Low-impact developments (LIDs) attempt to maintain predevelopment hydrologic and ecological functions of their catchments. In assessing the pre- and postdevelopment peak runoff rates from LIDs, the path of surface runoff is particularly important and the effective runoff coefficient might not be accurately estimated by the weighted average of runoff coefficients from the pervious and impervious areas (Guo, 2008). Postdevelopment runoff volume generally increases above predevelopment runoff volume due to increased imperviousness of the catchment, and Guo and Cheng (2008) showed that this increased runoff can be entirely compensated for by increasing the onsite retention volume by D_0 [L], according to the relation

$$\frac{D_0}{\overline{P}} = (C_0 - 1)(\Delta I)\ln(1 - C_v) \tag{10.44}$$

where $\overline{P}$ is the mean precipitation of individual rainfall events [L], C_0 is the predevelopment runoff coefficient [dimensionless], ΔI is the increase in imperviousness fraction between pre- and postdevelopment [dimensionless], and C_v is the capture rate of rainfall [dimensionless]. Values of $\overline{P}$ vary across the United States and are typically in the range of 10–20 mm (see Guo and Cheng, 2008, for map), C_0 is typically in the range of 0–0.1, ΔI is typically on the order of 0.1–0.5, and C_v is typically in the range of 0.75–0.85.

10.4.2 NRCS-TR55 Method

The Natural Resources Conservation Service (NRCS) computed the runoff from many small and midsize catchments using the NRCS regional 24-h hyetographs to describe the rainfall distribution, the NRCS curve-number model to calculate the rainfall excess, and the NRCS unit-hydrograph method to calculate the runoff hydrograph. These computations were performed using the TR-20 computer program. On the basis of these results, the NRCS proposed the *graphical peak-discharge method* or, more commonly, the *TR-55 method*, for estimating peak runoff rates from small and midsize catchments, with times of concentration in the range of 0.1–10 hours. In applying the TR-55 method, it is important to note that the NRCS regional 24-h hyetographs are designed to contain the (average) intensity of any duration of rainfall less than 24 h for the frequency of the event chosen (i.e., NRCS hyetographs are consistent with local IDF curves) and therefore peak runoff rates are generated from NRCS 24-h storms during a time interval of maximum rainfall excess roughly equal to the time of concentration of the catchment. The TR-55 method, named after the technical report in which it is described (SCS, 1986), expresses the peak runoff rate, q_p [m^3/s] as

$$\boxed{q_p = q_u A Q F_p} \tag{10.45}$$

where q_u is the unit peak discharge [m^3/s per cm of runoff per km^2 of catchment area], A is the catchment area [km^2], Q is the runoff [cm] from a 24-h storm with a given return period, and F_p is the pond and swamp adjustment factor [dimensionless]. The runoff, Q, is derived directly from the NRCS curve-number model, Equation 9.80, using the 24-h precipitation. F_p is derived from Table 10.8, assuming that the ponds and/or swampy areas are distributed throughout the catchment, and the unit-peak discharge, q_u, is obtained using the empirical relation

$$\log(q_u) = C_0 + C_1 \log t_c + C_2(\log t_c)^2 - 2.366 \tag{10.46}$$

where C_0, C_1, and C_2 are constants obtained from Table 10.9, and t_c is in hours. Values of C_0, C_1, and C_2 are functions of I_a/P, where I_a is the initial abstraction of the catchment and P is the 24-hour rainfall that causes the runoff, Q. The relationship given by Equation 10.46 is illustrated for Type II rainfall in Figure 10.3, where it is apparent that the unit peak discharge, q_u, decreases exponentially with increasing time of concentration, t_c, and for any given value of t_c the value of q_u decreases with increasing values of I_a/P. Higher curve numbers correspond to lower values of I_a/P. Although the relationship between q_u, t_c, and I_a/P shown in Figure 10.3 is for Type II rainfall, the relationship for other rainfall types are similar. Values of t_c in Equation 10.46 must be between 0.1 h and 10 h (calculated using the NRCS method described in Section 10.3.1). Values of I_a in Table 10.9 are derived using

TABLE 10.8: Pond and Swamp Adjustment Factor, F_p

Percentage of pond and swamp areas	F_p
0	1.00
0.2	0.97
1.0	0.87
3.0	0.75
5.0*	0.72

Note: *If the percentage of pond and swamp areas exceeds 5%, then consideration should be given to routing the runoff through these areas.

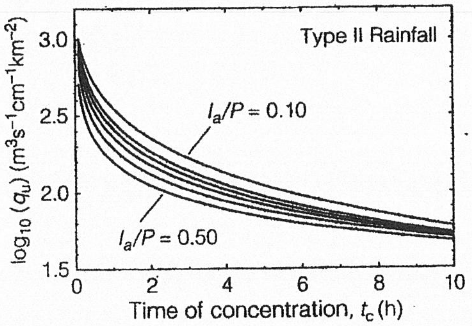
TABLE 10.9: Parameters Used to Estimate Unit Peak Discharge, q_u

Rainfall type	I_a/P	C_o	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

$$I_a = 0.2\,S \tag{10.47}$$

where S is obtained from the curve number in accordance with Equation 9.81. If $I_a/P < 0.1$, values of C_0, C_1, and C_2 corresponding to $I_a/P = 0.1$ should be used, and if $I_a/P > 0.5$, values of C_0, C_1, and C_2 corresponding to $I_a/P = 0.5$ should be used. These approximations result in reduced accuracy of the peak-discharge estimates (SCS, 1986), and McCuen and Okunola (2002) have noted that for times of concentration less than 0.3 h, the TR-55 method

FIGURE 10.3: relationship between unit peak discharge and time of concentration



may underestimate the peak discharge, relative to the TR-20 computer program, by as much as 15% for values of I_a/P near the lower limit of 0.1. The Federal Highway Administration (USFHWA, 1995) and the NRCS (SCS, 1986) have both recommended that the NRCS-TR55 method be used only with homogenous catchments, where the curve numbers vary within ±5 between zones, CN of the catchment should be greater than 40, t_c should be between 0.1 and 10 h, and t_c should be approximately the same for all main channels. The NRCS has developed public-domain software for direct calculation of peak flows using the TR-55 method, and engineers are encouraged to use the latest version of such software.

EXAMPLE 10.6

A 2.25-km^2 catchment with 0.2% pond area is estimated to have a curve number of 85, a time of concentration of 2.4 h, and a 24-h Type III precipitation of 13 cm. Estimate the peak runoff rate from the catchment.

Solution For CN = 85, the storage, S, is given by

$$S = \frac{1}{0.0394}\left(\frac{1000}{\text{CN}} - 10\right) = \frac{1}{0.0394}\left(\frac{1000}{85} - 10\right) = 45 \text{ mm}$$

For $P = 130$ mm, the runoff, Q, is given by

$$Q = \frac{[P - 0.2S]^2}{P + 0.8S} = \frac{[130 - 0.2(45)]^2}{130 + 0.8(45)} = 88 \text{ mm} = 8.8 \text{ cm}$$

From Table 10.8, $F_p = 0.97$. By definition

$$\frac{I_a}{P} = \frac{0.2S}{P} = \frac{(0.2)(45)}{130} = 0.069$$

Since $I_a/P < 0.1$, use $I_a/P = 0.1$ in Table 10.9, which gives $C_0 = 2.47317$, $C_1 = -0.51848$, $C_2 = -0.17083$, and since $t_c = 2.4$ h, Equation 10.46 gives

$$\begin{aligned}\log(q_u) &= C_o + C_1 \log t_c + C_2(\log t_c)^2 - 2.366 \\ &= 2.47317 - 0.51848\log(2.4) - 0.17083(\log 2.4)^2 - 2.366 \\ &= -0.116\end{aligned}$$

which leads to

$$q_u = 10^{-0.116} = 0.765 \text{ (m}^3\text{/s)/(cm·km}^2\text{)}$$

Therefore, according to the TR-55 method, the peak discharge, q_p, is given by Equation 10.45 as

$$q_p = q_u AQF_p = 0.765(2.25)(8.8)(0.97) = 14.7 \text{ m}^3\text{/s}$$

It is important to recognize that hydrologic models used to estimate peak-runoff rates are not highly accurate. Calibrated peak-runoff models often have standard errors of 25% or more, with uncalibrated models having significantly higher standard errors (McCuen, 2001).

Library of Congress Cataloging-in-Publication Data
Chin, David A.
Water-resources engineering / David A. Chin. – 3rd ed.
p. cm.
ISBN-13: 978-0-13-283321-9 (alk. paper)
ISBN-10: 0-13-283321-2 (alk. paper)
1. Hydraulics. 2. Hydrology. 3. Waterworks. 4. Water resources development. I. Title.

TC160.C52 2014
627–dc23 2012018911

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Cover Photo: United States Bureau of Reclamation

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Upper Saddle River, New Jersey 07458

Printed in the United States of America.

10 9 8 7 6 5 4 3 2 1

ISBN: 0-13-283321-2

Pearson Education Ltd., *London*
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