RUNOFF CALCULATIONS

The following provide the minimum necessary equations for determining runoff from a design storm, i.e., a storm with duration ≈ to the watershed's time of concentration. When peak flow is the critical design parameter engineers usually design for this storm duration because it represents the most intense storm (shortest duration) for which the entire watershed contributes flow to the outlet. This section emphasizes peak runoff; we will discuss design criteria for runoff volume later in conjunction with ponds, flood routing, and detention basin design

A. Time of Concentration:

B. Rational Method

C. Curve Number Method

1. Calculating Runoff Volume
2. Synthetic Triangular Hydrograph
3. Calculating Peak Runoff (NRCS Graphical Method)

A. Time of Concentration Equations

Dozens of equations have been proposed for the time of concentration. Below are four of the most commonly used that generally agree with each other within 25%. Eqs. A.3 and A.4 consistently predict longer times of concentration, especially for low runoff potentials. The following were adopted from Chow (19XX)

Kirpich (1940): $$t_c = 0.0078L^{0.77}S^{-0.385} \quad \text{(A.1)}$$

where t_c = time of concentration (min.)
L = length of channel or ditch from headwater to outlet (ft)
S = average watershed slope

Soil Conservation Service (SCS) (1972): $$t_c = \frac{L^{1.15}}{7700H^{0.38}} \quad \text{(A.2)}$$

where t_c = time of concentration (hr)
L = length of longest flow path (ft)
H = difference in elevation between outlet and most distant ridge

SCS Lag Equation (1973): $$t_c = 10L^{0.8}\,[(1000/CN) - 9\,]^{0.7} / (1900S^{0.5}) \quad \text{(A.3)}$$

where t_c = time of concentration (min.)
L = length of longest flow path (ft)
S = average watershed slope
CN = SCS curve number

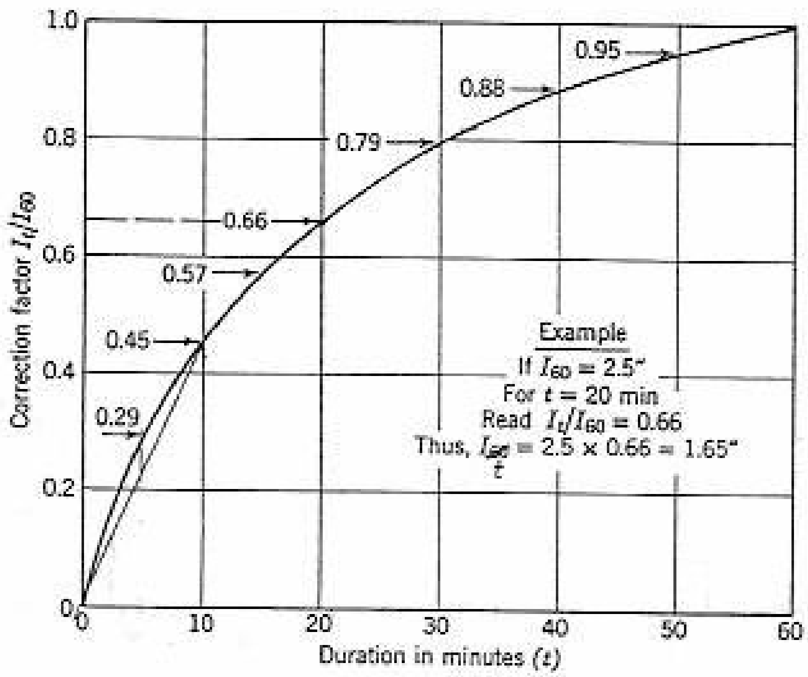
[Originally developed for agricultural areas; found to be reasonable for completely impervious watersheds; tends to overestimate for mixed use watersheds]

Federal Aviation Administration (1970): $$t_c = 1.8(1.1-C)L^{0.5}S^{-0.333} \quad \text{(A.4)}$$

where t_c = time of concentration (min.)
L = length of longest flow path (ft)
S = average watershed slope
C = rational method coefficient

[Originally developed for use on airfields but frequently used for urban watersheds]

$$I_t/I_{60} \approx \frac{1}{0.67 + 11(t)^{-0.86}}$$



$$\frac{P(t)}{P_{24}} = 0.5 + \frac{T}{24}\left[\frac{24.04}{2|T| + 0.04}\right]^{0.75},$$

where t is time and T is time − 12 in hours fits the type II curve with a slight discrepancy on either side of 12 hr.

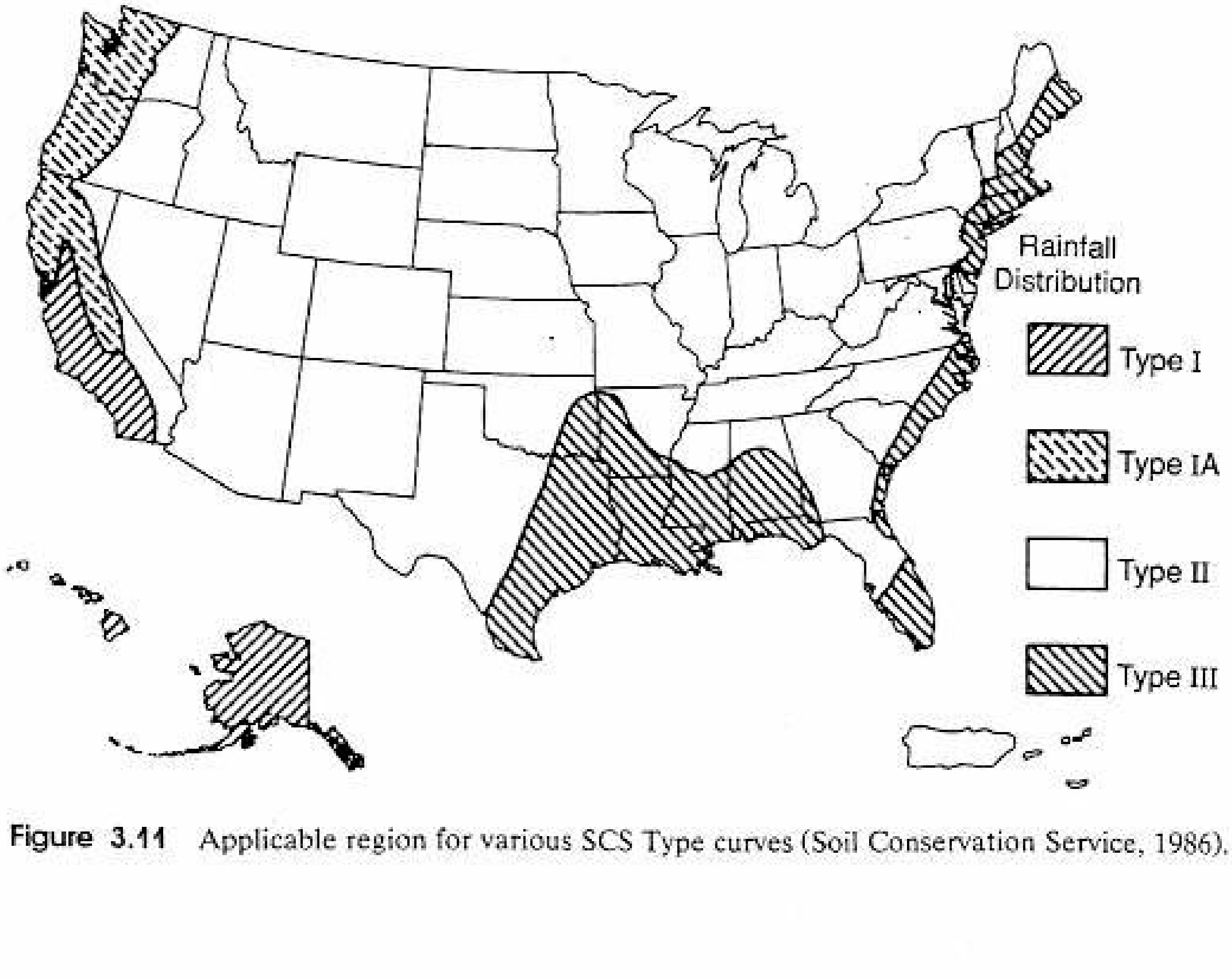


Figure 3.11 Applicable region for various SCS Type curves (Soil Conservation Service, 1986).

B. Rational Method

The Rational Method, a.k.a. Lloyd-Davies method if you are English, is probably the oldest runoff equation (documented use in the 1800s) and remains very popular in urban storm water design.

$$q_p = CiA \qquad (\text{ft}^3\ \text{s}^{-1}) \qquad \text{(B.1)}$$

$$q_p = 0.0028CiA \qquad (\text{m}^3\ \text{s}^{-1}) \qquad \text{(B.2)}$$

where q_p is the peak runoff rate, C is the runoff coefficient (tabulated based on land use), i is the rainfall intensity [in hr^{-1} (B.1), mm hr^{-1} (B.2)], and A is the watershed area [acres (B.1), ha (B.2)]. Remember to use a design storm with duration equal to the watershed's time of concentration, t_c. Runoff coefficients range from 0 (no runoff generated) to 1 (all rain becomes runoff). Note that the relationship between runoff and rainfall intensity implies Hortonian runoff processes.

Tables for runoff coefficients follow.

Table 4.1 Runoff Coefficient C for Agricultural Watersheds (Soil Group B)

Crop and Hydrologic Condition	Coefficient C for Rainfall Rates of		
	25 mm/h	100 mm/h	200 mm/h
Row crop, poor practice	0.63	0.65	0.66
Row crop, good practice	0.47	0.56	0.62
Small grain, poor practice	0.38	0.38	0.38
Small grain, good practice	0.18	0.21	0.22
Meadow, rotation, good	0.29	0.36	0.39
Pasture, permanent, good	0.02	0.17	0.23
Woodland, mature, good	0.02	0.10	0.15

Source: Horn and Schwab (1963).

Schwab et al.

Table 14-1. Values of Runoff Coefficient C

Type of drainage area	*Runoff coefficient, C*
Lawns:	
Sandy soil, flat, 2%	0.05–0.10
Sandy soil, average, 2–7%	0.10–0.15
Sandy soil, steep, 7%	0.15–0.20
Heavy soil, flat, 2%	0.13–0.17
Heavy soil, average, 2–7%	0.18–0.22
Heavy soil, steep, 7%	0.25–0.35
Business:	
Downtown areas	0.70–0.95
Neighborhood areas	0.50–0.70
Residential:	
Single-family areas	0.30–0.50
Multi units, detached	0.40–0.60
Multi units, attached	0.60–0.75
Suburban	0.25–0.40
Apartment dwelling areas	0.50–0.70
Industrial:	
Light areas	0.50–0.80
Heavy areas	0.60–0.90
Parks, cemeteries	0.10–0.25
Playgrounds	0.20–0.35
Railroad yard areas	0.20–0.40
Unimproved areas	0.10–0.30
Streets:	
Asphaltic	0.70–0.95
Concrete	0.80–0.95
Brick	0.70–0.85
Drives and walks	0.75–0.85
Roofs	0.75–0.95

Chow

C. Curve Number Method

1. Calculating Runoff Volume

The Curve Number Equation is actually a relationship between runoff volume and rain volume but because this method is ubiquitously used, especially for rural areas, associated methods have been developed to estimate peak runoff too. The basic equation is:

$$Q = \frac{(P - I_a)^2}{P - I_a + S} \qquad \text{(depth)} \qquad \text{(C.1)}$$

where Q is the runoff depth (to get volume, multiply by the watershed area), P is the rainfall depth, I_a is the initial abstraction, and S is the watershed storage. All units are depth, either inches or mm. The initial abstraction is conceptualized as the amount of rain that falls before runoff is initiated; this is usually grossly assumed to be 0.2S. Eq. (C.1) is usually written as:

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \qquad \text{(depth)} \qquad \text{(C.2)}$$

The S term is determined indirectly from tables relating qualitative land use information to a runoff index called the Curve Number (CN). The CN is related to S with:

$$S = \frac{1000}{CN} - 10 \qquad \text{(inches)} \qquad \text{(C.3a)}$$

$$S = \frac{25400}{CN} - 254 \qquad \text{(mm)} \qquad \text{(C.3a)}$$

Note that the implicit assumption that runoff is related to land use implies Hortonian runoff processes.

CN tables follow (SCS, 1972, NEH, sec. 4).

Chapter 2: Estimating runoff

SCS Runoff Curve Number method

The SCS Runoff Curve Number (CN) method is described in detail in NEH-4 (SCS 1985). The SCS runoff equation is

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

where

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

Initial abstraction (I_a) is all losses before runoff begins. It includes water retained in surface depressions, water intercepted by vegetation, evaporation, and infiltration. I_a is highly variable but generally is correlated with soil and cover parameters. Through studies of many small agricultural watersheds, I_a was found to be approximated by the following empirical equation:

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

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

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

S is related to the soil and cover conditions of the watershed through the CN. CN has a range of 0 to 100, and S is related to CN by

$$S = \frac{1000}{CN} - 10. \qquad \text{[Eq. 2-4]}$$

Figure 2-1 and table 2-1 solve equations 2-3 and 2-4 for a range of CN's and rainfall.

Factors considered in determining runoff curve numbers

The major factors that determine CN are the hydrologic soil group (HSG), cover type, treatment, hydrologic condition, and antecedent runoff condition (ARC). Another factor considered is whether impervious areas outlet directly to the drainage system (connected) or whether the flow spreads over pervious areas before entering the drainage system (unconnected). Figure 2-2 is provided to aid in selecting the appropriate figure or table for determining curve numbers.

CN's in table 2-2 (*a* to *d*) represent average antecedent runoff condition for urban, cultivated agricultural, other agricultural, and arid and semiarid rangeland uses. Table 2-2 assumes impervious areas are directly connected. The following sections explain how to determine CN's and how to modify them for urban conditions.

Hydrologic soil groups

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

Most urban areas are only partially covered by impervious surfaces: the soil remains an important factor in runoff estimates. Urbanization has a greater effect on runoff in watersheds with soils having high infiltration rates (sands and gravels) than in watersheds predominantly of silts and clays, which generally have low infiltration rates.

Any disturbance of a soil profile can significantly change its infiltration characteristics. With urbanization, native soil profiles may be mixed or removed or fill material from other areas may be introduced. Therefore, a method based on soil

Table 2-2a.—Runoff curve numbers for urban areas[1]

Cover description		Curve numbers for hydrologic soil group—			
Cover type and hydrologic condition	Average percent impervious area[2]	A	B	C	D
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, etc.)[3]:					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (excluding right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
Natural desert landscaping (pervious areas only)[4]		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
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Developing urban areas					
Newly graded areas (pervious areas only, no vegetation)[5]		77	86	91	94
Idle lands (CN's are determined using cover types similar to those in table 2-2c).					

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

[2]The average percent impervious area shown was used to develop the composite CN's. Other assumptions are as follows: impervious areas are directly connected to the drainage system, impervious areas have a CN of 98, and pervious areas are considered equivalent to open space in good hydrologic condition. CN's for other combinations of conditions may be computed using figure 2-3 or 2-4.

[3]CN's shown are equivalent to those of pasture. Composite CN's may be computed for other combinations of open space cover type.

[4]Composite CN's for natural desert landscaping should be computed using figures 2-3 or 2-4 based on the impervious area percentage (CN = 98) and the pervious area CN. The pervious area CN's are assumed equivalent to desert shrub in poor hydrologic condition.

[5]Composite CN's to use for the design of temporary measures during grading and construction should be computed using figure 2-3 or 2-4, based on the degree of development (impervious area percentage) and the CN's for the newly graded pervious areas.

Table 2-2b.—Runoff curve numbers for cultivated agricultural lands[1]

Cover description			Curve numbers for hydrologic soil group—			
Cover type	Treatment[2]	Hydrologic condition[3]	A	B	C	D
Fallow	Bare soil	—	77	86	91	94
	Crop residue cover (CR)	Poor	76	85	90	93
		Good	74	83	88	90
Row crops	Straight row (SR)	Poor	72	81	88	91
		Good	67	78	85	89
	SR + CR	Poor	71	80	87	90
		Good	64	75	82	85
	Contoured (C)	Poor	70	79	84	88
		Good	65	75	82	86
	C + CR	Poor	69	78	83	87
		Good	64	74	81	85
	Contoured & terraced (C&T)	Poor	66	74	80	82
		Good	62	71	78	81
	C&T + CR	Poor	65	73	79	81
		Good	61	70	77	80
Small grain	SR	Poor	65	76	84	88
		Good	63	75	83	87
	SR + CR	Poor	64	75	83	86
		Good	60	72	80	84
	C	Poor	63	74	82	85
		Good	61	73	81	84
	C + CR	Poor	62	73	81	84
		Good	60	72	80	83
	C&T	Poor	61	72	79	82
		Good	59	70	78	81
	C&T + CR	Poor	60	71	78	81
		Good	58	69	77	80
Close-seeded or broadcast legumes or rotation meadow	SR	Poor	66	77	85	89
		Good	58	72	81	85
	C	Poor	64	75	83	85
		Good	55	69	78	83
	C&T	Poor	63	73	80	83
		Good	51	67	76	80

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

[2] *Crop residue cover* applies only if residue is on at least 5% of the surface throughout the year.

[3] Hydrologic condition is based on combination of factors that affect infiltration and runoff, including (a) density and canopy of vegetative areas, (b) amount of year-round cover, (c) amount of grass or close-seeded legumes in rotations, (d) percent of residue cover on the land surface (good ≥ 20%), and (e) degree of surface roughness.

Poor: Factors impair infiltration and tend to increase runoff.

Good: Factors encourage average and better than average infiltration and tend to decrease runoff.

Table 2-2c.—Runoff curve numbers for other agricultural lands[1]

Cover description		Curve numbers for hydrologic soil group—			
Cover type	Hydrologic condition	A	B	C	D
Pasture, grassland, or range—continuous forage for grazing.[2]	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow—continuous grass, protected from grazing and generally mowed for hay.	—	30	58	71	78
Brush—brush-weed-grass mixture with brush the major element.[3]	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	[4]30	48	65	73
Woods—grass combination (orchard or tree farm).[5]	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods.[6]	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	[4]30	55	70	77
Farmsteads—buildings, lanes, driveways, and surrounding lots.	—	59	74	82	86

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

[2]*Poor:* <50% ground cover or heavily grazed with no mulch.
Fair: 50 to 75% ground cover and not heavily grazed.
Good: >75% ground cover and lightly or only occasionally grazed.

[3]*Poor:* <50% ground cover.
Fair: 50 to 75% ground cover.
Good: >75% ground cover.

[4]Actual curve number is less than 30; use CN = 30 for runoff computations.

[5]CN's shown were computed for areas with 50% woods and 50% grass (pasture) cover. Other combinations of conditions may be computed from the CN's for woods and pasture.

[6]*Poor:* Forest litter, small trees, and brush are destroyed by heavy grazing or regular burning.
Fair: Woods are grazed but not burned, and some forest litter covers the soil.
Good: Woods are protected from grazing, and litter and brush adequately cover the soil.

SOIL SERIES USED IN NEW YORK
AND THEIR HYDROLOGIC GROUPS

ADAMS	A	BROADALBIN	C	DALTON	C
ADJIDAUMO	D	BROCKPORT	D	DANLEY	C
ADRIAN	A/D	BUCKLAND	C	DANNEMORA	D
AGAWAM	B	BURDETT	C	DARIEN	C
ALBRIGHTS	C	BURNHAM	D	DAWSON	A/D
ALDEN	D	BUSTI	C	DEERFIELD	B
ALLAGASH	B	BUXTON	C	DEFORD	A/D
ALLARD	B	CAMBRIDGE	C	DEKALB	C
ALLIS	D	CAMILLUS	B	DEPEYSTER	C
ALTMAR	B	CAMRODEN	C	DERB	C
ALTON	A	CANAAN	C	DIXMONT	C
AMBOY	C	CANADICE	D	DORA	B/D
AMENIA	B	CANANDAIGUA	D	DOVER	B
ANGOLA	C	CANASERAGA	C	DUANE	B
APPLETON	C	CANEADEA	D	DUNKIRK	B
AQUENTS	D	CANFIELD	C	DUTCHESS	B
AQUEPTS		CANTON	B	EDWARDS	B/D
AQUOLLS		CARBONDALE	A/D	EELWEIR	C
ARKPORT	B	CARLISLE	A/D	ELKA	C
ARNOT	C/D	CARROLLTON	C	ELMRIDGE	C
ASHVILLE	D	CARVER	A	ELMWOOD	C
ATHERTON	B/D	CASTILE	B	ELNORA	B
ATKINS	D	CATHRO	A/D	EMPEYVILLE	C
ATSION	C/D	CAVODE	C	ENFIELD	B
AU GRES	B	CAYUGA	C	ENSLEY	B/D
AURELIE	D	CAZENOVIA	B	ERIE	C
AURORA	C	CHADAKOIN	B	ERNEST	C
BARBOUR	B	CHAGRIN	B	ESSEX	C
BARCELONA	C	CHARLTON	B	FAHEY	B
BARRE	D	CHATFIELD	B	FARMINGTON	C
BASH	C	CHAUMONT	D	FARNHAM	B
BASHER	B	CHAUTAUQUA	C	FLACKVILLE	C
BATH	C	CHEEKTOWAGA	D	FLUVAQUENTS	
BECKET	C	CHENANGO	A	FONDA	D
BECRAFT	B	CHESHIRE	B	FREDON	C
BELGRADE	B	CHIPPENY	D	FREETOWN	D
BENSON	D	CHIPPEWA	D	FREMONT	C
BERKSHIRE	B	CHOCORUA	D	FREWSBURG	C
BERNARDSTON	C	CHURCHVILLE	D	GALEN	B
BERRYLAND	B/D	CLAVERACK	C	GALOO	C/D
BESEMAN	A/D	CLYMER	B	GALWAY	B
BICE	B	COHOCTAH	B/D	GEORGIA	C
BIDDEFORD	D	COLLAMER	C	GETZVILLE	D
BIRDSALL	D	COLONIE	A	GILPIN	C
BLASDELL	A	COLOSSE	A	GLOUCESTER	A
BOMBAY	B	COLTON	A	GLOVER	C/D
BONAPARTE	A	CONESUS	B	GRANBY	A/D
BONO	D	CONSTABLE	A	GREENE	B
BOOTS	A/D	COOK	D	GREENWOOD	A/D
BRACEVILLE	C	COSAD	C	GRENVILLE	B
BRAYTON	C	COVEYTOWN	C	GROTON	A
BRIDGEHAMPTON	B	COVINGTON	D	GUFF	D
BRIGGS	A	CRARY	C	GUFFIN	D
BRINKERTON	D	CROGHAN	B	GULF	B/D

HAIGHTS	B
HALCOTT	C/D
HALSEY	C/D
HAMLIN	B
HANNAWA	D
HARTLAND	B
HAVEN	B
HAWKSNEST	C/D
HEMPSTEAD	B
HENRIETTA	B/D
HERKIMER	B
HERMON	A
HEUVELTON	C
HILTON	B
HINCKLEY	A
HINESBURG	C
HOGANSBURG	B
HOLDERTON	B
HOLLIS	C/D
HOLYOKE	C/D
HOMER	B
HONEOYE	B
HOOSIC	A
HORNELL	D
HOWARD	A
HUDSON	C
HUMAQUEPTS	
HYDRAQUENTS	
ILION	D
INSULA	D
IPSWICH	D
IRA	C
IVORY	C
JOLIET	D
JUNIUS	C
KALURAH	B
KANONA	D
KARS	A
KEARSARGE	B
KENDAIA	C
KINGSBURY	D
KINSMAN	C
KINZUA	B
KNICKERBOCKER	A
LACKAWANNA	C
LAGROSS	A
LAIRDSVILLE	D
LAKEMONT	D
LAMSON	B/D
LANESBORO	C
LANGFORD	C
LANSING	B
LEICESTER	C
LEWBEACH	C
LIMA	B
LIMERICK	C
LINLITHGO	B
LIVINGSTON	D
LOBDELL	B
LOCKPORT	D
LONDONDERRY	C/D
LORDSTOWN	C
LOWVILLE	B
LOXLEY	A/D
LUPTON	A/D
LYMAN	C/D
LYME	C
LYONS	D
MACOMB	B
MACOMBER	C
MADALIN	D
MADRID	B
MALONE	C
MANAHAWKIN	D
MANHEIM	C
MANLIUS	C
MAPLECREST	B
MARCY	D
MARDIN	C
MARILLA	C
MARLOW	C
MARTISCO	B/D
MASSENA	C
MATOON	D
MATUNUCK	D
MEDIFIBRISTS	
MEDIHEMISTS	
MEDISAPRISTS	
MELROSE	C
MENLO	D
MERRIMAC	A
MIDDLEBURY	B
MILLSITE	B
MINEOLA	A
MINO	C
MINOA	C
MOHAWK	B
MONARDA	D
MONGAUP	C
MONTAUK	C
MORRIS	C
MOSHERVILLE	C
MUCK	D
MUNSON	D
MUNUSCONG	B/D
MUSKELLUNGE	D
MUSKINGUM	C
NASSAU	C
NAUMBURG	C
NEHASNE	B
NELLIS	B
NEVERSINK	D
NEWSTEAD	C
NIAGARA	C
NICHOLVILLE	C
NORWICH	D
NUNDA	C
OAKVILLE	A
OCCUM	B
OCHREPTS	
ODESSA	D
ONDAWA	B
ONOVILLE	C
ONTARIO	B
ONTEORA	C
OQUAGA	C
ORPARK	C
ORTHENTS	
OSSIPEE	D
OTISVILLE	A
OVID	C
PALATINE	B
PALMS	A/D
PALMYRA	B
PANTON	D
PATCHIN	D
PAWCATUCK	D
PAWLING	B
PAXTON	C
PERU	C
PHELPS	B
PHILO	B
PINCKNEY	C
PITS	
PITTSFIELD	B
PITTSTOWN	C
PLAINFIELD	A
PLYMOUTH	A
PODUNK	B
POMPTON	B
POOTATUCK	B
POPE	B
POTSDAM	C
PSAMMENTS	
PUNSIT	C
PYRITIES	B
QUETICO	D
RAQUETTE	B
RAYNE	B
RAYNHAM	C
RAYPOL	C
RED HOOK	C

RED WATER	B	TOR	D	WOOSTER	C
REMSEN	D	TORULL	D	WORDEN	C
RHINEBECK	D	TOWERVILLE	B	WORTH	C
RICKER	A	TRESTLE	B	WURTSBORO	C
RIDGEBURY	C	TROUT RIVER	A	WYALUSING	D
RIFLE	A/D	TUGHILL	D	YALESVILLE	C
RIGA	D	TULLER	D		
RINGLING	A	TUNBRIDGE	C		
RIPPOWAM	C	TUNKHANNOCK	A		
RIVERHEAD	B	UDIFLUVENTS	B		
ROCK OUTCROP	D	UDIPSAMMENTS			
ROMULUS	D	UDORTHENTS	A		
RUMNEY	C	UNADILLA	B		
RUSE	D	URBAN LAND			
SACO	D	VALOIS	B		
SALMON	B	VARICK	D		
SAPRISTS	A/D	VARYSBURG	B		
SAUGATUCK	C	VENANGO	C		
SCANTIC	D	VERGENNES	C		
SCARBORO	D	VLY	C		
SCHOHARIE	C	VOLUSIA	C		
SCHROON	B	WADDINGTON	A		
SCHUYLER	B	WAKELAND	C		
SCIO	B	WAKEVILLE	B		
SCITUATE	C	WALLACE	B		
SCRIBA	C	WALLINGTON	C		
SEARSPORT	D	WALLKILL	C/D		
SEBAGO	D	WALPOLE	C		
SHAKER	C	WAMPSVILLE	B		
SKERRY	C	WAPPINGER	B		
SLOAN	B/D	WAREHAM	C		
SODUS	C	WARNERS	C		
ST. ALBANS	B	WASSAIC	B		
STAFFORD	C	WATCHAUG	B		
STISSING	C	WAUMBEK	B		
STOCKBRIDGE	C	WAYLAND	C/D		
STOCKHOLM	C	WEAVER	C		
STOWE	C	WEGATCHIE	D		
SUCCESS	A	WELLSBORO	C		
SUDBURY	B	WESTBURY	C		
SUN	D	WESTLAND	B/D		
SUNAPEE	B	WETHERSFIELD	C		
SUNCOOK	A	WHARTON	C		
SUNY	D	WHATELY	D		
SURPLUS	C	WHITMAN	D		
SUTTON	B	WILLETTE	A/D		
SWANTON	C/D	WILLIAMSON	C		
SWARTSWOOD	C	WILLOWEMOC	C		
SWORMVILLE	C	WILPOINT	D		
TACONIC	C/D	WINDSOR	A		
TAWAS	A/D	WINOOSKI	B		
TEEL	B	WOODBRIDGE	C		
TIOGA	B	WOODLAWN	B		
TOQUERVILLE	D	WOODSTOCK	D		

2.Synthetic Triangular Hydrograph

One simple way to estimate peak runoff from runoff volume is to assume a synthetic hydrograph shape and relate volume and peak geometrically. There are dozens of hydrograph approaches that can be used but the simplest is the triangular hydrograph; given the crudeness of the types of runoff estimates used in engineering, more sophisticated hydrograph approaches are usually unnecessary. The triangular hydrograph is shown below.

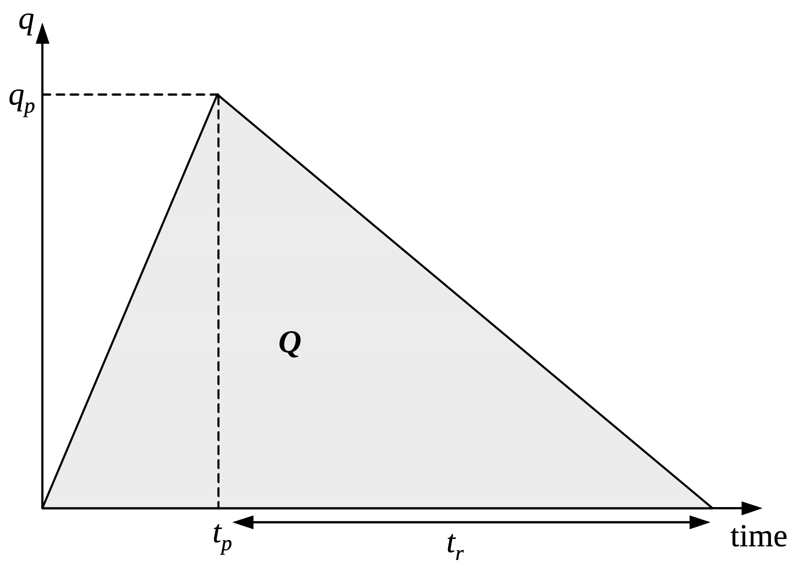


Figure C.1: Schematic of a synthetic triangular runoff hydrograph

From the figure it is obvious that the peak discharge is simply:

$$q_p = \frac{2Q}{(t_p + t_r)} \tag{C.4}$$

where Q is in units of volume and the equation is unit consistent. Commonly, $t_p = 1.1t_c$ and the recession time, $t_r = 1.67t_p$. Eq. C.4 is then:

$$q_p = \frac{2Q}{2.937t_c} \tag{C.5}$$

It is obviously also possible to convert peak runoff estimates into volumes using the synthetic hydrograph concept.

3. Calculating Peak Runoff (NRCS Graphical Method)

The NRCS developed a highly empirical approach to calculating peak runoff for their TR-20 and TR-55 computer programs. It uses the following equation:

$$q_p = q_u A Q_{24} \tag{C.4}$$

where q_u is a coefficient called the unit peak discharge (read from a graph), A is the watershed area (mi^2), and Q_{24} is the runoff from the 24-hr design event calculated with Eq. (C.2). Notice that in this approach the impact of the watershed's time of concentration is incorporated into the q_u factor rather than the design storm duration.

A chart for qu as a function of t_c, P, and I_a follows that is appropriate for most of the contiguous US; other charts are available in the TR-55 manual or various texts (see references). Be careful with units; I recommend keeping depths in inches and areas in mi^2.

Chapter 4: Graphical Peak Discharge method

This chapter presents the Graphical Peak Discharge method for computing peak discharge from rural and urban areas. The Graphical method was developed from hydrograph analyses using TR-20, "Computer Program for Project Formulation—Hydrology" (SCS 1983). The peak discharge equation used is

$$q_p = q_u A_m Q F_p \qquad \text{[Eq. 4-1]}$$

where

q_p = peak discharge (cfs);
q_u = unit peak discharge (csm/in);
A_m = drainage area (mi^2);
Q = runoff (in); and
F_p = pond and swamp adjustment factor.

The input requirements for the Graphical method are as follows: (1) T_c (hr), (2) drainage area (mi^2), (3) appropriate rainfall distribution (I, IA, II, or III), (4) 24-hour rainfall (in), and (5) CN. If pond and swamp areas are spread throughout the watershed and are not considered in the T_c computation, an adjustment for pond and swamp areas is also needed.

Peak discharge computation

For a selected rainfall frequency, the 24-hour rainfall (P) is obtained from appendix B or more detailed local precipitation maps. CN and total runoff (Q) for the watershed are computed according to the methods outlined in chapter 2. The CN is used to determine the initial abstraction (I_a) from table 4-1. I_a/P is then computed.

If the computed I_a/P ratio is outside the range shown in exhibit 4 (4-I, 4-IA, 4-II, and 4-III) for the rainfall distribution of interest, then the limiting value should be used. If the ratio falls between the limiting values, use linear interpolation. Figure 4-1 illustrates the sensitivity of I_a/P to CN and P.

Peak discharge per square mile per inch of runoff (q_u) is obtained from exhibit 4-I, 4-IA, 4-II, or 4-III by using T_c (chapter 3), rainfall distribution type, and I_a/P ratio. The pond and swamp adjustment factor is obtained from table 4-2 (rounded to the nearest table value). Use worksheet 4 in appendix D to aid in computing the peak discharge using the Graphical method.

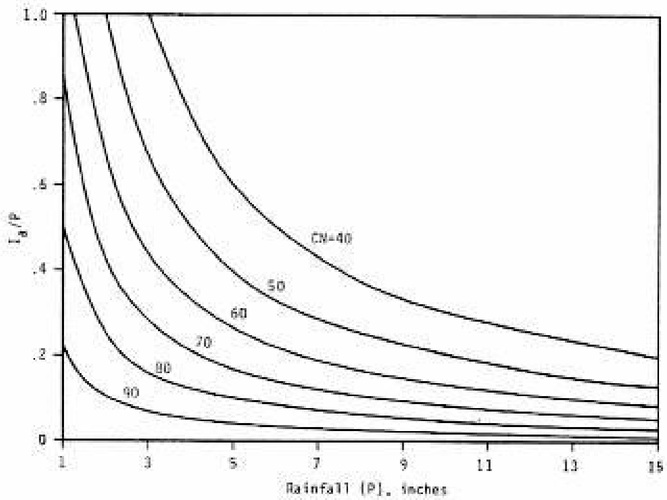
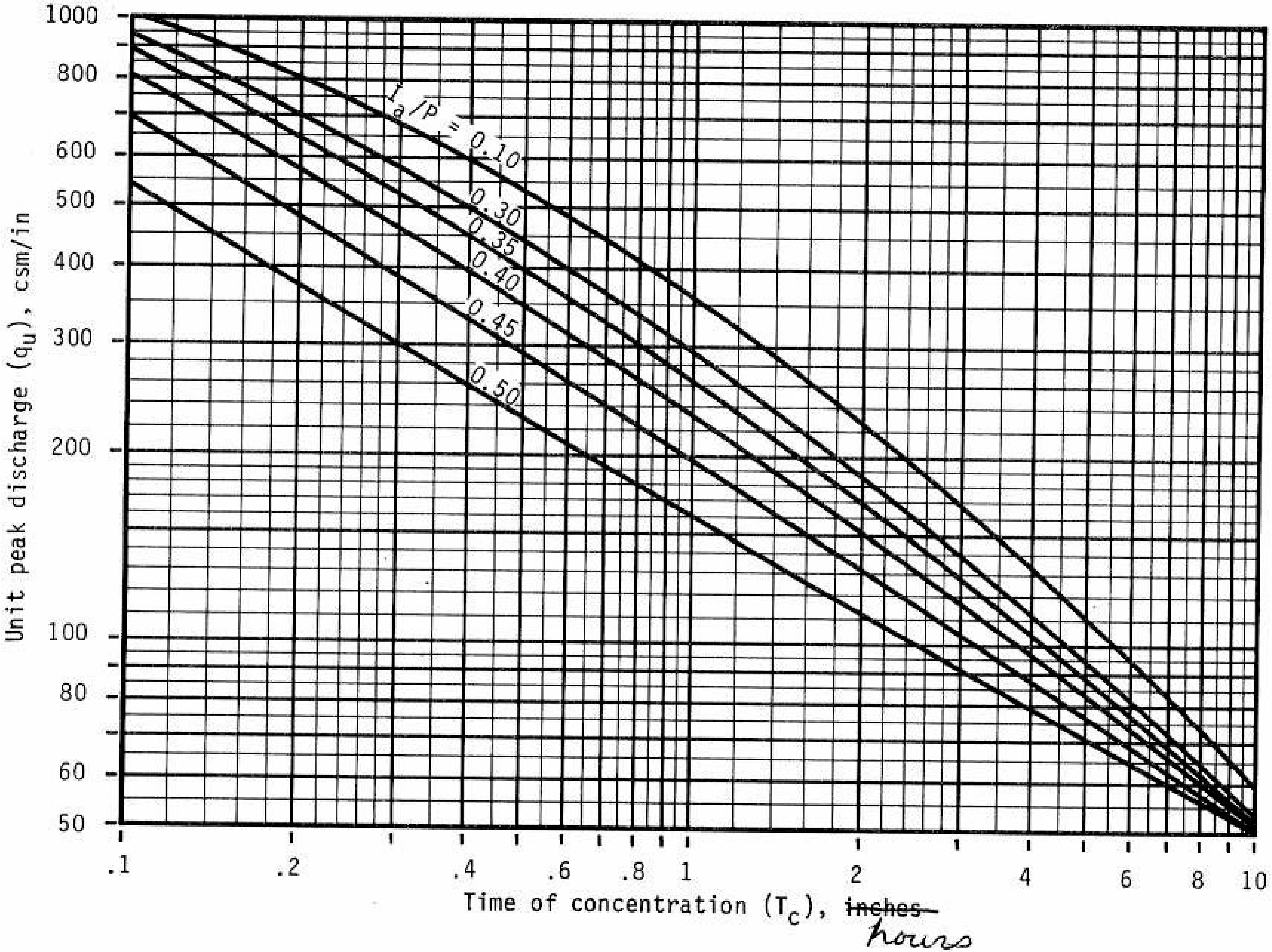


Figure 4-1.—Variation of I_a/P for P and CN.

Table 4-1.—I_a values for runoff curve numbers

Curve number	I_a (in)	Curve number	I_a (in)
40	3.000	70	0.857
41	2.878	71	0.817
42	2.762	72	0.778
43	2.651	73	0.740
44	2.545	74	0.703
45	2.444	75	0.667
46	2.348	76	0.632
47	2.255	77	0.597
48	2.167	78	0.564
49	2.082	79	0.532
50	2.000	80	0.500
51	1.922	81	0.469
52	1.846	82	0.439
53	1.774	83	0.410
54	1.704	84	0.381
55	1.636	85	0.353
56	1.571	86	0.326
57	1.509	87	0.299
58	1.448	88	0.273
59	1.390	89	0.247
60	1.333	90	0.222
61	1.279	91	0.198
62	1.226	92	0.174
63	1.175	93	0.151
64	1.125	94	0.128
65	1.077	95	0.105
66	1.030	96	0.083
67	0.985	97	0.062
68	0.941	98	0.041
69	0.899		

Exhibit 4-II: Unit peak discharge (q_u) for SCS type II rainfall distribution



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

References:

SCS. 1972. *National Engineering Handbook (NEH), Section 4, Hydrology*. US Gov't Press, USDA.
Chow XXXX
SCS. 1986. *Urban Hydrology for Small Watersheds*, Technical Release-55 (TR-55). USDA.

For further information:

Tollner, E.W. 2002. *Natural Resources Engineering*. Iowa State Press, Ames. pp. 576.
Ward, A.D. and S.W. Trimble. *Environmental Hydrology*. Lewis Publishers. New York. pp. 475.
Dunne, T. and L.B. Leopold. *Water in Environmental Planning*. W.H. Freemanbd and Co. New York. pp. 818.
Chin, D.A. *Water Resources Engineering*. Prentice Hall. Upper Saddle River. pp. 750.