5.0 Calculating the Stormwater Runoff Volumes Associated with the Stormwater Management Criteria

5.1 Overview

Section 4.0 presented a set of post-construction stormwater management criteria (SWM Criteria) that can be applied to new development and redevelopment activities occurring within the Coastal Nonpoint Source Management Area and Area of Special Interest. These SWM Criteria help translate the integrated, green infrastructure-based approach to natural resource protection, stormwater management and site design detailed in this Coastal Stormwater Supplement (CSS) into a set of quantitative criteria that can be used to design a post-construction stormwater management system on a development site.

While Section 4.0 provided general information about each of these SWM Criteria, it did not provide guidance on calculating the stormwater runoff volumes associated with them. Therefore, this Section provides information about using accepted hydrologic methods to calculate the stormwater runoff volumes associated with the SWM Criteria that apply to a development site. These calculations can be used to plan and design a post-construction stormwater management system that will satisfy the stormwater management and site planning and design criteria presented in this CSS.

Although there are a number of hydrologic methods that can be used to evaluate site hydrology, the hydrologic methods presented in this Section were selected because of their accuracy in predicting stormwater runoff rates and volumes and because there are a variety of guidance materials and computer programs that support their use.

5.2 Calculating the Stormwater Runoff Volume Associated with the Stormwater Runoff Reduction Criteria (SWM Criteria #1)

The amount of stormwater runoff reduction needed to satisfy the stormwater runoff reduction criteria (SWM Criteria #1), known as the runoff reduction volume (RR_v), can be calculated by multiplying the depth of rainfall generated by the target runoff reduction rainfall event (e.g., 85th percentile storm event, 90th percentile storm event) by the site area and a volumetric runoff coefficient (R_v):

$$RR_v = (P)(R_v)(A) \div (12)$$

Where:

- RR_v = runoff reduction volume (acre-feet)
- P = target runoff reduction rainfall (inches)
- R_v = volumetric runoff coefficient
- A = site area (acres)
- 12 = unit conversion factor (in./ft.)

Schueler (1987) demonstrated that a site's volumetric runoff coefficient, R_v, is directly related to the amount of impervious cover found on the site:

$$R_v = 0.05 + 0.009(I)$$

Where:
I = site imperviousness (%)

Except on development sites located within 1/2-mile of a shellfish harvesting area, the amount of rainfall generated by the target runoff reduction rainfall event (i.e., 85th percentile storm event) is 1.2 inches. Therefore, on most development sites located within coastal Georgia, RR_v can be calculated using the following equation:

$$RR_v = (1.2 \text{ in.})(R_v)(A) \div (12)$$

Where:
RR_v = runoff reduction volume (acre-feet)
R_v = volumetric runoff coefficient
A = site area (acres)
12 = unit conversion factor (in./ft.)

On development sites located within 1/2-mile of a shellfish harvesting area (Section 4.5.1), the amount of rainfall generated by the target runoff reduction rainfall event (i.e., 90th percentile storm event) is 1.5 inches. On these development sites, RR_v can be calculated using the following equation:

$$RR_v = (1.5 \text{ in.})(R_v)(A) \div (12)$$

Where:
RR_v = runoff reduction volume (acre-feet)
R_v = volumetric runoff coefficient
A = site area (acres)
12 = unit conversion factor (in./ft.)

Additional Information

Additional information about calculating the stormwater runoff volume associated with the stormwater runoff reduction criteria (SWM Criteria #1) is provided below:

- Measuring Impervious Area: The amount of impervious cover found on a development site can be read directly from a set of development plans or calculated using aerial photography and appropriate computer software.

- Multiple Drainage Areas: When a development site contains or is divided into multiple drainage areas, it is *recommended* that RR_v be calculated and addressed separately within each drainage area.

- Off-Site Drainage Areas: Stormwater runoff from off-site drainage areas may be diverted and conveyed around a development site and excluded from the RR_v calculations.

Example

Box 5.1 demonstrates how to calculate the stormwater runoff volume associated with the stormwater runoff reduction criteria (SWM Criteria #1) on a development site.

Box 5.1: Calculating the Runoff Reduction Volume

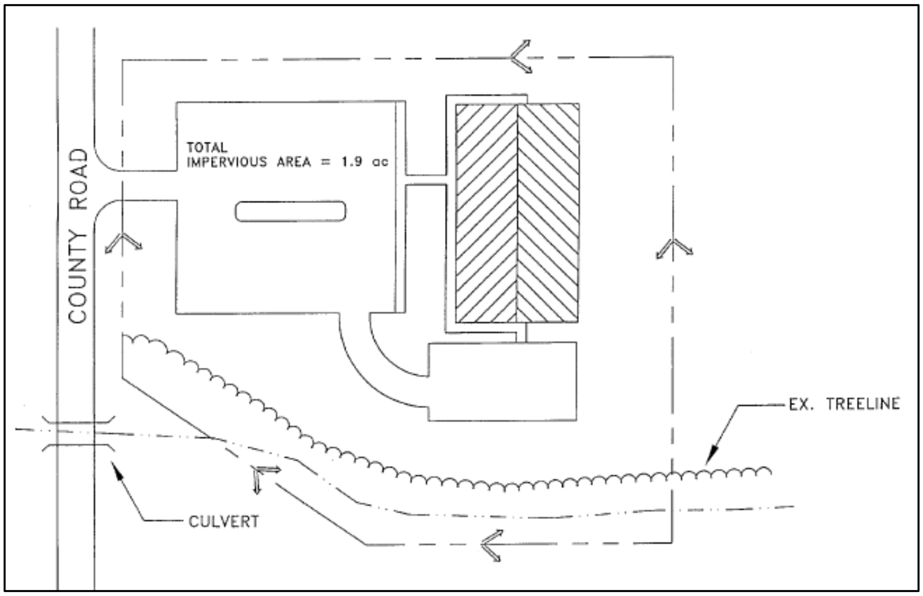

Figure 5.1: Bay Street Community Center, Savannah, GA
(Source: Atlanta Regional Commission, 2001)

Site Data
Site Area, A = 3.0 acres
Pre-Development Impervious Area = 0.0 acres
Post-Development Impervious Area = 1.9 acres
Soils = Hydrologic Soil Group "B" Soils

Hydrologic Data
Target Runoff Reduction Rainfall Event = 1.2 inches
Pre-Development Site Imperviousness, I_{pre} = 0.0 ÷ 3.0 = 0.0%
Post-Development Site Imperviousness, I_{post} = 1.9 ÷ 3.0 = 63.3%

(1) Compute Volumetric Runoff Coefficient, Rv
Rv = 0.05 + 0.009(I)
Rv = 0.05 + 0.009(63.3) = 0.62

(2) Compute Runoff Reduction Volume, RRv
RRv = (1.2 in.)(Rv)(A) ÷ (12 in./ft.)
RRv = (1.2 in.)(0.62)(3.0 ac.) ÷ (12 in./ft.)
RRv = 0.186 ac-ft

5.3 Calculating the Stormwater Runoff Volume Associated with the Water Quality Protection Criteria (SWM Criteria #2)

The water quality protection criteria (SWM Criteria #2) states that if any of the stormwater runoff volume generated by the target runoff reduction rainfall event (e.g., 85^{th} percentile storm event, 90^{th} percentile storm event) cannot be r*educed* on a development site, due to site characteristics or constraints, it should be *intercepted and treated* in one or more stormwater management practices that: (1) provide for at least an 80 percent reduction in TSS loads; and (2) reduce nitrogen and bacteria loads to the *maximum extent practical*. Consequently, the hydrologic methods used to calculate the stormwater runoff volume associated with this SWM Criteria are the same as those described in Section 5.2.

5.4 Calculating the Stormwater Runoff Volume Associated with the Aquatic Resource Protection Criteria (SWM Criteria #3)

An estimate of the amount of storage needed to provide 24 hours of extended detention for the stormwater runoff volume generated by the 1-year, 24-hour storm event, which is known as the aquatic resource protection volume (ARP_v), can be obtained using the nine-step procedure outlined below. This procedure, which was originally developed by Harrington (1987), is a modified version of the Graphical Peak Discharge and Storage Volume Estimation Methods presented in *Technical Release 55* (TR-55) (NRCS, 1986). Although the procedure outlined below can be used to estimate the aquatic resource protection volume (ARP_v), standard storage routing procedures should be used to conduct the final design of any post-construction stormwater management system used on a development site.

5.4.1 Step 1: Determine the Amount of Rainfall Generated by the 1-Year, 24-Hour Storm Event

The amount of rainfall generated by the 1-year, 24-hour storm event varies depending on the location of the development site within the 24-county coastal region. It can be determined using the rainfall tables for Brunswick and Savannah provided in Appendix A of Volume 2 of the *Georgia Stormwater Management Manual* (ARC, 2001).

5.4.2 Step 2: Determine the Runoff Curve Number for the Development Site Under Post-Development Conditions

According to the Natural Resources Conservation Service (NRCS, 1986), the principal factors affecting the relationship between rainfall and runoff are soil type, land cover, land cover treatment, land cover hydrologic condition and antecedent moisture condition. The SCS Runoff Curve Number Method (NRCS, 1986) uses a combination of these factors to assign a runoff coefficient to an area, such as a development site. These runoff coefficients, known as runoff curve numbers (CNs), summarize the runoff potential of a particular area; the higher an area's CN, the higher its runoff potential. Each of the factors that influence an area's CN are discussed briefly below.

Soil Type

Since different soil types have different infiltration rates, soils have a significant influence on the relationship between rainfall and runoff on a development site. Based on their observed minimum infiltration rates, the SCS Runoff Curve Number Method (NRCS, 1986) places different soil types into one of four hydrologic soil groups (HSGs):

- Group A: Group A soils have low runoff potential and high infiltration rates even when thoroughly wetted. They consist chiefly of deep, well to excessively drained sand or gravel.

- Group B: Group B soils have moderate infiltration rates when thoroughly wetted and consist chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures.

- Group C: Group C soils have low infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes downward movement of water and soils with moderately fine to fine texture.

- Group D: Group D soils have high runoff potential. They have very low infiltration rates when thoroughly wetted and consist chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface and shallow soils over nearly impervious material.

Information about the different soil types that can be found in coastal Georgia, including information about their assigned HSGs, can be found in Appendix A of TR-55 (NRCS, 1986) and in Appendix B of Volume 2 of the *Georgia Stormwater Management Manual* (ARC, 2001). Natural Resources Conservation Service soil surveys also provide information about the different soil types that can be found throughout the 24-county coastal region.

It is important to note that the land development process may significantly alter the soils found on a development site. Native soils may be removed, fill materials from other development sites may be introduced and clearing, grading and other land disturbing activities (e.g., compaction) may reduce soil infiltration rates. Consequently, the HSGs originally assigned to the soil types found on a development site may no longer apply to those soils after the land development process has been completed. In these situations, it is recommended that new HSGs be assigned to the soils according to their texture (Table 5.1), provided that significant compaction of the soils has not occurred (Brakensiek and Rawls, 1983).

Table 5.1: Classifying Hydrologic Soil Groups According to Soil Texture (Source: NRCS, 1986)

Hydrologic Soil Group	Soil Texture
A	Sand, loamy sand or sandy loam
B	Silt loam or loam
C	Sandy clay loam
D	Clay loam, silty clay loam, sandy clay, silty clay, or clay

The Ocean County, NJ Soil Conservation District (OCSCD, 2001), investigated the effects of soil compaction on soil infiltration rates and hydrologic soil group classifications. The study found that soil compaction leads to a significant reduction in soil infiltration rates and a significant increase in stormwater runoff volumes on development sites. The study found that, although the soils found on a particular development site could be classified as HSG A or B soils, based on soil survey data and soil texture information (Table 5.1), observations showed that the actual infiltration rates of the soils were less 0.15 in./hr, which is more characteristic of HSG Group C or D soils (OCSCD, 2001). Therefore, it is *recommended* that some effort be made to account for the effects of soil compaction when assigning new HSGs to the soil types found on a development site. Until more extensive guidance on this topic is available, it may advisable to adjust a particular soil's HSG down by a group or two, depending on the extent of compaction that has occurred or will occur on the development site.

Land Cover

In the SCS Runoff Curve Number Method (NRCS, 1986), this parameter is used to represent the type of land cover found on a development site. Land cover types included the SCS Runoff Curve Number Method (NRCS, 1986) include vegetation, litter, mulch, bare soil and impervious surfaces. There are a number of methods that can be used to determine the land cover found on a development site, including field reconnaissance and interpretation from aerial photography and land use maps.

Land Cover Treatment

In the SCS Runoff Curve Number Method (NRCS, 1986), this parameter is used to further describe the land cover found on a development site. It applies mainly to cultivated agricultural lands and addresses land management practices, such as contouring, terracing, crop rotation, grazing control and reduced tillage.

Land Cover Hydrologic Condition

The land cover hydrologic condition factor is used to describe the effects of land cover type and land cover treatment on soil infiltration rates. The SCS Runoff Curve Number Method (NRCS, 1986) defines three possible hydrologic conditions for land covers:

- Good: Land covers in good hydrologic condition usually have the lowest runoff potential for a given hydrologic soil group, land cover and land cover treatment.

- Fair: Land covers in fair hydrologic condition usually have a moderate runoff potential for a given hydrologic soil group, land cover and land cover treatment.

- Poor: Land covers in poor hydrologic condition usually have the highest runoff potential for a given hydrologic soil group, land cover and land cover treatment.

Some of the factors that play a role in defining the hydrologic condition of a given land cover include: (1) density of canopy or vegetation on lawns, croplands and other vegetated areas; (2) amount of year-round vegetative cover; (3) amount of grass or close-seeded legumes in crop rotations; (4) percent of residue cover; and (5) degree of surface roughness.

Antecedent Moisture Condition

The antecedent moisture condition (AMC) (also known as the *antecedent runoff condition*), is used to describe the runoff potential of a particular area prior to a storm event. The AMC is an attempt to account for the variation in observed CNs that occurs at a site from one storm event to the next. This variation in CNs is a result of the change in soil infiltration rates and soil water storage capacities that occur within the soil profile in between storm events, due to evapotranspiration, infiltration and drainage (NRCS, 1985).

In the SCS Runoff Curve Number Method (NRCS, 1986), three different AMCs can be used to describe the runoff potential of a particular hydrologic soil group, land cover, land cover treatment and land cover hydrologic condition prior to a storm event:

- AMC-I: AMC-I represents relatively dry antecedent moisture conditions. It represents the upper limit of the soil infiltration rates and soil water storage capacities that can be measured on a development site.

- AMC-II: AMC-II represents average antecedent moisture conditions and is the AMC most commonly used in stormwater design. It represents the average value of the soil infiltration rates and soil water storage capacities that can be measured on a development site.

- AMC-III: AMC-III represents relatively wet antecedent moisture conditions. It represents the lower limit of the soil infiltration rates and soil water storage capacities that can be measured on a development site.

Although correctly describing the runoff potential of a particular area prior to a storm event is essential to the application of the SCS Runoff Curve Number Method (NRCS, 1986), there is limited guidance on how to accomplish this task. Previous versions of Section 4 of the National Engineering Handbook (NEH-4) (NRCS, 1964), stated that the AMC of a particular hydrologic soil group, land cover, land cover treatment and land cover hydrologic condition can be determined by evaluating the total amount of rainfall that has fallen on a site in a five-day period leading up to the design storm event (i.e., total 5-day antecedent rainfall) and comparing them to the seasonal rainfall limits listed in Table 5.2.

Table 5.2: Antecedent Moisture Conditions and Seasonal Rainfall Limits (Source: NRCS, 1964)

Antecedent Moisture Condition	Total 5-Day Antecedent Rainfall (in.)	
	Dormant Season	Growing Season
AMC-I	Less than 0.5	Less than 1.4
AMC-II	0.5 to 1.1	1.4 to 2.1
AMC-III	More than 1.1	More than 2.1

5.4.2.1 Runoff Curve Numbers

Tables 5.3-5.5 list the runoff curve numbers associated with the average antecedent moisture conditions (i.e., AMC-II) for urban, cultivated agricultural and other agricultural lands.

Table 5.3: Runoff Curve Numbers for Urban Lands[1]
(Source: NRCS, 1986)

Land Cover and Hydrologic Condition	Average Percent Impervious Area[2]	Curve Numbers for Hydrologic Soil Group			
		A	B	C	D
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	59	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 (CNs are determined using cover types similar to those in Table 5.5)					

Notes:
1 Average moisture condition and $I_a = 0.2S$
2 The average percent impervious area shown was used to develop the composite CNs. 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. CNs for other combinations of conditions may be computed using Figure 2-3 or 2-4 in TR-55 (NRCS, 1986).
3 CNs shown are equivalent to those of pasture. Composite CNs may be computed for other combinations of open space cover type.
4 Composite CNs for natural desert landscaping should be computed using Figures 2-3 or 2-4 in TR-55 (NRCS, 1986) based on the impervious area percentage (CN = 98) and the pervious area CN. The pervious area CNs are assumed equivalent to desert shrub in poor hydrologic condition.
5 Composite CNs to use for the design of temporary measures during grading and construction should be computed using Figures 2-3 or 2-4 in TR-55 (NRCS, 1986) based on the degree of development (impervious area percentage) and the CNs for the newly graded pervious areas.

**Table 5.4: Runoff Curve Numbers for Cultivated Agricultural Lands[1]
(Source: NRCS, 1986)**

Land 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

Notes:
1 Average moisture 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, (d) percent of residue cover on the land surface (good $\geq$ 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 5.5: Runoff Curve Numbers for Other Agricultural Lands[1] (Source: NRCS, 1986)

Land 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	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

Notes:
1 Average moisture 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 CNs shown were computed for areas with 50% woods and 50% grass (pasture) cover. Other combinations of conditions may be computed from the CNs 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.

5.4.3 Step 3: Compute the Stormwater Runoff Volume Generated by the 1-Year, 24-Hour Storm Event Under Post-Development Conditions

The stormwater runoff volume generated by the 1-year, 24-hour storm event can be calculated using the SCS Runoff Equation (NRCS, 1986):

$$Q = \frac{P - (0.2)(\frac{1000}{CN} - 10)}{P + (0.8)(\frac{1000}{CN} - 10)} \times A \div 12$$

Where:
- Q = stormwater runoff volume (acre-feet)
- P = rainfall (inches)
- CN = runoff curve number
- A = site area (acres)
- 12 = unit conversion factor (in./ft.)

5.4.4 Step 4: Determine the Initial Abstraction and Initial Abstraction Ratio Under Post-Development Conditions

Through the study of many small agricultural watersheds, the Natural Resource Conservation Service (NRCS, 1986) found that the following equation can be used to relate the initial abstraction (I_a) to a site's CN:

$$I_a = (0.2)(\frac{1000}{CN} - 10)$$

Where:
- I_a = initial abstraction (inches)
- CN = runoff curve number

The initial abstraction (I_a) represents the fraction of the rainfall that is retained in surface depressions, intercepted by vegetation or lost to evaporation and infiltration before runoff begins. Table 5.6 summarizes the values of I_a for a range of CNs.

Table 5.6: Initial Abstraction Values for Runoff Curve Numbers (Source: NRCS, 1986)

CN	I_a	CN	I_a	CN	I_a
40	3.000	60	1.333	80	0.500
41	2.878	61	1.279	81	0.469
42	2.762	62	1.226	82	0.439
43	2.651	63	1.175	83	0.410
44	2.545	64	1.125	84	0.381
45	2.444	65	1.077	85	0.353
46	2.348	66	1.030	86	0.326
47	2.255	67	0.985	87	0.299
48	2.167	68	0.941	88	0.273
49	2.082	69	0.899	89	0.247

Table 5.6: Initial Abstraction Values for Runoff Curve Numbers (Source: NRCS, 1986)					
CN	I_a	CN	I_a	CN	I_a
50	2.000	70	0.857	90	0.222
51	1.922	71	0.817	91	0.198
52	1.846	72	0.778	92	0.174
53	1.774	73	0.740	93	0.151
54	1.704	74	0.703	94	0.128
55	1.636	75	0.667	95	0.105
56	1.571	76	0.632	96	0.083
57	1.509	77	0.597	97	0.062
58	1.448	78	0.564	98	0.041
59	1.390	79	0.532		

Once the I_a has been determined, the initial abstraction ratio (I_a/P) can be determined simply by dividing the initial abstraction (I_a) by the amount of rainfall generated by the target (i.e., 1-year, 24-hour) storm event (P).

5.4.5 Step 5: Determine the Time of Concentration for the Development Site Under Post-Development Conditions

Travel time (T_t) is the time that it takes for stormwater runoff to travel from one point to the next on a development site. It can be computed using the following equation:

$$T_t = \frac{L}{(3600)(V)}$$

Where:

T_t = travel time (hours)
L = length of flow path (feet)
V = average flow velocity (feet per second)
3600 = unit conversion factor (sec./hr.)

The time of concentration (T_c) is the time that it takes for stormwater runoff to travel from the most hydraulically distant point on a development site to a point of interest, such as stormwater pond or stormwater outfall. It is computed by determining the flow path that stormwater runoff will follow on the development site and summing the T_t values for the various flow segments found on that flow path:

$$T_c = T_{t1} + T_{t2} + ... + T_{tm}$$

Where:

T_c = time of concentration (hours)
m = number of flow segments

Stormwater runoff can move across a development site as sheet flow, shallow concentrated flow, open channel flow or some combination of the three. Each of these flow types is described briefly below.

Sheet Flow

Sheet flow is flow over a planar surface. It usually occurs in the most upstream reaches of a flow path or stream. It is affected by surface roughness and land slope.

The travel time within a sheet flow segment can be computed using Manning's kinematic solution (Overton and Meadows, 1976):

$$Tt = \frac{(0.007)(nL)^{0.8}}{(P_2)^{0.5}(s)^{0.4}}$$

Where:

T_t = travel time (hours)
n = Manning's roughness coefficient for sheet flow
L = length of sheet flow segment (feet)
P_2 = amount rainfall generated by 2-year, 24-hour rainfall event (inches)
s = slope of hydraulic grade line or land slope (ft./ft.)

This simplified form of the Manning's kinematic solution is based on the following assumptions: (1) shallow, steady, uniform flow; (2) constant intensity of rainfall excess (the portion of rainfall available for runoff); (3) rainfall duration of 24 hours; and (4) infiltration has minor effects on travel time.

The amount of rainfall generated by the 2-year, 24-hour rainfall event can be determined using the rainfall tables for Brunswick and Savannah provided in Appendix A of Volume 2 of the *Georgia Stormwater Management Manual* (ARC, 2001). Values for Manning's roughness coefficient for sheet flow (n) can be obtained from Table 5.7.

Table 5.7: Manning's Roughness Coefficients for Sheet Flow (Source: NRCS, 1986)

Surface Description	n[1]
Smooth surfaces (concrete, asphalt, gravel, or bare soil)	0.011
Fallow (no residue)	0.05
Cultivated soils:	
Residue cover $\leq$ 20%	0.06
Residue cover > 20%	0.17
Grass:	
Short grass prairie	0.15
Dense grasses[2]	0.24
Bermuda grass	0.41
Range (natural)	0.13
Woods:[3]	
Light underbrush	0.40
Dense underbrush	0.80

Notes:
1 The n values are a composite of information compiled by Engman (1986).
2 Includes species such as weeping lovegrass, bluegrass, buffalo grass, blue grama grass and native grass mixtures.
3 When selecting n, consider cover to a height of about 0.1 ft. This is the only part of the plant cover that will obstruct sheet flow.

Shallow Concentrated Flow

After a maximum of 75 to 150 feet, sheet flow typically becomes shallow concentrated flow. The average velocity for this type of flow can be determined by using Figure 5.2, in which average velocity is provided as a function of watercourse slope and channel type.

The average velocity of shallow concentrated flow can also be computed using the following equations, which can also be used to compute the velocity of shallow concentrated flow on watercourse slopes less than 0.005 ft./ft. (NRCS, 1986):

Unpaved Surface

$$V = 16.1345(s)^{0.5}$$

Where:
V = average velocity (ft./sec.)
S = slope of hydraulic grade line or watercourse slope (ft./ft.)

Paved Surface

$$V = 20.3282(s)^{0.5}$$

Where:
V = average velocity (ft./sec.)
s = slope of hydraulic grade line or watercourse slope (ft./ft.)

After determining the average velocity of shallow concentrated flow, use the following equation to estimate the travel time within the shallow concentrated flow segment:

$$T_t = \frac{L}{(3600)(V)}$$

Where:
T_t = travel time (hours)
L = length of shallow concentrated flow segment (feet)
V = average velocity of shallow concentrated flow (feet per second)
3600 = unit conversion factor (sec./hr.)

Open Channel Flow

Open channel flow is assumed to begin where surveyed cross section information has been obtained, where channels are visible on aerial photographs, where channels have been identified by the local development review authority or where blue lines, which indicate streams, appear on U.S. Geological Survey (USGS) quadrangle maps. Manning's equation or water surface profile information can be used to estimate the average flow velocity within an open channel segment. The average flow velocity within an open channel segment is usually determined at bankfull conditions within the channel of interest.

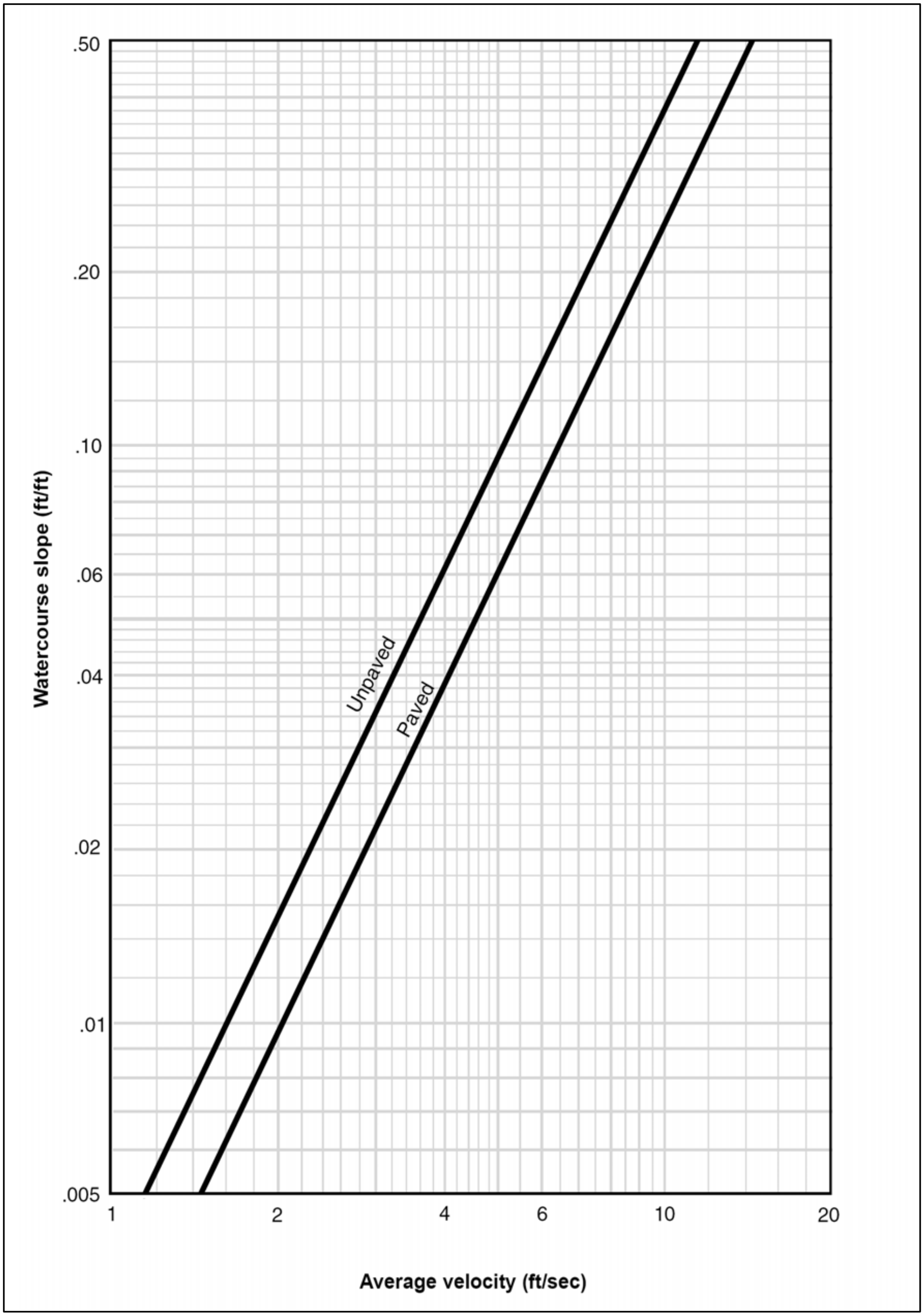

Figure 5.2: Average Velocities for Estimating Travel Time for Shallow Concentrated Flow
(Source: Natural Resources Conservation Service, 1986)

Manning's equation is:

$$V = \frac{(1.49)(R_h)^{2/3}(s)^{1/2}}{n}$$

Where:

- V = average velocity of open channel flow (feet per second)
- R_h = hydraulic radius (feet)
- s = slope of hydraulic grade line or channel slope (ft./ft.)
- n = Manning's roughness coefficient for open channel flow

Values for Manning's roughness coefficient for open channel flow (n) can be obtained from standard hydrology textbooks. The hydraulic radius (R_h) of an open channel cross section can be computed using the following equation:

$$R_h = \frac{A}{P_w}$$

Where:

- R_h = hydraulic radius (feet)
- A = flow area of open channel cross section (square feet)
- P_w = wetted perimeter of open channel cross section (feet)

After determining the average velocity of open channel flow, use the following equation to estimate the travel time within the open channel flow segment:

$$T_t = \frac{L}{(3600)(V)}$$

Where:

- T_t = travel time (hours)
- L = length of open channel flow segment (feet)
- V = average velocity of open channel flow (feet per second)
- 3600 = unit conversion factor (sec./hr.)

5.4.6 Step 6: Compute the Uncontrolled Peak Discharge Under Post-Development Conditions

The next step in the procedure is to compute the uncontrolled peak discharge generated on the development site by the 1-year, 24-hour storm event under post-development conditions. This requires the unit peak discharge (q_u) to be determined.

The unit peak discharge (q_u) can be determined using the previously obtained values of I_a/P (Section 5.4.4) and T_c (Section 5.4.5), knowledge about the rainfall distribution on the development site (e.g., Type II, Type III) (Figure 5.3) and Figure 5.4 or Figure 5.5, whichever is appropriate. If the initial abstraction ratio (I_a/P) is outside the range of values provided in the figures, then the appropriate boundary value of q_u should be used. Linear interpolation can be used to estimate q_u when the value of I_a/P falls between the values provided in the figures.

The uncontrolled peak discharge (q_i) generated on the development site by the 1-year, 24-hour storm event can be determined using the unit peak discharge (q_u) and the following equation:

$q_i = (q_u)(A)(Q)(F_p)$

Where:

- q_i = uncontrolled peak discharge (cubic feet per second)
- q_u = unit peak discharge (cubic feet per second per square mile per inch)
- Q = stormwater runoff volume (inches)
- A = site area (square miles)
- F_p = pond and swamp adjustment factor

The pond and swamp adjustment factor (F_p) is used to account for pond and swamp areas that are spread across a development site and are not accounted for in the time of concentration (T_c) calculations (Section 5.4.5). Values for the pond and swamp adjustment factor (F_p) can be obtained from Table 5.8.

Table 5.8: Adjustment Factor (F_p) for Pond and Swamp Areas That Are Spread Across a Development Site (Source: NRCS, 1986)

% of Site in Pond and Swamp Areas	F_p	% of Site in Pond and Swamp Areas	F_p
0.0	1.00	3.0	0.75
0.2	0.97	5.0	0.72
1.0	0.87		

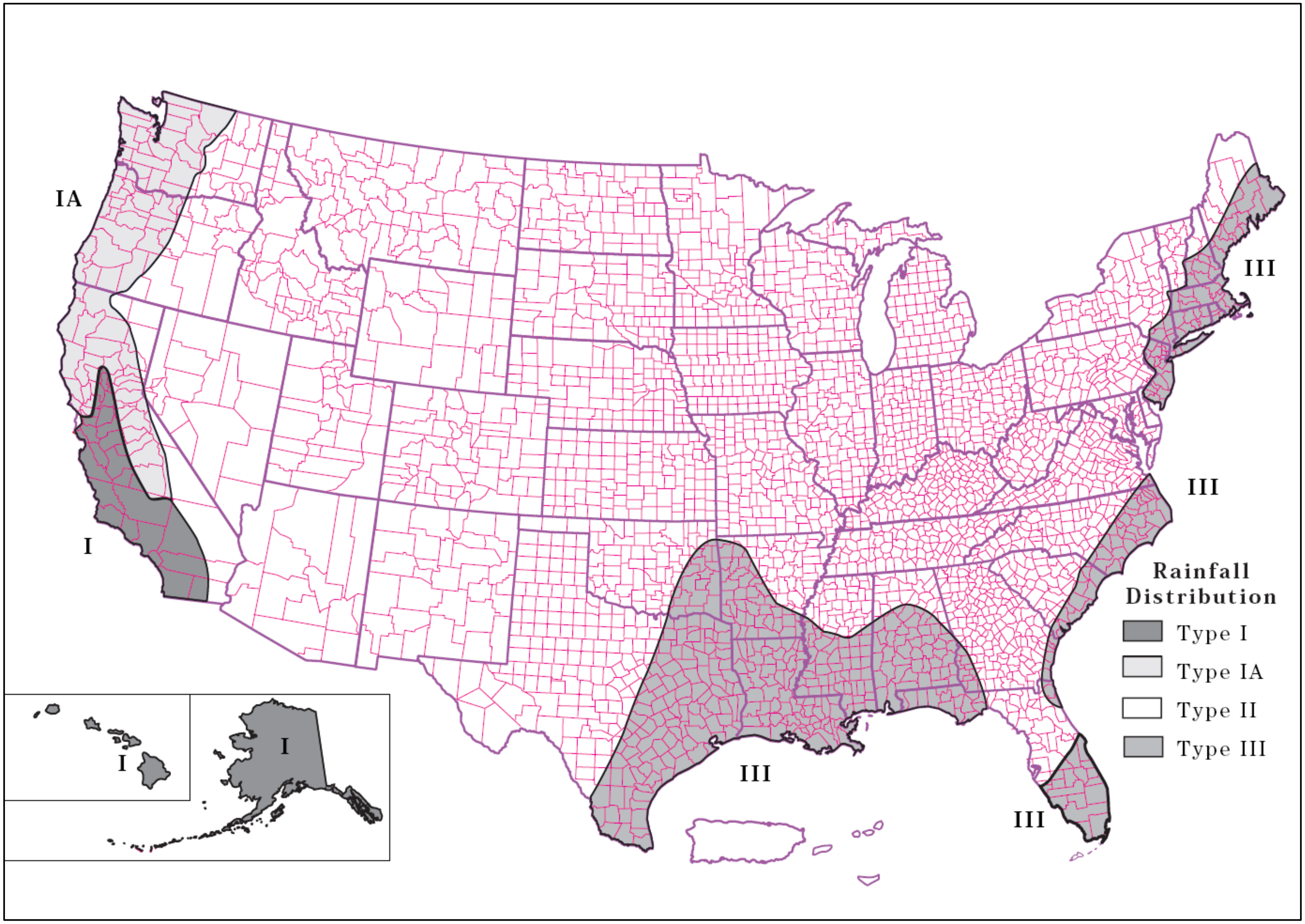

Figure 5.3: Approximate Geographic Boundaries for NRCS (SCS) Rainfall Distributions
(Source: Natural Resources Conservation Service, 1986)

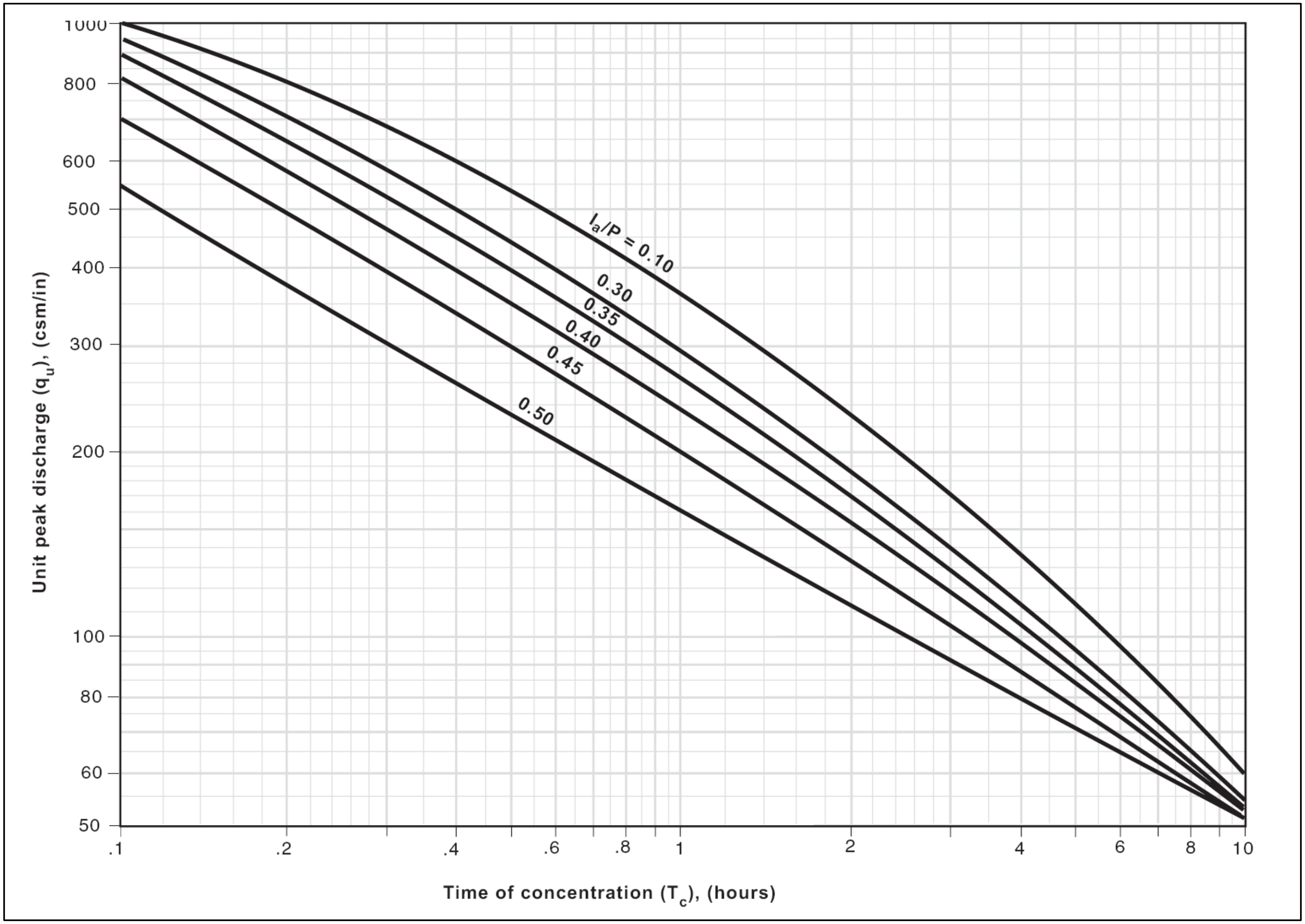

Figure 5.4: Unit Peak Discharge for NRCS (SCS) Type II Rainfall Distribution
(Source: Natural Resources Conservation Service, 1986)

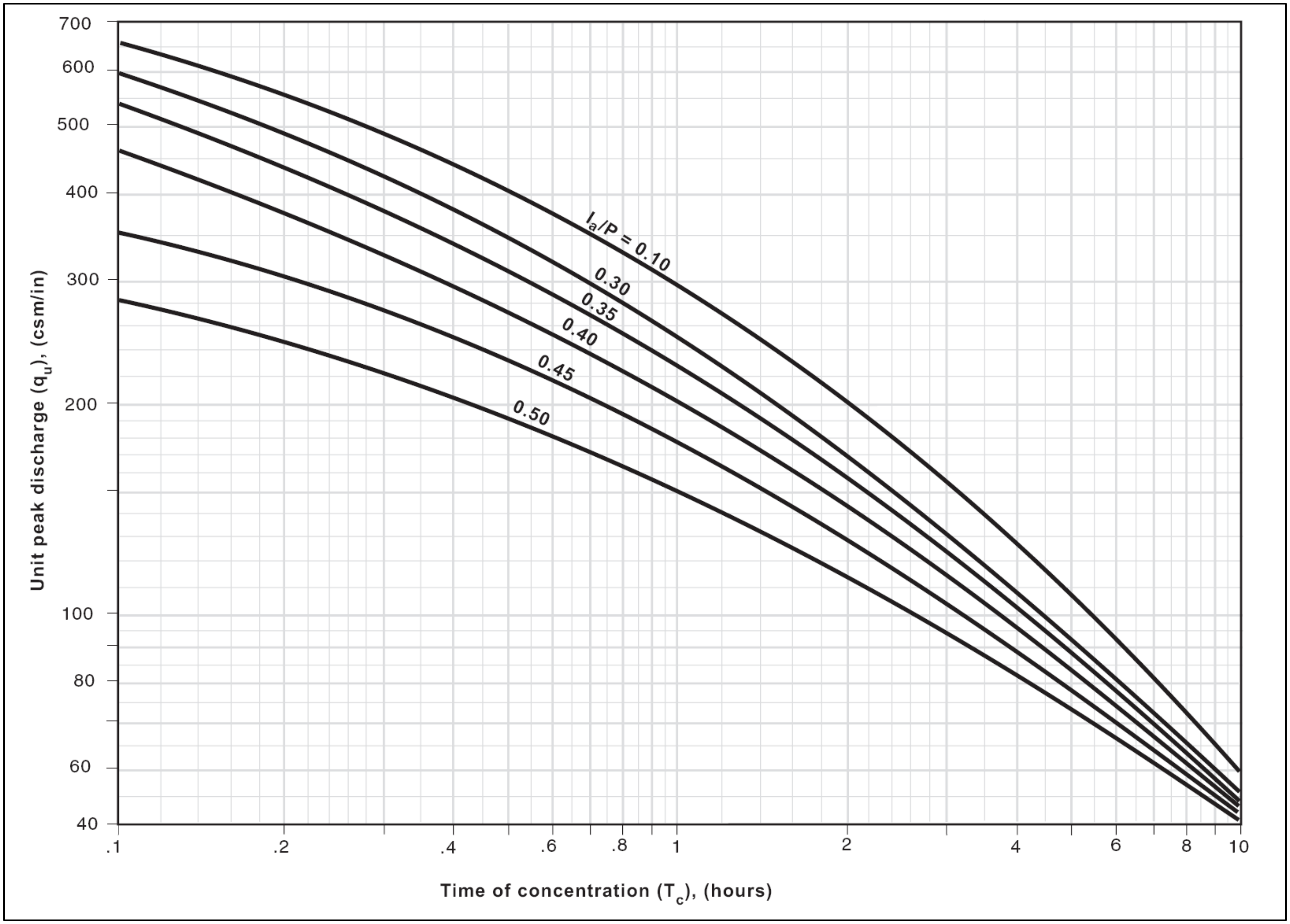

Figure 5.5: Unit Peak Discharge for NRCS (SCS) Type III Rainfall Distribution
(Source: Natural Resources Conservation Service, 1986)

5.4.7 Step 7: Determine the Ratio of the Controlled Peak Discharge to the Uncontrolled Peak Discharge

The value of the ratio of the controlled peak discharge to the uncontrolled peak discharge (q_o/q_i) can be determined using the previously obtained value of the unit peak discharge (q_u) (Section 5.4.6), the required extended detention time (T) (i.e., 24 hours) and Figure 5.6.

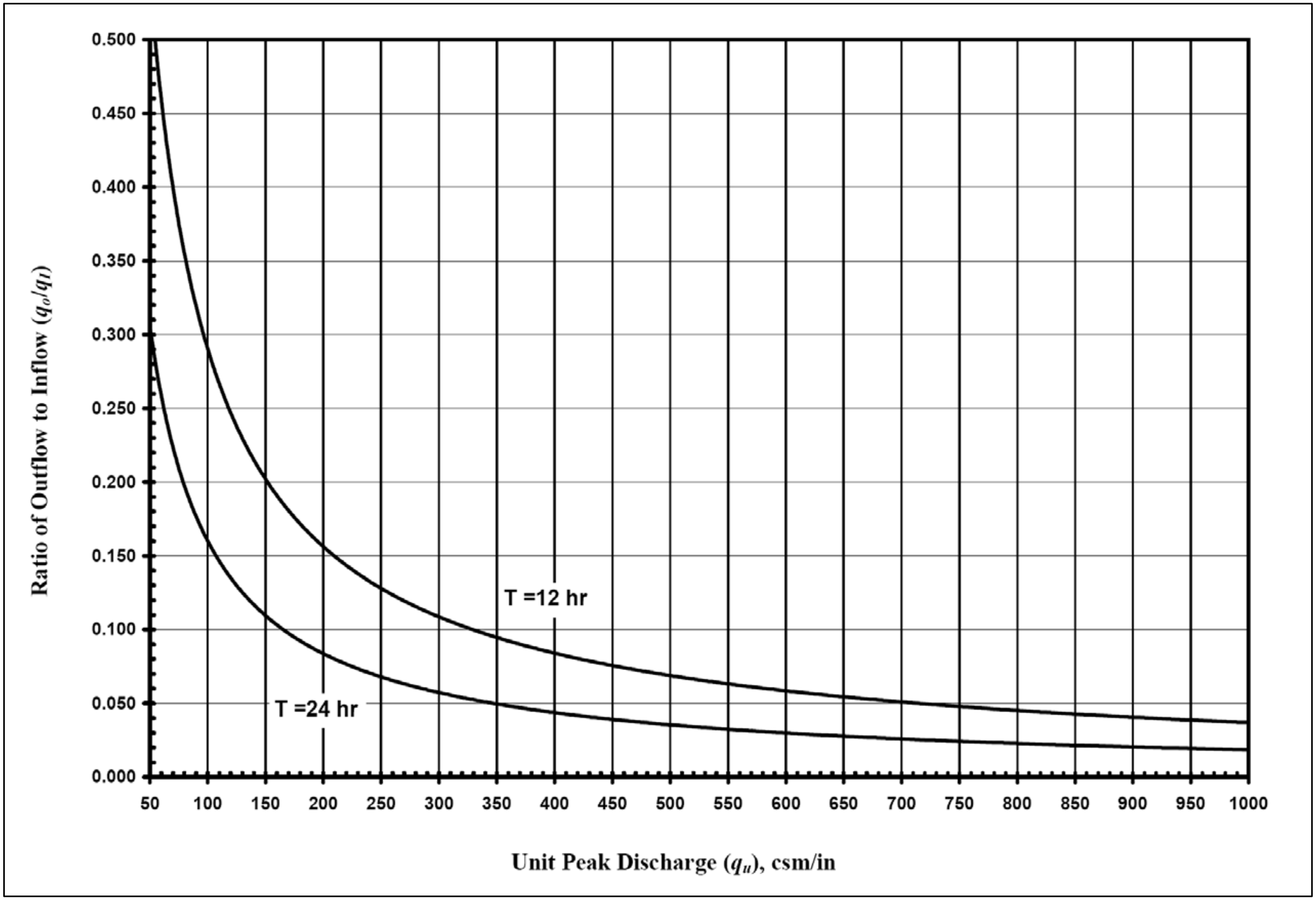

Figure 5.6: Ratio of Uncontrolled Peak Discharge to Controlled Peak Discharge
(Source: Atlanta Regional Commission, 2001)

5.4.8 Step 8: Calculate the Ratio of the Required Storage Volume to the Stormwater Runoff Volume

The value of the ratio of the required storage volume to the stormwater runoff volume (V_s/V_r) can be determined using knowledge about the rainfall distribution on the development site (e.g., Type II, Type III) (Figure 5.5) and Figure 5.7.

When determining the amount of storage needed to provide 24 hours of extended detention for the stormwater runoff volume generated by the 1-year, 24-hour storm event, the ratio of the required storage volume to the stormwater runoff volume (V_s/V_r) can also be calculated numerically for a Type II or Type III rainfall distribution (Harrington, 1987):

$$V_s/V_r = 0.683 - (1.43)(q_o/q_i) + (1.64)(q_o/q_i)^2 - (0.804)(q_o/q_i)^3$$

Where:

- V_s = required storage volume (acre-feet)
- V_r = stormwater runoff volume (acre-feet)
- q_o = controlled peak discharge (cubic feet per second)
- q_i = uncontrolled peak discharge (cubic feet per second)

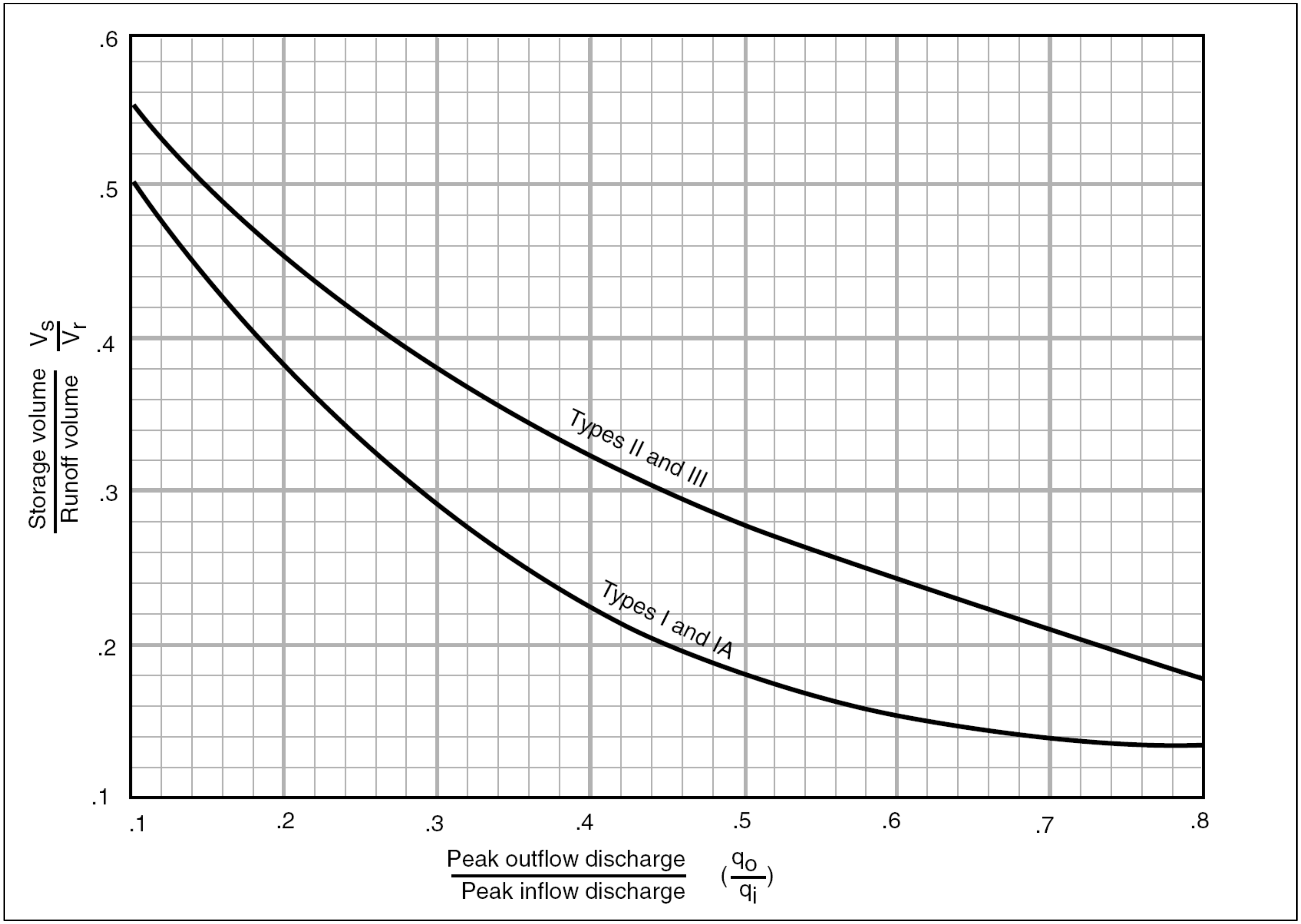

Figure 5.7: Approximate Detention Basin Routing for NRCS (SCS) Type I, IA, III and III Rainfall Distributions
(Source: Natural Resources Conservation Service, 1986)

5.4.9 Step 9: Determine the Required Storage Volume

The final step in the procedure is to determine the amount of storage needed to provide 24 hours of extended detention for the stormwater runoff volume generated by the 1-year, 24-hour storm event. The required storage volume can be determined using the previously obtained value of V_s/V_r (Section 5.4.8) and the following equation:

$V_s = (V_s/V_r)(V_r)$

Where:
- V_s = required storage volume (acre-feet)
- V_r = stormwater runoff volume (acre-feet)

The stormwater runoff volume generated by the 1-year, 24-hour storm event under post development conditions (V_r) can be computed using the following equation:

$$V_r = \frac{(Q)(A)}{12}$$

Where:
- Q = stormwater runoff volume (inches)
- A = site area (acres)
- 12 = unit conversion factor (in./ft.)

Additional Information

Additional information about calculating the stormwater runoff volume associated with the aquatic resource protection criteria (SWM Criteria #3) is provided below:

- Hydrograph Generation: SCS hydrograph generation methods (NRCS, 1986) can be used to develop hydrographs for the stormwater runoff generated by the 1-year, 24-hour storm event on a development site. These methods are described in TR-55 (NRCS, 1986) and Section 2.1 of Volume 2 of the *Georgia Stormwater Management Manual* (ARC, 2001).

- Multiple Drainage Areas: When a development site contains or is divided into multiple drainage areas, it is *recommended* that ARP_v be calculated and addressed separately within each drainage area.

- Off-Site Drainage Areas: Stormwater runoff from off-site drainage areas may be diverted and conveyed around a development site and excluded from the ARP_v calculations. Alternatively, off-site stormwater runoff may be routed through the on-site post-construction stormwater management system. Off-site stormwater runoff that is routed through an on-site post-construction stormwater management system should be modeled according to "existing conditions."

5.5 Calculating the Stormwater Runoff Volume Associated with the Overbank Flood Protection Criteria (SWM Criteria #4)

An estimate of the amount of storage needed to ensure that the peak discharge generated by the 25-year, 24-hour storm event under post-development conditions, which is known as the overbank peak discharge (Q_{p25}), does not exceed the peak discharge generated by the same storm event under pre-development conditions, can be obtained using the fourteen-step procedure outlined in Table 5.9. This procedure involves using the Graphical Peak Discharge and Storage Volume Estimation Methods presented in *Technical Release 55* (TR-55) (NRCS, 1986). Although the procedure outlined below can be used to estimate the amount of storage needed to attenuate the overbank peak discharge (Q_{p25}), standard storage routing procedures should be used to conduct the final design of any post-construction stormwater management system used on a development site.

Table 5.9: Calculating the Stormwater Runoff Volume Associated with the Overbank Flood Protection Criteria

Step	Description
Step 1	**Determine the Amount of Rainfall Generated by the 25-Year, 24-Hour Storm Event** The amount of rainfall generated by the 25-year, 24-hour storm event varies depending on the location of the development site within the 24-county coastal region. It can be determined using the rainfall tables for Brunswick and Savannah provided in Appendix A of Volume 2 of the *Georgia Stormwater Management Manual* (ARC, 2001).
Pre-Development Hydrologic Conditions	
Step 2	**Determine the Runoff Curve Number for the Development Site Under Pre-Development Conditions** The procedures used to determine the runoff curve number (CN) for a development site under pre-development conditions are described in Section 5.4.2.
Step 3	**Compute the Stormwater Runoff Volume Generated by the 25-Year, 24-Hour Storm Event Under Pre-Development Conditions** The procedures used to compute the stormwater runoff volume generated by the 25-year, 24-hour storm event under pre-development conditions are described in Section 5.4.3.
Step 4	**Determine the Initial Abstraction and Initial Abstraction Ratio Under Pre-Development Conditions** The procedures used to determine the initial abstraction (I_a) and initial abstraction ratio (I_a/P) under pre-development conditions are described in Section 5.4.4.
Step 5	**Determine the Time of Concentration for the Development Site Under Pre-Development Conditions** The procedures used to determine the time of concentration (T_c) for a development site under pre-development conditions are described in Section 5.4.5.
Step 6	**Compute the Peak Discharge Under Pre-Development Conditions** The procedures used to compute the peak discharge (q_o) for a development site under pre-development conditions are described in Section 5.4.6.
Post-Development Hydrologic Conditions	
Step 7	**Determine the Runoff Curve Number for the Development Site Under Post-Development Conditions** The procedures used to determine the runoff curve number (CN) for a development site under post-development conditions are described in Section 5.4.2.
Step 8	**Compute the Stormwater Runoff Volume Generated by the 25-Year, 24-Hour Storm Event Under Post-Development Conditions** The procedures used to compute the stormwater runoff volume generated by the 25-year, 24-hour storm event under post-development conditions are described in Section 5.4.3.
Step 9	**Determine the Initial Abstraction and Initial Abstraction Ratio Under Post-Development Conditions** The procedures used to determine the initial abstraction (I_a) and initial abstraction ratio (I_a/P) under post-development conditions are described in Section 5.4.4.
Step 10	**Determine the Time of Concentration for the Development Site Under Post Development Conditions** The procedures used to determine the time of concentration (T_c) for a development site under post-development conditions are described in Section 5.4.5.
Step 11	**Compute the Uncontrolled Peak Discharge Under Post-Development Conditions** The procedures used to compute the uncontrolled peak discharge (q_i) for a development site under post-development conditions are described in Section 5.4.6.
Storage Volume Estimation	
Step 12	**Determine the Ratio of the Pre-Development Peak Discharge to the Post-Development Peak Discharge** The value of the ratio of the pre-development peak discharge to the post-development peak discharge (q_o/q_i) can be determined simply by dividing the pre-development peak discharge (q_o) (Step 6) by the uncontrolled post-development peak discharge (q_i) (Step 11).
Step 13	**Calculate the Ratio of the Required Storage Volume to the Stormwater Runoff Volume** The value of the ratio of required storage volume to the stormwater runoff volume (V_s/V_r) can be determined by using the ratio of the pre-development peak discharge to the uncontrolled post-development peak discharge (q_o/q_i) (Step 12) and Figure 5.7.

Table 5.9: Calculating the Stormwater Runoff Volume Associated with the Overbank Flood Protection Criteria	
Step	**Description**
Step 14	**Determine the Required Storage Volume** The final step in the procedure is to determine the amount of storage needed to ensure that the peak discharge generated by the 25-year, 24-hour storm event under post-development conditions does not exceed the peak discharge generated by the same storm event under pre-development conditions. The required storage volume can be determined using the previously obtained value of V_s/V_r (Step 13) and the following equation: $V_s = (V_s/V_r)(V_r)$ Where: V_s = required storage volume (acre-feet) V_r = stormwater runoff volume (acre-feet) The stormwater runoff volume generated by the 25-year, 24-hour storm event under post development conditions (V_r) can be computed using the following equation: $V_r = (Q)(A) \div 12$ Where: Q = stormwater runoff volume (inches) A = site area (acres) 12 = unit conversion factor (in./ft.)

Additional Information

Additional information about calculating the stormwater runoff volume associated with the overbank flood protection criteria (SWM Criteria #4) is provided below:

- Hydrograph Generation: SCS hydrograph generation methods (NRCS, 1986) can be used to develop hydrographs for the stormwater runoff generated by the 25-year, 24-hour storm event on a development site. These methods are described in TR-55 (NRCS, 1986) and Section 2.1 of Volume 2 of the *Georgia Stormwater Management Manual* (ARC, 2001).

- Multiple Drainage Areas: When a development site contains or is divided into multiple drainage areas, it is *recommended* that Q_{p25} be calculated and addressed separately within each drainage area.

- Off-Site Drainage Areas: Stormwater runoff from off-site drainage areas may be diverted and conveyed around a development site and excluded from the Q_{p25} calculations. Alternatively, off-site stormwater runoff may be routed through the on-site post-construction stormwater management system. Off-site stormwater runoff that is routed through an on-site post-construction stormwater management system should be modeled according to "existing conditions."

5.6 Calculating the Stormwater Runoff Volume Associated with the Extreme Flood Protection Criteria (SWM Criteria #5)

An estimate of the amount of storage needed to ensure that the peak discharge generated by the 100-year, 24-hour storm event under post-development conditions, which is known as the extreme peak discharge (Q_{p100}), does not exceed the peak discharge generated by the same storm event under pre-development conditions, can be obtained using the fourteen-step procedure outlined in Table 5.10. This procedure involves using the Graphical Peak Discharge and Storage Volume Estimation Methods presented in *Technical Release 55* (TR-55) (NRCS, 1986). Although the procedure outlined below can be used to estimate the amount of storage needed to attenuate the extreme peak discharge (Q_{p100}), standard storage routing procedures should be used to conduct the final design of any post-construction stormwater management system on a development site.

Table 5.10: Calculating the Stormwater Runoff Volume Associated with the Extreme Flood Protection Criteria	
Step	**Description**
Step 1	**Determine the Amount of Rainfall Generated by the 25-Year, 24-Hour Storm Event** The amount of rainfall generated by the 100-year, 24-hour storm event varies depending on the location of the development site within the 24-county coastal region. It can be determined using the rainfall tables for Brunswick and Savannah provided in Appendix A of Volume 2 of the *Georgia Stormwater Management Manual* (ARC, 2001).
Pre-Development Hydrologic Conditions	
Step 2	**Determine the Runoff Curve Number for the Development Site Under Pre-Development Conditions** The procedures used to determine the runoff curve number (CN) for a development site under pre-development conditions are described in Section 5.4.2.
Step 3	**Compute the Stormwater Runoff Volume Generated by the 100-Year, 24-Hour Storm Event Under Pre-Development Conditions** The procedures used to compute the stormwater runoff volume generated by the 100-year, 24-hour storm event under pre-development conditions are described in Section 5.4.3.
Step 4	**Determine the Initial Abstraction and Initial Abstraction Ratio Under Pre-Development Conditions** The procedures used to determine the initial abstraction (I_a) and initial abstraction ratio (I_a/P) under pre-development conditions are described in Section 5.4.4.
Step 5	**Determine the Time of Concentration for the Development Site Under Pre-Development Conditions** The procedures used to determine the time of concentration (T_c) for a development site under pre-development conditions are described in Section 5.4.5.
Step 6	**Compute the Peak Discharge Under Pre-Development Conditions** The procedures used to compute the peak discharge (q_o) for a development site under pre-development conditions are described in Section 5.4.6.
Post-Development Hydrologic Conditions	
Step 7	**Determine the Runoff Curve Number for the Development Site Under Post-Development Conditions** The procedures used to determine the runoff curve number (CN) for a development site under post-development conditions are described in Section 5.4.2.
Step 8	**Compute the Stormwater Runoff Volume Generated by the 100-Year, 24-Hour Storm Event Under Post-Development Conditions** The procedures used to compute the stormwater runoff volume generated by the 100-year, 24-hour storm event under post-development conditions are described in Section 5.4.3.
Step 9	**Determine the Initial Abstraction and Initial Abstraction Ratio Under Post-Development Conditions** The procedures used to determine the initial abstraction (I_a) and initial abstraction ratio (I_a/P) under post-development conditions are described in Section 5.4.4.
Step 10	**Determine the Time of Concentration for the Development Site Under Post Development Conditions** The procedures used to determine the time of concentration (T_c) for a development site under post-development conditions are described in Section 5.4.5.
Step 11	**Compute the Uncontrolled Peak Discharge Under Post-Development Conditions** The procedures used to compute the uncontrolled peak discharge (q_i) for a development site under post-development conditions are described in Section 5.4.6.
Storage Volume Estimation	
Step 12	**Determine the Ratio of the Pre-Development Peak Discharge to the Post-Development Peak Discharge** The value of the ratio of the pre-development peak discharge to the post-development peak discharge (q_o/q_i) can be determined simply by dividing the pre-development peak discharge (q_o) (Step 6) by the uncontrolled post-development peak discharge (q_i) (Step 11).
Step 13	**Calculate the Ratio of the Required Storage Volume to the Stormwater Runoff Volume** The value of the ratio of required storage volume to the stormwater runoff volume (V_s/V_r) can be determined by using the ratio of the pre-development peak discharge to the uncontrolled post-development peak discharge (q_o/q_i) (Step 12) and Figure 5.7.

Table 5.10: Calculating the Stormwater Runoff Volume Associated with the Extreme Flood Protection Criteria	
Step	**Description**
Step 14	**Determine the Required Storage Volume** The final step in the procedure is to determine the amount of storage needed to ensure that the peak discharge generated by the 100-year, 24-hour storm event under post-development conditions does not exceed the peak discharge generated by the same storm event under pre-development conditions. The required storage volume can be determined using the previously obtained value of V_s/V_r (Step 13) and the following equation: $V_s = (V_s/V_r)(V_r)$ Where: V_s = required storage volume (acre-feet) V_r = stormwater runoff volume (acre-feet) The stormwater runoff volume generated by the 100-year, 24-hour storm event under post development conditions (V_r) can be computed using the following equation: $V_r = (Q)(A) \div 12$ Where: Q = stormwater runoff volume (inches) A = site area (acres) 12 = unit conversion factor (in./ft.)

Additional Information

Additional information about calculating the stormwater runoff volume associated with the extreme flood protection criteria (SWM Criteria #5) is provided below:

- Hydrograph Generation: SCS hydrograph generation methods (NRCS, 1986) can be used to develop hydrographs for the stormwater runoff generated by the 100-year, 24-hour storm event on a development site. These methods are described in TR-55 (NRCS, 1986) and Section 2.1 of Volume 2 of the *Georgia Stormwater Management Manual* (ARC, 2001).

- Multiple Drainage Areas: When a development site contains or is divided into multiple drainage areas, it is *recommended* that Q_{p100} be calculated and addressed separately within each drainage area.

- Off-Site Drainage Areas: Stormwater runoff from off-site drainage areas may be diverted and conveyed around a development site and excluded from the Q_{p100} calculations. Alternatively, off-site stormwater runoff may be routed through the on-site post-construction stormwater management system. Off-site stormwater runoff that is routed through an on-site post-construction stormwater management system should be modeled according to “existing conditions.”

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