method	0	0.14	1.03	3.90	10.97	26.34
% deviation →	100	50	15.57	8.67	7.85	8.28

Example 5: Determine the runoff amount from a series of rainfalls of 1, 2, 4, 8 16, and 32 inches that occurred over W-1 watershed located in Waco, Texas, U.S.A. The major soil type of this watershed is Houston Black Clay or equivalent and the acreage of land use and treatment are as below:

Land use and treatment	% area
Row crop, straight row, poor rotation	58
Small grain, straight, poor rotation	25
Pasture (including hay), fair condition	15
Farmsteads and roads	2

Solution: The Houston Black Clay soil can be characterized by the hydrologic soil group D. CNs for AMC II for various land uses and treatments are derived from Table 1 and weighted CN is determined as below:

Land use and treatment	% area	CN	Weighted CN
Row crop, straight row, poor rotation	58	91	89.2≈89
Small grain, straight, poor rotation	25	88	
Pasture (including hay), fair condition	15	84	
Farmsteads and roads	2	94	

Corresponding to the weighted CN = 89 that holds for AMC II, the respective CN values for AMC I and AMC III are derived from Table 6 as 76 and 96. The computations are shown in Table 12. In this table, col. 1 indicates the event number, cols. 2-4 describe the date, col. 5 shows the observed rainfall (inches) of the day, col. 6 the antecedent 5-d rainfall (inches), col. 7 the observed runoff (inches) of the day, col. 8 AMC, col. 9 the corresponding curve number, col. 10 the computed runoff using the curve number of col. 9, col. 11 the errors between the observed and computed runoff amounts, and col. 12 the square of the error for computing the root mean square error. It is noted that within a storm, for example, the storm of 1940 occurred on Nov. 22-25, AMC is computed by adding the previous rainfall amounts. On day 22, the antecedent 5-d rainfall (P_5) was equal to 0.18 inches, it was 4.92 inches on November 23 computed by adding 0.18 to the previous day rainfall, and so on. It assumes negligible rainfall contribution during the beginning days of the antecedent 5-days or, in other words, the antecedent rainfall amount of November 23 corresponds to the 6-d antecedent rainfall instead of 5-d one. Based on these P_5-values, AMC is determined from Table 5 and the resulting CN from Table 6. Using these curve numbers, the direct runoff values are computed for each rainfall amount using equation (5). It is apparent from Table 12 that the errors between observed and computed runoff values range from −1.3 to 0.56 inches and the root mean square error is 2.04 inches.

Example 6: Taking the Example 5 watershed as a gauged watershed, derive CN values for AMC I through AMC III for this watershed.

Solution: The CN-values from given P-Q data sets are computed using equation (7). The computed values from P-Q data of Example 5 are shown in Table 13. It is apparent from this table that CN ranges between 51 and 99. The median CN value is equal to 91. Thus, the CN values for AMC I, AMC II, and AMC III are 51, 92, and 99, respectively. The NEH-4 table (Table 6) yields CN values equal to 76, 89, and 96 for AMC I, AMC II, and AMC III, respectively, which are close to the computed values, provided event 6 is excluded from the data set.

Table 12. Computation of direct runoff for a series of rainfalls (Example 5)

Event	Year	Month	Day	Rainfall (inch)	P_5 (inch)	Obs. Runoff (inch)	AMC	CN	Comp. Runoff (inch)	Error (inch)	$(Error)^2$
1	1940	Nov.	22	4.74	0.18	2.32	I	76	2.32	0.00	0.00
2			23	2.2	4.92	2.02	III	96	1.77	0.25	0.06
3			24	2.03	6.94	1.39	III	96	1.61	-0.22	0.05
4			25	0.38	8.97	0.26	III	96	0.13	0.13	0.02
5	1941	June	10	2.39	1.38	2.05	III	96	1.96	0.09	0.01
6	1942	Sept.	7	3.89	0.22	0.35	I	76	1.65	-1.30	1.69
7			8	3.36	4.11	2.02	III	96	2.91	-0.89	0.79
8			9	0.78	7.47	0.46	III	96	0.44	0.02	0.00
9	1943	June	5	1.58	0.09	0.51	I	76	0.22	0.29	0.08
10	1944	April	29	3.63	0	1.56	I	76	1.45	0.11	0.01
11			30	2.64	3.63	2.15	III	96	2.21	-0.06	0.00
12		May	1	6.37	6.27	5.92	III	96	5.90	0.02	0.00
13			2	1.1	12.64	0.13	III	96	0.73	-0.60	0.36
14	1945	March	2	0.77	0.41	0.23	I	76	0.00	0.23	0.05
15			3	2.5	1.18	2.15	III	96	2.07	0.08	0.01
16	1946	May	12	2.9	1.08	2.11	III	96	2.46	-0.35	0.12
17			13	0.95	3.98	0.84	III	96	0.59	0.25	0.06
18	1947	March	18	1.74	0	0.85	I	76	0.29	0.56	0.31
19	1948	April	25	3.1	0.5	1.17	I	76	1.08	0.09	0.01
20	1949	July	4	2.86	0.03	1.07	I	76	0.92	0.15	0.02
21	1950	Feb.	12	1.94	1.08	1.09	III	96	1.52	-0.43	0.18
22	1951	June	16	1.64	1.28	0.19	II	89	0.74	-0.55	0.30
Sum											4.15
Root Mean Square Error (inches)											2.04

Table 13: CN computation for a gauged watershed (Example 6)

Event	Year	Month	Day	Rainfall (inch)	Runoff (o) (inch)	S	CN
1	1940	Nov.	22	4.74	2.32	3.16	76
2			23	2.2	2.02	0.16	98
3			24	2.03	1.39	0.69	94
4			25	0.38	0.26	0.13	99
5	1941	June	10	2.39	2.05	0.31	97
6	1942	Sept.	7	3.89	0.35	9.44	51
7			8	3.36	2.02	1.55	87
8			9	0.78	0.46	0.38	96
9	1943	June	5	1.58	0.51	1.74	85
10	1944	April	29	3.63	1.56	2.91	77
11			30	2.64	2.15	0.47	96
12		May	1	6.37	5.92	0.39	96
13			2	1.1	0.13	2.38	81
14	1945	March	2	0.77	0.23	0.91	92
15			3	2.5	2.15	0.32	97
16	1946	May	12	2.9	2.11	0.81	92
17			13	0.95	0.84	0.1	99
18	1947	March	18	1.74	0.85	1.16	90
19	1948	April	25	3.1	1.17	2.9	77
20	1949	July	4	2.86	1.07	2.71	79
21	1950	Feb.	12	1.94	1.09	1.03	91
22	1951	June	16	1.64	0.19	3.58	74
Median CN value							91

Data: Example (5)

ADVANTAGES AND LIMITATIONS OF THE SCS-CN METHOD

The SCS-CN method has several advantages over other methods. It is a simple conceptual method for estimation of the direct surface runoff amount from a storm rainfall amount, and is well supported by empirical data. The method relies on only one parameter, the curve number CN, which is a function of the major runoff-producing watershed characteristics: Four hydrologic soil groups; the land use and treatment classes, including agricultural, range forest, and urban; and the hydrologic surface condition of native pasture, such as poor, fair, and good. It is fairly well documented for its inputs (soil, land use/treatment, surface condition, and antecedent moisture condition), its features are readily grasped, well established, and accepted for use in the United States and other countries.

Mockus noted several problems associated with the SCS-CN method. For example, it does not contain any expression for time and ignores the impact of rainfall intensity and its temporal distribution. As indicated by Cowan, time was not incorporated in the method because (a) sufficiently reliable data were not available to describe infiltration rates for a wide range of SVL complexes and (b) there was no reliable method available for distributing rainfall in time. Rallison and Miller described several other limitations which were of concern, for example, the availability of reliable data in varying geographic and environmental conditions, reproducibility of the runoff amount by the method even beyond the enveloping SVL curves, and so on.

As envisaged by Ponce and Hawkins, Rallison and Miller among others, the SCS-CN method has yet to be established for its credibility and acceptance. Being an agency methodology, the method has been isolated from the rigors of peer review. The information supplied in NEH-4 is less than complete. There is a lack of clear guidance on how to vary antecedent condition, especially for lower curve numbers and/or rainfall amounts, for the curve number exhibits sensitivity to the antecedent condition. Since the method was originally developed for agricultural sites, it performs best on these watersheds, fairly on range sites, and poorly in application to forest sites. There is no explicit provision for spatial scale effects. CNs for areas less than 227 ha in southeastern Arizona tended to decrease with increasing watershed size, exhibiting a significant role of channel transmission losses. Although Mockus indicated the applicability of the method to even large catchments, the lack of clear guidance still exists if it can reliably be applied to small, mid, or large size catchments. Ponce and Hawkins, however, cautioned against the use of the method to watersheds larger than 250 sq. km.

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