Estimating storm runoff

The amount of precipitation, whether it occurs as rain or snow, is the potential source of water that may run off small watersheds. The kind of soil and the type of vegetation affect the amount of water that runs off. Terraces and diversions, along with steepness and shape of a watershed, affect the rate at which water runs off.

A spillway is provided to bypass surface runoff after the pond is filled. The tables and charts in the following sections should be used to estimate the peak discharge rates for the spillway. They provide a quick and reliable estimate of runoff rates and associated volumes for a range of storm rainfall amounts, soil groups, land use, cover conditions, and watershed slopes.

Hydrologic groupings of soils

Soils are classified in four hydrologic groups according to infiltration and transmission rates:

A—These soils have a high infiltration rate. They are chiefly deep, well-drained sand or gravel. The runoff potential is low.

B—These soils have a moderate infiltration rate when thoroughly wet. They are chiefly moderately deep, well-drained soils of moderately fine to moderately coarse texture.

C—These soils have a slow infiltration rate when wet. These moderately fine to fine texture soils have a layer that impedes downward movement of water.

D—These soils have a very slow infiltration rate. They are chiefly clay soils that have a high swelling potential, soils with a permanent high water table, soils with a claypan at or near the surface, and shallow soils over nearly impervious material. The runoff potential is high.

The NRCS district conservationist or your county extension agent can help you classify the soils for a given pond site in one of the four hydrologic groups.

Runoff curve numbers

Tables 1 through 4 show numerical runoff ratings for a range of soil-use-cover complexes. Because these numbers relate to a set of curves developed from the NRCS runoff equation, they are referred to as curve numbers (CN) in these tables.

The watershed upstream from a farm pond often contains areas represented by different curve numbers. A weighted curve number can be obtained based on the percentage of area for each curve number. For example, assume that the watershed above a pond is mainly (three-fourths) in good pasture and a soil in hydrologic group B. The remainder is cultivated with conservation treatment on a soil in hydrologic group C.

A weighted curve number for the total watershed would be:

3/4 x 61 = 46 (approximately)
1/4 x 76 = 20 (approximately)
Weighted = 66

Table 1 Runoff curve numbers for urban areas 1/

Cover description	Average percent impervious area 2/	Curve numbers for hydrologic soil group 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 3)					

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 in NRCS Technical Release 55, Urban Hydrology for Small Watersheds.

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 figure 2-3 or 2-4 in Technical Release 55, 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 in Technical Release 55, based on the degree of development (impervious area percentage) and the CN's for the newly graded pervious areas.

Table 2 Runoff curve numbers for agricultural lands 1/

Cover type	Cover description: Treatment 2/	Hydrologic condition 3/	Curve numbers for hydrologic soil group: 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
Closed-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 percent 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) percentage 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 3 Runoff curve numbers for other agricultural lands 1/

Cover description		Curve numbers for hydrologic soil group			
Cover type	Hydrologic condition 3/	A	B	C	D
Pasture, grassland, or range—continuous 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	30 4/	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	30 4/	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 505 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.

Table 4 Runoff curve numbers for arid and semiarid rangelands 1/

Cover description		Curve numbers for hydrologic soil group			
Cover type	Hydrologic condition 2/	A 3/	B	C	D
Herbaceous—mixture of grass, forbs, and low-growing brush, with brush the minor element	Poor	—	80	87	93
	Fair	—	71	81	89
	Good	—	62	74	85
Oak-aspen—mountain brush mixture of oak brush, aspen, mountain mahogany, bitter brush, maple, and other brush.	Poor	—	66	74	79
	Fair	—	48	57	63
	Good	—	30	41	48
Pinyon-juniper—pinyon, juniper, or both grass understory	Poor	—	75	85	89
	Fair	—	58	73	80
	Good	—	41	61	71
Sagebrush with grass understory	Poor	—	67	80	85
	Fair	—	51	63	70
	Good	—	35	47	55
Desert shrub—major plants include saltbush, greasewood, creosotebush, blackbrush, bursage, palo verde, mesquite, and cactus	Poor	63	77	85	88
	Fair	55	72	81	86
	Good	49	68	79	84

1/ Average runoff condition, and $I_a = 0.2S$. For range in humid regions, use table 3.
2/ Poor: <30% ground cover (litter, grass, and brush overstory).
Fair: 30 to 70% ground cover.
Good: >70% ground cover.
3/ Curve numbers for group A have been developed only for desert shrub.

Volume of storm runoff

Often knowing how much water runs off from a big storm as well as the rate at which it flows is good. The volume is needed to compute needed storage as well as the peak discharge rate.

The figures in table 5 are the depth (in inches) at which the storm runoff, if spread evenly, would cover the entire watershed. For example, the volume of runoff from a 3-inch rainfall on a 100-acre watershed with the weighted curve number of 66 would be:

0.55 inch (interpolated between 0.51 and 0.72 inches)
100 acres x 0.55 inch = 55 acre-inches
55 acre-inches ÷ 12 = 4.55 acre-feet
55 acre-inches x 27,152 gallons per acre-inch = 1.5 million gallons (approximately)

Table 5 Runoff depth, in inches

Rainfall (inches)	Curve number 60	65	70	75	80	85	90
1.0	0	0	0	0.03	0.08	0.17	0.32
1.2	0	0	0.03	0.07	0.15	0.28	0.46
1.4	0	0.02	0.06	0.13	0.24	0.39	0.61
1.6	0.01	0.05	0.11	0.20	0.34	0.52	0.76
1.8	0.03	0.09	0.17	0.29	0.44	0.65	0.93
2.0	0.06	0.14	0.24	0.38	0.56	0.80	1.09
2.5	0.17	0.30	0.46	0.65	0.89	1.18	1.53
3.0	0.33	0.51	0.72	0.96	1.25	1.59	1.98
4.0	0.76	1.03	1.33	1.67	2.04	2.46	2.92
5.0	1.30	1.65	2.04	2.45	2.89	3.37	3.88
6.0	1.92	2.35	2.87	3.28	3.78	4.31	4.85
7.0	2.60	3.10	3.62	4.15	4.69	5.26	5.82
8.0	3.33	3.90	4.47	5.04	5.62	6.22	6.81
9.0	4.10	4.72	5.34	5.95	6.57	7.19	7.79
10.0	4.90	5.57	6.23	6.88	7.52	8.16	8.78
11.0	5.72	6.44	7.13	7.82	8.48	9.14	9.77
12.0	6.56	7.32	8.05	8.76	9.45	10.12	10.76

Rainfall amounts and expected frequency

Maps in U.S. Weather Bureau Technical Paper 40 (USWP-TP-40), Rainfall Frequency Atlas of the United States, show the amount of rainfall expected in a 24-hour period. These maps have also been reprinted in Hydrology for Small Urban Watershed, Technical Release 55. Contact your local NRCS field office for rainfall amounts on maps.

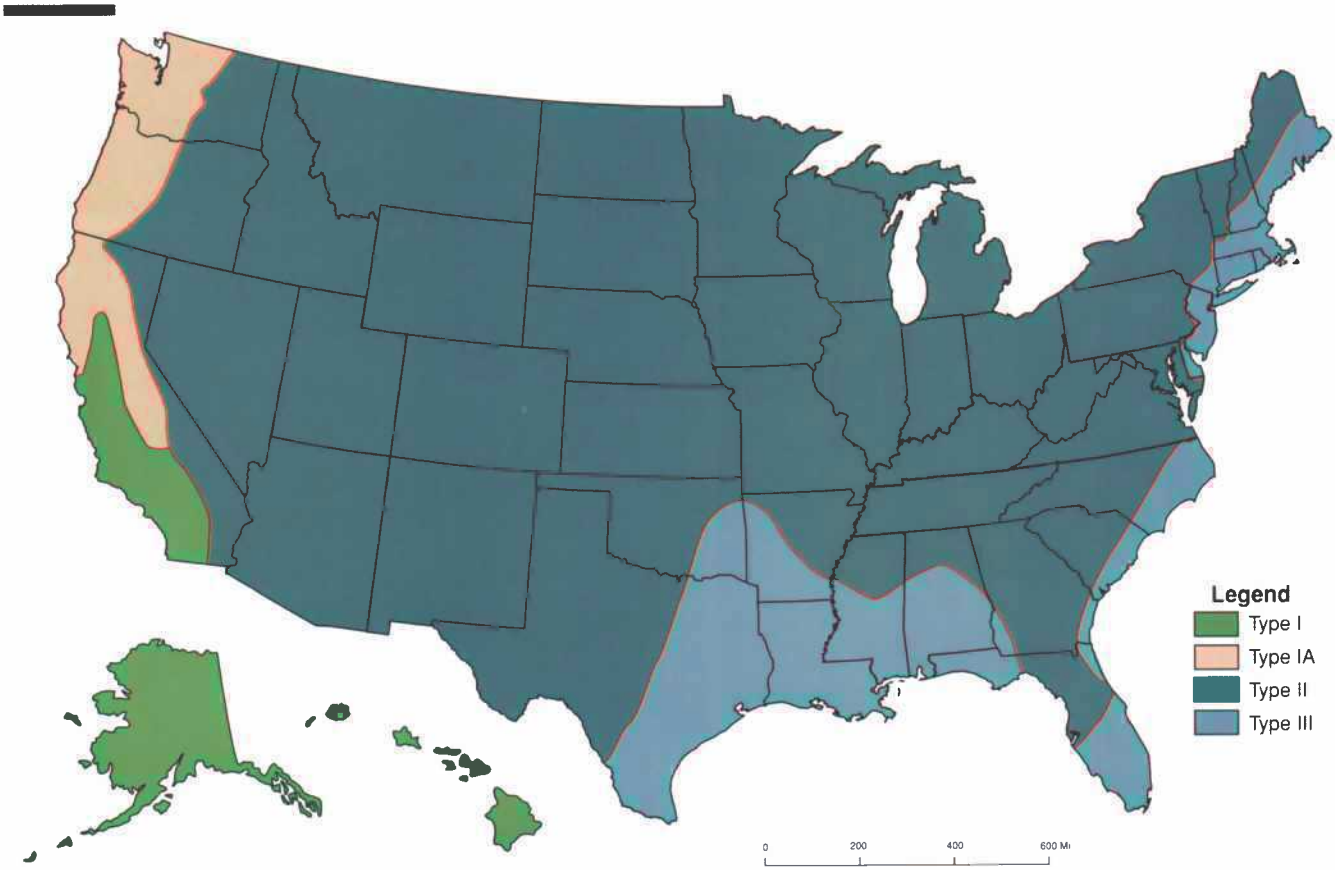
Designing an ordinary pond spillway to accommodate the peak rate of runoff from the most intense rainstorm ever known or anticipated is not practical. The spillway for an ordinary farm pond generally is designed to pass the runoff from a 25-year frequency storm. This means a storm with only a 4 percent chance of occurring in any year or the size beyond which larger storms would not occur more often than an average of once in 25 years. Designing for a 50-year storm frequency is recommended for spillways for larger dams. A 10-year storm frequency may be adequate for sizing the spillway in small ponds.

Rainfall distribution

The highest peak discharges from small watersheds are usually caused by intense, brief rainfalls that may occur as part of a longer duration storm. Different rainfall distributions with respect to time have been developed for four geographic areas of the United States. For each of these areas, a set of synthetic rainfall distributions having nested rainfall intensities were developed. These distributions maximize the rainfall intensities by incorporating selected storm duration intensities within those needed for longer durations at the same probability level.

In figure 15, type I and IA represent the Pacific maritime climate with wet winters and dry summers. Type III represents Gulf of Mexico and Atlantic coastal areas where tropical storms bring large rainfall amounts. Type II represents the rest of the country.

Figure 15 Approximate geographic boundaries for NRCS rainfall distributions



Peak discharge rate

The slope of the land above the pond affects the peak discharge rate significantly. The time of concentration along with the runoff curve number, storm rainfall, and rainfall distribution are used to estimate the peak discharge rate. This rate is used to design the auxiliary spillway width and depth of flow.

Time of concentration

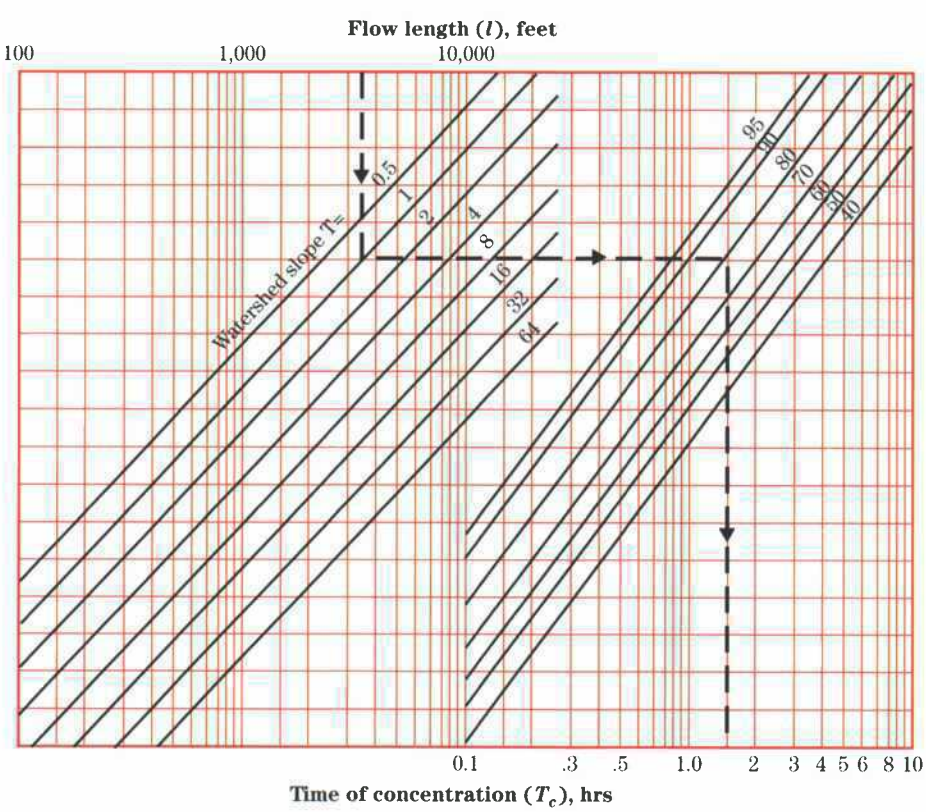
Time of concentration (T_c) is the time it takes for runoff to travel from the hydraulically most distant point of the watershed to the outlet. T_c influences the peak discharge and is a measure of how fast the water runs off the land. For the same size watershed, the shorter the T_c, the larger the peak discharge. This means that the peak discharge has an inverse relationship with T_c. T_c can be estimated for small rural watersheds using equation 1. Figure 16 is a nomograph for solving this equation.

$$T_c = \frac{l^{0.8}\left[\frac{(1000)-9}{CN}\right]^{0.7}}{1140\,Y^{0.5}} \qquad \text{[Eq. 1]}$$

where:

T_c = time of concentration, hr
l = flow length, ft
CN = runoff curve number
Y = average watershed slope, %

Figure 16 Time of concentration (T_c) nomograph



Average watershed slope

The average watershed slope (Y) is the slope of the land and not the watercourse. It can be determined from soil survey data or topographic maps. Hillside slopes can be measured with a hand level, lock level, or clinometer in the direction of overland flow. Average watershed slope is an average of individual land slope measurements. The average watershed slope can be determined using equation 2:

$$Y = \frac{100CI}{A} \qquad \text{[Eq. 2]}$$

where:

Y = average slope, %
C = total contour length, ft
I = contour interval, ft
A = drainage area, ft^2

Flow length

Flow length (l) is the longest flow path in the watershed from the watershed divide to the outlet. It is the total path water travels overland and in small channels on the way to the outlet. The flow length can be determined using a map wheel, or it can be marked along the edge of a paper and converted to feet.

I_a/P ratio

The watershed CN is used to determine the initial abstraction (I_a) from table 6. I_a/P ratio is a parameter that indicates how much of the total rainfall is needed to satisfy the initial abstraction. The larger the I_a/P ratio, the lower the unit peak discharge (q_u) for a given T_c.

Table 6 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		

Estimating peak discharge rates

The unit peak discharge (q_u) is obtained from figure 17 depending on the rainfall type. Figure 15 shows the approximate geographic boundaries for the four rainfall distributions. T_c and I_a/P values are needed to obtain a value for q_u from the exhibit. The peak discharge (q_p in ft^3/s) is computed as the product of the unit peak discharge (q_u in ft^3/s/ac-in), the drainage area (A in acres), and the runoff (Q in inches).

$$q_p = q_u \times A \times Q \qquad \text{[Eq. 3]}$$

Example 1 Estimating peak discharge rates

Known:

Drainage area = 50 acres
Cole County, Missouri
Flow Path 'l' = 1,600 feet
Watershed Slope 'Y' = 4 percent
25-year, 24-hour rainfall = 6 inches
Type II rainfall distribution
Runoff Curve Number = 66
(from example in runoff curve number section)

Solution:

Find T_c
Enter figure 16, T_c = 0.60 hours

Find I_a/P
Enter table 6, use CN = 66, I_a = 1.030
I_a/P = 1.030/6.0 inches = 0.172

Find runoff
Enter table 5, at rainfall = 6.0 inches and runoff curve number = 66,
Read runoff = 2.44 inches. (Note: It was necessary to interpolate between RCN 65 and 70.)

Find the peak discharge for spillway design.
Enter figure 17(c):
q_u = 0.7
$q_p = q_u$ x A x Q
q_p = 0.7 x 50 x 2.44 = 85 ft^3/s

Figure 17a Unit peak discharge (q_u) for Type I storm distribution

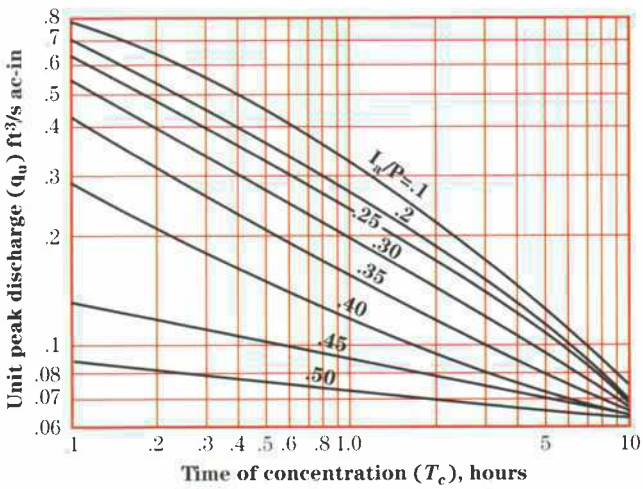


Figure 17b Unit peak discharge (q_u) for Type IA storm distribution

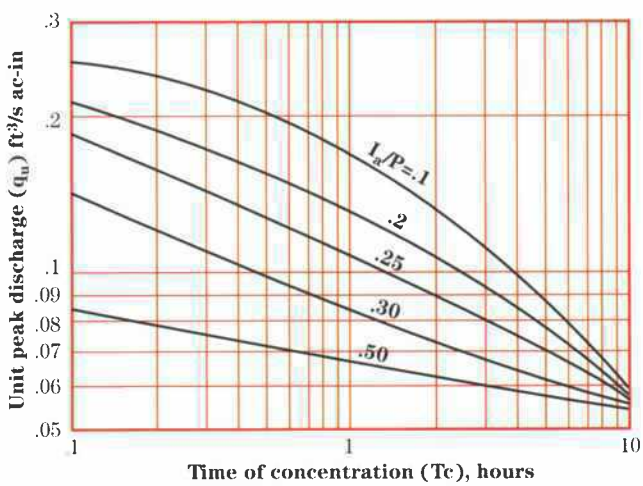


Figure 17c Unit peak discharge (q_u) for Type II storm distribution

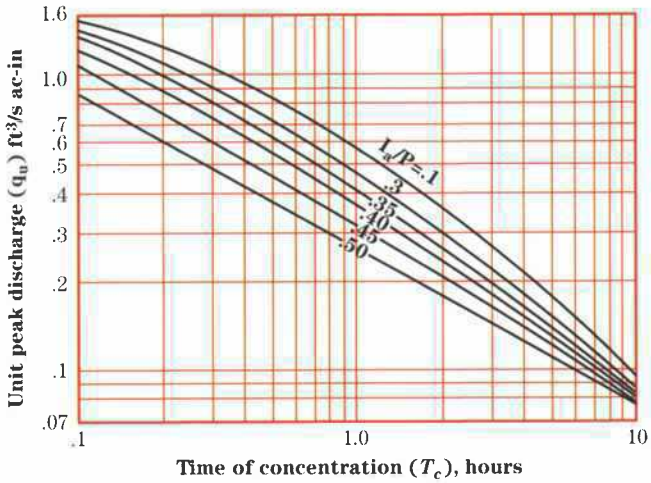
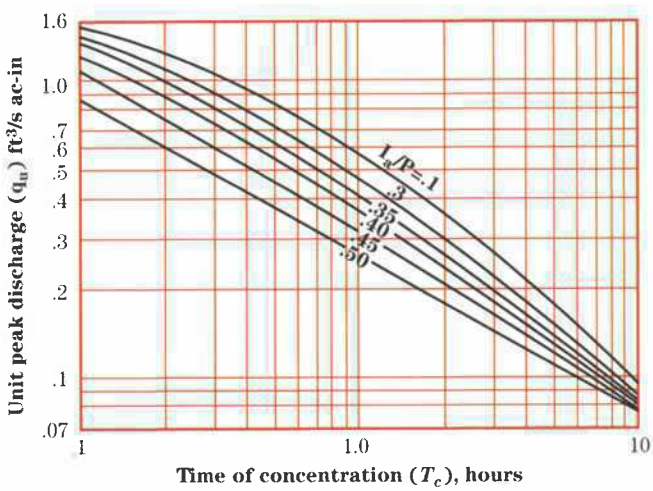



Figure 17d Unit peak discharge (q_u) for Type III storm distribution