CHAPTER 6: ESTIMATING RUNOFF AND STORMWATER DISCHARGE
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CHAPTER 6: ESTIMATING RUNOFF AND STORMWATER DISCHARGE

6.1 INTRODUCTION

Runoff occurs whenever there is precipitation in excess of that which can be absorbed by pervious materials (soils, etc.). Land cover types and changes to land cover types affect the amount of runoff and stormwater discharge that occurs in conjunction with a storm event. The conversion of rural land and open spaces to urban land uses usually increases soil erosion and the discharge and volume of stormwater runoff within a watershed. These increases are due to pervious surfaces being converted to impervious surfaces, natural water flow patterns being altered, and to other changes that occur to watersheds in response to precipitation.

This chapter provides information to assist the developer, planner, landowner or regulator in estimating the amount of runoff and stormwater discharge from a watershed and the amounts of runoff and stormwater discharge due to changes to a watershed. The information in this chapter is taken from *Urban Hydrology for Small Watersheds, U.S. Department of Agriculture Soil Conservation Service Engineering Technical Release 55 (TR-55)* (USDA-SCS, 1986). Information in this chapter was compiled by Mario A. Morales, USDA Natural Resources Conservation Service (NRCS), Resource Conservation and Development Coordinator for the Virgin Islands. For more information, contact the Virgin Islands' USDA-NRCS Field Office or your local Cooperative Extension Service office.

6.2 ESTIMATING RUNOFF - THE SCS CURVE NUMBER METHOD

The SCS Curve Number (CN) Method is described in detail in USDA-SCS (1985). The equation used by the curve number method is of the form:

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \quad \textbf{[Eq. 6-1]}$$

where

Q	=	runoff (inches)
P	=	rainfall (inches)
S	=	potential maximum retention after runoff begins (inches)
I_a	=	initial abstraction (inches)

The initial abstraction term (I_a) encompasses all losses that occur before runoff begins. It includes water retained in surface depressions, water intercepted by vegetation, evapotranspiration, 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:

$$I_a = 0.2 * S \quad \textbf{[Eq. 6-2]}$$

By removing I_a as an independent parameter, this approximation allows the use of a combination of S and P to produce a unique runoff amount. Substituting equation 6-2 into equation 6-1 yields:

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \quad \textbf{[Eq. 6-3]}$$

S is related to the soil and cover conditions of the watershed through a **Curve Number (CN)**. CN has a range of 0 to 100, and S is related to CN by the equation:

$$S = \frac{100}{CN} - 10 \quad \textbf{[Eq. 6-4]}$$

Figure 6.1 and Table 6.1 solve equations 6-3 and 6-4 for a range of curve numbers and rainfall amounts.

6.2.1 Factors Considered in Determining Runoff Curve Numbers

The primary factors that determine CN are the hydrologic soil group (HSG), cover type, hydrologic condition, and antecedent runoff condition (ARC). Another factor to consider is whether impervious areas outlet directly to the stormwater drainage system (**connected**) or whether the flow spreads over pervious areas before entering the drainage system (**unconnected**). Figure 6-2 is provided to aid in selecting the appropriate figure or table for determining curve numbers.

Curve numbers in Tables 6-2 (a-d) represent average antecedent runoff conditions for urban land uses, cultivated and other agricultural land uses, and arid and semiarid rangeland uses. Tables 6-2 assume impervious areas are directly connected. The following sections explain how to determine curve numbers and how to modify them for use with non-agricultural conditions.

6.2.1.a 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 Hydrologic Soil Groups – A, B, C, and D (see Table 6.3) – according to their minimum infiltration rate, which is obtained for bare soil after prolonged wetting. Table 6.3 defines these groups and provides the hydrologic group classification for soils in the U.S. Virgin Islands.

Most urban areas are only partially covered by impervious surfaces, thus, soils remain an important factor in runoff estimates. The effect of urbanization on runoff is greater in watersheds that have soils with high infiltration rates (sands and gravels) than in watersheds with predominately silt and clay soils, which generally have low infiltration rates.

Any disturbance of a soil profile can significantly change infiltration characteristics. With urbanization, native soil profiles may be mixed or removed, or fill material from other areas may be introduced. Assistance in determining HSG for altered soils is available from the Natural Resources Conservation Service Field Office on St. Croix. The soils in the watershed of interest may be identified from the revised U.S. Virgin Islands Soil Survey (USDA-NRCS, 1995), which can be obtained from the USDA Service Center in Gallows Bay, St. Croix, from the UVI Conservation Data Center, St. Thomas (on CD-ROM), or from the UVI Cooperative Extension Service, St. Thomas. The text of the Soil Survey can also be downloaded in pdf format from www.statlab.iastate.edu/soils/soildiv/surveys/virgnis.pdf.

6.2.1.b Cover Type

Tables 6.2 (a-d) address most cover types found in urbanizing areas, such as vegetation, bare soil, and impervious surfaces. There are a number of methods that can be used to determine cover type. The most common are field and aerial reconnaissance, photographs, and land use maps.

6.2.1.c Treatment

Treatment is a modifier for cover type (used only in Table 6.2 (b)) that describes the management of cultivated agricultural lands. It includes mechanical practices, such as contouring and terracing, and management practices, such as crop rotations and reduced or no tillage.

6.2.1.d Hydrologic Condition

Hydrologic condition indicates the effects of cover type and treatment on infiltration and runoff, and is generally estimated from plant density and residue cover on sample areas. Good hydrologic condition indicates that the soil usually has a low runoff potential for that specific hydrologic soil group, cover type, and treatment. Some factors to consider in estimating the effect of cover on infiltration and runoff are: canopy or density of lawns, crops or other vegetative areas; amount of year-round cover; amount of grass; percent of residue cover; and degree of surface roughness.

6.2.1.e Antecedent Runoff Condition

The index of runoff potential before a storm event is the **antecedent runoff condition** (ARC). ARC is an attempt to account for the variation in curve number at a site from storm to storm. The curve number for the average ARC at a site is the median value as taken from sample rainfall and runoff data. The curve numbers in Tables 6.2 are for the average ARC, which is used primarily for design applications. See USDA-SCS (1985) and Rallison and Miller (1981) for a more detailed discussion of storm-to-storm variation and a demonstration of upper and lower enveloping curves.

6.2.1.f Urban Impervious Area Modifications

Several factors, such as the percentage of impervious area and the means of conveying runoff from impervious areas to the stormwater drainage system, should be considered in computing the curve number for urban areas (Rawls et. al., 1981). For example, do the impervious areas connect directly to the drainage system or do they outlet onto lawns or other pervious areas where infiltration can occur?

6.2.1.g Connected Impervious Areas

An impervious area is considered connected if runoff from that area flows directly into the stormwater drainage system. It is also considered connected if runoff from the area occurs as concentrated shallow flow that runs over a pervious area and then into a drainage system. Urban curve numbers (Table 6.2(a)) were developed for typical land use relationships based on specific assumed percentages of impervious area. These curve number values were developed on the assumptions that pervious urban areas are equivalent to pasture in good hydrologic condition and impervious areas have a curve number of 98 and are directly connected to the stormwater drainage system. Some assumed percentages of impervious area are shown in Table 6.2(a).

If all of the impervious area is directly connected to the drainage system, but the impervious area percentages or the pervious land use assumptions in Table 6.2(a) are not applicable, use Figure 6.3 to compute a composite curve number. For example, Table 6.2(a) gives a curve number of 70 for a ½-acre lot in hydrologic soil group B with an assumed impervious area of 25%. However, if the lot has only 20% impervious area and a pervious area curve number of 61, then the composite curve number obtained from Figure 6.3 is 68. The decrease in curve number from 70 to 68 reflects the smaller percentage of impervious area for that parcel.

6.2.1.h Unconnected Impervious Areas

Runoff from these areas is spread over a pervious area as sheet flow. To determine curve number when all or part of the impervious area is not directly connected to the drainage system, use Figure 6.4 if total impervious area is less than 30 percent or use Figure 6.3 if the total impervious area is greater than 30 percent, because the absorptive capacity of the remaining pervious areas will not significantly affect runoff.

When impervious area is less than 30 percent, obtain the Composite Curve Number by entering the right half of Figure 6.4 with the percentage of total impervious area and the ratio of total unconnected impervious area to total impervious area. Then move left to the appropriate pervious curve number and read down to find the composite curve number. For example, for a ½-acre lot with 20 percent total impervious area (75 percent of which is unconnected) and pervious curve number of 61, the composite curve number from Figure 6.4 is 66. If all of the impervious area is connected, the resulting curve number (from Figure 6.3) would be 68.

6.2.1.i Rainfall

The highest peak discharges from small watersheds are usually caused by intense, brief rainfall that occurs as a distinct event or as a part of a longer storm. These rainfall events have intensities that vary greatly and normally do not extend over a very large area. Because of the great variability in storm events and the need for design information, synthetic (a typical storm event as calculated by NRCS) rainfall distributions have been developed by the USDA Natural Resources Conservation Service using U.S. National Weather Service data for typical storms. The twenty-four (24) hour storm, while longer than that needed to determine peaks for small drainage areas, is appropriate for determining runoff volumes. Therefore, a single storm duration and associated synthetic rainfall distribution can be used to represent not only peak discharge but also runoff volumes. The following twenty-four hour rainfall distribution charts are presented in Figures 6.5 through 6.11: the one-year, two-year, five-year, ten-year, twenty five-year, fifty-year, and one hundred-year storms.

6.2.1.i Runoff

When curve number and the amount of rainfall (P) have been determined for the watershed, runoff can be determined by using Figure 6.1, Table 6.1 or equations 6-3 and 6-4. The runoff amount calculated is usually rounded to the nearest hundredth of an inch.

6.2.2 Limitations

- Curve numbers describe average conditions that are useful for design purposes. If the rainfall event used is a historical storm, the modeling accuracy decreases.

- Use the runoff curve number equation with caution when recreating specific features of an actual storm. The equation does not contain an expression for time, and therefore, does not account for rainfall duration and intensity.

- The user should understand the assumption reflected in the initial abstraction term (I_a) and should ascertain that the assumption applies to the situation. I_a – which consists of interception, initial infiltration, surface depression storage, evapotranspiration, and other factors – was generalized as 0.2S based on data from agricultural watersheds (S is the potential maximum retention after runoff begins). This approximation can be especially important in an urban application because the combination of impervious areas with pervious areas can imply a significant initial loss that may not actually take place. The opposite effect – a greater initial loss – can occur if the impervious areas have surface depressions that store some runoff. To use a relationship other than $I_a = 0.2S$, one must re-calculate equation 6-3,

Figure 6.1, Table 6.1, and Tables 6.2 by using the original rainfall-runoff data to establish new S or CN relationships for each cover and hydrologic soil group.

- The curve number procedure is less accurate when runoff is less than 0.5 inches. A different procedure should be used to verify runoff accuracy in this case.

- The SCS runoff procedures apply only to direct surface runoff: do not overlook large sources of subsurface flow or high groundwater levels that contribute to runoff. These conditions are often related to hydrologic soil group A soils and wooded areas that have been assigned relatively low curve numbers in Tables 6.2. Good judgement and experience based on stream gage records are needed to adjust curve numbers as conditions warrant.

- When the weighted curve number is less than 40, use another procedure to determine runoff.

6.2.3 Examples

Four examples illustrate the procedure for computing runoff curve numbers (CN) and runoff (Q) in inches. A blank copy of TR-55 Worksheet 2 (used to compute CN and Q) is provided at the end of this chapter. Two of the four examples are based on an imaginary watershed on St. Thomas and the other two are based on a different imaginary watershed on St. Croix. Both examples are based on a 25-year, 24-hour storm event. The examples on St. Thomas calculate runoff based on acreage. The examples on St. Croix calculate runoff based on the percentage of acreage of soil types that comprise the watershed. Section 6.5 contains the completed TR-55 Worksheets for examples 1 through 4.

6.2.3.a Example 1

The site covers eighteen (18) acres at Bordeaux Hills, on the western end of St. Thomas. The acreage is classified as a Cramer soil, which is in hydrologic soil group C (see Table 6.3). A 25-year, 24-hour storm event produces a total rainfall (P) of 6.2 inches (see Figure 6.9).

Problem: Determine the curve number (CN) and volume of runoff (Q) for this site for the present cover condition of brush in fair hydrologic condition.

Solution: Refer to Table 6.2(c) to find a **curve number** of **70** for brush in fair hydrologic condition. Because this location has only one hydrologic soil group and cover type, Worksheet 2 is not needed. However, should a location have more than one hydrologic soil group or cover type, TR-55 Worksheet 2 should be used to calculate a **weighted curve number**.

To determine **direct runoff (Q)**, refer to Figure 6.9, which depicts the rainfall distribution for a 25-year, 24-hour storm event. For the western end of St. Thomas, the **rainfall (P)** is **6.2** inches. Next, refer to Figure 6.1 and locate 6.2 inches on the P axis (horizontal), and follow that line up the chart to the line that represents curve number 70. Trace the curve number 70 line left towards the Q axis (vertical) to find the **runoff volume of 2.95 inches**. (See completed Worksheet for this example in section 6.5.)

6.2.3.b Example 2

Problem: Determine the weighted curve number (CN) and volume of runoff (Q) for the same site but with a different cover type. The 18-acre site has been cleared for a housing development. Four (4) acres will remain in open space in good hydrologic condition. The remaining fourteen (14) acres will be developed into quarter-acre lots with thirty-eight percent (38%) impervious area.

Solution: First, refer to Table 6.2(a) to determine the curve number for each cover type. For open space with good hydrologic condition, the corresponding **curve number** is **74**. The **curve number** for quarter-acre lots with 38% impervious area is **83**. Each of these curve numbers is multiplied by its corresponding area and then averaged to obtain a weighted curve number:

$$CN = \frac{(74 * 4 \; acres) + (83 * 14 \; acres)}{18 \; acres} = 81 \quad (use \; 80)$$

The **rainfall value (P)** is the same as in Example 1 – **6.2 inches**. Next, refer to Figure 6.1, locate 6.2 inches on the horizontal (P) axis, follow the line up to the line representing curve number 80, and then move horizontally to the left to determine runoff from the vertical (Q) axis. This example yields a **direct runoff (Q) of four (4.1) inches**. (See worksheet for this example in section 6.5.)

6.2.3.c Example 3

The site covers twenty-five (25) acres at Villa La Reine Estates, mid-island St. Croix. Fifty-eight percent (58%) of the site has Arawak soils, hydrologic soil group B (see Table 6.3), and forty-two percent (42%) of the site is classified as a Cramer soil, which is in hydrologic soil group C (see Table 6.3). A 25-year, 24-hour storm event produces a total rainfall (P) of 8 inches (see Figure 6.9).

Problem: Determine the weighted curve number (CN) and runoff volume (Q) from this site for a fair cover condition in pasture on the Arawak soil.

Solution: Referring to Table 6.2(c), the curve number for fair pasture condition in hydrologic soil group B is **69**. The Cramer soil has good pasture condition. The curve number of good pasture condition in hydrologic soil group C is **74**. The **weighted curve number** for this site is obtained by multiplying each above curve number by its corresponding percentage of acreage as follows:

$$CN = \frac{(69 * 58\%) + (74 * 42\%)}{100\%} = 71.1 = 71 \quad (use \; 70)$$

The **rainfall value (P)** is determined to be **8.0** inches for the central area of St. Croix by referring to Figure 6.9. Next, refer to Figure 6.1 and locate 8 on the horizontal axis (P), follow the line up to the line representing curve number 70, then move horizontally to the vertical axis (Q) to determine a **runoff volume of 4.4 inches**. (See Worksheet for this example in section 6.5.)

6.2.3.d Example 4

Problem: Using the information in Example 3 (above), determine the weighted curve number and runoff volume for the Villa La Reine Estates site for a post-development scenario of forty-seven percent (47%) of the Arawak soil having quarter-acre lots with thirty-eight percent (38%) impervious area, eleven percent (11%) of the Arawak soil in open space with fair condition, thirty-six percent (36%) of the Cramer soil in quarter-acre lots with thirty-eight percent (38%) impervious area, and six percent (6%) of the Cramer soil in open space with good condition.

Solution: Referring to Table 6.2(a), we find the following curve numbers:

Soil, Group, Cover & Condition	Curve Number	Percent of Total Area
Arawak (B), 1/4-acre, 38% imperv.	75	47%
Arawak (B), open space, fair	69	11%
Cramer (C), 1/4-acre, 38% imperv.	83	36%
Cramer (C), open space, good	74	6%

The **weighted curve number** for this site (refer to example above) is:

$$CN = \frac{(75 * 47\%) + (69 * 11\%) + (83 * 36\%) + (74 * 6\%)}{100\%} = 77.16 \simeq 77$$

Using the **rainfall value** of **8.0**, refer to Figure 6.1, locate 8.0 along the horizontal axis (P), follow this line up to approximately 77 curve number, follow that left to the vertical axis (Q) to determine the **direct runoff volume of 5.2 inches**. (See worksheet for this example in Section 6.5.)

6.3 TIME OF CONCENTRATION AND TRAVEL TIME

Travel time (T_t) is the time it takes stormwater to travel from one location to another in a watershed. T_t is a component of **time of concentration (T_c)**, which is the time it takes for runoff to travel from the hydraulically-most-distant point of the watershed to a point of interest within the watershed. T_c is computed by summing all the travel time for consecutive components of the stormwater drainage system.

T_c influences the shape and peak of the runoff hydrograph (**def**). Urbanization usually increases T_c, thereby increasing the peak discharge (**def**). T_c can also be increased as a result of ponding behind small or inadequate drainage systems, including storm drain inlets and road culverts, or reduction of land slope through grading.

6.3.1 Factors Affecting Time of Concentration and Travel Time

6.3.1.a Surface Roughness

One of the most significant effects of urban development on stormwater velocity is the decrease in flow retardance. In undeveloped areas, stormwater runoff moves slowly as shallow overland flow through vegetation and over rough surfaces. When these areas are modified by urban development, stormwater moves much more rapidly over smooth, impervious paved areas and through gutters and storm drains. This leads to a significant decrease in the travel time of stormwater runoff through the watershed.

6.3.1.b Channel Shape and Flow Patterns

In small, non-urban watersheds, much of the total travel time results from overland flow in upstream areas. Typically, urbanization reduces overland flow distances by conveying storm runoff into a channel as soon as possible. Since channel designs have efficient hydraulic characteristics, runoff flow velocity increases and travel time decreases.

6.3.1.c Slope

Slopes may be increased or decreased by urbanization, depending upon the amount of site grading or the extent to which storm drains and ditches are used in the design of the stormwater management system. Slopes generally tend to increase when channels are straightened and decrease when overland flow is directed through storm drains, street gutters and swales, and diversions.

6.3.2 Computation of Travel Time and Time of Concentration

Stormwater moves through a watershed as sheet flow, shallow concentrated flow, open channel flow, or some combination of these. The type of flow that occurs is a function of the type of conveyance system and is best determined by field inspection.

Travel time (T_t) is the ratio of flow length to flow velocity:

$$T_t = \frac{L}{3600\ V} \qquad \textbf{[Eq. 6-5]}$$

where

T_t	=	travel time (hours)
L	=	flow length (feet)
V	=	average velocity (feet/second)
3600		is a conversion factor from seconds to hours

Time of concentration (T_c) is the sum of T_t values for the various consecutive flow segments:

$$T_t = T_{t1} + T_{t2} + \ldots + T_{tm} \qquad \textbf{[Eq. 6-6]}$$

where

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

6.3.3 Sheet flow

Sheet flow is flow over level surfaces. It usually occurs in the headwater of streams. With sheet flow, the friction value (**Manning's n**) is an effective roughness coefficient that includes the effect of raindrop impact; drag over the plane surface; obstacles such as litter, crop ridges, and rocks; and erosion and transportation of sediment. These "n" values are for very shallow flow depths of about one tenth (0.1) of a foot (1.2 inches). Table 6.4 gives Manning's n values for sheet flow for various surface conditions.

For sheet flow of less than 300 feet, use Manning's kinematic solution (Overton and Meadows, 1976) to compute T_t:

$$T_t = \frac{0.007\ (nL)^{0.8}}{P_2^{0.5}\ s^{0.4}} \qquad \text{[Eq. 6-7]}$$

where

T_t = travel time (hours)
n = Manning's roughness coefficient (see Table 6.4)
L = flow length (feet)
P_2 = 2-year, 24-hour rainfall (inches)
s = slope of hydraulic grade line (land slope, feet/feet)

This simplified form of the Manning's kinematic solution is based on the following assumptions: shallow steady uniform flow; constant intensity of rainfall excess (that part of a rain available for runoff); rainfall duration of 24 hours; and minor effect of infiltration on travel time.

6.3.4 Shallow Concentrated Flow

After traveling a maximum distance of 300 feet, sheet flow usually becomes shallow concentrated flow. The average velocity for this flow can be determined from Figure 6.12, in which average velocity is a function of watercourse slope and type of channel. For slopes less than 0.005 ft/ft, compute velocity using the following equations:

$$\begin{aligned} \textit{Unpaved}: \quad V &= 16.1345\ (s)^{0.5} \\ \textit{Paved}: \quad V &= 20.3282\ (s)^{0.5} \end{aligned} \qquad \text{[Eq. 6-8]}$$

where

V = average velocity (ft/s)
s = slope of hydraulic grade line (watercourse slope, ft/ft)

After determining average velocity in Figure 6.12, use equation 6-5 to estimate travel time for the shallow concentrated flow segment.

6.3.5 Open Channels

Open channels are assumed to begin where surveyed cross section information has been obtained, where channels are visible on aerial photographs, or where blue lines (indicating permanent or intermittent streams) appear on United States Geological Survey (USGS) quadrangle sheets. Manning's equation or water surface profile information can be used to estimate average flow velocity. Average flow velocity is usually determined for bank-full elevation.

Manning's equation is:

$$V = \frac{1.49\ r^{2/3}\ s^{1/2}}{n} \qquad \text{[Eq. 6-9]}$$

where
V = average velocity (ft/s)
r = hydraulic radius (ft) and is equal to a/p_w
p_w = wetted perimeter (ft)
a = cross sectional flow area (ft^2)
s = slope of the hydraulic grade line (channel slope, ft/ft)

n = Manning's roughness coefficient for open channel flow

Manning's n values for open channel flow can be obtained from standard textbooks such as Chow (1959) or Linsley et al. (1982). After average velocity is computed using equation 6-9, T_t for the channel segment can be estimated using equation 6-5.

6.3.6 Reservoirs, Lakes or Ponds

Sometimes it is necessary to estimate the velocity of flow through a reservoir, lake or pond at the outlet of a watershed. This travel time is normally very small and can be assumed to be zero.

6.3.7 Limitations

- Manning's kinematic solution should not be used for sheet flow longer than 300 feet. Equation 6-7 was developed for use with the four standard rainfall intensity-duration relationships.

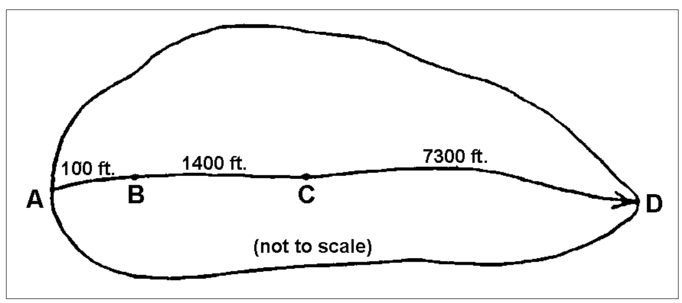
- In a watershed with storm drains, carefully identify the appropriate hydraulic flow path to estimate T_c. Storm drains generally handle only a small portion of a large event. The rest of the peak flow travels over streets, lawns, etc. to the outlet. Consult a standard hydraulics textbook to determine average velocity in pipes for either pressure or non-pressure flow.

- The minimum T_c used in TR-55 is 0.1 hour.

- A culvert or bridge can act as a reservoir outlet if there is significant storage behind it. The procedures in TR-55 can be used to determine the peak flow upstream of the culvert. Detailed storage routing procedures should be used to determine the outflow through the culvert.

6.3.8 Example 5

The sketch on the right shows a hypothetical watershed on St. Croix. The problem is to compute T_c at the outlet of the watershed (point D). The 2-year, 24-hour rainfall depth is 3.6 inches. All three types of flow occur from the hydraulically most distant point (A) to the point of interest (D). To compute T_c, first determine T_t for each segment from the following information:



St. Croix watershed for Example 5.

Segment AB: Sheet flow, dense grass cover, slope (s) = 0.01 ft/ft, and length (L) = 100 feet.
Segment BC: Shallow concentrated flow, unpaved, s = 0.01 ft/ft, and L = 1400 feet.
Segment CD: Channel flow, Manning's n = 0.05, flow area (a) = 27 ft^2, wetted perimeter (p_w = 28.2 feet, s = 0.005 ft/ft, and L = 7300 feet.

TR-55 Worksheet 3 is used to compute T_c. TR-55 Worksheet 3 is completed to solve Example 5 in section 6.5. A blank copy of TR-55 Worksheet 3 is provided for the user at the end of this Chapter.

6.4 GRAPHICAL PEAK DISCHARGE METHOD

This section 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:

$$q_p = q_u A_m Q F_p \qquad \textbf{[Eq. 6-10]}$$

where

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

The input requirements for the Graphical method are the T_c (hr); the drainage area (mi^2); the appropriate rainfall distribution (Type III for the Virgin Islands); the 24-hour rainfall (in); and the curve number. If pond and/or swamp areas are spread throughout the watershed and are not considered in the T_c computation, then an adjustment for pond and swamp areas is also required.

6.4.1 Peak Discharge Computation

For a selected rainfall frequency, the 24-hour rainfall (P) is obtained from Figures 6.5 to 6.11 or more detailed local precipitation maps. Curve number (CN) and direct runoff (Q) for the watershed are computed according to the methods outlined in Section 6.2. The curve number is used to determine the initial abstraction (I_a) from Table 6.5, and the I_a/P is then computed.

Peak discharge per square mile per inch of runoff (q_u) is obtained from Figure 6.13 by using T_c (see Section 6.3), rainfall distribution type, and I_a/P ratio. The pond and swamp adjustment factor is obtained from Table 6.6 (rounded to the nearest Table value). Use TR-55 Worksheet 4 provided at the end of this chapter to aid in computing the peak discharge using the Graphical method.

6.4.2 Limitations

The Graphical method provides a determination of peak discharge only. If a hydrograph is needed or watershed subdivision is required, use the Tabular Hydrograph method described in Chapter 5 of TR-55 (SCS, 1986). Use TR-20 if the watershed is very complex or if a higher degree of accuracy is required.

C The watershed must be hydrologically homogenous, that is, describable by one curve number. Land use, soils, and cover are distributed uniformly throughout the watershed.

C The watershed may have only one main drainage channel (stream or gut) or, if more than one, the branches must have nearly equal T_c's.

C This method cannot perform valley or reservoir routing.

C The F_p factor can be applied only for ponds or swamps that are not in the T_c flow path.

- Accuracy of peak discharge estimated by this method will be reduced if I_a/P values are used that are outside the range given in Figure 6.15. The limiting I_a/P values are recommended for use in this case.

- This method should be used only if the weighted curve number is greater than 40.

- When this method is used to develop estimates of peak discharge for both present and developed conditions of a watershed, use the same procedure for estimating T_c.

- T_c values with this method may range from 0.1 to 10 hours.

6.4.3 Example 6

Compute the 25-year peak discharge for the 25-acre watershed described in examples 3 and 5. Worksheet 4 in section 6.5 shows how q_p is computed for this example.

6.5 TR-55 WORKSHEET SOLUTIONS TO EXAMPLES

The following worksheets detail the computation of CN and Q for examples 1 through 4, the computation of T_c for example 5, and the computation of q_p for example 6.

Solution to Example 1.

Worksheet 2: Runoff curve number and runoff

Project Bordeaux Hill By MAM Date 10/01/01

Location St. Thomas Checked JJS Date 10/01/01

Circle One: (Present) Developed

1. Runoff Curve Number (CN)

Soil Name and Hydrologic Group (Appendix A)	Cover Description (cover type, treatment and hydrologic condition; percent impervious; unconnected/connected impervious area ratio)	CN 1/ Table 6-2	Fig. 6-3	Fig. 6-4	Area ☒ acres ☐ mi2 ☐ %	Product of CN x Area
Cramer, C	Brush (Bush), Fair condition	70			18	1260
				Totals =	18	1260

1/ Use only one CN source per line.

$$\text{CN (weighted)} = \frac{\text{total product}}{\text{total area}} = \frac{1260}{18} = 70;$$

Use CN = $\boxed{70}$

2. Runoff

		Storm #1	Storm #2	Storm #3
Frequency	yr	25		
Rainfall, P (24-hour)	in	6.2		
Runoff, Q	in	2.95		

(Use P and CN with Table 6-1, Figure 6-1 or Equations 6-3 and 6-4)

Solution to Example 2.

Worksheet 2: Runoff curve number and runoff

Project Bordeaux Hill By MAM Date 10/01/01

Location St. Thomas Checked JJS Date 10/01/01

Circle One: Present (Developed)

1. Runoff Curve Number (CN)

Soil Name and Hydrologic Group (Appendix A)	Cover Description (cover type, treatment and hydrologic condition; percent impervious; unconnected/connected impervious area ratio)	CN 1/ Table 6-2	CN 1/ Fig. 6-3	CN 1/ Fig. 6-4	Area ☒ acres ☐ mi2 ☐ %	Product of CN x Area
Cramer, C	Open Space, Good Condition	74			4	296
Cramer, C	1/4 acre lots, 38% impervious	83			14	1162
				Totals =	18	1458

1/ Use only one CN source per line.

CN (weighted) = $\frac{\text{total product}}{\text{total area}} = \frac{1458}{18} =$ 80 ; Use CN = $\boxed{80}$

2. Runoff

		Storm #1	Storm #2	Storm #3
Frequency	yr	25		
Rainfall, P (24-hour)	in	6.2		
Runoff, Q	in	4.0		

(Use P and CN with Table 6-1, Figure 6-1 or Equations 6-3 and 6-4)

Solution to Example 3.

Worksheet 2: Runoff curve number and runoff

Project: Villa La Reine Estates By: MAM Date: 10/01/01

Location: St. Croix, VI Checked: JJS Date: 10/01/01

Circle One: (Present) Developed

1. Runoff Curve Number (CN)

Soil Name and Hydrologic Group (Appendix A)	Cover Description (cover type, treatment and hydrologic condition; percent impervious; unconnected/connected impervious area ratio)	CN 1/ Table 6-2	CN 1/ Fig. 6-3	CN 1/ Fig. 6-4	Area ☒ acres ☐ mi2 ☐ %	Product of CN x Area
Arawak, B	Pasture, Fair Condition	69			58	4002
Cramer, C	Pasture, Good Condition	74			42	3108
				Totals =	100	7110

1/ Use only one CN source per line.

CN (weighted) $= \frac{\text{total product}}{\text{total area}} = \frac{7110}{100} = 71.1$; Use CN = $\boxed{70}$

2. Runoff

		Storm #1	Storm #2	Storm #3
Frequency	yr	25		
Rainfall, P (24-hour)	in	8.0		
Runoff, Q	in	4.4		

(Use P and CN with Table 6-1, Figure 6-1 or Equations 6-3 and 6-4)

Solution to Example 4.

Worksheet 2: Runoff curve number and runoff

Project Villa La Reine Estates By MAM Date 10/01/01

Location St. Croix, VI Checked JJS Date 10/01/01

Circle One: Present (Developed) ______

1. Runoff Curve Number (CN)

Soil Name and Hydrologic Group (Appendix A)	Cover Description (cover type, treatment and hydrologic condition; percent impervious; unconnected/connected impervious area ratio)	CN 1/ Table 6-2	CN 1/ Fig. 6-3	CN 1/ Fig. 6-4	Area ☒ acres ☐ mi2 ☐ %	Product of CN x Area
Arawak, B	1/4 acre lots, 38% impervious	75			47	3525
Arawak, B	Open Space, Fair Condition	69			11	759
Cramer, C	1/4 acre lots, 38% Impervious	83			36	2988
Cramer, C	Open Space, Good Condition	74			6	444
				Totals =	100	7716

1/ Use only one CN source per line.

CN (weighted) = $\frac{\text{total product}}{\text{total area}} = \frac{7716}{100} = 77.16$; Use CN = 77

2. Runoff

		Storm #1	Storm #2	Storm #3
Frequency	yr	25		
Rainfall, P (24-hour)	in	8.0		
Runoff, Q	in	5.0		

(Use P and CN with Table 6-1, Figure 6-1 or Equations 6-3 and 6-4)

Solution to Example 5.

Worksheet 3: Time of Concentration (Tc) or Travel Time (Tt)

Project: Villa La Reine Estates **By:** MAM **Date** 10/01/01

Location: St. Croix, VI **Checked** JJS **Date** 10/01/01

Circle one: Present (Developed)

Circle one: Tc Tt through subarea

NOTES: Space for as many as two segments per flow type can be used for each worksheet. Include a map, schematic, or description of flow segments.

Sheet Flow (Applicable to Tc only)

	Unit	Segment 1	Segment 2	Total
Segment ID		AB		
1. Surface description (Table 6-4)		Dense Grass		
2. Manning's roughness coefficient, n (Table 6-4)		0.24		
3. Flow length, L, (total L ≤ 300 ft)	ft	100		
4. Two-year 24-hour rainfall, P_2	in	3.6		
5. Land slope, s	ft/ft	0.01		
6. $Tt = \frac{0.007\,(nL)^{0.8}}{P_2^{0.5}\, s^{0.4}}$ Compute Tt	hr	0.3	+	= 0.3

Shallow Concentrated Flow

	Unit	Segment 1	Segment 2	Total
Segment ID		BC		
7. Surface description (paved or unpaved)		U		
8. Flow length, L	ft	1400		
9. Watercourse slope, s	ft/ft	0.01		
10. Average velocity, V (Figure 6-12)	ft/s	1.6		
11. $Tt = \frac{L}{3600\,V}$ Compute Tt	hr	0.24	+	= 0.24

Channel Flow

	Unit	Segment 1	Segment 2	Total
Segment ID		CD		
12. Cross sectional flow area, a	ft^2	27		
13. Wetted perimeter, p_w	ft	28.2		
14. Hydraulic radius, $r = \frac{a}{P_w}$ Compute r	ft	0.957		
15. Channel slope, s	ft/ft	0.005		
16. Manning's roughness coefficient, n		0.05		
17. $V = \frac{1.49\, r^{2/3}\, s^{1/2}}{n}$ Compute V	ft/s	2.05		
18. Flow length, L	ft	7300		
19. $Tt = \frac{L}{3600\,V}$ Compute Tt	hr	0.99	+	= 0.99
20. Watershed or subarea Tc or Tt (add Tt in steps 6, 11, and 19)	hr			1.53

Solution to Example 6.

Worksheet 4: Graphical Peak Discharge Method

Project Villa La Reine Estates By MAM Date 10/01/01

Location St. Croix, VI Checked JJS Date 10/01/01

Circle one: (Present) Developed

1. Data:

Drainage Area .... A_m = 0.039 mi^2 (acres/640)

Runoff curve number .... CN = 70 (from Worksheet 2)

Time of concentration .. Tc = 1.53 hr (from Worksheet 3)

Rainfall distribution type = III (I, IA, II, III)

Pond and swamp areas spread throughout watershed ...... = - percent of A_m (- acres or mi^2 covere

2. Frequency	yr	25		
3. Rainfall, P (24-hour)	in	8.0		
4. Initial abstraction, I_a (Use CN with table 6-5)	in	0.857		
5. Compute I_a /P		0.11		
6. Unit peak discharge, q_u (Use Tc and I_a /P with Figure 6-13)	csm/in	230		
7. Runoff, Q (From Worksheet 2)	in	4.4		
8. Pond and swamp adjustmetn factor, F_p (Use percent pond and swamp area with Table 6-6. Factor is 1.0 for zero percent pond and swamp area.)		1.0		
9. Peak discharge, q_p (Where $q_p = q_u A_m Q F_p$)	cfm	39.47		

6.6 FIGURES AND TABLES

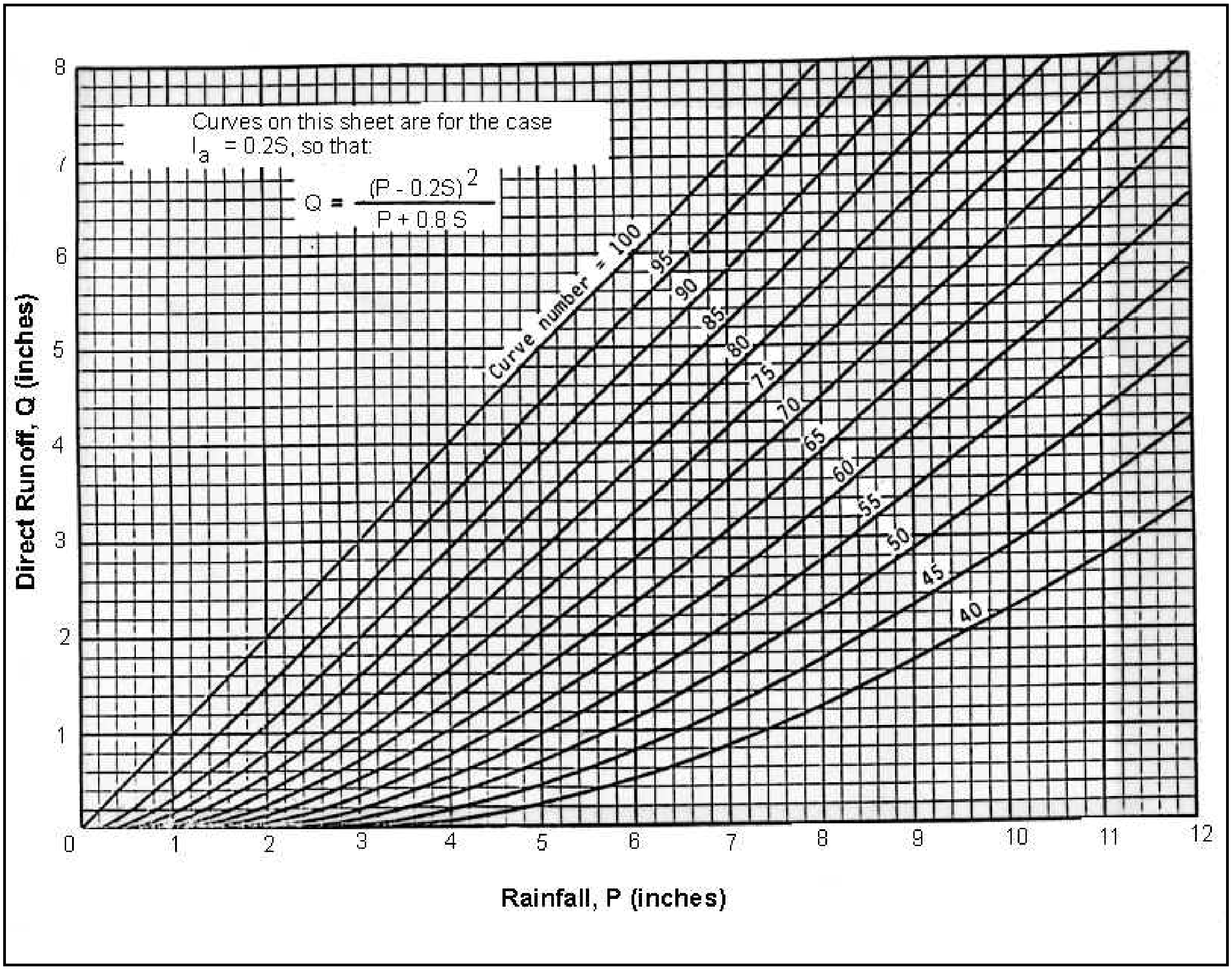


Figure 6.1. Solution of runoff equation for SCS curve number method (USDA-SCS, 1986).

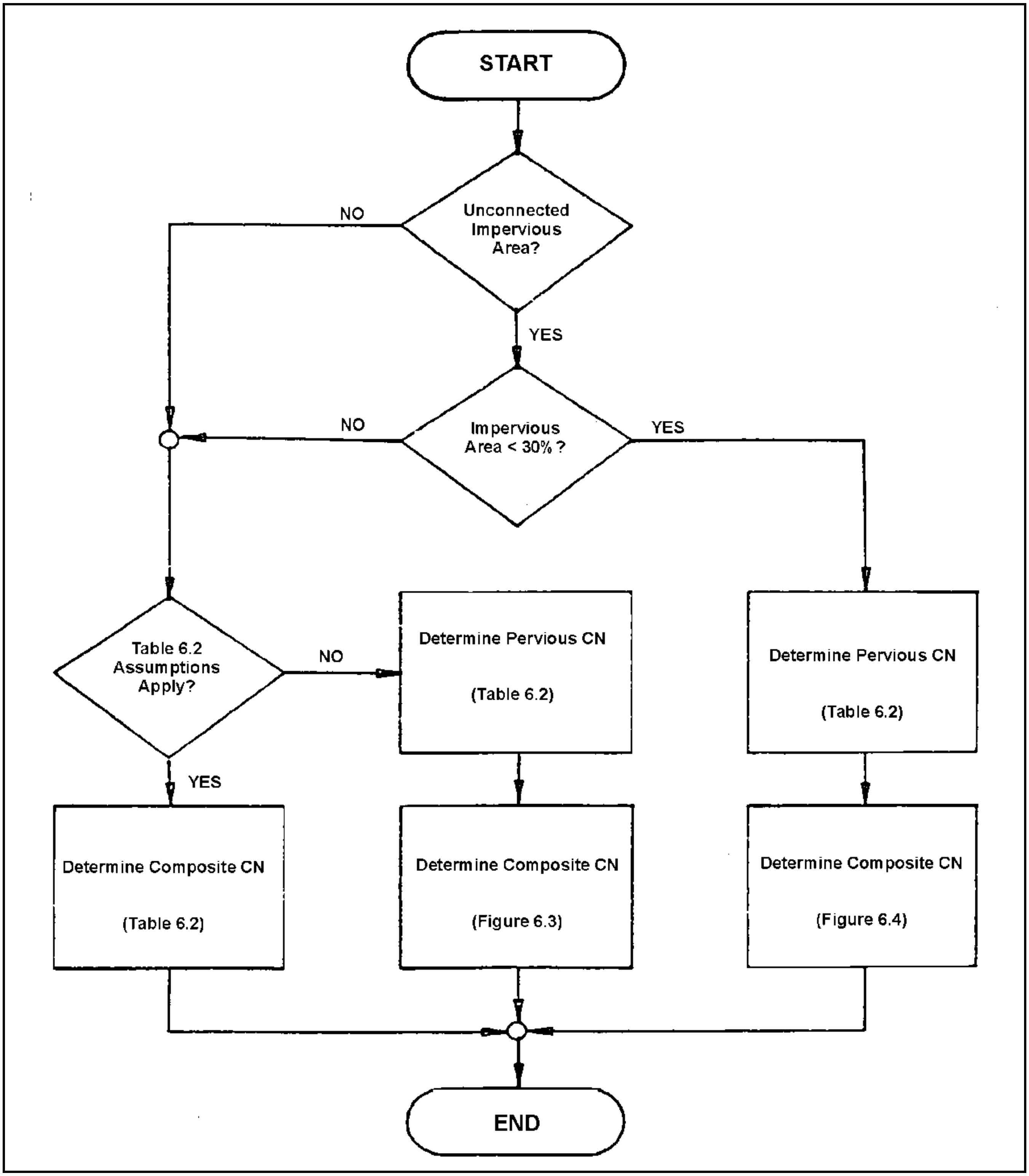


Figure 6.2. Flow chart for selecting the appropriate figure or table for determining runoff curve numbers (USDA-SCS, 1986).

Table 6.1. Runoff depth for selected CN's and rainfall amounts[1] (USDA-SCS, 1986).

Rain-fall	Runoff depth for curve number of --												
	40	45	50	55	60	65	70	75	80	85	90	95	98
	---inches---												
1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.08	0.17	0.32	0.56	0.79
1.2	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.07	0.15	0.27	0.46	0.74	0.99
1.4	0.00	0.00	0.00	0.00	0.00	0.02	0.06	0.13	0.24	0.39	0.61	0.92	1.18
1.6	0.00	0.00	0.00	0.00	0.01	0.05	0.11	0.20	0.34	0.52	0.76	1.11	1.38
1.8	0.00	0.00	0.00	0.00	0.03	0.09	0.17	0.29	0.44	0.65	0.93	1.29	1.58
2.0	0.00	0.00	0.00	0.02	0.06	0.14	0.24	0.38	0.56	0.80	1.09	1.48	1.77
2.5	0.00	0.00	0.02	0.08	0.17	0.30	0.46	0.65	0.89	1.18	1.53	1.96	2.27
3.0	0.00	0.02	0.09	0.19	0.33	0.51	0.71	0.96	1.25	1.59	1.98	2.45	2.77
3.5	0.02	0.08	0.20	0.35	0.53	0.75	1.01	1.30	1.64	2.02	2.45	2.94	3.27
4.0	0.06	0.18	0.33	0.53	0.76	1.03	1.33	1.67	2.04	2.46	2.92	3.43	3.77
4.5	0.14	0.30	0.50	0.74	1.02	1.33	1.67	2.05	2.46	2.91	3.40	3.92	4.26
5.0	0.24	0.44	0.69	0.98	1.30	1.65	2.04	2.45	2.89	3.37	3.88	4.42	4.76
6.0	0.50	0.80	1.14	1.52	1.92	2.35	2.81	3.28	3.78	4.30	4.85	5.41	5.76
7.0	0.84	1.24	1.68	2.12	2.60	3.10	3.62	4.15	4.69	5.25	5.82	6.41	6.76
8.0	1.25	1.74	2.25	2.78	3.33	3.89	4.46	5.04	5.63	6.21	6.81	7.40	7.76
9.0	1.71	2.29	2.88	3.49	4.10	4.72	5.33	5.95	6.57	7.18	7.79	8.40	8.76
10.0	2.23	2.89	3.56	4.23	4.90	5.56	6.22	6.88	7.52	8.16	8.78	9.40	9.76
11.0	2.78	3.52	4.26	5.00	5.72	6.43	7.13	7.81	8.48	9.13	9.77	10.39	10.76
12.0	3.38	4.19	5.00	5.79	6.56	7.32	8.05	8.76	9.45	10.11	10.76	11.39	11.76
13.0	4.00	4.89	5.76	6.61	7.42	8.21	8.89	9.71	10.42	11.10	11.76	12.39	12.76
14.0	4.65	5.62	6.55	7.44	8.30	9.12	9.91	10.67	11.39	12.08	12.75	13.39	13.76
15.0	5.33	6.36	7.35	8.29	9.19	10.04	10.85	11.63	12.37	13.07	13.74	14.39	14.76

[1] Interpolate the values shown to obtain runoff depths for CN's or rainfall amounts not shown.

Table 6.2.a. Runoff curve numbers for urban areas[1] (USDA-SCS, 1986).

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%)					
Fair condition (grass cover 50% to 75%)		68	79	86	89
Good condition (grass cover > 75%)		49	69	79	84
		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 drains (excluding right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way)					
Gravel (including right-of-way)		83	89	92	93
Dirt (including right-of-way)		76	85	89	91
		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 2.2(c))					

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 Figures 6.3 or 6.4.

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 6.3 or 6.4 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 Figures 6.3 or 6.4 based on the degree of development (impervious area percentage) and the CN's for the newly graded pervious areas.

Table 6.2.b. Runoff curve numbers for cultivated agricultural lands[1] (USDA-SCS, 1986).

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	86
	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 reside 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 6.2.c. Runoff curve numbers for other agricultural lands[1] (USDA-SCS, 1986).

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	80
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 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.

Table 6.2.d. Runoff curve numbers for arid and semi-arid rangelands[1] (USDA-SCS, 1986).

Cover description		Curve numbers for hydrologic soil group --			
Cover type	**Hydrologic Condition**[2]	**A**[3]	**B**	**C**	**D**
Herbaceous -- mixture of grass, weeds, 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 salt bush, greasewood, creosote bush, black brush, 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 6.2.c.

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.

Table 6.3. Hydrologic soil groups of the U.S. Virgin Islands (USDA-NRCS, 1995).

Group			
A	**B**	**C**	**D**
Jaucas	Arawak	Cramer	Annaberg
Lameshur	Cinnamon Bay	Dorothea	Aquents
Redhook	Parasol	Glynn	Beaches
	Sion	Jealousy	Carib
	Victory		Fredriksdal
			Hesselburg
			Hogensborg
			Maho Bay
			Rock Outcrop
			Salt Flats
			Sandy Point
			Solitude
			Southgate
			Sugar Beach
			Susannaberg

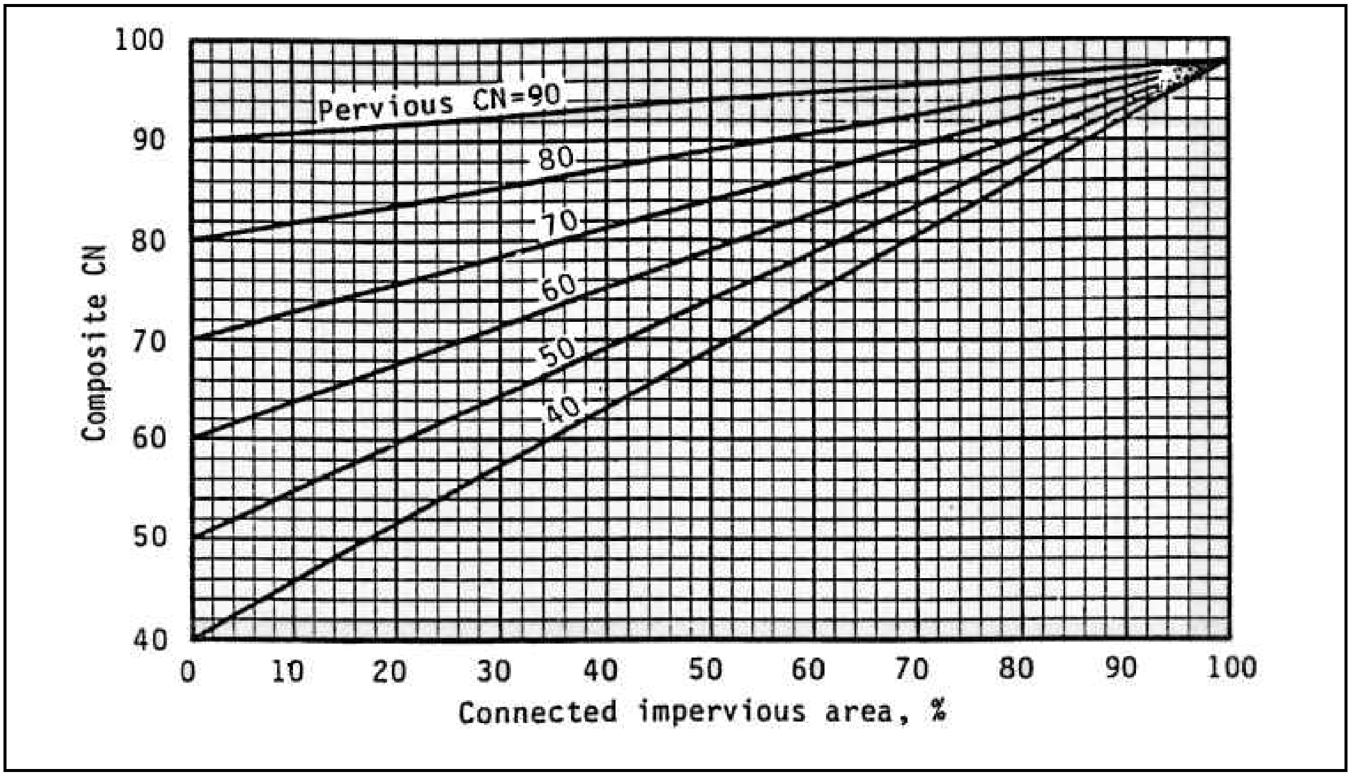


Figure 6.3. Composite CN with connected impervious area (USDA-SCS, 1986).

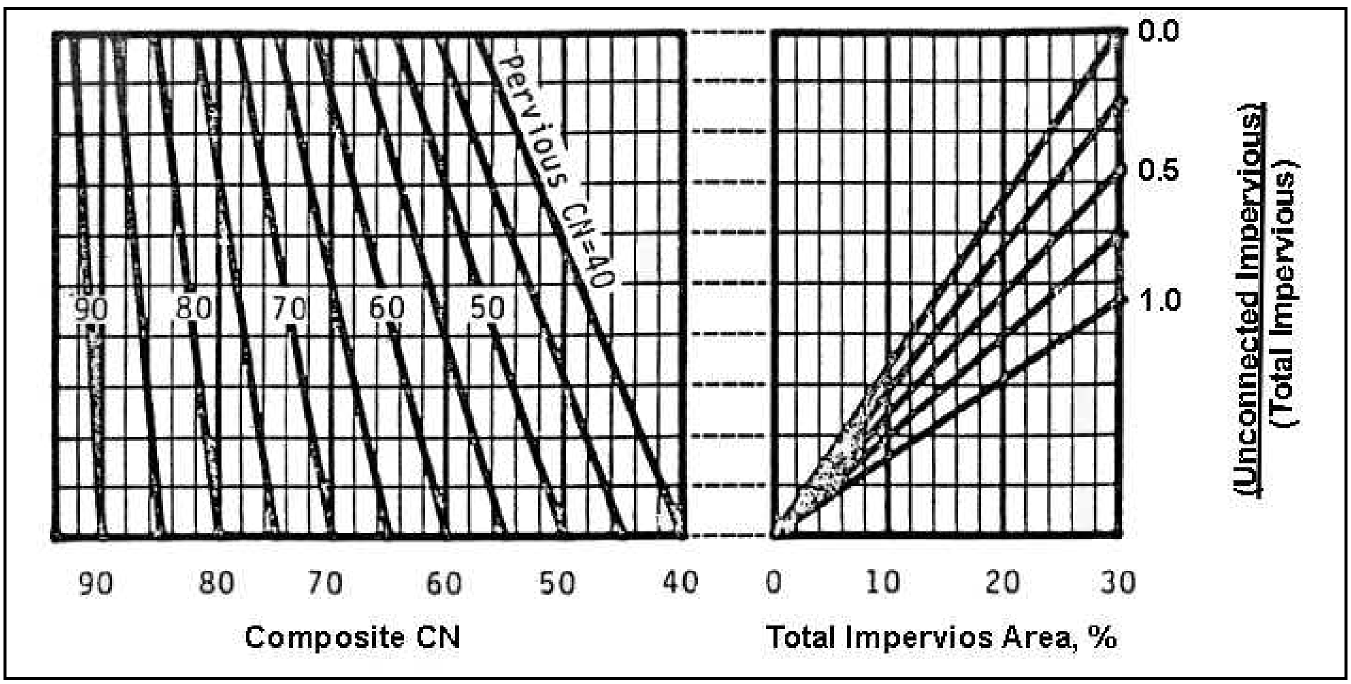


Figure 6.4. Composite CN with unconnected impervious areas and total impervious area less than 30% (USDA-SCS, 1986).

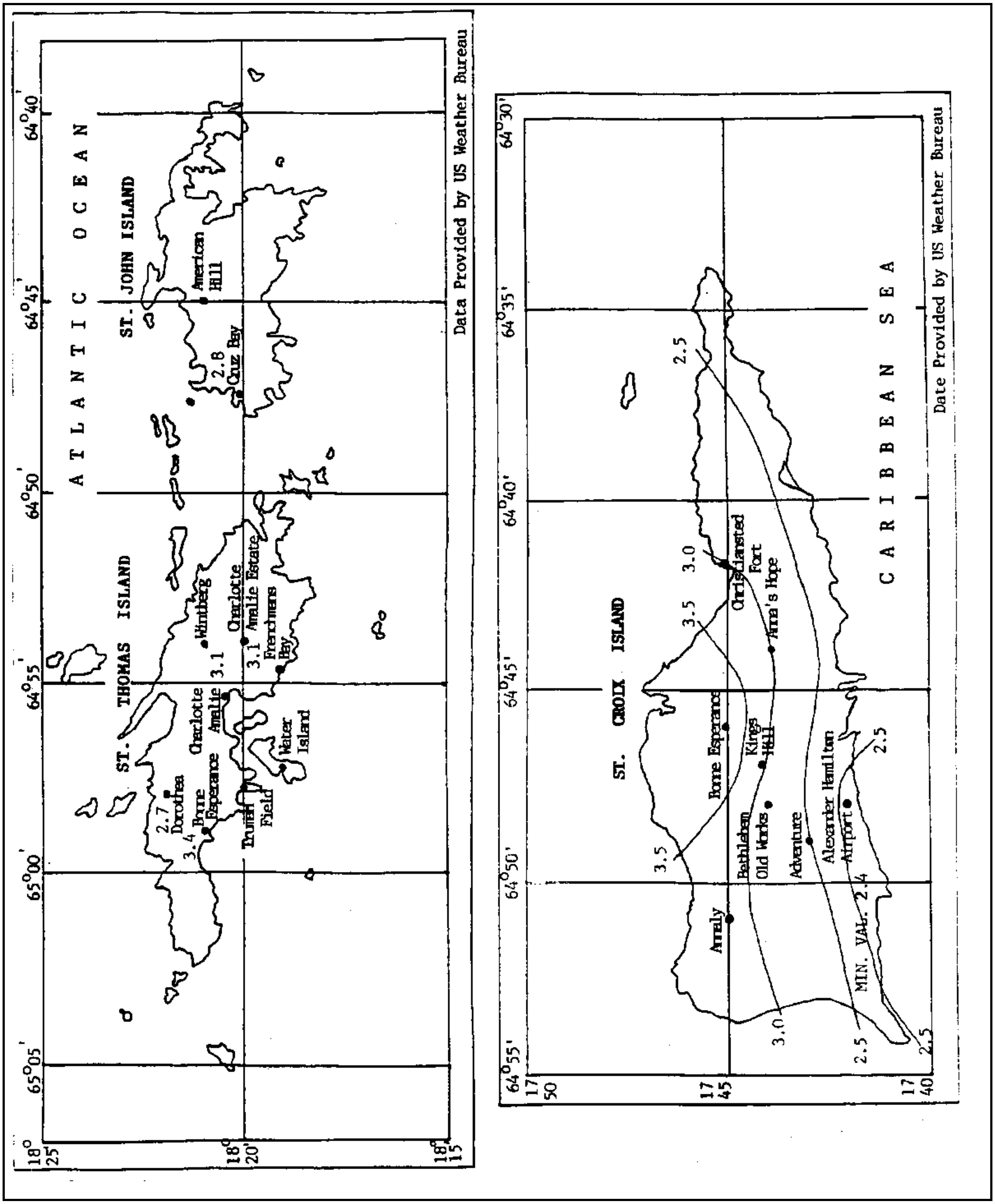


Figure 6.5. 1-year, 24-hour rainfall for the U.S. Virgin Islands (in.) (USDA-SCS, 1986).

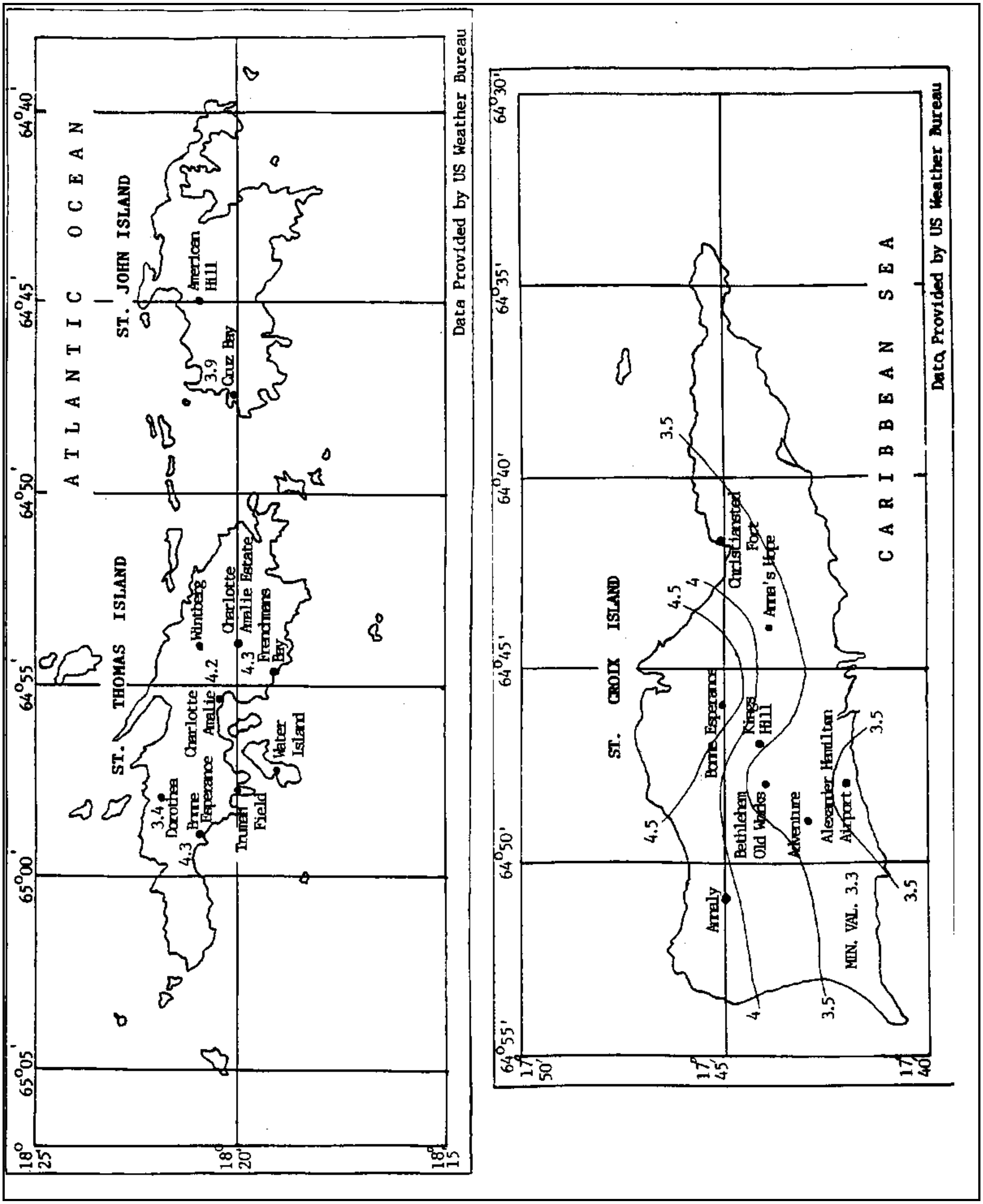


Figure 6.6. 2-year, 24-hour rainfall for the U.S. Virgin Islands (in.) (USDA-SCS, 1986).

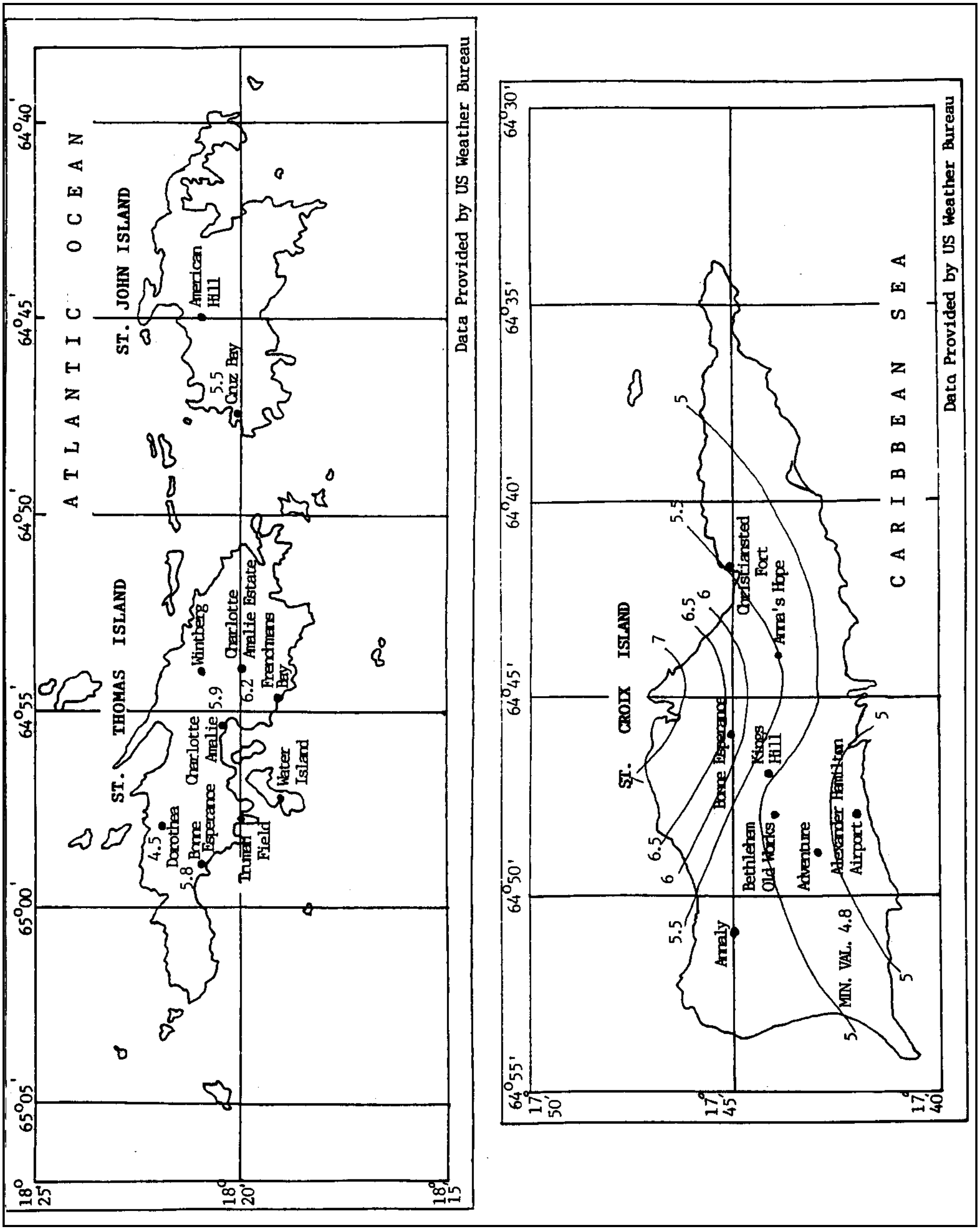


Figure 6.7. 5-year, 24-hour rainfall for the U.S. Virgin Islands (in.) (USDA-SCS, 1986).

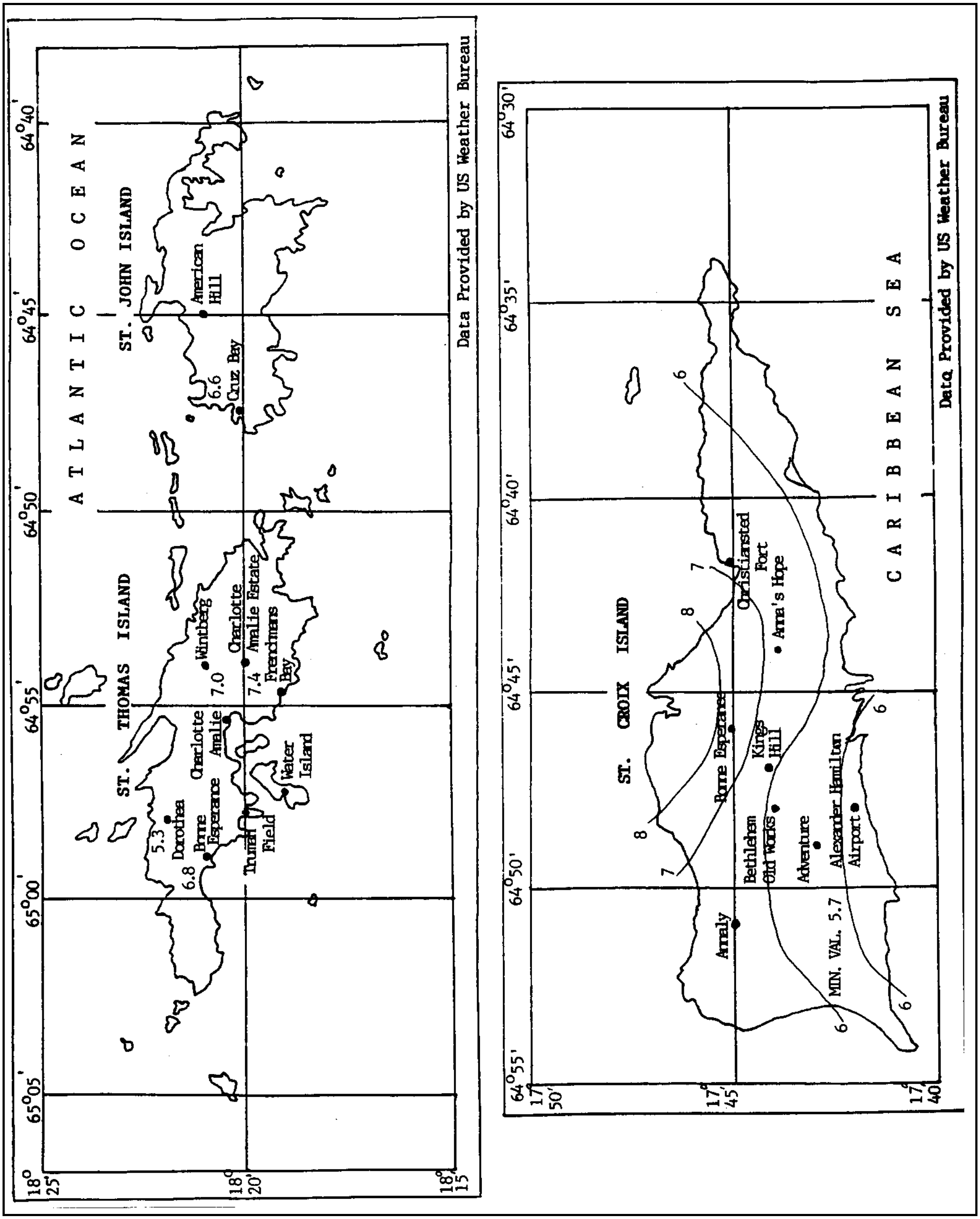


Figure 6.8. 10-year, 24-hour rainfall for the U.S. Virgin Islands (in.) (USDA-SCS, 1986).

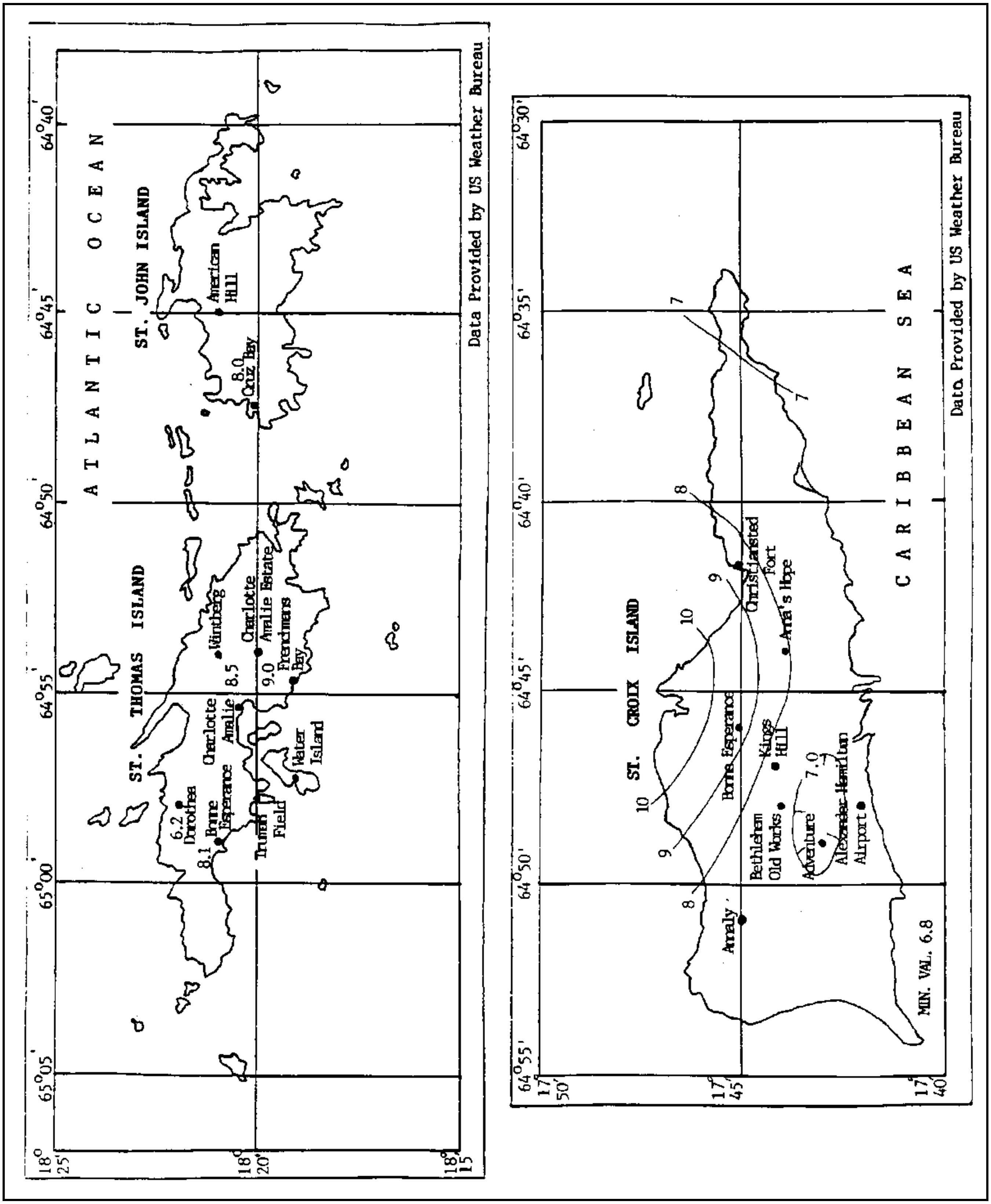


Figure 6.9. 25-year, 24-hour rainfall for the U.S. Virgin Islands (in.) (USDA-SCS, 1986).

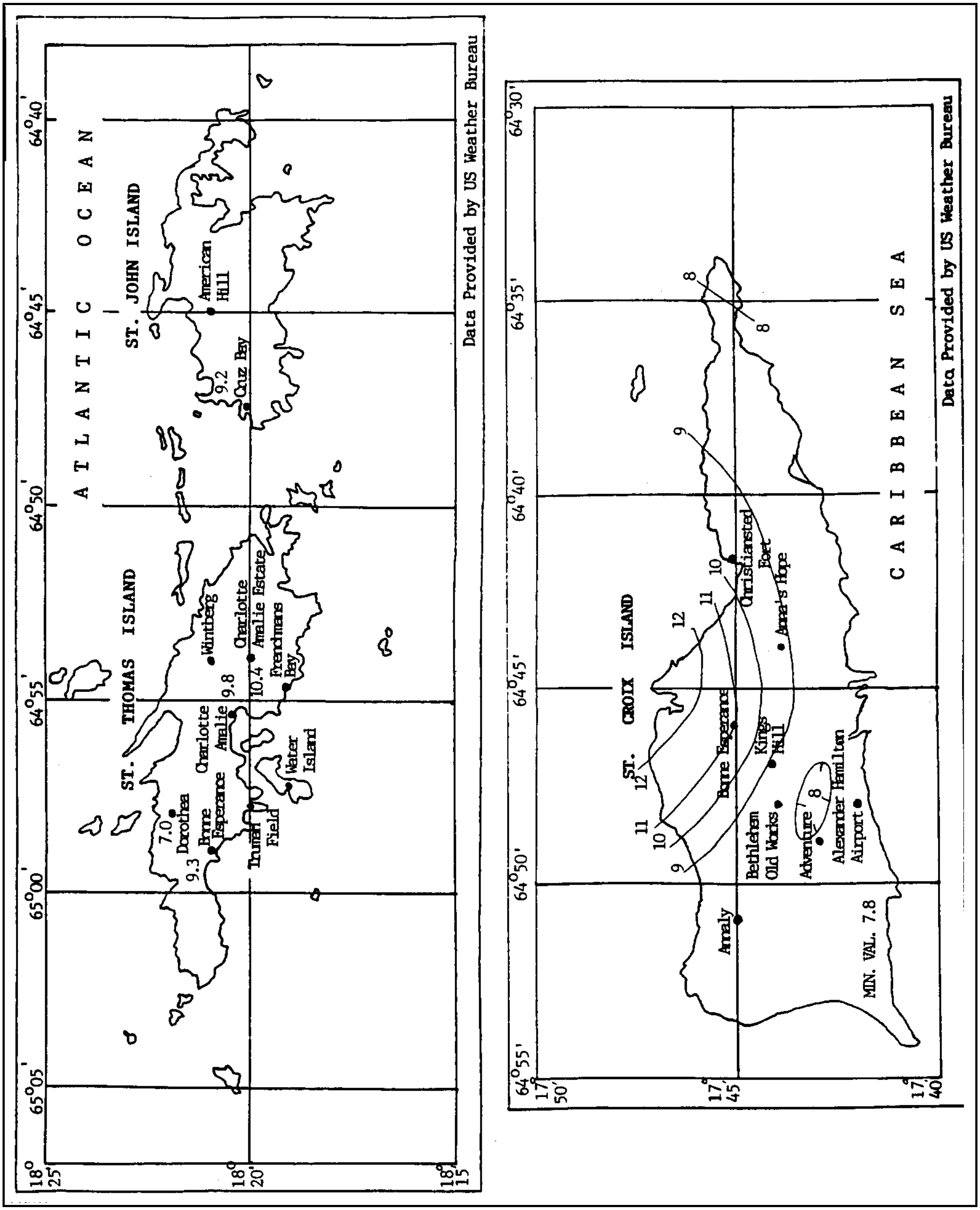


Figure 6.10. 50-year, 24-hour rainfall for the U.S. Virgin Islands (in.) (USDA-SCS, 1986).

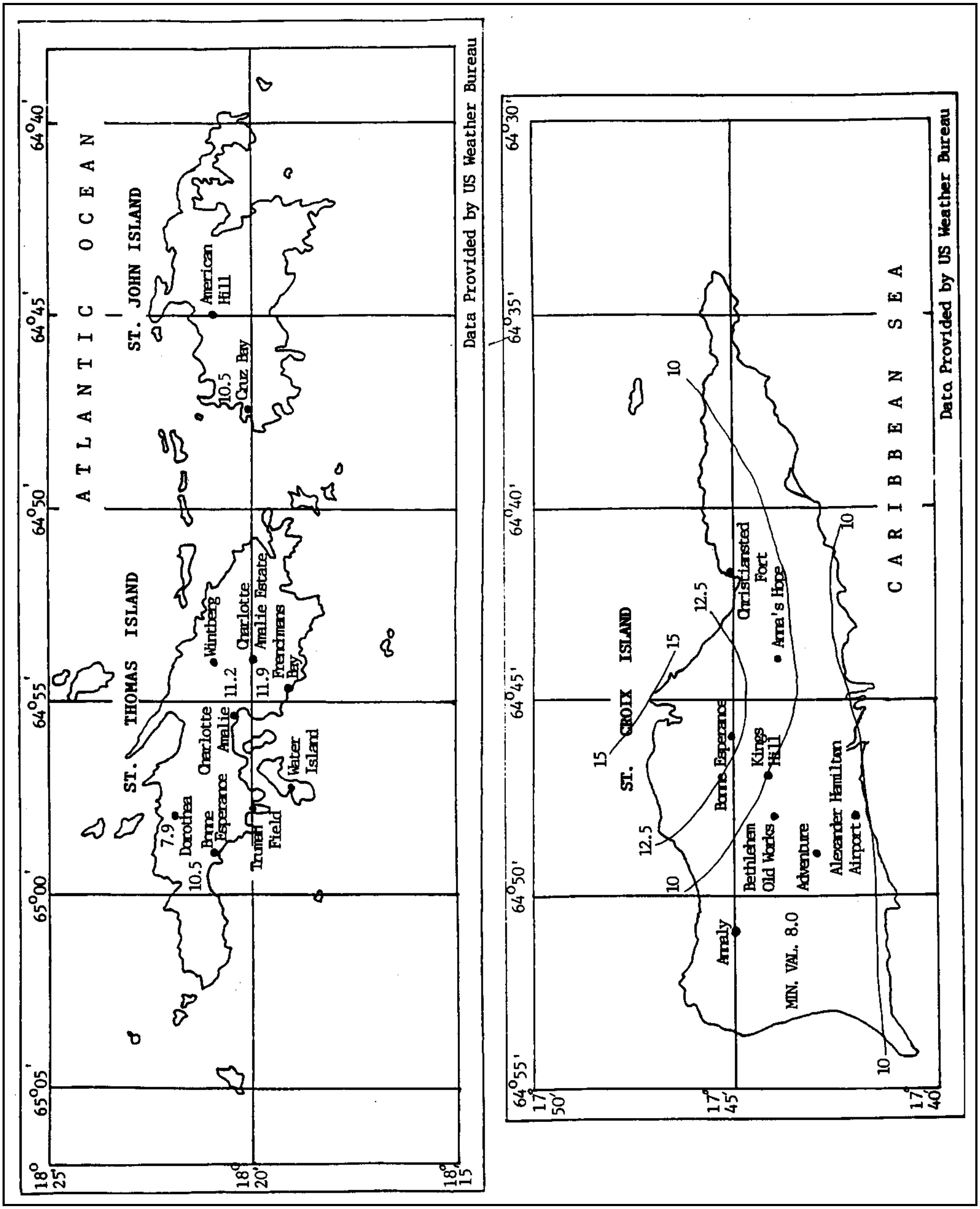


Figure 6.11. 100-year, 24-hour rainfall for the U.S. Virgin Islands (in.) (USDA-SCS, 1986).

Table 6.5. Roughness coefficients (Manning's n) for sheet flow (USDA-SCS, 1986).

Surface description	n[1]
Smooth surfaces (concrete, asphalt, gravel, or bare soil)	0.011
Fallow (no residue)	0.05
Cultivated soils:	
Residue cover < 20%	0.06
Residue cover $ 20%	0.17
Grass:	
Short grass	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

[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 GRA*
[3] *WHEN SELECTING N, CONSIDER COVER TO A HEIGHT OF ABOUT 0.1 FT. THIS IS THE ONLY PART OF THE PLANT COVE*

Table 6.4. I_a values for runoff curve numbers (USDA-SCS, 1986).

Curve number	I_a	Curve number	I_a
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		

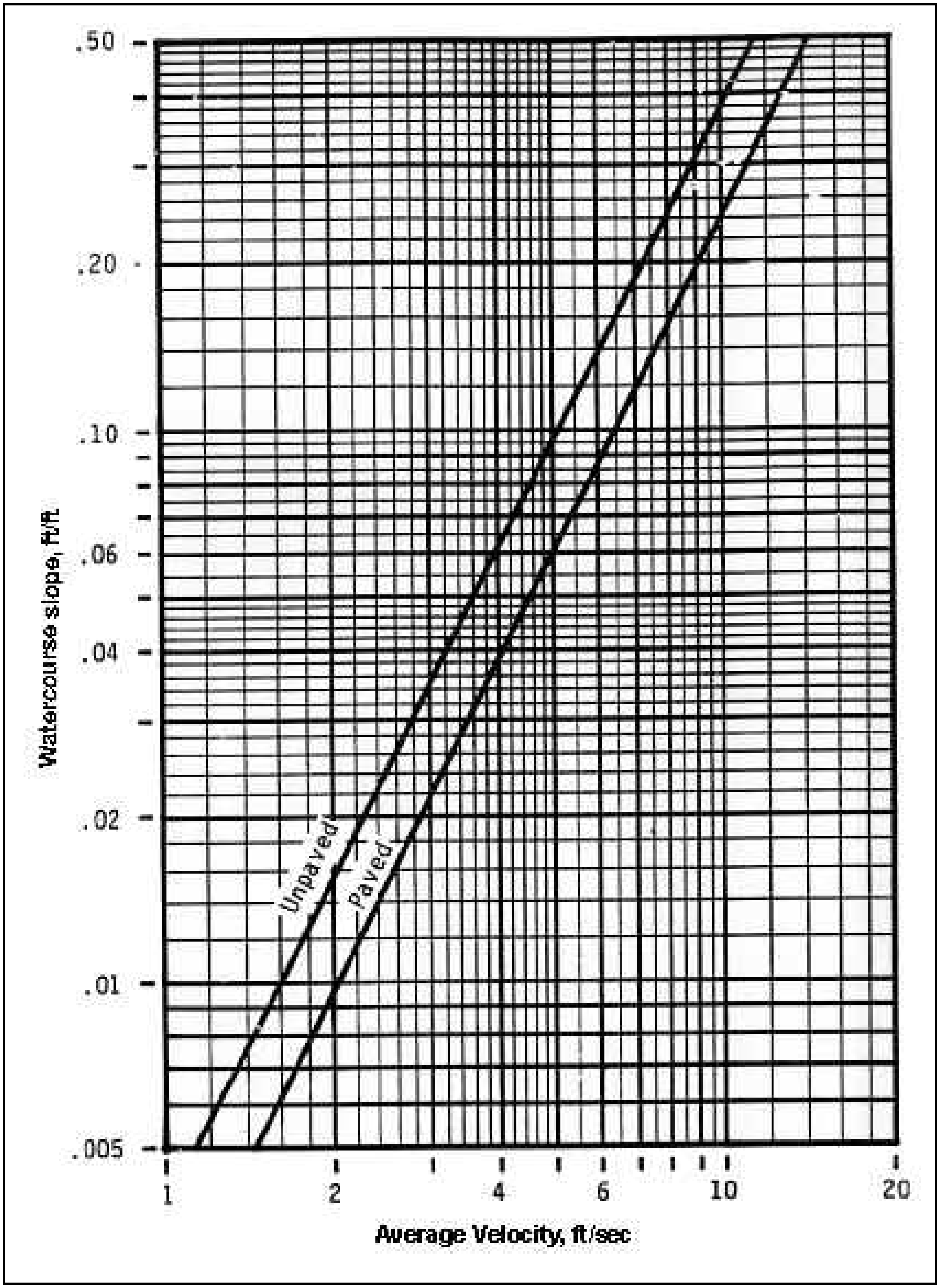


Figure 6.12. Average velocities for estimating travel time for shallow concentrated flow (USDA-SCS, 1986).

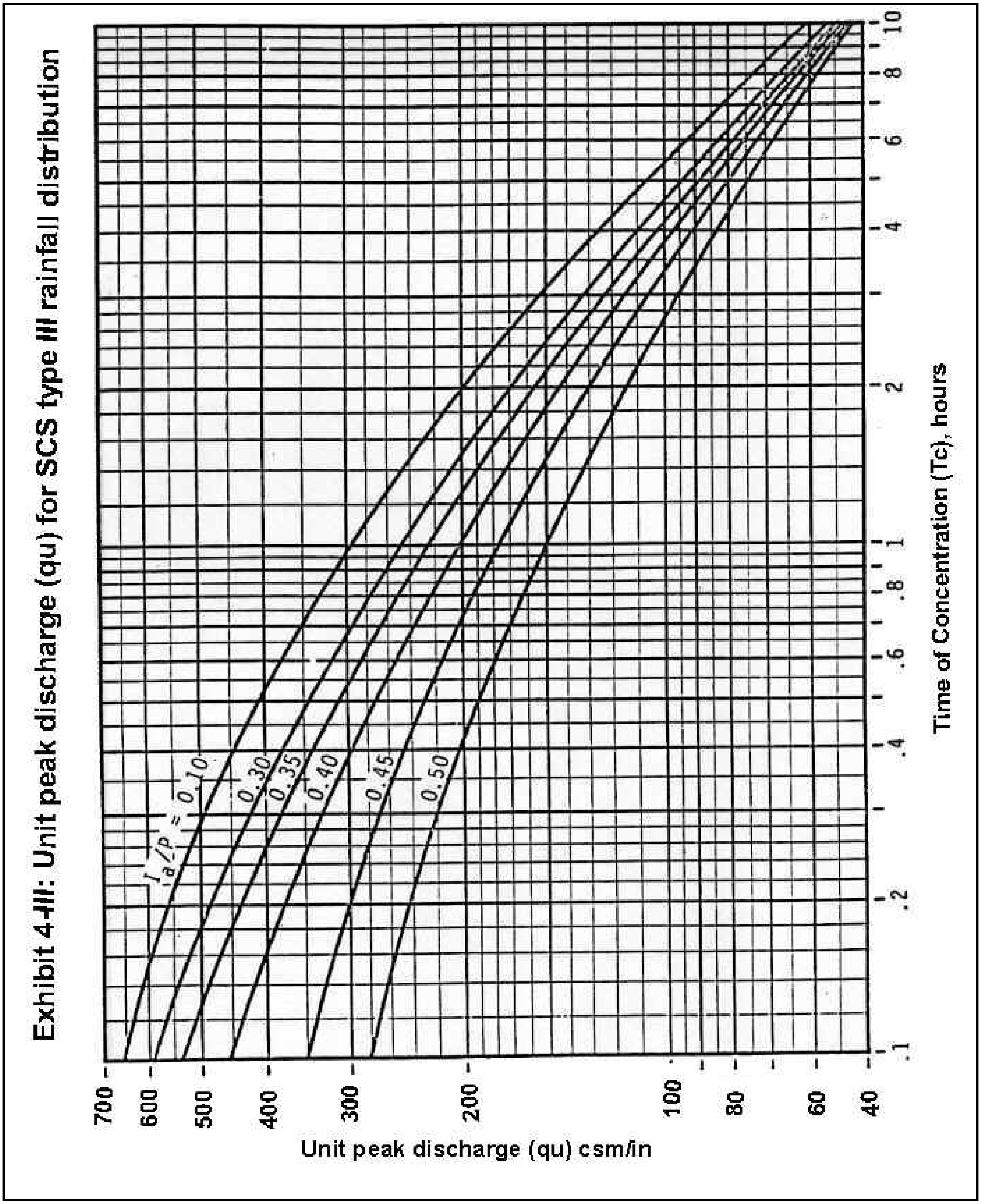


Figure 6.13. Unit peak discharge (q_u) for SCS Type-III rainfall distribution (the type that occurs in the U.S. Virgin Islands) (USDA-SCS, 1986).

Table 6.6. Adjustment factor (F_p) for pond and swamp areas that are spread throughout the watershed (USDA-SCS, 1986).

Percentage of pond and swamp areas	F_p
0.0	1.00
0.2	0.97
1.0	0.87
3.0	0.75
5.0	0.72

6.7 REFERENCES

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Worksheet 2: Runoff curve number and runoff

Project ______________________ By _____ Date ________

Location ______________________ Checked _____ Date ________

Circle One: Present Developed ______________________

1. Runoff Curve Number (CN)

Soil Name and Hydrologic Group (Appendix A)	Cover Description (cover type, treatment and hydrologic condition; percent impervious; unconnected/connected impervious area ratio)	CN 1/			Area ☒ acres ☐ mi2 ☐ %	Product of CN x Area
		Table 6-2	Fig. 6-3	Fig. 6-4		
					Totals = 18	1260

1/ Use only one CN source per line.

CN (weighted) = $\frac{\text{total product}}{\text{total area}} = \frac{1260}{18} =$ 70 ; Use CN = $\boxed{70}$

2. Runoff

		Storm #1	Storm #2	Storm #3
Frequency	yr	25		
Rainfall, P (24-hour)	in	6.2		
Runoff, Q	in	2.95		

(Use P and CN with Table 6-1, Figure 6-1 or Equations 6-3 and 6-4)

Worksheet 3: Time of Concentration (Tc) or Travel Time (Tt)

Project: ______________________ By: ______ Date ______

Location: ______________________ Checked ______ Date ______

Circle one: Present Developed ______________________

Circle one: Tc Tt through subarea ______________________

NOTES: Space for as many as two segments per flow type can be used for each worksheet. Include a map, schematic, or description of flow segments.

Sheet Flow (Applicable to Tc only)	Segment ID				
1. Surface description (Table 6-4)					
2. Manning's roughness coefficient, n (Table 6-4) ..					
3. Flow length, L, (total $L \leq 300$ ft)	ft				
4. Two-year 24-hour rainfall, P_2	in				
5. Land slope, s	ft/ft				
6. $Tt = \frac{0.007\,(nL)^{0.8}}{P_2^{0.5}\ s^{0.4}}$ Compute Tt	hr		+	=	
Shallow Concentrated Flow	Segment ID				
7. Surface description (paved or unpaved)					
8. Flow length, L	ft				
9. Watercourse slope, s	ft/ft				
10. Average velocity, V (Figure 6-12)	ft/s				
11. $Tt = \frac{L}{3600\ V}$ Compute Tt	hr		+	=	
Channel Flow	Segment ID				
12. Cross sectional flow area, a	ft^2				
13. Wetted perimeter, p_w	ft				
14. Hydraulic radius, $r = \frac{a}{p_w}$ Compute r	ft				
15. Channel slope, s	ft/ft				
16. Manning's roughness coefficient, n					
17. $V = \frac{1.49\ r^{2/3}\ s^{1/2}}{n}$ Compute V	ft/s				
18. Flow length, L	ft				
19. $Tt = \frac{L}{3600\ V}$ Compute Tt	hr		+	=	
20. Watershed or subarea Tc or Tt (add Tt in steps 6, 11, and 19)	hr				

Worksheet 4: Graphical Peak Discharge Method

Project ______________________________ By _____ Date ________

Location ______________________________ Checked _____ Date ________

Circle one: (Present) Developed ______________________________

1. Data:

   Drainage Area .... A_m = ________ mi^2 (acres/640)

   Runoff curve number .... CN = ________ (from Worksheet 2)

   Time of concentration .. Tc = ________ hr (from Worksheet 3)

   Rainfall distribution type = ________ (I, IA, II, III)

   Pond and swamp areas spread throughout watershed ...... = ________ percent of A_m (____ acres or mi^2 covere

2. Frequency	yr			
3. Rainfall, P (24-hour)	in			
4. Initial abstraction, I_a .... (Use CN with table 6-5)	in			
5. Compute I_a /P				
6. Unit peak discharge, q_u .... (Use Tc and I_a /P with Figure 6-13)	csm/in			
7. Runoff, Q .... (From Worksheet 2)	in			
8. Pond and swamp adjustmetn factor, F_p .... (Use percent pond and swamp area with Table 6-6. Factor is 1.0 for zero percent pond and swamp area.)				
9. Peak discharge, q_p .... (Where $q_p = q_u A_m Q F_p$)	cfm			