5.2.6 Effect of Unconnected Impervious Area on Curve Numbers

Many local drainage policies are requiring runoff that occurs from certain types of impervious land cover (i.e., rooftops, driveways, patios) to be directed to pervious surfaces rather than being connected to storm drain systems. Such a policy is based on the belief that disconnecting these impervious areas will require smaller and less costly drainage systems and lead both to increased ground water recharge and to improvements in water quality. If disconnecting some impervious surfaces will reduce both the peak runoff rates and volumes of direct flood runoff, credit should be given in the design of drainage systems. The effect of disconnecting impervious surfaces on runoff rates and volumes can be accounted for by modifying the CN.

There are three variables involved in the adjustment: the pervious area CN, the percentage of impervious area, and the percentage of the imperviousness that is unconnected. Because Figure 5.3a for computing composite CN values is based on the pervious area CN and the percentage of imperviousness, a correction factor was developed to compute the composite CN. The correction is a function of the percentage of unconnected imperviousness, which is shown in Figure 5.3b. The use of the correction is limited to drainage areas having percentages of imperviousness that are less than 30 percent.

As an alternative to Figure 5.3b, the composite curve number (CN_c) can be computed by:

$$CN_c = CN_p + \left(P_i/100\right)\left(98 - CN_p\right)\left(1 - 0.5R\right) \quad \text{for } P_i \le 30\% \tag{5.24}$$

where,

P_i = percent imperviousness

R = ratio of unconnected impervious area to the total impervious area.

Equation 5.24, like Figure 5.3b, is limited to cases where the total imperviousness (P_i) is less than 30 percent.

5.2.7 I_a/P Parameter

I_a/P is a parameter that is necessary to estimate peak discharge rates. I_a denotes the initial abstraction, and P is the 24-hour rainfall depth for a selected return period. For a given 24-hour rainfall distribution, I_a/P represents the fraction of rainfall that must occur before runoff begins.

5.2.8 Peak Discharge Estimation

The following equation can be used to compute a peak discharge with the SCS method:

$$q_p = q_u A Q \tag{5.25}$$

where,

q_p = peak discharge, m^3/s (ft^3/s)

q_u = unit peak discharge, m^3/s/km^2/mm (ft^3/s/ mi^2/in)

A = drainage area, km^2 (mi^2)

Q = depth of runoff, mm (in).

The unit peak discharge is obtained from the following equation, which requires the time of concentration (t_c) in hours and the initial abstraction/rainfall (I_a/P) ratio as input:

$$q_u = \alpha\, 10^{C_0 + C_1 \log t_c + C_2 [\log (t_c)]^2} \tag{5.26}$$

where,

C_o, C_1, and C_2 = regression coefficients given in Table 5.5 for various I_a/P ratios

α = unit conversion constant equal to 0.000431 in SI units and 1.0 in CU units.

The runoff depth (Q) is obtained from Equation 5.21 and is a function of the depth of rainfall P and the runoff CN. The I_a/P ratio is obtained directly from Equation 5.20.

Table 5.5. Coefficients for SCS Peak Discharge Method

Rainfall Type	I_a/P	C_0	C_1	C_2
I	0.10	2.30550	-0.51429	-0.11750
	0.20	2.23537	-0.50387	-0.08929
	0.25	2.18219	-0.48488	-0.06589
	0.30	2.10624	-0.45695	-0.02835
	0.35	2.00303	-0.40769	0.01983
	0.40	1.87733	-0.32274	0.05754
	0.45	1.76312	-0.15644	0.00453
	0.50	1.67889	-0.06930	0.0
IA	0.10	2.03250	-0.31583	-0.13748
	0.20	1.91978	-0.28215	-0.07020
	0.25	1.83842	-0.25543	-0.02597
	0.30	1.72657	-0.19826	0.02633
	0.50	1.63417	-0.09100	0.0
II	0.10	2.55323	-0.61512	-0.16403
	0.30	2.46532	-0.62257	-0.11657
	0.35	2.41896	-0.61594	-0.08820
	0.40	2.36409	-0.59857	-0.05621
	0.45	2.29238	-0.57005	-0.02281
	0.50	2.20282	-0.51599	-0.01259
III	0.10	2.47317	-0.51848	-0.17083
	0.30	2.39628	-0.51202	-0.13245
	0.35	2.35477	-0.49735	-0.11985
	0.40	2.30726	-0.46541	-0.11094
	0.45	2.24876	-0.41314	-0.11508
	0.50	2.17772	-0.36803	-0.09525

The peak discharge obtained from Equation 5.26 assumes that the topography is such that surface flow into ditches, drains, and streams is relatively unimpeded. Where ponding or wetland areas occur in the watershed, a considerable amount of the surface runoff may be retained in temporary storage. The peak discharge rate should be reduced to reflect this condition of increased storage. Values of the pond and swamp adjustment factor (F_p) are provided in Table 5.6. The adjustment factor values in Table 5.6 are a function of the percent of the total watershed area in ponds and wetlands. If the watershed includes significant portions of pond and wetland storage, the peak discharge of Equation 5.25 can be adjusted using the following:

$$q_a = q_p F_p \tag{5.27}$$

where,

q_a = adjusted peak discharge, m^3/s (ft^3/s).

Table 5.6. Adjustment Factor (F_p) for Pond and Wetland Areas

Area of Pond and Wetland (%)	F_p
0	1.00
0.2	0.97
1.0	0.87
3.0	0.75
5.0	0.72

The SCS method has a number of limitations. When these conditions are not met, the accuracy of estimated peak discharges decreases. The method should be used on watersheds that are homogeneous in CN; where parts of the watershed have CNs that differ by 5, the watershed should be subdivided and analyzed using a hydrograph method, such as TR-20 (SCS, 1984). The SCS method should be used only when the CN is 50 or greater and the t_c is greater than 0.1 hour and less than 10 hours. Also, the computed value of I_a/P should be between 0.1 and 0.5. The method should be used only when the watershed has one main channel or when there are two main channels that have nearly equal times of concentration; otherwise, a hydrograph method should be used. Other methods should also be used when channel or reservoir routing is required, or where watershed storage is either greater than 5 percent or located on the flow path used to compute the t_c.

Example 5.4. A small watershed (17.6 ha) is being developed and will include the following land uses: 10.6 ha of residential (0.1 ha lots), 5.2 ha of residential (0.2 ha lots), 1.2 ha of commercial property (85 percent impervious), and 0.4 ha of woodland. The development will necessitate upgrading of the drainage of a local roadway at the outlet of the watershed. The peak discharge for a 10-year return period is determined using the SCS graphical method.

The weighted CN is computed using the CN values of Table 5.4:

Land Cover	Lot Size (ha)	Lot Size (acres)	Soil Group	5.2.8.1.1	Area (ha)	Area (acres)	A*CN (ha)	A*CN (acres)
Residential	0.2	0.5	B	70	5.2	12.8	364	896
Residential	0.1	0.25	B	75	4.6	11.4	345	855
Residential	0.1	0.25	C	83	6.0	14.8	498	1228
Commercial (85% Imp.)			C	94	1.2	3.0	113	282
Woodland (Good condition)			C	70	0.6	1.5	42	105
Total					17.6	43.5	1,362	3366

The weighted CN is:

Variable	Value in SI	Value in CU
$CN_w = \frac{\sum A * CN}{\sum A}$	$= \frac{1{,}362}{17.6} = 77.4 \; (use\ 77)$	$= \frac{3{,}366}{43.5} = 77.4 \; (use\ 77)$

The time of concentration is computed using the velocity method for conditions along the principal flowpath:

Conveyance Type	Slope (%)	K	Length (m)	V (m/s)	Length (ft)	V (ft/s)	T_t (h)
Woodland (overland)	2.3	0.152	25	0.23	82	0.76	0.03
Grassed waterway	2.1	0.457	275	0.66	902	2.19	0.12
Grassed waterway	1.8	0.457	250	0.61	820	2.02	0.11
Concrete-lined channel	1.8	-	50	4.62	164	15.1	0.00
			600		1968		0.26

The velocity was computed for the concrete-lined channel using Manning's equation, with n = 0.013 and hydraulic radius of 0.3 m (1ft). The sum of the travel times for the principal flowpath is 0.26 hours.

The rainfall depth is obtained from an IDF curve for the locality using a storm duration of 24 hours and a 10-year return period. (Note that the t_c is not used to find the rainfall depth when using the SCS graphical method. A storm duration of 24 hours is used.) For this example, a 10-year rainfall depth of 122 mm (4.8 in) is assumed. For a CN of 77, S equals 76 mm (3.0 in) and I_a equals 15 mm (0.6 in). Thus, I_a/P is 0.12. The rainfall depth is computed with Equation 5.21:

Variable	Value in SI	Value in CU
$Q = \frac{(P - 0.2S)^2}{P + 0.8\ S}$	$= \frac{(122\ - 0.2(76))^2}{122\ + 0.8(76)} = 62\ mm$	$= \frac{(4.8\ - 0.2(3.0))^2}{4.8\ + 0.8(3.0)} = 2.45\ in$

The unit peak discharge is computed with Equation 5.26 by interpolating c_0 , c_1, and c_2 from Table 5.5 using a type II distribution. The peak discharge is also calculated as follows.

Variable	SI Unit	**CU Unit**
$q_u = 10^{2.5444-0.61587\ \log(0.26)-0.15928[\log(0.26)]}$	$= (0.000431)\ 10^{2.85}$ $= 0.305\ m^3/s/km^2/mm$	$= (1)\ 10^{2.85}$ $= 708\ ft^3/s/mi^2/in$
$q_p = q_u A Q$	$= 0.305\ (0.176\ km^2)(62\ mm)$ $= 3.3\ m^3/s$	$= 708\ (0.068\ mi^2)\ (2.46\ in)$ $= 120\ ft^3/s$

5.3 RATIONAL METHOD

One of the most commonly used equations for the calculation of peak discharges from small areas is the rational formula. The rational formula is given as:

$$Q = \frac{1}{\alpha}\ C\ i\ A \tag{5.28}$$

where,

Q = the peak flow, m³/s (ft³/s)

i = the rainfall intensity for the design storm, mm/h (in/h)

A = the drainage area, ha (acres)

C = dimensionless runoff coefficient assumed to be a function of the cover of the watershed and often the frequency of the flood being estimated

α = unit conversion constant equal to 360 in SI units and 1 in CU units.

5.3.1 Assumptions

The assumptions in the rational formula are as follows:

1. The drainage area should be smaller than 80 hectares (200 acres).
2. The peak discharge occurs when the entire watershed is contributing.
3. A storm that has a duration equal to t_c produces the highest peak discharge for this frequency.
4. The rainfall intensity is uniform over a storm time duration equal to the time of concentration, t_c. The time of concentration is the time required for water to travel from the hydrologically most remote point of the basin to the outlet or point of interest.
5. The frequency of the computed peak flow is equal to the frequency of the rainfall intensity. In other words, the 10-year rainfall intensity, i, is assumed to produce the 10-year peak discharge.

5.3.2 Estimating Input Requirements

The runoff coefficient, C, is a function of ground cover. Some tables of C provide for variation due to slope, soil, and the return period of the design discharge. Actually, C is a volumetric coefficient that relates the peak discharge to the "theoretical peak" or 100 percent runoff, occurring when runoff matches the net rain rate. Hence C is also a function of infiltration and other hydrologic abstractions. Some typical values of C for the rational formula are given in