Chapter 23

What is the Impervious Area Curve Number?

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The curve number (CN) of the impervious surface of a residential watershed in east-central Florida was determined by calibration against observed data. Evidently the curve number of the impervious surface was closer to 94 or 95 than 98 which is the value typically used. It is important to know if CN is 95 or 98 because a 1-inch (25 mm) rainfall will produce approximately 0.79 in (20 mm) of runoff if CN = 98 and 0.56 in (14 mm) of runoff if CN = 95 yielding a rather large difference 28.8%. These percentage differences, which are even larger for smaller storm events, can become very significant if the curve number method is being used to design systems to accommodate the “first flush” from impervious surfaces. The first flush is the runoff generated during the rising limb of the storm events. It is also important to know the CN value if the SCS method is being used to estimate annual runoff or annual pollutant loads, since the bulk of the annual rainfall, and consequently pollutant loading is due to small (less than 1 inch or 25 mm) rainfall events. Observations supporting CN = 98 are scarce. This study indicates a need for further field investigations and more data, in all parts of the country, to determine better curve number values for impervious surfaces. The objectives of this chapter are to:

1. discuss two calibration methods for estimating curve numbers, and
2. present results that appear to indicate that the curve number for impervious surfaces, under certain climates, may be lower than 98.

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23.1 Introduction

The runoff curve number method, developed by the United States Department of Agriculture (USDA) Soil Conservation Service (SCS), is widely used to compute runoff from rainfall (Hawkins 1993; Ponce and Hawkins 1996). The SCS runoff equation, based on a study on many small experimental watersheds, is:

$$Q = \left[\frac{(P - I_a)^2}{(P - I_a + S)} \right] \text{ for } P > I_a \quad (23.1a)$$

$$Q = 0 \quad \text{for } P < 0.2S \quad (23.1b)$$

where:

- P = rainfall depth (inches)
- Q = storm runoff depth (inches), and
- S = potential maximum retention after runoff begins (in inches).
- I_a = initial abstraction

The initial abstraction, I_a, contains all the loss terms prior to beginning of runoff (SCS 1986). The SCS found the value of I_a to be highly variable since it includes water retained in the surface depressions, water intercepted by vegetation, evaporation, and infiltration. However, through studies of many small agricultural watersheds, it was found that:

$$I_a = 0.2S \quad (23.1c)$$

Substituting Equation 23.1c in Equation 23.1b yields:

$$Q = \left[\frac{(P - 0.2S)^2}{(P + 0.8S)} \right] \text{ for } P > 0.2S \quad (23.1d)$$

In the SCS method, S is related to the soil and cover conditions of the watershed by the curve number:

$$S = \left(\frac{1000}{CN} \right) - 10 \quad (23.2a)$$

where:

CN = a dimensionless number; depends on the hydrologic soil group (HSG), cover type, treatment, hydrologic condition, and antecedent moisture conditions.

Equation 23.2a can be rearranged to yield:

$$CN = \left(\frac{1000}{S + 10} \right) \quad (23.2b)$$

In the SCS method, practically all soils are classified into four HSGs (A, B, C, and D) according to their minimum infiltration rate. Type A and D soils have the lowest and highest runoff potential, respectively. The method's popularity stems partly from the fact that practically every soil type (over 4000 soils) in the United States have been categorized into the four HSGs by the Soil Conservation Service (SCS 1975, SCS 1986). The SCS has also provided tables which allow users to determine CN values, under average antecedent conditions, if the HSG and cover of the soil are known. However, Equation 23.1d can be applied for all antecedent moisture conditions, and not just for average conditions, since the SCS also provides equations (Chow et al. 1988) to convert the estimated CN value, under average conditions, to values which would be more appropriate under dry or wet antecedent conditions. This approach of using handbook supplied tables to estimate curve numbers, when field data are not available, is sometimes convenient, and will be termed the "handbook" method from here on.

The accuracy of the method in predicting runoff depth, Q , from a watershed is based on two factors:

1. the precision of Equation 23.1d in correctly modeling the rainfall-runoff relationship for that watershed, and
2. the accuracy of the estimated CN values.

Both aspects have been discussed by several researchers. An excellent description of the origin and evolution of Equation 23.1d, and its ability to estimate runoff depths has been provided by Rallison (1980). The conceptual and empirical foundations of the curve number method, and its perceived advantages and disadvantages, have also been discussed by Bosznay (1989) and Ponce and Hawkins (1996) among others. There is also literature on the importance of accurate curve number estimation (Hawkins 1975), and methods for determining curve numbers (Rawls et al. 1981, Hawkins 1993). Theoretically CN can range from 0 to 100, but in practice SCS (1986) provides a range for pervious covers from 30 (e.g. meadows in good condition in Type A soils) to 94 for bare Type D soils. A description of how SCS obtained the CN values for the pervious covers of their experimental watersheds can be found in SCS (1972).

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CN for impervious surfaces was first assigned a value of 100 (SCS 1972, Chapter 9) under the assumption that all rainfall on impervious surfaces gets converted to runoff. Subsequently, presumably after realizing that almost all of the so called “impervious” surfaces are either slightly porous or have some capacity to adsorb water, and consequently there is some retention even in impervious surfaces, the CN for impervious surfaces was assigned a value of 98 (SCS 1975, SCS 1986). However, to the authors’ knowledge, no real evidence (empirical or theoretical), describing why 98 was selected (and not, for example, 97 or 99) has ever been presented. A footnote on the bottom of one of the tables in SCS (1975), (and also in Chow et al. (1988)), which states that *in some warmer climates of the country a curve number of 95 may be used (for impervious surfaces)*. Again, although the statement makes sense, no explanation for this statement was offered in either document. This particular footnote was subsequently removed from SCS (1986). However, data substantiating the footnote was found by Pitt (1987) who measured rainfall and runoff during controlled runoff experiments conducted on rough and smooth textured streets in Toronto, Ontario. Rainfall was simulated at a constant intensity in these experiments. Pitt (1987) measured the initial losses for the smooth and rough streets to be 0.44 mm and 0.70 mm, respectively; substituting these values for Ia in Equation 23.1a, he found that the curve numbers for these streets ranged between 96 and 100. Pitt (1987) also noted that

1. curve number values decreased with increasing rain depth, and
2. curve number values decreased with increasing rainfall intensity.

Since the temperature range during these experiments was between 17 and 27 degrees Celsius, it appears likely that CN values could be even lower in warmer climates such as that in Florida where temperatures, during the wet season (between June and September) range from 21 degrees Celsius to 40 degrees Celsius, and where the bulk of the runoff occurs during intense afternoon thundershowers. Analysis of Pitt’s data, however, showed little variation in the computed CN values when Ia/S ratio was varied between 0.01 and 0.3.

It probably does not matter whether the CN value is 95 or 99 if the rainfall depth is large. It can be shown, using Equation 23.1a, that a 203 mm (8 in) rainfall will produce approximately 198 mm (7.8 in) of runoff if CN = 98, and 188 mm (7.4 in) of runoff if CN = 95, yielding a difference of only 4.6%. However, a 25 mm (1 in) rainfall will produce approximately 20 mm (0.79 in) of runoff if CN = 98, and 14.2 mm (0.56 in) of runoff if CN = 95, yielding a rather large difference of 28.8%. Similarly, a 25 mm (1 in) rainfall will produce approximately 23 mm (0.89 in) of runoff if CN = 99, a difference of 12.3% compared to the runoff produced for CN = 98. These respective percentage differences, which are even larger for smaller storm events can become very significant if the curve number method is used in water quality studies. For example, Pitt and McLean (1986) found that almost 90% of the annual stormwater discharges of most

pollutants were associated with rains less than 20 mm (0.8 in) in depth. Heavy metal discharges were even more associated with small rains, while nutrient discharges were associated with slightly larger rains. Pandit and Gopalakrishnan (1996) and Pandit and Gopalakrishnan (1997) also found that the frequent small rains are much more important when estimating seasonal and annual pollutant loads than the larger rains most commonly used for flood calculations. Furthermore, for practical reasons, in almost all planning and engineering studies, typically 13 mm (0.5 in) to 51 mm (2 in) storm events are used to find CN values by calibration. These calibrated CN values can produce significant errors if used to compute runoff and loadings from larger rainfall events.

Methods for estimating CN can be grouped into two categories: (i) handbook method and (ii) calibration methods. The handbook method makes use of tables provided in SCS (1986), or similar publications, to determine CN. Calibration methods use observations to estimate CN.

23.2 Description of Handbook and Calibration Methods

23.2.1 Handbook Method

Typically, CN for the pervious portion of a watershed is estimated by:

1. identifying the soil type in the watershed through soil survey maps or field borings;
2. identifying the HSG from tables provided in various publications (e.g. SCS 1975, SCS 1986);
3. identifying the cover of the soil; and
4. obtaining CN from tables provided in SCS (1986).

The weighted average CN for a watershed, comprising a pervious and an impervious portion, is:

$$CN_w = CN_p f_p + CN_i f_i \quad (23.4a)$$

where:

$$\begin{aligned} CN_w &= \text{the weighted average curve number,} \\ CN_p &= \text{curve number for the pervious area,} \\ CN_i &= \text{curve number for the impervious areas,} \\ f_p &= \text{fractional area under pervious land use,} \\ f_i &= \text{fractional area under impervious land use.} \end{aligned}$$

An important consideration in the curve number method is that it considers only “directly connected” impervious areas (DCIA) as impervious. 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 to be part of the pervious area. The reasoning for this is that this runoff, since it passed over a pervious area as sheet flow, will infiltrate in the same manner as if it originated from the pervious area. Based on this reasoning, Equation 23.4a can be modified to:

$$CN_w = CN_p (1 - f_i) + CN_i f_i \quad (23.4b)$$

where f_i now refers to the fraction of directly connected impervious area.

23.2.2 Calibration Methods

CN can be determined by calibration if rainfall-runoff observations from several storm events are available. Hawkins (1973), using the quadratic formula, simplified Equation 23.1a to:

$$S = 5 [P + 2Q - (4Q^2 + 5PQ)^{1/2}] \quad (\text{for } Q > 0) \quad (23.5)$$

The CN of the watershed can be calculated by Equation 23.5, in conjunction with Equation 23.2b, using observed P and Q. It should be emphasized that this calibration method is useful for estimating CN for homogeneous watersheds. If used for a watershed that also has a significant directly connected impervious area, the method will provide a weighted CN for the watershed, and not the CN of the pervious portion of the watershed.

A different calibration approach needs to be taken to estimate CN of the pervious portion of a watershed that also has a significant fraction of directly connected impervious area;

$$V_T = V_p + V_i \quad (23.6)$$

where:

- V_p = runoff volume from the pervious portion of the watershed
- V_i = runoff volume from the directly connected impervious portions of the watershed,
- V_T = total runoff volume from the watershed.

Equation 23.6 can be modified:

$$A_T Q_T = A_p Q_p + A_i Q_i \quad (23.7)$$

where:

- A_p = pervious area,
- A_i = directly connected impervious area,
- A_T = total watershed area,
- Q_p = runoff depth from the pervious portion of the watershed
- Q_i = runoff depth from the directly connected impervious portions of the watershed, and
- Q_T = total runoff depth.

In the curve number method, the pervious and impervious runoff depths, Q_p and Q_i , are:

$$Q_p = \left[\frac{(P - 0.2S_p)^2}{(P + 0.8S_p)} \right] \quad \text{for } P > 0.2S_p \quad (23.8a)$$

and

$$Q_i = \left[\frac{(P - 0.2S_i)^2}{(P + 0.8S_i)} \right] \quad \text{for } P > 0.2S_i \quad (23.8b)$$

where:

- S_p = potential maximum retention in the pervious area, and
- S_i = potential maximum retention in the impervious area.

In Equations 23.8a and 23.8b, S_p and S_i are given by:

$$S_p = \left(\frac{1000}{CN_p} \right) - 10 \quad (23.9a)$$

and

$$S_i = \left(\frac{1000}{CN_i} \right) - 10 \quad (23.9b)$$

where:

- CN_p = curve number for the pervious portion of the watershed,
- CN_i = curve number for the impervious portion of the watershed.

In most studies, Q_T is known because it is measured at the outfall, and A_p , A_i and A_T are estimated from maps, aerial photographs, or site observations. If CN_i is assumed to be 98, then Q_i can be obtained by Equations 23.8b and 23.9b, and the only unknown, Q_p , can be obtained by rearranging Equation 23.7:

$$Q_p = (A_T Q_T - A_i Q_i) / (A_p) \quad (23.10a)$$

or

$$Q_p = (Q_T - f_i Q_i) / (f_p) \quad (23.10b)$$

The potential maximum retention, S_p , can be calculated by transforming Equation 23.5:

$$S_p = 5 [P + 2Q_p - (4Q_p^2 + 5PQ_p)^{1/2}] \quad (23.11)$$

and CN_p can be calculated from Equation 23.9a. Note that Equation 23.11 can be used only if Q_p , calculated from Equation 23.10b, is greater than zero. How can one calculate Q_p to be less than or equal to zero from Equation 23.10b? It can happen if the actual value of CN_i is not really 98 but smaller; in this case, the incorrect use of $CN_i = 98$ may yield abnormally high values of Q_i , thus making the term $f_i Q_i$ greater than Q_T in Equation 23.10b.

23.3 Site Description and Data Collection

Rainfall and runoff data, for the purpose of this study, were collected from a 1.17 ha (2.88 acre), residential watershed comprising single family homes on both sides of a street. The watershed is located in the city of Cocoa Beach which lies on the central-east coast of Florida. The watershed consists of ten houses on each side of the street. The lots are approximately 0.14 ha (0.34 acres), however, runoff from the backyard drains into other outfalls, leaving a net watershed area of 1.17 ha (2.88 acres). The areas of the two land use categories and the total impervious area, shown in Table 23.1, were carefully estimated with the help of Brevard County Geodetic Information Survey (GIS) maps and field surveys. The directly connected impervious areas, also shown in Table 23.1, were estimated from site visits, after accounting for the fact that the roof runoff from many of the houses passed over grassy areas as sheet flow. The watershed has primarily Canaveral soil (SCS 1974) which is designated as Type C soil by SCS (1986). A pervious CN of 74 (Table 23.1) was determined from SCS (1986) since the cover on the pervious surfaces were grassed lawns under good hydrologic condition.

Table 23.1 Watershed description.

Total Area (ha) (1)	1.17
Residential Area (ha) (1)	1.00
Area of Road (ha) (1)	0.17
Total Impervious Area (ha) (1)	0.71
Directly Connected Impervious Area, DCIA (ha) (2)	0.51
Percentage Imperviousness of Watershed	61
DCIA of Residential Area (percentage)	43
Curve Number of Pervious Area (3)	74

(1) : obtained from GIS maps and field survey

(2) : estimated from field survey

(3) : obtained from SCS (1986)

All rainfall and runoff sampling was done with an automatic sampler (America Sigma Streamline 800 SL sampler) with an integral flow meter. Rainfall was measured in increments of 0.25 mm (0.01 inches). Runoff measurements were taken with the help of a weir and an automatic data logger. A 90 degree V-notch weir was installed at the outfall of the watershed, a 12-inch (300 mm) diameter pipe, for accurate flowrate measurements. Stage heights, measured every minute by the automatic sampler, were converted to flowrates using the appropriate weir equation. Data from six storms events were collected from the period between July 28, 1994, and July 10, 1995. Data from other storm events were lost either due to equipment malfunction or backup of water in the storm pipe due to excess rain.

23.4 Curve Number Estimations

The pervious and impervious curve number, as well as the weighted curve number of the watershed were determined by various methods.

23.4.1 Handbook Method

The weighted CN for the watershed, using $CN_p = 74$ and $CN_i = 98$ was found to be 84 from Equation 23.4b.

23.4.2 Calibration Methods

The observed rainfall and runoff depths, for six rainfall events are shown in Table 23.2. The weighted CN, estimated by Equation 23.5 in conjunction with Equation 23.2b, ranged from 89 to 95. The average and median weighted CN values were both 91. The average CN is accepted as the CN most representative

Table 23.2 Curve number estimation from data collected during storm events; watershed assumed to be homogeneous.

Storm Date	Rainfall Depth P (Measured) cm	Runoff Volume (Measured) litres	Runoff Depth Q (Measured) cm	Potential Abs. S (Eq 23.5) cm	Initial Abs. 0.2S cm	Curve Number (Eq 23.2b)
28-Jul-94	1.14	14459	0.12	2.57	0.51	91
14-Jan-95	1.17	16003	0.14	2.53	0.51	91
20-Feb-95	0.86	18668	0.16	1.46	0.29	95
28-Feb-95	2.08	51699	0.44	3.22	0.64	89
24-Apr-95	1.19	15874	0.14	2.62	0.52	91
10-Jul-95	0.74	6892	0.06	1.87	0.37	93
				Average		91

of the watershed in most engineering studies, however, the Soil Conservation Service, in their original investigations (SCS 1972) used sample median values to represent CN for their experimental watersheds under average conditions.

An attempt was made to determine CN of the pervious portion of the watershed by using, as described earlier, storm rainfall and runoff observations in combination with Equations 23.10b and 23.9a. A drawback of the method is that the CN_i has to be assumed. As shown in Table 23.3, the assumption of $CN_i = 98$ yielded fractional runoff depth ($f_i Q_i$) values to be higher than the measured runoff depth, Q_T . This, in turn, caused Equation 23.10b to yield negative values of Q_p . These data appear to indicate that either the impervious curve number for this watershed may have been less than 98 during the measured storm events or the DCIA may be less than the estimated 43%. Trial and error solutions showed that, if $CN_i = 98$, the term $f_i Q_i$ became greater than Q_T for all six events only when f_i was less than 0.15 (or DCIA was less than 15%). Since the fractional directly connected impervious area was quite precisely calculated from GIS maps and site visits, a DCIA = 15% or less appeared to be completely unreasonable, and these solutions were considered unacceptable.

Similar trial and error solutions (Table 23.4) indicated that, if $f_i = 0.43$, the term $f_i Q_i$ became greater than Q_T for all six events only when CN_i was 94 or lower. When CN_i was assumed to be 94, the estimated pervious CN_p ranged from 78 and 93 (average = 86) as shown in Table 23.4. The computed CN_p were found to be sensitive to the selected values of CN_i and f_i . The extreme sensitivity of the CN_p to CN_i and f_i was because the Q_p values were relatively small compared to $f_i Q_i$ (Table 23.4) and, therefore, even modest changes in CN_i and f_i caused large

Table 23.3 Estimation of fractional impervious runoff depth when $CN_i = 98$.

Storm Date	Rainfall Depth P (Measured)	Runoff Volume (Measured)	Runoff Depth Q_T (Measured)	Runoff Depth Q_i (Eq 23.8b) ($CN_i = 98$)	$f_i Q_i$ ($CN_i = 98$)	Runoff Depth Q_p (Eq 23.10b)
	cm	litres	cm	cm	cm	inches
28-Jul-94	1.14	14459	0.12	0.693	0.298	*
14-Jan-95	1.17	16003	0.14	0.716	0.308	*
20-Feb-95	0.86	18668	0.16	0.452	0.194	*
28-Feb-95	2.08	51699	0.44	1.568	0.674	*
24-Apr-95	1.19	15874	0.14	0.739	0.318	*
10-Jul-95	0.74	6892	0.06	0.348	0.150	*

• value could not be calculated since $f_i Q_i > Q_T$

$f_i Q_i$ (Table 23.4) and, therefore, even modest changes in CN_i and f_i caused large fluctuations in estimated CN_p . This calibration technique, therefore, does not appear to be very robust if the fractional pervious runoff is much smaller than the fractional impervious runoff.

23.5 Conclusions

Most urban watersheds have a pervious and impervious area; the handbook method or standard calibration methods are unable to provide CN for these areas; rather they provide a weighted CN which ranges somewhere between the CN of the pervious and impervious areas. Data collected in Cocoa Beach showed that there can be substantial differences in the estimated weighted CN estimated by the two methods; the handbook method estimated a CN of 84 while the calibration method yielded 91. A new calibration technique, which can yield CN of the pervious or impervious portion of the watershed, provided convincing evidence that the impervious curve number for the study watershed was closer to 94 or 95 than 98. Results from this study indicate that further field investigations, and assembly of more data, in all parts of the country, are required to determine CN for impervious surfaces.

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Table 23.4 Pervious curve number estimation from data collected during storm events; impervious and pervious areas are assigned different CN values.

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