R. Pitt
June 17, 2004

Module 3: Regional Rainfall Conditions and Site Hydrology for Construction Site Erosion Evaluations

Introduction: Hydrology for the Design of Construction Erosion Controls

This chapter provides an overview of hydrology analysis techniques appropriate for the design of construction site erosion controls. The NRCS's TR-55 procedure will be used in this chapter, as it provides most of the needed information and is generally applicable to conditions found on most construction sites.

The reference list contains the URL for an on-line copy of TR-55, *Urban Hydrology for Small Watersheds* by the US Dept. of Agric./Soil Conservation Service (now NRCS) (1986). Recently, a Windows version of TR-55 (WinTR55) has become available (beta version) that can be used to greatly simplify these calculations, and that appropriate URL is also given. TR-55 provides a good set of tools to determine a number of hydrology parameters needed for effective design of construction site erosion controls. The following list shows typical controls and the types of hydrology information needed for complete evaluations and design (later chapters will review and present examples of how this information is used in these designs):

- Mulches - water velocities and water depth
- Ditch liners - water velocities and water depth
- Slope down shoots - peak flow rates
- Diversion dikes and swales - peak flow rates
- Filter fabric fences - water velocities and hydrographs
- Sediment ponds - water volume and hydrographs

Factors Affecting Runoff

- Rainfall

The extent of the storm, and the distribution of rainfall during the storm, are two major factors which affect the peak rate of runoff. The storm distribution can be thought of as a measure of how the rate of rainfall (intensity) varies within a given time interval. If a certain amount of precipitation was measured in a given 24-hour period, this precipitation may have occurred over the entire 24-hour period or in just one hour. The duration of the rain (and the peak intensity) directly affect the runoff rates.

The size of the storm is often described by the length of time over which precipitation occurs, the total amount of precipitation occurring and how often this same storm might be expected to occur (frequency). Thus, a 10-year, 24-hour storm can be thought of as a storm producing the amount of rain in 24 hours with a 10% chance of occurrence in any given year.

- Antecedent Moisture Content

The runoff from a given storm is affected by the existing soil moisture content resulting from the precipitation preceding the event of interest (defined as a five day period by the NRCS). This has a much smaller effect in areas having mostly paved surfaces. On construction sites, this factor can be important.

- Surface Cover

The type of cover and its condition affects the runoff volume through its influence on the infiltration rate of soil. Bare soil at a construction site generates more runoff than forested or grass land for a given soil type. As a site develops, paving areas reduces the surface storage and infiltration capacity of the area and thus increases the amount of runoff.

The foliage and its litter maintain the soils infiltration potential by preventing the sealing of the soil surface from the impact of the raindrops. Some of the raindrops are retained on the surface of the foliage, increasing their chance of being evaporated back to the atmosphere. Some of the intercepted moisture is so long draining from the plant down to the soil that it is withheld from the initial period of runoff. Foliage also transpires moisture into the atmosphere thereby creating a moisture deficiency in the soil which must be replaced by rainfall before runoff occurs. Vegetation, including its ground litter, forms numerous barriers along the path of the water flowing over the surface of the land which slows the water down and reduces its peak rate of runoff.

- Soils

In general, the higher the rate of infiltration, the lower the quantity of stormwater runoff. Fine textured soils, such as clay, produce a higher rate of runoff than do coarse textured soils, such as sand. In addition, compacted soils also produce much more runoff than natural soils (Pitt, *et al.* 1999). Sites having clay soils are much more susceptible to compaction problems than most other soils.

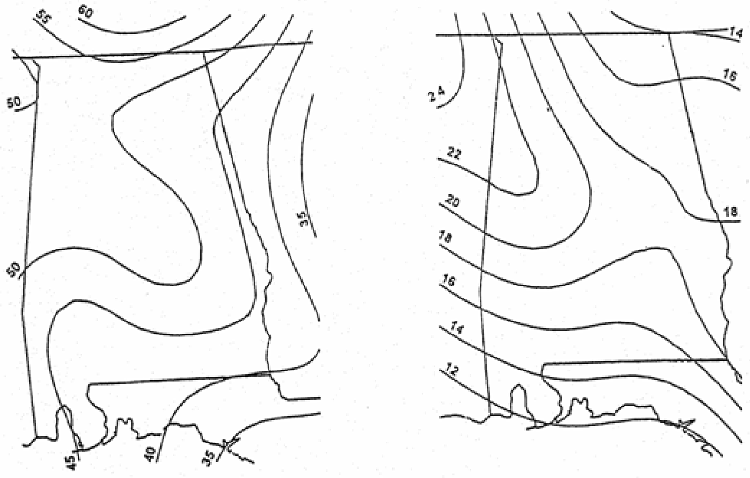
- Time of Concentration

The time of concentration (Tc) is the longest time needed for runoff to originate from the complete project site. The time of concentration effects the peak and shape of the hydrograph. With land clearing and subsequent development, the drainage efficiency usually dramatically increases, with associated much greater peak runoff values that occur earlier in the storm. In addition, land development (and soil compaction) decease the infiltration capacity of the site, further increasing the runoff volume, and peak rate of runoff.

Local Rainfall Conditions Relevant to Construction Site Erosion and Sediment Control Design

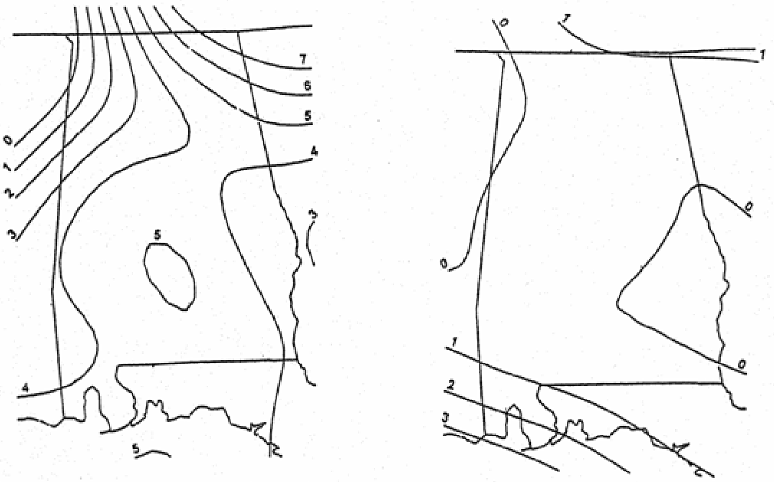
The following discussion is an example assessment of typical Alabama rain conditions to determine the frequency of highly erosive rains and the relative importance of various rains in generating construction site erosion yields. Figures 3-1 through 3-3 show the general variations of rain conditions over Alabama. These figures were prepared by Pitt and Durrans (1995) as part of a research project for the Alabama Dept. of Transportation. These analyses used data from the 1976 and 1977 rain period. These two years were determined to be representative of the average conditions from 1948 through 1994 based on total rain depth and the monthly distribution of rains. These data were obtained from EarthInfo (Golden, CO) CD-ROMS which are archives of the official NOAA data. Figure 3-1 is a contour map of the total annual rain depth, based on analyses at more than 120 rain gage stations located in Alabama and in surrounding states. There is little variability in rain conditions over most of the state (50 to 56 inches per year). The northwestern corner has less rain (down to about 46 inches), while the rain depth increases substantially moving towards the gulf coast (as high as 66 inches per year). There are usually a few more than 100 separate rain events per year in Alabama, defined using a minimum of 6 hours for the interevent period, with the smallest rains being 0.01 inches and the largest approaching 10 inches. Figure 3-2 presents the percentages of these annual rains having at least 0.25, 1.00, 2.5, and 5.00 inches. Few, if any, of the rains are likely greater than 5 inches in the central and northern portions of the state, but several rains greater than this amount likely occur each year near the coast. At least 40 to 50% of all rains are at least 0.25 inches in depth throughout the state. Figure 3-3 shows the percentages of all storm interevent periods that are at least 3 and 15 days. Most interevent periods are about 3 days throughout the state, but few last as long as 2 weeks, especially near the gulf coast.

Figure 3-1. Annual rainfall variations over Alabama (Pitt and Durrans 1995).



PROBABILITY OF RAIN DEPTH 0.25" OR GREATER

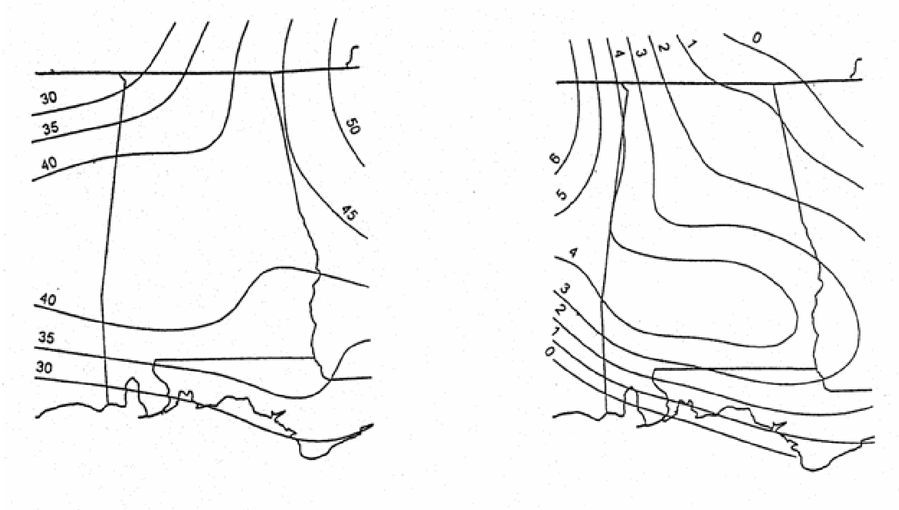
PROBABILITY OF RAIN DEPTH 1.00" OR GREATER



PROBABILITY OF RAIN DEPTH 2.50" OR GREATER

PROBABILITY OF RAIN DEPTH 5.00" OR GREATER

Figure 3-2. Probabilities of individual rain storms having various rain depths in Alabama (Pitt and Durrans 1995).



Probabilities of rains having at least 3 day antecedent dry periods.

Probabilities of rains having at least 15 day antecedent dry periods.

Figure 3-3. Rain storm interevent periods for Alabama (Pitt and Durrans 1995).

Typical Birmingham Rain Conditions

Monthly rain depths from 1955 to 1986 were examined to identify a single rain year that had total depths and rain distributions similar to the long-term average conditions. The years 1975 and 1976 were found to both have similar rain conditions that were close to these average conditions. Individual events in these years were identified using hourly rain records for descriptive statistical summaries. A rain event was defined as a series of hourly observations containing no more than six adjacent hours having no rain. This definition has been commonly used in many urban runoff studies as it produces discrete runoff hydrographs. The six hour period of no rain also almost always allows urban streams to return to near baseflow conditions. Tables 3-1 and 3-2 summarize these rains.

Table 3-1. Birmingham Rain Depth Distributions (average for 1975 and 1976)

Rain depth range (inches)	**Interevent period (days)**	**Annual number of rains in range (out of 100 rains per year)**	**Total rain in range (inches)**	**% of annual rain in range**	**Accumulative % of rain in range**
0 to 0.5	4	62	15.5	25	25
0.5 to 1.0	10	19	14.3	23	48
1.0 to 1.5	21	9	11.3	17	65
1.5 to 2.0	41	3	5.3	8	73
2.0 to 2.5	56	3	6.8	10	83
2.5 to 3.0	122	2	5.5	8	91
3.0 to 3.5	183	1	3.5	3	94
3.5 to 4.0	365	1	3.8	6	100

Table 3-2. Birmingham Runoff Volume Distributions for Typical Construction Site

Rain depth range (inches)	**Volumetric runoff coefficient (Rv)**	**Annual runoff in range (inches)**	**% of runoff in range**	**Accumulative % of runoff in range**
0 to 0.5	0.27	4.2	19	19
0.5 to 1.0	0.34	4.9	22	41
1.0 to 1.5	0.36	4.1	17	58
1.5 to 2.0	0.39	2.0	9	67
2.0 to 2.5	0.41	2.8	11	78
2.5 to 3.0	0.44	2.4	10	88
3.0 to 3.5	0.45	1.5	4	92
3.5 to 4.0	0.48	1.8	8	100
Total, or weighted average:	0.36	23.7	100	

Table 3-1 lists the expected rainfall distribution for typical Birmingham conditions. There are about 100 individual rains per year in Birmingham, ranging from 0.01 to about 4 inches in depth. Most of the rains are less than 0.5 inches in depth, but more than one-half of the total annual rain depth is associated with rains greater than one inch. Rain interevent periods are important when determining the periods of time that bare ground may remain unprotected at construction sites. The interevent periods shown on this table are for all rains greater than the minimum rain in the range. As an example, rains greater than 2 inches occur about every 56 days, while rains greater than 0.5 inch occur about every 10 days.

Table 3-2 summarizes the runoff quantities that may be expected for each rain depth class, for a typical construction site area. More than half of the runoff from this area is associated with rains less than 1.5 inches in depth. Less than 20 percent of the runoff is associated with rains greater 2.5 inches in depth. Only rains greater than about 1.25 inches will contribute runoff quantities greater than 0.5 inches, a commonly used detention criterion contained in runoff control ordinances. The first 0.5 inch of runoff from all rains therefore includes all rains smaller than about 1.25 inches, plus portions of larger rains. The remaining runoff, after the first 0.5 inch, totals about 5.5 inches for typical construction areas using the 1975 and 1976 Birmingham rains.

Erosion Yields for Different Alabama Rain Categories

It is possible to estimate the relative erosion contributions of different rains, as shown in Tables 3-17 through 3-21. Thronson (1973) presented the following equation to estimate the erosion potential for individual rains, when complete intensity information is not available:

where P is the rain depth, in inches, and dur is the rain duration, in hours. This equation was proposed for the original SCS type II rain category which was applicable for the complete US, except for the extreme west coast. Long-term rain series data for Huntsville, Birmingham, Tuscaloosa, Montgomery, and Mobile were extracted from EarthInfo CD-ROMS (Golden, CO) and processed in SLAMM (www.winslamm.com) to combine the hourly data into individual rain records. Each rain was defined as having at least a 6 hour dry interevent period. About 50 years of data were available for each city, although some of the records were incomplete. The number of events evaluated for each city ranged from about 2500 to 5200 separate rains. The calculations were made for each of 12 rain categories and the total annual R was estimated by multiplying the partial R for each category by the number of events in each category. The calculated annual R values for these 5 cities were slightly larger (differences of 6 to 34%) than the published annual R values. The main reason for these differences is that the published annual R values are median values for many separate years, while the R values used here were averaged values, which would be larger. The calculated R values for each category were therefore adjusted to indicate the approximate portion of the total annual R associated with the different rain categories.

The larger rains contribute most of the erosion potential for Alabama conditions. For all of these cities, except Mobile, the rain depth associated with the median of the annual R is about 2 inches, while it is about 2.5 inches for Mobile. About 5% of the annual rains are therefore responsible for about half of the annual erosion potential. Because of the long rain record used here, these rain series include several rare events, including the “50-year” event. It may be impractical to design erosion controls that can effectively withstand these very large events. Except for Mobile, rains greater than 4 inches occur less than once a year in most parts of the state. If a “typical” rain year was examined, the effects of these very large rains would be somewhat diminished. When the 1976 rain year for Birmingham was examined (a typical year for local rains), for example, the rain depth associated with the median erosion potential was reduced to about 1.75 inches.

Table 3-17. Erosion Potential Analysis for Huntsville Rains Occurring from 1958 through 1999

Rain range (inches)	Mid Point Rain (inches)	Duration (hours)	Average Intensity (in/hr)	#/year in range category	% of rains in category	Thronson R	% of annual R in category	Accumulative % of total R
0.01 to 0.05	0.03	3	0.01	22.5	26.0	0.1	0.0	0.0
0.06 to 0.10	0.08	7	0.01	8.1	9.4	0.2	0.1	0.1
0.11 to 0.25	0.18	8	0.02	13.3	15.4	1.7	0.6	0.6
0.26 to 0.50	0.38	10	0.04	13.9	16.0	8.1	2.7	3.3
0.51 to 0.75	0.63	12	0.05	9.3	10.8	15.2	5.1	8.4
0.76 to 1.00	0.88	14	0.06	5.7	6.6	18.0	6.0	14.4
1.01 to 1.50	1.26	16	0.08	6.6	7.6	43.0	14.3	28.7
1.51 to 2.00	1.76	18	0.10	3.2	3.8	41.9	14.0	42.7
2.01 to 2.50	2.26	20	0.11	1.6	1.9	34.2	11.4	54.1
2.51 to 3.00	2.76	24	0.12	0.8	0.9	24.9	8.3	62.4
3.01 to 4.00	3.5	30	0.12	0.8	0.9	35.2	11.7	74.2
over 4.01	5.27	36	0.15	0.7	0.9	77.5	25.8	100.0
4425 events	51.1 years	12.03 in. max rain	Totals:	86.5	100.0	300.0	100.0	

Table 3-18. Erosion Potential Analysis for Birmingham Rains Occurring from 1948 through 1999

Rain range (inches)	Mid Point Rain (inches)	Duration (hours)	Average Intensity (in/hr)	#/year in range category	% of rains in category	Thronson R	% of annual R in category	Accumulative % of total R
0.01 to 0.05	0.03	3	0.01	22.9	20.7	0.1	0.0	0.0
0.06 to 0.10	0.08	7	0.01	17.4	15.8	0.4	0.1	0.1
0.11 to 0.25	0.18	8	0.02	17.3	15.6	2.4	0.7	0.8
0.26 to 0.50	0.38	10	0.04	19.5	17.6	12.4	3.5	4.4
0.51 to 0.75	0.63	12	0.05	9.4	8.5	16.6	4.8	9.1
0.76 to 1.00	0.88	14	0.06	8.3	7.5	28.6	8.2	17.3
1.01 to 1.50	1.26	16	0.08	7.9	7.2	56.4	16.1	33.4
1.51 to 2.00	1.76	18	0.10	3.8	3.5	53.9	15.4	48.8
2.01 to 2.50	2.26	20	0.11	1.6	1.5	38.0	10.9	59.7
2.51 to 3.00	2.76	24	0.12	0.8	0.7	26.3	7.5	67.2
3.01 to 4.00	3.5	30	0.12	1.1	1.0	57.0	16.3	83.5
over 4.01	5.67	36	0.16	0.4	0.4	57.9	16.5	100.0
4583 events	41.5 years	13.58 in. max rain	Totals:	110.5	100.0	350.0	100.0	

Table 3-19. Erosion Potential Analysis for Tuscaloosa Rains Occurring from 1958 through 1999

Rain range (inches)	Mid Point Rain (inches)	Duration (hours)	Average Intensity (in/hr)	#/year in range category	% of rains in category	Thronson R	% of annual R in category	Accumulative % of total R

0.01 to 0.05	0.03	3	0.01	6.9	11.8	0.0	0.0	0.0
0.06 to 0.10	0.08	7	0.01	10.3	17.5	0.4	0.1	0.1
0.11 to 0.25	0.18	8	0.02	9.4	16.0	1.9	0.5	0.6
0.26 to 0.50	0.38	10	0.04	10.3	17.5	9.8	2.6	3.2
0.51 to 0.75	0.63	12	0.05	6.3	10.7	16.7	4.5	7.7
0.76 to 1.00	0.88	14	0.06	4.5	7.7	23.3	6.2	13.9
1.01 to 1.50	1.26	16	0.08	5.2	8.9	55.8	14.9	28.8
1.51 to 2.00	1.76	18	0.10	2.6	4.5	55.2	14.7	43.5
2.01 to 2.50	2.26	20	0.11	1.4	2.4	48.3	12.9	56.4
2.51 to 3.00	2.76	24	0.12	0.7	1.2	35.6	9.5	65.9
3.01 to 4.00	3.5	30	0.12	0.6	1.1	47.1	12.6	78.4
over 4.01	5.33	36	0.15	0.5	0.8	80.8	21.6	100.0
2535 events	43.2 years	11.76 in. max rain	Totals:	58.7	100.0	375.0	100.0	

Table 3-20. Erosion Potential Analysis for Montgomery Rains Occurring from 1948 through 1999

Rain range (inches)	Mid Point Rain (inches)	Duration (hours)	Average Intensity (in/hr)	#/year in range category	% of rains in category	Thronson R	% of annual R in category	Accumulative % of total R
0.01 to 0.05	0.03	3	0.01	25.1	25.2	0.1	0.0	0.0
0.06 to 0.10	0.08	7	0.01	9.6	9.7	0.2	0.1	0.1
0.11 to 0.25	0.18	8	0.02	16.9	17.0	2.2	0.6	0.7
0.26 to 0.50	0.38	10	0.04	15.8	15.9	9.6	2.7	3.4
0.51 to 0.75	0.63	12	0.05	9.5	9.6	16.2	4.5	7.9
0.76 to 1.00	0.88	14	0.06	6.2	6.2	20.4	5.7	13.6
1.01 to 1.50	1.26	16	0.08	7.8	7.9	53.6	14.9	28.5
1.51 to 2.00	1.76	18	0.10	3.7	3.7	50.4	14.0	42.6
2.01 to 2.50	2.26	20	0.11	2.0	2.0	43.7	12.2	54.7
2.51 to 3.00	2.76	24	0.12	1.0	1.0	32.7	9.1	63.8
3.01 to 4.00	3.5	30	0.12	1.0	1.0	48.7	13.6	77.4
over 4.01	5.49	36	0.15	0.7	0.7	81.1	22.6	100.0
5121 events	51.5 years	10.96 in. max rain	Totals:	99.4	100.0	359.0	100.0	

Table 3-21. Erosion Potential Analysis for Mobile Rains Occurring from 1948 through 1999

Rain range (inches)	Mid Point Rain (inches)	Duration (hours)	Average Intensity (in/hr)	#/year in range category	% of rains in category	Thronson R	% of annual R in category	Accumulative % of total R
0.01 to 0.05	0.03	3	0.01	30.5	26.0	0.1	0.0	0.0
0.06 to 0.10	0.08	7	0.01	12.5	10.7	0.4	0.1	0.1
0.11 to 0.25	0.18	8	0.02	19.1	16.4	3.0	0.4	0.5
0.26 to 0.50	0.38	10	0.04	17.3	14.8	12.8	1.9	2.4
0.51 to 0.75	0.63	12	0.05	10.6	9.0	21.7	3.2	5.7
0.76 to 1.00	0.88	14	0.06	6.9	5.9	27.6	4.1	9.8
1.01 to 1.50	1.26	16	0.08	8.4	7.2	69.5	10.3	20.1
1.51 to 2.00	1.76	18	0.10	4.4	3.8	72.4	10.8	30.8
2.01 to 2.50	2.26	20	0.11	2.9	2.5	78.9	11.7	42.6
2.51 to 3.00	2.76	24	0.12	1.5	1.3	58.4	8.7	51.2
3.01 to 4.00	3.5	30	0.12	1.5	1.3	86.2	12.8	64.0
over 4.01	6.03	36	0.17	1.4	1.2	242.0	36.0	100.0
5239 events	44.7 years	11.81 in. max rain	Totals:	117.0	100.0	673.0	100.0	

Table 3-22 shows the variation of these large rains for the 1948 through 1999 rain period for Birmingham (41.5 years of data due to some missing data periods). From 1 to 8 (an average of 4.1) of these rains occur each year, but no obvious pattern is indicated. Table 3-23 examines these highly erosive rains for each month of the year, for this same Birmingham rain period. May through November appears to have fewer of these rains, however, September had the largest number of any month.

3-22. Number of Large Rains (>2 inches) per Year for Birmingham.

year	#/year	year	#/year	year	#/year
48	4	62	4	76	7
49	2	63	6	77	8
50	7	64	8	88	3
51	6	65	2	89	2
52	2	66	5	90	3
53	4	67	6	91	3
54	3	68	5	92	5
55	1	69	6	93	1
56	3	70	5	94	4
57	8	71	4	95	4

58	2	72	3	96	5
59	2	73	5	97	1
60	1	74	3	98	6
61	6	75	5	99	2
total:	172	min	1	st dev	2.0
average	4.1	max	8	COV	2.0

Table 3-23. Birmingham Rains by Month

	2.00 to 2.50	2.51 to 3.00	3.01 to 4.00	over 4.01	total
January	7	2	4	4	17
February	7	2	4	1	14
March	9	5	5	2	21
April	5	1	5	1	12
May	7	4	4	1	16
June	6	0	5	0	11
July	5	2	2	2	11
August	4	5	1	1	11
September	9	7	5	1	22
October	0	3	5	1	9
November	8	1	1	1	11
December	6	2	6	3	17
Total for 41.5 years of record	73	34	47	18	172
Average (#/year):	1.8	0.8	1.1	0.4	4.1

Intensity, Duration and Frequency (IDF) Information for Rains Used to Design Erosion Controls

As noted above, rains having high intensities typically contribute the highest erosion yields. Individual rains that may occur in any month can contribute excessive erosion losses. Very rare rains, occurring at most only once every year and usually much less frequently, typically receive the most attention for flooding and drainage studies. When these rare rains do occur, great erosion yields will occur and most erosion and sediment control devices will fail. As an example, Figure 3-4 shows the peak rain intensities for short rain durations and long return periods for Birmingham, AL. Rains having average intensities of almost 3 inches per hour lasting for 30 minutes are expected to occur with a 50 percent probability every year. Five minute peak rain intensities of more than 6 inches per hour also occur with a probability of at least 50 percent every year. Table3-3 lists the approximate rain depths (inches) and average rain intensities (inches per hour) associated with rain, durations from 1 to 24 hours and return frequencies of 1 to 100 years for Birmingham. Also shown on this table are three maximum probable events, associated with 6, 12, and 24 hour rain durations. It would be very difficult to design effective erosion and sediment control practices that can withstand the high runoff rates than may occur during many of these "design storm" events.

Figure 3-4. Intensity, duration, and frequency (IDF) curve for Birmingham, AL

Table 3-3. Rare Birmingham Rain Conditions

Duration (hours)	Probability (P, % occurrence per year)	Frequency (1/P, years)	Rain Depth (inches)	Rain Intensity (inches per hour)
1	100	1	1.5	1.5
2	100	1	1.9	1.0
3	100	1	2.1	0.7
6	100	1	2.5	0.4
12	100	1	3.0	0.3
24	100	1	3.5	0.1
1	20	5	2.3	2.3
2	20	5	2.8	1.4
3	20	5	3.1	1.0
6	20	5	3.8	0.6
12	20	5	4.5	0.4
24	20	5	5.3	0.2
1	10	10	2.6	2.6
2	10	10	3.3	1.7
3	10	10	3.5	1.2
6	10	10	4.3	0.7
12	10	10	5.1	0.4
24	10	10	6.0	0.3
1	4	25	3.1	3.1
2	4	25	3.6	1.8
3	4	25	4.0	1.3
6	4	25	5.0	0.8
12	4	25	6.0	0.5
24	4	25	6.9	0.3
1	2	50	3.4	3.4
2	2	50	4.0	2.0
3	2	50	4.4	1.5
6	2	50	5.5	0.9
12	2	50	6.6	0.6
24	2	50	7.6	0.3
1	1	100	3.8	3.8
2	1	100	4.4	2.2
3	1	100	4.9	1.6
6	1	100	6.0	1.0
12	1	100	7.2	0.6
24	1	100	8.4	0.4
6	Maximum probable event		31	5.2
12	Maximum probable event		37	3.1
24	Maximum probable event		42	1.8

Appendix 3B contains rainfall distribution maps for the whole country.

The Alabama Rainfall Atlas is available at: http://www.bama.ua.edu/~rain/. This web site, prepared by Dr. Rocky Durrans of the University of Alabama for the Alabama Dept. of Transportation, calculates and presents IDF curves for any location in the state of Alabama. IDF equation coefficients were calculated based on long term rain records for many state locations. This web site then interpolates the coefficients for any location on the state map and presents graphical and tabular IDF information. The IDF information is presented for 2 to 500 year rains and for 5 minutes to 48 hours durations. The web site will also produce SCS design hyetographs. Figure 3-6 is the main map that is displayed for the Atlas. The user simply clicks the mouse anywhere an IDF calculation is desired, and selects if a map or table (or both) is desired. In most cases, the “partial duration” option is probably desired in order to be more consistent with historical NOAA IDF curves (not a significant difference for the large, rare, rains, but more of an effect on the smaller events). These IDF curves are likely to vary from the “official” older NOAA IDF curves as they are obtained from more recent data (the Alabama Rainfall Atlas values seem to be slightly smaller than the NOAA values). The bottom button is then clicked to accept the choices and the desired outputs are produced. Figure 3-7 is an example for Mobile, AL, showing both an IDF graph and a table. This is a preliminary product and the “print” options indicated are not yet functioning. However, it is possible to use a simple print screen utility to capture the calculated IDF information.

Figure 3-6. Opening map for the Alabama Rainfall Atlas.

Figure 3-7. IFD information produced by the Alabama Rainfall Atlas for Mobile, AL.

Figures 3-8 and 3-9 refer to the SCS rain distribution types that are commonly used in urban drainage design. The cumulative rain distribution in Figure 3-8 shows how the rain intensities vary throughout this hypothetical event. The slope of this curve, averaged over the time of concentration (described later) is the rain intensity that corresponds to the value on the IDF curve. Figure 3-9 shows which of these rain types are applicable for different southeastern US areas. Most of the US uses type II rains, but the gulf coast and eastern seaboard use type III rains. Type I and IA are used in some parts of the western states.

Figure 3-8. Cumulative distribution curves for different SCS rain types.

Figure 3-9. SCS rain distribution types for southeastern US (NRCS 2002b)

Appendix 3B includes a map showing the rainfall distribution types for the country.

Selection of Design Storms for Varying Risks and Project Durations

The selection of appropriate control practices must consider potentially high runoff flow rates corresponding to relatively large rains. As an example, the use of filter fences is not recommended in channels that drain large areas. Filter fences are most suitable for controlling sheet flows originating from relatively small areas. More robust sediment control practices, such as wet detention ponds, are needed for treating runoff from large areas. Similarly, the use of unreinforced mulches can only be used on flat slopes with small contributing areas. The following paragraphs describe how to select an appropriate "design storm" based on acceptable failure rates and exposure periods.

The following equation (from McGhee 1991) can be used to calculate the probability that a rain having a return period of "n" years, will occur at least once in the next "y" years:

Figure 3-10 is a plot (McGhee 1991) illustrating this relationship, but modified to show the probability of an event not being exceeded during the design period. As an example, one needs to be certain, with a 90% probability that a failure would not occur during a 5-year project period (the exposure period, or T_d). A storm having a 50 year return period (T) would be the appropriate design storm frequency for this condition.

Figure 3-10. Probability of design storm (design return period) not being exceeded during the project life (design period) (from McGhee 1991).

Obviously, if failure could possibly lead to serious property damage or loss of life, then the probability of an event that may cause such failure not occurring during the project design life will need to be very large. Similarly, if only minor inconvenience will be associated with a failure, then the probability of that event not occurring during the design period can be much less. Table 3-4 illustrates several examples for a typical construction period of one year. The design storms could therefore vary greatly for different elements on the same project site. A filter fence failure may not be very serious if the site runoff is also being captured by a downstream sediment pond. However, the failure of the pond could cause much greater problems. Similarly, the slope along a filled embankment near a building foundation could cause structural failure if massive erosion occurred on the slope. In these cases and for a one year construction period, the filter fence may be designed using a 1.9 year design storm (acceptable failure probability of 50% in the one year period), the pond may require a 10 year design storm (acceptable failure probability of 10% in the one year period), while the slope near the building may need a 20+ year design storm (acceptable failure probability of <5% in the one year period).

Table 3-4. Design Storm Return Periods Associated with Different Probability Levels for a 1-year Construction Period

Probability of storm not being exceeded in a one year (T_d on Fig 2.5) construction period	Design storm return period (T on Fig 2.5)
50%	1.9 year
75%	6.5
90%	10
95%	20

Methods of Determining Runoff

Many different methods of computing runoff have been developed. Some of the methods and limitations of each are summarized on Table 3-5 and summarized below (from Illinois 1989).

Table 3-5. Selection Criteria for Runoff Calculation Methods (Illinois 1988)

Output Requirements	Drainage Area	Appropriate Method				
Peak Discharge Only	Up to 20 acres	1		3	4	5
	Up to 2,000 acres		2	3	4	5
	Up to 5 square miles		2	3		5
	Up to 20 square miles		2	3		5
Peak Discharge and Total Runoff Volume	Up to 2,000 acres		2	3	4	5
	Up to 5 square miles		2	3		5
	Up to 20 square miles		2	3		5
Runoff Hydrograph	Up to 5 square miles		2	3		5
	Up to 20 square miles		2	3		5

1 Rational Method
2 SCS TR-20 Method
3 SCS TR-55 Tabular Method
4 SCS TR-55 Graphical Peak Discharge Method
5 COE HEC-1 Method

1. The Rational Method is an empirical formula used for computing peak rates of runoff that has been used in urban areas for over 100 years (Q=CiA). It is useful for estimating runoff on relatively small areas such as roof tops, parking lots, or other homogeneous areas. Use of the rational equation should be limited to drainage areas less than 20 acres that do not vary in surface character and do not have branched drainage systems. The most serious drawback of the rational method is that it gives only the peak discharge and provides no information on the time distribution of the storm runoff, disallowing routing of hydrographs through the drainage system or storage structures. Furthermore, the choice of “C” and “Tc” when choosing “i” in the rational method is more an art of judgment than a precise account of the antecedent moisture condition or an aerial distribution of rainfall intensity. Many errors have been reported in the use of the Rational Method, and it cannot be easily verified. Modifications of the rational method have similar limitations. The rational method may be applicable in small, isolated sections of construction sites. The rational method will be used later in this chapter, and in the next chapter, for predicting sheetflow runoff depth needed for shear stress calculations for isolated slopes.

2. The SCS-TR-20 computer program utilizes hydrologic soil and cover runoff curve numbers to determine runoff volumes and unit hydrographs to determine peak rates of discharge and combined hydrographs. Factors needed to use the method are the 24-hour rainfall amount, a given rainfall distribution, runoff curve numbers, time of concentration, travel time, and drainage area. This procedure probably should not be used for drainage areas less than 50 acres or more than 20 square miles. It is very useful for larger drainage basins, especially when there are a series of structures or several tributaries to be studied. Recently, a preliminary Windows version of TR-20 has become available, making the method easier to use.

3. The SCS TR-55 Tabular hydrograph is an approximation of the more detailed SCS TR-20 method. The Tabular Method divides the watershed into subareas, computes an outflow hydrograph for each, and then combines and routes each subarea hydrograph to the outlet. It is especially useful for measuring the effects of changing land use in a part of a watershed. It can also be used to determine the effects of hydraulic structures and combinations of structures, including channel modifications, at different locations in a watershed. The Tabular Method should not be used when large changes in the curve number occur among subareas within a watershed and when runoff volumes are less than about 1.5 inches for curve numbers less than 60. For most watershed conditions, however, this procedure is adequate to determine the effects of urbanization on peak rates of discharge for subareas up to approximately 20 square miles in size. The recent preliminary Windows version of TR-55 has many improvements and is much easier to use than the older manual method or the original computer version. It is applicable for many conditions at construction sites and will be described later in this chapter.

4. The SCS TR-55 Graphical Method calculates peak discharge using an assumed unit hydrograph and an evaluation of the soils, slope, and surface cover characteristics of the watershed. The assumed unit hydrograph is based on design considerations rather than meteorological factors. Correction factors for swampy or ponding conditions can be used. This method is a component of the older TR-55 procedures and is not included in the new Windows version of TR-55. It is not a very suitable tool, as it has most of the same limitations as the rational method (specifically no hydrograph routing capabilities).

5. The COE-HEC 1 provides similar evaluation as the SCS TR-20. It is a rainfall-runoff model that can be calibrated to gauge records. Like TR-20, it can be used on both simple and complex watersheds. Several years ago, the older HEC-1 was superseded by the HEC-HMS (Hydrologic Modeling System) that is a Windows based program and much easier to use. Because of its complexity, it is not a very suitable tool for use at most construction sites. However, if complex conditions exist, like at some highway sites where relatively large streams are crossed by the construction activities, its use may be warranted.

Use of the SCS (NRCS) TR-55 Method for Construction Site Hydrology Evaluations

General Description of TR-55 for Small Watersheds

The complete User Guide for TR-55 (1986 version) can be downloaded from: http://www.wcc.nrcs.usda.gov/water/quality/common/tr55/tr55.pdf. According to the NRCS (2002), Technical Release 55 (TR-55) Urban Hydrology for Small Watersheds was first issued in January 1975 as a simplified procedure to calculate the storm runoff volume, peak rate of discharge, hydrographs and storage volumes required for storm water management structures (SCS 1975). This initial version involved manual methods and assumed the Type II rainfall distribution for all calculations. In June 1986, major revisions were made in TR-55 by adding three additional rainfall distributions (Type I, IA and III) and programming the computations. Time of concentration was estimated by splitting the hydraulic flow path into separate flow phases (SCS 1986). This 1986 version is the last non-computerized version and has been widely used for drainage design in urban areas.

Even though the manual version of TR-55 is currently being phased out, its use may still be of interest when examining construction sites. In addition, the User Guide for TR-55 (SCS 1986) contains a more through description of the basic processes included in the model. A later discussion presents a description and example of the Windows version of the program.

Only the following site characteristics are needed to use TR-55: drainage area, curve number (CN), and time of concentration (Tc). With this information, it is possible to develop a hydrograph for a specific design storm. If in a complex drainage area, the watershed can be subdivided into subwatersheds for routing the flows through the system. The following paragraphs describe the elements of TR-55 that are of most interest for use on construction sites, and present examples for its use.

Selection of the Curve Number

The first part of using TR-55 is to select the curve number. The curve number is simply the single parameter that relates runoff to rainfall. This is illustrated in Figure 3-11. The following equation shows how the CN is used to calculated the runoff depth, Q in inches, from the precipitation depth, P in inches, and the curve number, CN:

$$Q = \frac{\left[P - 0.2\left(\frac{1000}{CN} - 10\right)\right]^2}{P + 0.8\left(\frac{1000}{CN} - 10\right)}$$

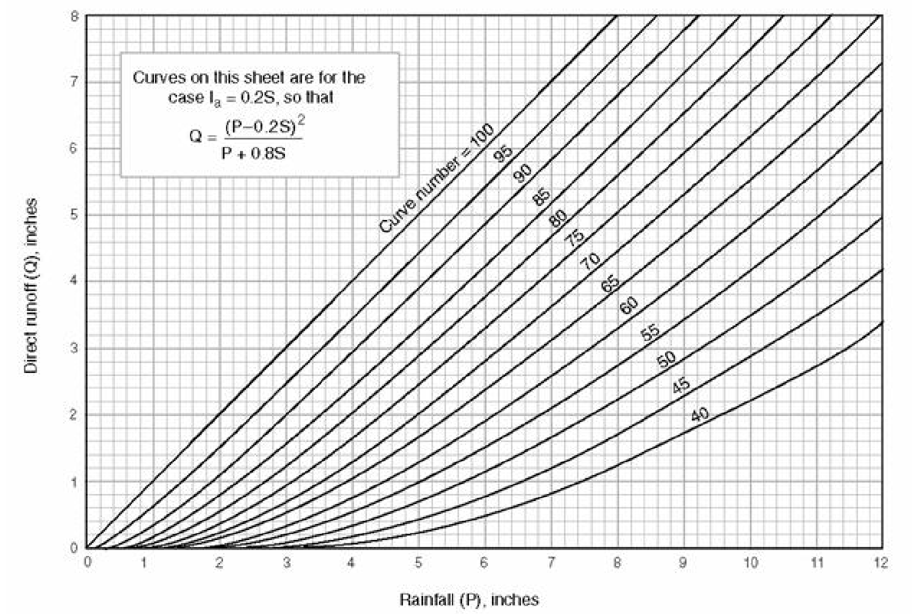
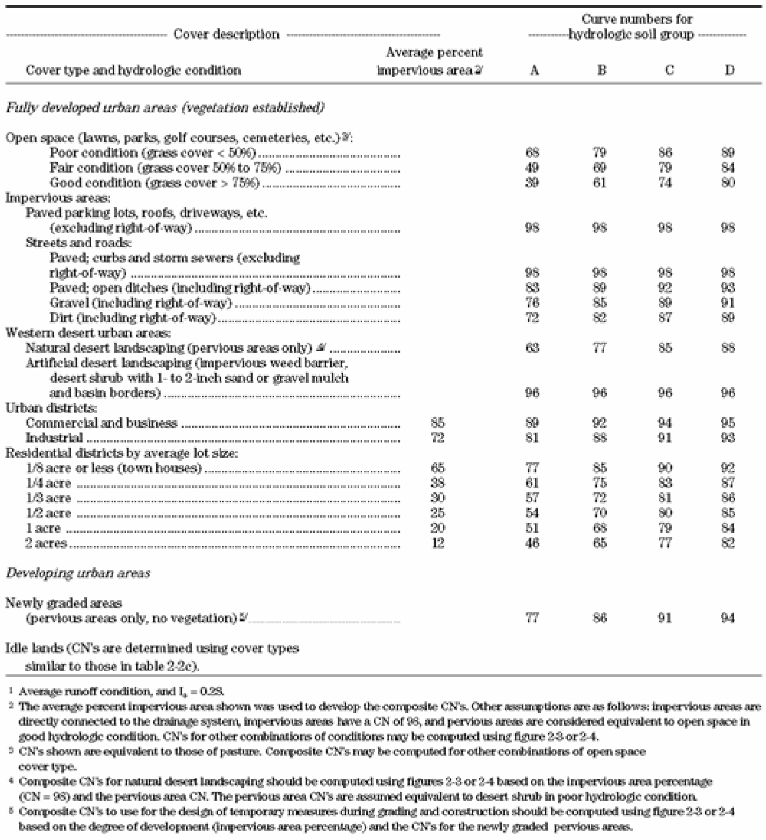


Figure 3-11. Basic SCS rainfall-runoff relationship for different CN values (SCS 1986).

Tables 3-6 and 3-7 are used to select the most appropriate curve numbers for an area. For construction sites, Table 3-6 shows that newly graded areas have curve numbers ranging from 77 for A type soils to 94 for D type soils. These are relatively high compared to typical pre-development conditions (woods ranging from 30 to 77), reflecting the increase in runoff volume during the period of construction, and the associated increased runoff rate.

Table 3-6. Typical Curve Number Values for Urban Areas (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%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (excluding right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
Natural desert landscaping (pervious areas only) [4]		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)		96	96	96	96
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Developing urban areas					
Newly graded areas (pervious areas only, no vegetation) [5]		77	86	91	94
Idle lands (CN's are determined using cover types similar to those in table 2-2c).					

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

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

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

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

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

Table 3-7. Typical Curve Number Values for Pasture, Grassland, and Woods (SCS 1986)

Soil Characteristics
The hydrologic soil groups (HSG) shown on the curve number tables greatly affect the selected curve number for a specific cover type or landuse type. The following are the descriptions for the four soil categories, as given by the SCS (1986):

> “Group A soils have low runoff potential and high infiltration rates, even when thoroughly wetted. They consist chiefly of deep, well to excessively drained sands or gravels and have a high rate of water transmission (greater than 0.30 in/hr).
>
> 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 coarser textures. These soils have a moderate rate of water transmission (0.15 to 0.30 in/hr).
>
> 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 textures. These soils have a low rate of water transmission (0.05 to 0.15 in/hr).
>
> 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 imperious material. These soils have a very low rate of water transmission (0 to 0.05 in/hr).”

The transmission rates noted above are the rates that water moves within the soil and is controlled by the soil profile. These are not the same as the water infiltration rates which are the rates that water enters the soil at the soil surface and are therefore controlled by surface conditions. For undisturbed natural conditions, the soil characteristics are usually obtained from local county soil maps that are available from the county USDA offices for all areas of the US. Consider the following example from a local county soil survey. Figure 3-11b is a small section of the soil survey map for the Cripple Creek Church area, adjacent to Cripple Creek and North River, in Tuscaloosa County, AL. The maps are also aerial photographs (usually several decades old) that show the presence of woods, agricultural operations, and land development features, along with waterways. The large numbers (15 and 22) are the sections numbers. These sections are located in R. 10 W. and T. 18 S. The small numbers (21, 23, and 33) refer to the soil types within the dark outlines. These are the soils of interest for this area. About two soil samples per square mile were obtained and analyzed by USDA soil scientists in the preparation of these maps, so they are not absolutely accurate for small areas. They were able to extend the likely areas associated with each soil type based on surface features and using aerial photographs. As an example, soil 21 (Montevallo) are generally in the bottom lands along the creeks. Table 3-7b lists some of the characteristics of these soils pertaining to erosion and runoff considerations, while Table 3-7c shows detailed particle-size information for samples obtained at different depths for Smithdale soil (the only one of these 3 with this information given in the soil survey) and Table 3-7d lists some potential problems that may be encountered if the site is to be used for building development.

Figure 3-11b. Cripple Creek Church, Tuscaloosa County, AL, soil survey.

Table 3-7b. Soil Survey Characteristics for Area Near Cripple Creek Church, Tuscaloosa County, AL

Soil number (name) and depth	Hydrologic Soil Group	Depth to Bedrock (inches)	Permeability (in/hr)	Erosion Factor, k	Tolerable Soil Loss, T (tons/ac/yr)	Organic Matter (%)	
21 (Montevallo)	D	10-20			2	0.5-2	
0-7			0.6-2.0	0.37			
7-12			0.6-2.0	0.32			
12-20			--	--			
23 (Nauvoo)	B	40-60			3	0.5-2	
0-17			2.0-6.0	0.28			
17-35			0.6-2.0	0.32			
35-41			0.6-2.0	0.32			
41-60			--	--			
33 (Smithdale)	B	>60			5	0.5-2	
0-5			2.0-6.0	0.28			
5-42			0.6-2.0	0.24			
42-72			2.0-6.0	0.28			

Table 3-7c. Particle-Size Distribution for Smithdale Soil (percent in size category, less than 2 mm)

Sample Number	Depth (inches)	Horizon	Clay (<0.002 mm)	Silt (0.002 – 0.05 mm)	Sand (0.05 – 2.0 m)	Cation Exchange Capacity (meq/100 mL)
S77AL-125-11-1	0-5	Ap	2.8	29.2	68.0	3.65
S77AL-125-11-2	5-20	B21t	22.2	34.9	42.9	9.02
S77AL-125-11-3	20-42	B22t	20.2	29.1	50.7	5.36
S77AL-125-11-4	42-52	B23t	12.3	26.5	61.2	4.06
S77AL-125-11-5	52-72	B2t	21.2	12.8	66.0	3.52

Table 3-7d. Building Site Development Limitations

Soil	Shallow Excavations	Local Streets and Roads	Dwellings with Basements	Lawns and Landscaping
21 (Montevallo)	Severe (depth to rock, slope)	Severe (slope)	Severe (depth to rock, slope)	Severe (droughty, slope, thin soil layer)
23 (Nauvoo)	Slight	Moderate (low strength)	Slight	Slight
33 (Smithdale)	Moderate (slope)	Moderate (slope)	Moderate (slope)	Moderate (slope)

The information summarized on these tables is only a small fraction of the tremendous amount of information in the soil surveys. Unfortunately, not all of this information can be used for developed areas, or for areas undergoing development. Soils are dramatically altered during construction projects. These changes range from stripping off the topsoil and compacting the remaining soil, to removing large amounts of native soils in cut operations, to bringing in large amounts of new material if fill is needed. The surface soils exposed to potential erosion and which affects the amount of runoff at the site can therefore vary for different construction phases.

Therefore, it is important to determine the native soils on the proposed construction site (an overlay of soil types is usually required for most erosion control plans). Widely varying soil characteristics on the site should be especially noted. Descriptions of how the soils (and topography) will be affected and changed are also needed. The excavations and fills during different construction phases should be described by the depth of material to be removed, or brought in, and the resulting surface soils. The SCS (1986) notes that due to urbanization, the soil profile may be considerably altered and the soil survey data may not be applicable for final surface soil conditions. They recommend that the hydrologic soil group be estimated based on the soil texture. They provide the following list to estimate the soil groups, based on texture, provided that significant compaction has not occurred:

HSG	Soil Textures
A	Sand, loamy sand, or sandy loam
B	Silt, silt loam or loam
C	Sandy clay loam
D	Clay loam, silty clay loam, sandy clay, silty clay, or clay

Figure 3-11c shows the standard USDA soil triangle with the hydrologic soil groups marked, based on the above categories. Soil compaction can have severe effects on the runoff potential of soils and needs to be considered. Table 3-7e shows the results of controlled laboratory tests measuring the water transmission rates for different soil mixtures with varying levels of compaction. Also shown are the effects of duration for some of the test conditions. In all cases, except for the clay loam, the uncompacted soils behaved as predicted and as shown on the USDA soil triangle, Figure 3-11c. Clay loam had a unexpectedly high water transmission rate for the uncompacted soil. In all cases, except for 100% sand, compaction resulted in significantly reduced water transmission rates, resulting in a different HSG than if uncompacted. All severely compacted soils, except for 100% sands, are in the D category. Sands remain in the A category for all compaction conditions. During the tests, the transmission rates for sands dropped significantly, but still remained in the HSG A category.

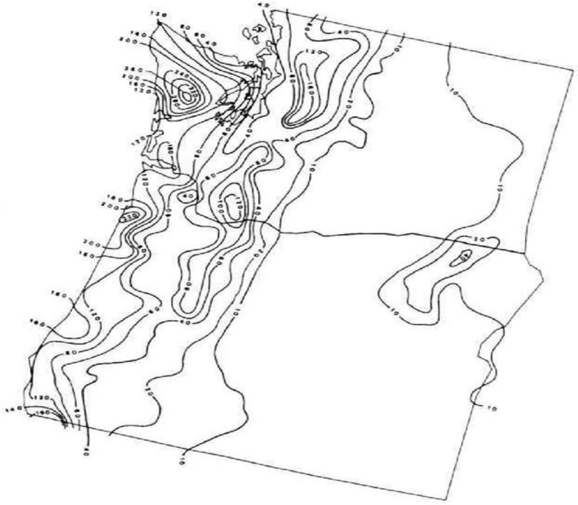


Figure 3-11c. USDA standard soil triangle, with hydrologic soil groups for disturbed soils.

Table 3-7e. Laboratory Water Transmission Tests for Various Soil Textures and Densities (densities and observed infiltration rates for different durations) (Pitt, *et al.* 2002)

	Hand Compaction	**Standard Compaction**	**Modified Compaction**
Sand (100% sand)	Density: 1.36 g/cc (ideal for roots) 0 to 1.6 hrs: A	Density: 1.71 g/cc (may affect roots) 0 to 2.7 hrs: A	Density: 1.70 g/cc (may affect roots) 0 to 2.7 hrs: A
Silt (100% silt)	Density: 1.36 g/cc (close to ideal for roots) 0 to 35 hrs: B	Density: 1.52 g/cc (may affect roots) 0 to 48 hrs: D	Density: 1.75 g/cc (will likely restrict roots) 0 to 48 hrs: D
Clay (100% clay)	Density: 1.45 g/cc (may affect roots) 0 to 48 hrs: D	Density: 1.62 g/cc (will likely restrict roots) 0 to 100 hrs: D	Density: 1.88 g/cc (will likely restrict roots) 0 to 100 hrs: D
Sandy Loam (70% sand, 20% silt, 10% clay)	Density: 1.44 g/cc (close to ideal for roots) 0 to 7.5 hrs: A	Density: 1.88 g/cc (will likely restrict roots) 0 to 3.82 hrs: A 3.82 to 24.32 hrs: B	Density: 2.04 g/cc (will likely restrict roots) 0 to 175 hrs: D
Silty Loam (70% silt, 20% sand, 10% clay)	Density: 1.40 g/cc (may affect roots) 0 to 7.22 hrs: B 7.22 to 47 hrs: C	Density: 1.64 g/cc (will likely restrict roots) 0 to 144 hrs: D	Density: 1.98 g/cc (will likely restrict roots) 0 to 144 hrs: D
Clay Loam (40% silt, 30% sand, 30% clay)	Density: 1.48 g/cc (may affect roots) 0 to 6.1 hrs: A	Density: 1.66 g/cc (will likely restrict roots) 0 to 93 hrs: D	Density: 1.95 g/cc (will likely restrict roots) 0 to 93 hrs: D

Time of Concentration Calculations

The time of concentration needs to be determined for each subwatershed in the study area. It is usually necessary to investigate several candidate flow paths in order to be relatively certain of the one that takes the longest time to reach the end of the subwatershed area. There are many different time of concentration formulas typically presented in hydrology textbooks, usually for different conditions and locations. The SCS/NRCS method has become relatively common recently and it is necessary to use this method when using TR-55 (and TR-20). This method separates the flow path into three segments: sheetflow, shallow concentrated flow, and channel flow. In some cases, especially for small sites, only sheetflow and possibly shallow concentrated flow may be evident. The candidate flow paths are drawn on a site topographic map, usually originate on the subwatershed boundary, and proceeding all the way to the bottom of the subwatershed. Sheetflow is usually the first element considered and normally is assumed to last for a maximum of 300ft, using a kinematic solution to Manning's equation. Some states limit its' use to even shorter lengths. The flow path is then assumed to occur as shallow concentrated flow, until a designated channel on the topographic map is reached (usually taken as a designated creek or stream on a USGS quadrangle map). When several candidate flow paths are evaluated, the one with the longest travel time is assumed to represent the time of concentration for the subwatershed. If a rain lasts for that time period, runoff will therefore occur from the complete area, resulting in maximum runoff rates.

The following discussions show how the travel times are calcualted for each flow path element.

Sheetflow

The following equation (a kinematic solution to the Manning's equation) is used in the SCS procedures to calculate the travel time along the sheetflow path segment:

Where:

T_t = travel time (hr)
n = Manning roughness coefficient (for sheet flow)
L = flow length (ft) (maximum of 300 ft.)
P_2 = 2-year, 24-hour rainfall depth (in), and
s = slope of hydraulic grade line (land slope, ft/ft)

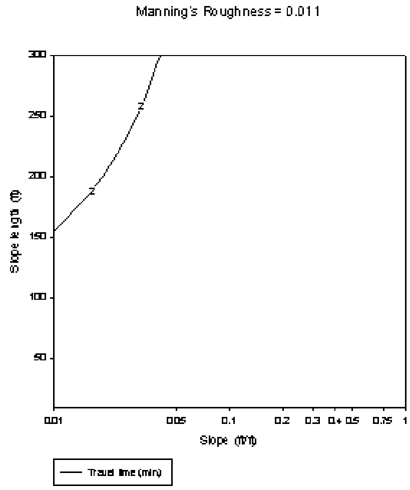
The sheetflow Manning's n roughness coefficient values are different from the channel lining roughness coefficients. Table 3-8 lists these sheetflow values. These are all greater than the channel lining n values for the rougher surfaces, due to the shallow nature of the flows. As an example, a common channel lining n value for grass is 0.024, while the sheetflow n value for grass is 0.24, or 10 times higher. The grass has a much greater effect on flow when the flow is shallow than when the flow is deep. However, the smooth surface sheetflow n values (0.011) are very similar to the values that would be used for these surfaces in channels. This is because these smooth surfaces have a minimal effect on shallow and deeper flows due to their relatively low roughness heights. An important factor for construction sites is the roughness coefficient of 0.011 for bare soils, compared to cultivated soils (with mulch covers of >20%) of 0.17, and dense grasses of 0.24. Natural woods can have n coefficients of 0.4 to 0.8, depending on the height of the underbrush. Figure 3-12 includes graphs that can be used to estimate the travel time for different sheetflow conditions, calculated using the above SCS sheetflow formula, using a P_2 value of 4.2 inches (appropriate for Birmingham, AL). If the P2 ratio is not 4.2 inches, the Figure 3-12 values can be adjusted using the above sheetflow equation.

Table 3-8. Sheetflow Manning's Equation Roughness Coefficients (SCS 1986)

Surface Description	Sheetflow Roughness Factor, n
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 prairie	0.15
Dense grass[1]	0.24
Bermudagrass	0.41
Range (natural)	0.13
Woods[2]	
Light underbrush	0.40
Dense underbrush	0.80

[1] includes species such as weeping lovegrass, bluegrass, buffalo grass, blue gama grass, and native grass mixtures

[2] When selecting n for woods, consider cover to a height of about 0.1 ft. This is the only part of the plant cover that will obstruct sheet flow.

<table>
<tr>
<td>


Smooth surfaces (concrete, asphalt, gravel, or bare soil)
</td>
<td>

Fallow (no residue)
</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</table>

Cultivated soils: residue cover ≤ 20%	**Cultivated soils: residue cover > 20%**

Figure 3-12. Sheetflow travel times.

Grass: short grass prairie	**Grass, dense (weeping lovegrass, bluegrass, buffalo grass, blue gama grass, and native grass mixtures**
Grass: burmudagrass	**Range (natural)**

Figure 3-12. Sheetflow travel times (cont).

Woods, light underbrush (considering cover to height of about 0.1 ft)	**Woods: dense underbrush (considering cover to height of about 0.1 ft)**

Figure 3-12. Sheetflow travel times (cont).

Shallow Concentrated Flow

After a maximum of 300 ft., sheetflow usually becomes shallow concentrated flow which is characterized by much narrower flow paths and faster flows. The following equations are used to calculate the velocities of this flow segment, based on the nature of the surface (paved or unpaved). Figure 3-13 contains graphical solutions for these equations.

(Unpaved)

(Paved)

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

These two equations are based on a solution of the Manning equation with different assumptions for *n* (Manning roughness coefficient) and R (hydraulic radius, ft). For unpaved areas, *n* is 0.05 and R is 0.4 ft; for paved areas, *n* is 0.025 and R is 0.2 ft. The travel time associated with the shallow concentrated flow segment is calculated using this velocity and the flow path length.

Figure 3-13 . Shallow concentrated flow velocities (SCS 1986).

Channel Flow
If the flow path includes a designated channel shown on a USGS quadrangle map, the Manning’s equation is used to calculate the velocity in the channel reach. The travel time in the reach is then calculated using this channel-full velocity and the length of the channel.

Where:

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

This is the conventional Manning’s equation, and appropriate channel lining n coefficients are used.

Example Travel Time Calculation
The TR-55 User Guide (SCS 1986) includes the following example. Figure 3-14 shows a watershed in Dyer County, which is located in northwestern Tennessee. The problem is to compute Tc 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 Tc, first determine Tt for each segment from the following information:

Segment AB: Sheetflow; dense grass; slope (s) = 0.01 ft/ft; and length (L) = 100 ft.
Segment BC: Shallow concentrated flow; unpaved; s = 0.01 ft/ft; and L = 1400 ft.
Segment CD: Channel flow; Manning’s n = 0.05; flow area (a) = 27 ft^2;
wetted perimeter (pw) = 28.2 ft; s = 0.005 ft/ft; and L=7300ft.

Figure 3-14. Watershed for TR-55 Tt calculation example (SCS 1986).

Figure 3-15 is the SCS worksheet showing the calculations for the above problem. In this case, each flow segment is comprised of a single condition of slope and cover. In many cases, the individual flow segments may need to be broken up into subunits to represent different slopes or roughness coefficients. The travel times for each of the segments are added. For the sheetflow segment, however, the travel length must still be less than 300 ft. in total, not for each calculation interval. Worksheet 3 has two columns to facilitate two segments for each portion. Additional segments may be needed. In this example, the total travel time for this flow path from A to D is 1.53 hours, with almost 1 hour associated with the channel flow time. For small sites, including most construction sites, the sheetflow segment will likely comprise the largest portion of the total flow time.

Again, in order to determine the time of concentration for the watershed, several different candidate flow paths are usually needed to be evaluated and the one with the longest travel time is used as the time of concentration. This may not be the path with the longest travel distance, but may be a shorter path affected by shallower slopes and rougher covers.

Figure 3-15. Calculation example for travel time problem (SCS 1986).

Tabular Hydrograph Method

The SCS TR-55 tabular hydrograph method (SCS 1986) can be used to develop a hydrograph for each subwatershed area than can then be routed through the downstream project segments. This method will also produce the total runoff volume and the peak flow rate. This method is not used in the new WinTR-55; this computerized version uses the more complete routing procedures from TR-20. However, the following is still presented as an optional method and to illustrate the sensitivity of Tc and CN selections. Appendix 3A includes all of the tabular hydrograph tables that can be used to calculate hydrographs for all locations in the US.

Example Tabular Hydrograph Calculation

The following example is from the TR-55 manual (SCS 1986) and illustrates how the Tc, CN, and other site characteristics are used to develop and route hydrographs for a complex watershed.

This example computes the 25-year frequency peak discharge at the downstream end of subarea 7 shown in Figure 3-16. This example is for present conditions and uses the worksheets presented in SCS (1986). Calculate the present condition CN, Tc, and Tt for each subarea, using the procedures in TR-55 chapters 2 and 3. These values are entered on worksheet 5a (Figure 3-17). Then, the tabular hydrograph tables are used to determine the normalized hydrograph for downstream locations.

The hydrograph tables are presented in SCS (1986) according to rain type (there are sections of tables for types I, Ia, II, and III rain distributions). The first step is to find the table section pertaining to the rain distribution for the study area. In this case, the area has type II rains. The type II rain hydrograph tables are further grouped according to the Tc for the subarea, ranging from 0.1 to 2 hours. In the case for subarea #1, the Tc is 1.5 hours, so pg 5-37 from SCS (1986) is used (Table 3-9). Each page is further divided into three segments, corresponding to Ia/P ratios of 0.10, 0.30, and 0.50. The Ia is the initial abstractions for the area (not to be confused with rain distribution type Ia) and are a direct function of the CN value. These are given in the User Guide (SCS table 5-1), and on Table 3-16b. The P is the total rain depth being evaluated. The top set of values are used for Ia/P ratios of ≤ 0.2, the middle set for ratios from 0.2 to 0.4, while the bottom set is used for ratios of > 0.4 (interpolation is not used; WinTR-55 and TR-20 calculate more precise values based on actual site conditions). In this case, the #1 subarea Ia/P is 0.18, so the top set of values are used. Finally, each segment has 12 lines representing different travel times from the bottom of the subwatershed area to the location of interest. The largest unit peak runoff rate values (csm/in, or cubic feet per second of runoff per square mile of drainage area, per inch of direct runoff) on each line start close to 12 hours for the top time, and shift to the right as the travel time increases. The shift between the largest values for each row is equal to the differences in the travel times between each line, representing routing of the hydrographs as they travel downstream. For the #1 subarea, the Tt is 2.5 hours. Therefore, the line near the bottom of the top segment, representing 2.5 hours, is used. The values in the table represent normalized hydrographs and are multiplied by AmQ (the factor of the watershed area, in mi^2 and the direct runoff in inches) to obtain the flow values in traditional units of ft^3/sec, or cfs. These final cfs values are written on worksheet 5b (Table 3-10). As an example, the appropriate values for the peak discharge (q) for subarea 4 at 14.6 hr is:

$$q = qt(AmQ) = (274)(0.70) = 192 \text{ cfs}$$

Once all the prerouted subarea hydrographs have been tabulated on worksheet 5b, they are summed to obtain the composite hydrograph. The resulting 25-year frequency peak discharge is 720 cfs at 14.3 hr, as shown on Table 3-10.

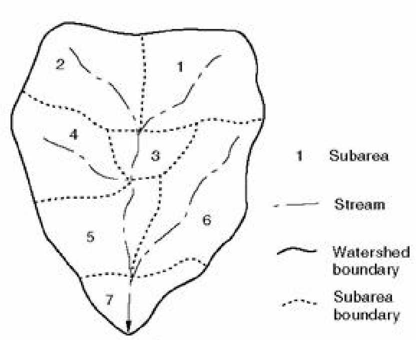


Figure 3-16. Example watershed for tabular hydrograph calculations (SCS 1986).

Table 3-16b. I_a Values for Runoff Curve Numbers (SCS 1986)

Curve Number	I_a (inch)	Curve Number	I_a (inch)	Curve Number	I_a (inch)
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
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		

Figure 3-17. Worksheet 5a for showing basic watershed data (SCS 1986).

Table 3-9. Tabular Hydrograph Table for Example Problem (SCS 1986, pg 5-37)

Table 3-10. Worksheet 5b for Example Hydrograph Calculation (SCS 1986)

Tabular Hydrograph Example for Urban Watershed

The following example is for a typical urban watershed, having four subareas that are quite different in their development characteristics. The following lists the procedure for evaluating this area:

1) subdivide the watershed into relatively homogeneous subareas (as shown in Figure 3-18)

Figure 3-18. Relatively homogeneous subareas in example urban watershed.

2) calculate the drainage for each subarea:

I	0.10 mi^2
II	0.08
III	0.6
IV	0.32
Total:	1.12

3) calculate the time of concentration (Tc) for each subarea (TR-55 chapter 3):

I	0.2 hrs
II	0.1
III	0.3
IV	0.1

4) calculate the travel time (Tt) from each subarea discharge location to the location of interest (outlet of total watershed in this example) (TR-55 chapter 3):

I	0.1 hrs
II	0.05
III	0.05
IV	0

5) select the curve number (CN) for each subarea:

I	Strip commercial, all directly connected	CN = 97
II	Medium density residential area, grass swales	CN = 46
III	Medium density residential area, curbs and gutters	CN = 72
IV	Low density residential area, grass swales	CN = 40

6) rainfall distribution: Type II for all areas

7) 24-hour rainfall depth for storm: 4.1 inches

8) calculate total runoff (inches) from CN and rain depth (from SCS fig. 2-1)

I	CN = 97	P = 4.1 in.	Q = 3.8 in.
II	CN = 46	P = 4.1 in.	Q = 0.25
III	CN = 72	P = 4.1 in.	Q = 1.5
IV	CN = 40	P = 4.1 in.	Q = 0.06

9) determine Ia for each subarea (assumes Ia = 0.2 S) (SCS table 5-1):

I	CN = 97	Ia = 0.062 in.
II	CN = 46	Ia = 2.348 in.
III	CN = 72	Ia = 0.778 in.
IV	CN = 40	Ia = 3.000 in.

10) calculate the ratio of Ia to P

I	Ia/P = 0.062/4.1 = 0.015
II	Ia/P = 2.348/4.1 = 0.57
III	Ia/P = 0.778/4.1 = 0.19
IV	Ia/P = 3.000/4.1 = 0.73

11) use worksheets SCS 5a and 5b to summarize above data and to calculate the composite hydrograph. These are shown in Tables 3-11 and 3-12.

Table 3-11. SCS Worksheet 5a for Urban Example

Table 3-12. SCS Worksheet 5b for Urban Example

The peak flow is seen to be 910 cfs, occurring at 12.3 hours. Figure 3-19 is a plot of the 3 main components, plus the total hydrograph. Subarea III contributed most of the peak flow to the total hydrograph, while subareas II and IV contributed insignificant flows. The following chapter section introduces WinTR-55 and presents this same example. The main differences is that WinTR-55 requires a description of the channel as it calculates the travel times and conducts the channel routing using a more precise procedure. In addition, the hydrograph development uses TR-20, instead of the tabular hydrograph method.

Figure 3-19. Plot of individual and composite hydrograph for urban example.

Example use of WinTR55

The following discussion is summarized from the WinTR-55 user guide information, while the example uses the previously described information.

A WinTR-55 work group was formed in the spring of 1998 to modernize and revise TR-55 and the computer software. The current changes included: upgrading the source code to Visual Basic, changing the philosophy of data input, developed a Windows interface and output post-processor, enhanced the hydrograph-generation capability of the software and flood route hydrographs through stream reaches and reservoirs.

The availability and technical capabilities of the personal computer have significantly changed the philosophy of problem-solving for the engineer. Computer availability eliminated the need for TR-55 manual methods, thus the manual portions (graphs and tables) of the user document have been eliminated. The WinTR-55 user manual (NRCS 2002a) covers the procedures used in and the operation of the WinTR-55 computer program. Part 630 of the Natural Resources Conservation Service (NRCS) National Engineering Handbook provides detailed information on NRCS hydrology and is the technical reference for WinTR-55.

Program Description

WinTR-55 is a single-event rainfall-runoff small watershed hydrologic model. The model generates hydrographs from both urban and agricultural areas and at selected points along the stream system. Hydrographs are routed downstream through channels and/or reservoirs. Multiple sub-areas can be modeled within the watershed.

Model Overview

A watershed is composed of subareas (land areas) and reaches (major flow paths in the watershed). Each subarea has a hydrograph generated from the land area based on the land and climate characteristics provided. Reaches can be designated as either channel reaches where hydrographs are routed based on physical reach characteristics or as storage reaches where hydrographs are routed through a reservoir based on temporary storage and outlet characteristics. Hydrographs from sub-areas and reaches are combined as needed to accumulate flow as water moves from the upland areas down through the watershed reach network. The accumulation of all runoff from the watershed is represented at the watershed outlet. Up to ten sub-areas and ten reaches may be included in the watershed.

WinTR-55 uses the TR-20 (NRCS 2002b) model for all of the hydrograph procedures: generation, channel routing, storage routing, and hydrograph summation. Figure 3-20 is a diagram showing the WinTR-55 model, its relationship to TR-20, and the files associated with the model.

Figure 3-20. WinTR-55 system schematic (NRCS 2002a).

Capabilities and Limitations
WinTR-55 hydrology has the capability to analyze watersheds that meet the criteria listed in Table 3-13:

Table 3-13. WinTR-55 Capabilities & Limitations (NRCS 2002a)

Variable	Limits
Minimum area	No absolute minimum is included in the software. However, carefully examine results from sub-areas less than 1 acre.
Maximum area	25 square miles (6,500 hectares)
Number of Subwatersheds	3-10
Time of concentration for any sub-area	$0.1 \text{ hour} \le T_c \le 10 \text{ hour}$
Number of reaches	0-10
Types of reaches	Channel or Structure
Reach Routing	Muskingum-Cunge
Structure Routing	Storage-Indication
Structure Types	Pipe or Weir
Structure Trial Sizes	3-3
Rainfall Depth[1]	Default or user-defined 0 – 50 inches (0-1,270 mm)
Rainfall Distributions	NRCS Type I, IA, II, III, NM60, NM65, NM70, NM75, or user-defined
Rainfall Duration	24-hour
Dimensionless Unit Hydrograph	Standard peak rate factor 484, or user-defined (e.g. Delmarva—see Example 3)
Antecedent Moisture Condition	2 (average)

[1] Although no minimum rain depth is listed by the NRCS in the above table, it must be recognized that the original SCS curve number methods, incorporated in this newer version, are not accurate for small storms. In most cases, larger storms used for drainage design are reasonably well suited to this method. Pitt (1987) and Pitt, *et al*. (2002) showed that rain depths less than 2 or 3 inches can have significant errors when using the CN approach.

Model Input
The various data used in the WinTR-55 procedures are user entered via a series of input windows in the model. A description of each of the input windows follows the figure. Data entry is needed only on the windows that are applicable to the watershed being evaluated.

Minimum Data Requirements. While WinTR-55 can be used for watersheds with up to ten sub-areas and up to ten reaches, the simplest run involves only a single sub-area. Data required for a single sub-area run can be entered on the TR-55 Main Window. These data include**: Identification Data**-User, -State, -County, -Project, and -Subtitle; **Dimensionless Unit Hydrograph**; **Storm Data; Rainfall Distribution**; and **Subarea Data.** The subarea data can be entered directly into the Subarea Entry and Summary table**: Subarea name, subarea description, subarea flows to reach/outlet**, **area**, **runoff curve number** (RCN), and **time of concentration** (T_c). Detailed information for the subarea RCN and T_c can be entered here or on other windows; if detailed information is entered elsewhere the computational results are displayed in this window.

Watershed Subareas and Reaches. To properly route stream flow to the watershed outlet, the user must understand how WinTR-55 relates watershed subareas and stream reaches. Figure 3-21 and Table 3-14 show a typical watershed with multiple sub-areas and reaches.

Figure 3-21. Sample Watershed Schematic (NRCS 2002a)

Table 3-14. Sample Watershed Flows (NRCS 2002a)

Subarea	Flows into Upstream End of	Reach	Flows into
Area I	Reach A	Reach A	Reach C
Area II	Reach C	Reach B	Reach C
Area III	Reach C	Reach C	OUTLET
Area IV	Reach B	Reach D	OUTLET
Area V	Reach C	Reach E	OUTLET
Area VI	Reach E		
Area VII	OUTLET		
Area VIII	OUTLET		
Area IX	Reach D		
Area X	OUTLET		

Reaches define flow paths through the watershed to its outlet. Each subarea and reach contribute flow to the upstream end of a receiving reach or to the Outlet. Accumulated runoff from all sub-areas routed through the watershed reach system, by definition, is flow at the watershed outlet.

Processes
WinTR-55 relies on the TR-20 model for all hydrograph processes. These include: hydrograph generation, combining hydrographs, channel routing, and structure routing. The program now uses a Muskingum-Cunge method of channel routing (Chow, *et al.* 1988; Maidment 1993; Ponce 1989). The storage-indication method (NRCS NEH Part 630, Chapter 17) is used to route structure hydrographs.

Example WinTR-55 Setup and Operation

An application using WinTR-55 and the previously presented urban watershed example, is shown on Figures 3-22 through 3-31. Figures 3-32 and 3-33 are other screens available in WinTR-55 that can be used to aid in the calculation of some of the site data, while Figure 3-34 is used for detention facilities (structures).

Figure 3-22. WinTR-55 opening screen.

Figure 3-23. WinTR-55 small watershed basic information screen.

Figure 3-24. WinTR-55 reach data screen.

Figure 3-25. WinTR-55 reach flow path screen.

Figure 3-26. WinTR-55 reach routing screen.

Figure 3-27. WinTR-55 storm data screen (information automatically determined by location).

Figure 3-28. WinTR-55 event selection/run screen.

Figure 3-29. WinTR-55 calculated hydrograph summary screen.

Figure 3-30. WinTR-55 hydrograph plot screen.

Figure 3-31. WinTR-55 report generation screen.

Figure 3-32. WinTR-55 land use details screen (if data not directly entered).

Figure 3-33. WinTR-55 time of concentration details screen/calculator (if data not directly entered).

Figure 3-34. WinTR-55 structure data screen for detention facilities.

This WinTR-55 example resulted in a peak flow for the 2-yr storm of about 730 cfs, compared to the previously calculated value of 910 cfs. This difference is due to the different routing procedure used, plus the more precise hydrograph development procedure in the updated WinTR-55 version compared to the tabular hydrograph method.

Example Applications to Construction Sites

As indicated previously, there are a number of situations where WinTR-55 (or TR-55) can be used to advantage when evaluating construction sites, including the design of erosion and sediment controls. These may include:

- Determination of flows going away from the site affecting downstream areas. Downstream erosion controls may include filter fencing along the project perimeter, or sediment ponds, depending on flow conditions. These controls must be completed before any on-site construction is started.

- Determination of upland flows coming towards the disturbed areas. These flows must be diverted by swales or dikes, or safely carried through the construction sites. Channel design will be based on the expected flow conditions. These controls must be completed after the downstream controls, and before any on-site controls are started.

- Determination of on-site flows on slopes going towards filter fencing, sediment ponds, or other controls. Needed to also evaluate shear stress on channels and on slopes.

Figure 3-35 is an example site regional map (drawn on a USGS quadrangle) showing a construction site, and associated upland and downslope drainages. This chapter illustrated how it is possible to easily calculate the runoff characteristics affecting the site and downslope areas for different rain conditions. In addition, detailed site conditions for different project phases can also be evaluated for the design of appropriate erosion and sediment controls.

Figure 3-35. Determination of general upslope and downslope drainage areas from construction site.

Figure 3-36 shows subdrainages for the upslope, downslope, and on-site areas for this example construction site. Table 3-15 summarizes the characteristics of these areas, along with the hydrologic information needs for each area. Most of the site will be cleared and graded, except for the two small areas near the downslope edge. The upslope diversions (for U2 and U3) will carry the upslope water to the main channel. As an example, the diversion length for U2 is 900 ft long and the elevation drop is 70 ft. The channel slope for this diversion is therefore 70/900 = 0.08, or 8%.The runoff from the O1 and O2 on-site areas will be controlled by slope mulches and filter fences, before the runoff drains to the on-site main channel. A sediment pond will be constructed at the downslope property boundary before this main channel leaves the site, receiving runoff from U1, U2, U3, O1, and O2. This table shows 2 different rain depths for some conditions, based on the following discussion and Table 3-17.

Table 3-16 and Figure 3-37 is an example using WinTR55 for this site. This example is for a sediment pond at the downslope boundary. Subareas O3, O4, O5, O6, and O7 are all very small and do not drain to this pond site, but drain towards the perimeter filter fabric fences. The reach data assumed for reach A (the main channel to the outlet) is as follows: 1240 ft. long at 0.04 (4%) slope, n = 0.08, and bottom width = 10 ft. The channel side slopes are 1 to 3. Table 3-16 shows subareas O1 and O2 draining into reach A, but they actually drain directly to the outlet (the pond).

Figure 3-36. Subdrainage areas on and near construction site.

Table 3-15. Upslope and On-Site Subdrainage Area Characteristics for Construction Site and TR-55 Calculations

Area Notation	Location	Objective	Area (acres)	Area (Am, mi^2)	Cover n	Average flow path slope	CN (all "C" soils)	Ia (in.)	Rain depth, P (in.)	Ia/P	Tc (min)	Tc (hr)
U1	Upslope – direct to on site stream	Hydrograph (to be combined with U2 and U3)	37.4	0.058	0.4	8%	73	0.74	5.5	0.13	29	0.48
U2	Upslope – diversion to on site stream	Peak flow rate and hydrograph (to be combined with U1 and U3)	14.6	0.023	0.4	11.5	73	0.74	5.5	0.13	25	0.42
U3	Upslope – diversion to on site stream	Peak flow rate and hydrograph (to be combined with U1 and U2)	2.4	0.0038	0.4	12.7	73	0.74	5.5	0.13	20.7	0.35
O1	On site – drainage to sediment pond and main site stream (also slope protection needed)	Peak flow rate and hydrograph	12.6	0.020	0.011	10	91	0.198	6.6 8.4	0.03 0.02	3.5	0.06
O2	On site – drainage to filter fence and main site stream (also slope protection needed)	Peak flow rate and hydrograph	7.1	0.011	0.011	10.5	91	0.198	4.0 6.0	0.05 0.03	1.6	0.03
O3	On site – towards perimeter filter fence (also slope protection needed)	Peak flow rate and hydrograph	6.1	0.0095	0.011	5	91	0.198	4.0 6.0	0.05 0.03	4.1	0.07
O4	On site – towards perimeter filter fence (also slope protection needed)	Peak flow rate and hydrograph	3.1	0.0048	0.011	6.7	91	0.198	4.0 6.0	0.05 0.03	3.3	0.06
O5	On site – towards perimeter filter fence (also slope protection needed)	Peak flow rate and hydrograph	1.8	0.0028	0.011	11.3	91	0.198	4.0 6.0	0.05 0.03	1.5	0.03
O6	On site – nothing (will remain undisturbed)	na	1.3	0.0020	0.24	6.7	na	na	na	na	na	na
O7	On site – nothing (will remain undisturbed)	na	0.3	0.00047	0.24	10	na	na	na	na	na	na

Table 3-15. Upslope and On-Site Subdrainage Area Characteristics for Construction Site and TR-55 Calculations (cont.)

Area Notation	Location	Direct Runoff, Q (inches)	area-depth (AmQ), (mi^2-inches)	Peak unit area flow rate (csm/in)	Peak discharge (ft^3/sec)
U1	Upslope – direct to on site stream	2.8	0.16	411	66
U2	Upslope – diversion to on site stream	2.8	0.064	449	29
U3	Upslope – diversion to on site stream	2.8	0.011	449	4.9
O1	On site – drainage to sediment pond and main site stream (also slope protection needed)	5.4 7.3	0.11 0.15	662	73 99
O2	On site – drainage to filter fence and main site stream (also slope protection needed)	3.0 5.0	0.033 0.055	662	22 36
O3	On site – towards perimeter filter fence (also slope protection needed)	3.0 5.0	0.029 0.048	662	19 32
O4	On site – towards perimeter filter fence (also slope protection needed)	3.0 5.0	0.014 0.024	662	9.3 16
O5	On site – towards perimeter filter fence (also slope protection needed)	3.0 5.0	0.0084 0.014	662	5.6 9.3
O6	On site – nothing (will remain undisturbed)	na	na	na	na
O7	On site – nothing (will remain undisturbed)	na	na	na	na

Table 3-16 WinTR55 Example for Sediment Pond (10-year rain event)

Figure 3-37. Subcatchment and outfall hydrographs for sediment pond location, WinTR55 example.

Design Storms for Different Site Controls

All of the information needed to calculate the expected flows from these upslope and on-site areas is shown on Table 3-17, except for the design storm. The area has a SCS type III rain distribution and the construction period will be one year. The different site features will require different design storms due to the different levels of protection that are appropriate. Table 3-17 lists the features and the (assumed) acceptable failure rates during this one year period, along with the corresponding design storm frequency and associated 24 hr rain total appropriate for the area. The design storms range from 4.0 to 8.4 inches in depth and the times of concentration range from 1.5 to 30 minutes. The design rain intensities could be very large for some of these design elements.

Table 3-17. Acceptable Levels of Protection for Different Site Activities

Site Construction Control	Acceptable Failure Rate during Site Construction Activities	Design Storm Return Period (years)	24-hr Rain Depth Associated with this Design Storm Return Period
Diversion channels	25%	6.5	5.5
Main site channel	5%	20	6.6
Site slopes	10%	10	6.0
Site filter fences	50%	1.9	4.0
Sediment pond	5% and 1%	20 and 100	6.6 and 8.4
Downslope perimeter filter fences	10%	10	6.0

Runoff Water Depth

In some designs (for shear stress calculations in the next chapter), the water depth is also needed for sheetflows. The following equation can be used to calculate the estimated water depth for sheetflow, based on the Manning's equation (R, the hydraulic radius is equal to the flow depth for sheetflow):

where: y is the flow depth (in feet),
q is the unit width flow rate (Q/W, the total flow rate, in ft^3/sec, divided by the slope width, in ft.)
n is the sheet flow roughness coefficient, and
s is the slope (as a fraction)

Important Internet Links

Alabama Rainfall Atlas:
http://bama.ua.edu/~rain/

WinTR-55 computer program (new windows beta version):
http://www.wcc.nrcs.usda.gov/hydro/hydro-tools-models-wintr55.html

TR-55 1986 documentation and early version of TR55 program:
http://www.wcc.nrcs.usda.gov/hydro/hydro-tools-models-tr55.html

TR-20 computer program (new windows beta version):
http://www.wcc.nrcs.usda.gov/hydro/hydro-tools-models-wintr20.html

National Engineering Handbook, Part 630 HYDROLOGY
http://www.nrcs.usda.gov/technical/ENG/neh.html

US Army Corps of Engineers, Hydrologic Management System User Guide (replacement for HEC-1) and River Analysis System User Guide for water surface profile calculations (replacement for HEC-2):
http://www.hec.usace.army.mil/

References

Chow, V. T., Maidment, D. R, and Mays, L. W., *Applied Hydrology*, McGraw-Hill, 586 pages. 1988.

HEC. *HEC-RAS User's Manual*, Version 2.0. US Army Corps of Engineers, Hydrologic Engineering Center, April 1997.

Illinois. *Illinois Procedures and Standards for Urban Soil Erosion and Sedimentation Control*. Association of Illinois Soil and Water Conservation Districts, Springfield, IL 62703. 1989.

Maidment, D. R. (ed.), *Handbook of Hydrology*, McGraw-Hill, 1422 pages. 1993.

McGee, T.J. *Water Supply and Sewerage*. McGraw-Hill, Inc., New York. 1991.

NRCS. National Engineering Handbook, Part 630 HYDROLOGY, downloaded June 23, 2002 at: http://www.wcc.nrcs.usda.gov/water/quality/common/neh630/4content.html

NRCS. *SITES Water Resource Site Analysis Computer Program User's Guide*. United States Department of Agriculture, Natural Resources Conservation Service. 469 pp. 2001.

NRCS. *WinTR-55 User Manual*. US Dept. of Agriculture, Natural Resources Conservation Service. Downloaded on June 23, 2002 from: http://www.wcc.nrcs.usda.gov/water/quality/common/tr55/tr55-beta.html Version dated April 23, 2002a.

NRCS. *TR-20 System: User Documentation*. United States Department of Agriculture, Natural Resources Conservation Service. 105 pp. 2002b (draft).

Ponce, V.M., *Engineering Hydrology*, Prentice Hall, 640 pages. 1989.

Pitt, R. *Small Storm Urban Flow and Particulate Washoff Contributions to Outfall Discharges*, Ph.D. Dissertation, Civil and Environmental Engineering Department, University of Wisconsin, Madison, WI, November 1987.

Pitt, R. and S.R. Durrans. *Drainage of Water from Pavement Structures*. Alabama Dept. of Transportation. 253 pgs. September 1995.

Pitt, R., J. Lantrip, R. Harrison, C. Henry, and D. Hue. *Infiltration through Disturbed Urban Soils and Compost-Amended Soil Effects on Runoff Quality and Quantity*. U.S. Environmental Protection Agency, Water Supply and Water Resources Division, National Risk Management Research Laboratory. EPA 600/R-00/016. Cincinnati, Ohio. 231 pgs. December 1999.

Pitt, R., M. Lilburn, S. Nix, S.R. Durrans, S. Burian, J. Voorhees, and J. Martinson *Guidance Manual for Integrated Wet Weather Flow (WWF) Collection and Treatment Systems for Newly Urbanized Areas (New WWF Systems).* U.S. Environmental Protection Agency. 612 pgs. 1999.

Pitt, R, S. Chen, and S. Clark. "Compacted urban soils effects on infiltration and bioretention stormwater control designs." *Global Solutions for Urban Drainage; 9IUCD*. CD-ROM Proceedings of the 9th International Urban Drainage Conference, edited by E.W. Strecker and W.C. Huber., Sept 8-13, 2002, Portland, OR. Sponsored by the ASCE, Reston, VA, and the International Water Association, London. 2002.

SCS. *Urban Hydrology for Small Watersheds.* Technical Release 55, US Department of Agriculture, Soil Conservation Service. 91 pp. 1975.

SCS (now NRCS). *Urban Hydrology for Small Watersheds*. US Dept. of Agric., Soil Conservation Service. 156 pgs. 1986.

SCS. *Time of Concentration,* Hydrology Technical Note No. N4. United States Department of Agriculture, Soil Conservation Service, Northeast National Technical Center. 12 pp. 1986.

Thronson, R.E. *Comparative Costs of Erosion and Sediment Control, Construction Activities*. U.S. Environmental Protection Agency. EPA430/9-73-016. Washington, D.C. 1973.

Welle, P.I., Woodward, D. E., Fox Moody, H.*, A Dimensionless Unit Hydrograph for the Delmarva Peninsula*, Paper No. 80-2013, ASAE 1980 Summer Meeting, 18 pp. 1980.

Appendix 3-A. Tabular Hydrograph Unit Discharges (from TR-55, SCS 1986)

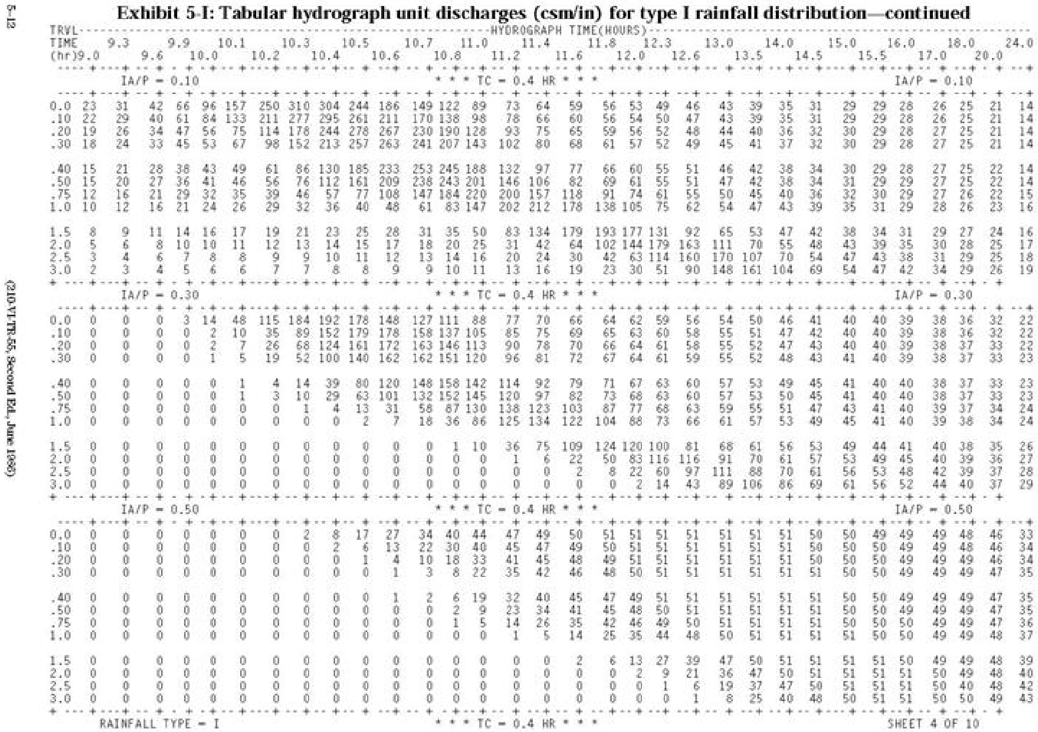
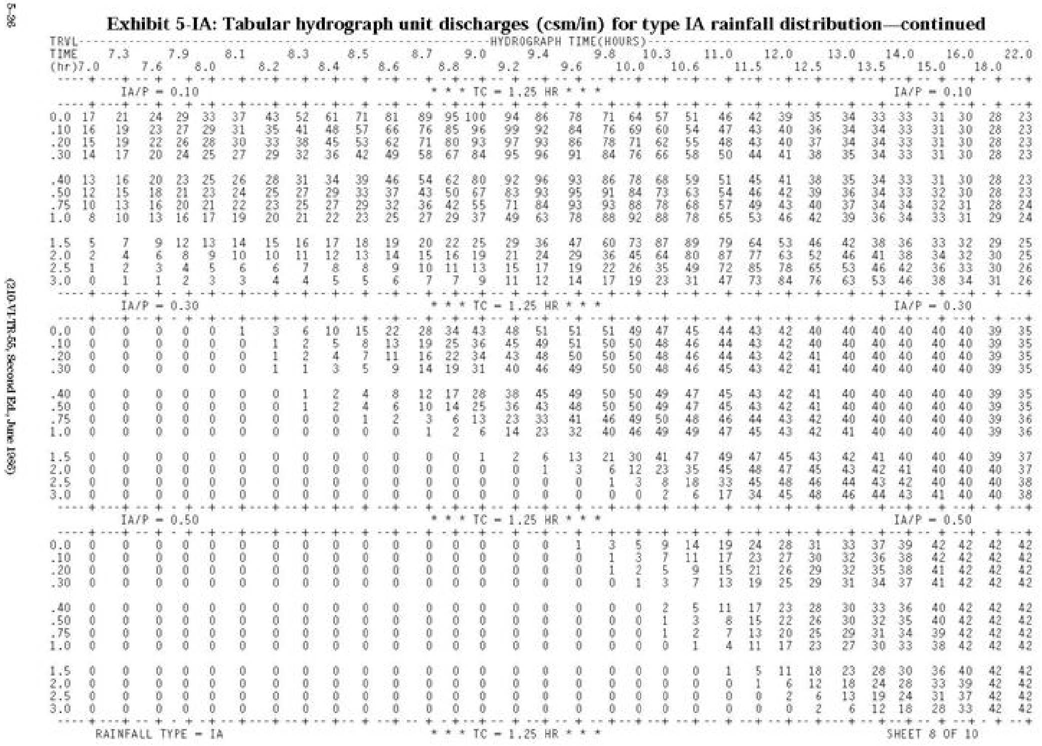


Exhibit 5-I: Tabular hydrograph unit discharges (csm/in) for type I rainfall distribution—continued

TRVL	HYDROGRAPH TIME(HOURS)																															
TIME (hr)	9.0	9.3	9.6	9.9	10.0	10.1	10.2	10.3	10.4	10.5	10.6	10.7	10.8	11.0	11.2	11.4	11.6	11.8	12.0	12.3	12.6	13.0	13.5	14.0	14.5	15.0	15.5	16.0	17.0	18.0	20.0	24.0
IA/P = 0.10														* * * TC = 0.4 HR * * *															IA/P = 0.10			
0.0	23	31	42	66	96	157	250	310	304	244	186	149	122	89	73	64	59	56	53	49	46	43	39	35	31	29	29	28	26	25	21	14
.10	22	29	40	61	84	133	211	277	295	261	211	170	138	98	78	66	60	56	54	50	47	43	39	35	31	29	29	28	26	25	21	14
.20	19	26	34	47	56	75	114	178	244	278	267	230	190	128	93	75	65	59	56	52	48	44	40	36	32	30	29	28	27	25	21	14
.30	18	24	33	45	53	67	98	152	213	257	263	241	207	143	102	80	68	61	57	52	49	45	41	37	32	30	29	28	27	25	21	14
.40	15	21	28	38	43	49	61	86	130	185	233	253	245	188	132	97	77	66	60	55	51	46	42	38	34	30	29	28	27	25	22	14
.50	15	20	27	36	41	46	56	76	112	161	209	238	243	201	146	106	82	69	61	55	51	47	42	38	34	31	29	29	27	25	22	14
.75	12	16	21	29	32	35	39	46	57	77	108	147	184	220	200	157	118	91	74	61	55	50	45	40	36	32	30	29	27	26	22	15
1.0	10	12	16	21	24	26	29	32	36	40	48	61	83	147	202	212	178	138	105	75	62	54	47	43	39	35	31	29	28	26	23	16
1.5	8	9	11	14	16	17	19	21	23	25	28	31	35	50	83	134	179	193	177	131	92	65	53	47	42	38	34	31	29	27	24	16
2.0	5	6	8	10	10	11	12	13	14	15	17	18	20	25	31	42	64	102	144	179	163	111	70	55	48	43	39	35	30	28	25	17
2.5	3	4	6	7	8	8	9	9	10	11	12	13	14	16	20	24	30	42	63	114	160	170	107	70	54	47	43	38	31	29	25	18
3.0	2	3	4	5	6	6	7	7	8	8	9	9	10	11	13	16	19	23	30	51	90	148	161	104	69	54	47	42	34	29	26	19
IA/P = 0.30														* * * TC = 0.4 HR * * *															IA/P = 0.30			
0.0	0	0	0	3	14	48	115	184	192	178	148	127	111	88	77	70	66	64	62	59	56	54	50	46	41	40	40	39	38	36	32	22
.10	0	0	0	0	2	10	35	89	152	179	178	158	137	105	85	75	69	65	63	60	58	55	51	47	42	40	40	39	38	36	32	22
.20	0	0	0	0	2	7	26	68	124	161	172	163	146	113	90	78	70	66	64	61	58	55	52	47	43	40	40	39	38	37	33	22
.30	0	0	0	0	1	5	19	52	100	140	162	162	151	120	96	81	72	67	64	61	59	55	52	48	43	41	40	39	38	37	33	23
.40	0	0	0	0	0	1	4	14	39	80	120	148	158	142	114	92	79	71	67	63	60	57	53	49	45	41	40	40	38	37	33	23
.50	0	0	0	0	0	1	3	10	29	63	101	132	152	145	120	97	82	73	68	63	60	57	53	50	45	41	40	40	38	37	33	23
.75	0	0	0	0	0	0	0	1	4	13	31	58	87	130	138	123	103	87	77	68	63	59	55	51	47	43	41	40	39	37	34	24
1.0	0	0	0	0	0	0	0	0	0	2	7	18	36	86	125	134	122	104	88	73	66	61	57	53	49	45	41	40	39	38	34	24
1.5	0	0	0	0	0	0	0	0	0	0	0	0	1	10	36	75	109	124	120	100	81	68	61	56	53	49	44	41	40	38	35	26
2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	6	22	50	83	116	116	91	70	61	57	53	49	45	40	39	36	27
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	8	22	60	97	111	88	70	61	56	53	48	42	39	37	28
3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	14	43	89	106	86	69	61	56	52	44	40	37	29
IA/P = 0.50														* * * TC = 0.4 HR * * *															IA/P = 0.50			
0.0	0	0	0	0	0	0	0	2	8	17	27	34	40	44	47	49	50	51	51	51	51	51	51	51	50	50	49	49	49	48	46	33
.10	0	0	0	0	0	0	0	0	2	6	13	22	30	40	45	47	49	50	51	51	51	51	51	51	50	50	50	49	49	48	46	34
.20	0	0	0	0	0	0	0	0	0	1	4	10	18	33	41	45	48	49	51	51	51	51	51	51	50	50	50	49	49	49	46	34
.30	0	0	0	0	0	0	0	0	0	0	1	3	8	22	35	42	46	48	50	51	51	51	51	51	51	50	50	49	49	49	47	35
.40	0	0	0	0	0	0	0	0	0	0	1	2	6	19	32	40	45	47	49	51	51	51	51	51	51	50	50	49	49	49	47	35
.50	0	0	0	0	0	0	0	0	0	0	0	0	2	9	23	34	41	45	48	50	51	51	51	51	51	50	50	49	49	49	47	35
.75	0	0	0	0	0	0	0	0	0	0	0	0	1	5	14	26	35	42	46	49	50	51	51	51	51	50	50	50	49	49	47	36
1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	5	14	25	35	44	48	50	51	51	51	51	50	50	49	49	48	37
1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	6	13	27	39	47	50	51	51	51	51	50	49	49	48	39
2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	9	21	36	47	50	51	51	51	51	50	49	48	40
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	6	19	37	47	50	51	51	51	50	40	48	42
3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	8	25	40	48	50	51	51	50	50	49	43

RAINFALL TYPE = I * * * TC = 0.4 HR * * * SHEET 4 OF 10



5-98

Exhibit 5-IA: Tabular hydrograph unit discharges (csm/in) for type IA rainfall distribution—continued

```
TRVL-------------------------------------------------------------HYDROGRAPH TIME(HOURS)--------------------------------------------------------------
TIME        7.3       7.9       8.1       8.3       8.5       8.7       9.0       9.4       9.8      10.3      11.0      12.0      13.0      14.0      16.0      22.0
(hr)   7.0       7.6       8.0       8.2       8.4       8.6       8.8       9.2       9.6      10.0      10.6      11.5      12.5      13.5      15.0      18.0
-----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+
          IA/P = 0.10                                   * * * TC = 1.25 HR * * *                                             IA/P = 0.10
-----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+
 0.0    17   21   24   29   33   37   43   52   61   71   81   89   95  100   94   86   78   71   64   57   51   46   42   39   35   34   33   33   31   30   28   23
 .10    16   19   23   27   29   31   35   41   48   57   66   76   85   96   99   92   84   76   69   60   54   47   43   40   36   34   34   33   31   30   28   23
 .20    15   19   22   26   28   30   33   38   45   53   62   71   80   93   97   93   86   78   71   62   55   48   43   40   37   34   34   33   31   30   28   23
 .30    14   17   20   24   25   27   29   32   36   42   49   58   67   84   95   96   91   84   76   66   58   50   44   41   38   35   34   33   31   30   28   23

 .40    13   16   20   23   25   26   28   31   34   39   46   54   62   80   92   96   93   86   78   68   59   51   45   41   38   35   34   33   31   30   28   23
 .50    12   15   18   21   23   24   25   27   29   33   37   43   50   67   83   93   95   91   84   73   63   54   46   42   39   36   34   33   32   30   28   23
 .75    10   13   16   20   21   22   23   25   27   29   32   36   42   55   71   84   93   93   88   78   68   57   49   43   40   37   34   34   32   31   28   24
 1.0     8   10   13   16   17   19   20   21   22   23   25   27   29   37   49   63   78   88   92   88   78   65   53   46   42   39   36   34   33   31   29   24

 1.5     5    7    9   12   13   14   15   16   17   18   19   20   22   25   29   36   47   60   73   87   89   79   64   53   46   42   38   36   33   32   29   25
 2.0     2    4    6    8    9   10   10   11   12   13   14   15   16   19   21   24   29   36   45   64   80   87   77   63   52   46   41   38   34   32   30   25
 2.5     1    2    3    4    5    6    6    7    8    8    9   10   11   13   15   17   19   22   26   35   49   72   85   78   65   53   46   42   36   33   30   26
 3.0     0    1    1    2    3    3    4    4    5    5    6    7    7    9   11   12   14   17   19   23   31   47   73   84   76   63   53   46   38   34   31   26
-----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+
          IA/P = 0.30                                   * * * TC = 1.25 HR * * *                                             IA/P = 0.30
-----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+
 0.0     0    0    0    0    0    1    3    6   10   15   22   28   34   43   48   51   51   51   49   47   45   44   43   42   40   40   40   40   40   40   39   35
 .10     0    0    0    0    0    0    1    2    5    8   13   19   25   36   45   49   51   50   50   48   46   44   43   42   40   40   40   40   40   40   39   35
 .20     0    0    0    0    0    0    1    2    4    7   11   16   22   34   43   48   50   50   50   48   46   44   43   42   41   40   40   40   40   40   39   35
 .30     0    0    0    0    0    0    1    1    3    5    9   14   19   31   40   46   49   50   50   48   46   45   43   42   41   40   40   40   40   40   39   35

 .40     0    0    0    0    0    0    0    1    2    4    8   12   17   28   38   45   49   50   50   49   47   45   43   42   41   40   40   40   40   40   39   35
 .50     0    0    0    0    0    0    0    1    2    4    6   10   14   25   36   43   48   50   50   49   47   45   43   42   41   40   40   40   40   40   39   35
 .75     0    0    0    0    0    0    0    0    0    1    2    3    6   13   23   33   41   46   49   50   48   46   44   43   42   40   40   40   40   40   39   36
 1.0     0    0    0    0    0    0    0    0    0    0    0    1    2    6   14   23   32   40   46   49   49   47   45   43   42   41   40   40   40   40   39   36

 1.5     0    0    0    0    0    0    0    0    0    0    0    0    0    1    2    6   13   21   30   41   47   49   47   45   43   42   41   40   40   40   39   37
 2.0     0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    1    3    6   12   23   35   45   48   47   45   43   42   41   40   40   40   37
 2.5     0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    1    3    8   18   33   45   48   46   44   43   42   40   40   40   38
 3.0     0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    2    6   17   34   45   48   46   44   43   41   40   40   38
-----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+
          IA/P = 0.50                                   * * * TC = 1.25 HR * * *                                             IA/P = 0.50
-----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+
 0.0     0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    1    3    5    9   14   19   24   28   31   33   37   39   42   42   42   42
 .10     0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    1    3    7   11   17   23   27   30   32   36   38   42   42   42   42
 .20     0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    1    2    5    9   15   21   26   29   32   35   38   41   42   42   42
 .30     0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    1    3    7   13   19   25   29   31   34   37   41   42   42   42

 .40     0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    2    5   11   17   23   28   30   33   36   40   42   42   42
 .50     0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    1    3    8   15   22   26   30   32   35   40   42   42   42
 .75     0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    1    2    7   13   20   25   29   31   34   39   42   42   42
 1.0     0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    1    4   11   17   23   27   30   33   38   42   42   42

 1.5     0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    1    5   11   18   23   28   30   36   40   42   42
 2.0     0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    1    6   12   18   24   28   33   39   42   42
 2.5     0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    2    6   13   19   24   31   37   42   42
 3.0     0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    2    6   12   18   28   33   42   42
-----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+
        RAINFALL TYPE = IA                              * * * TC = 1.25 HR * * *                                             SHEET 8 OF 10
```

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

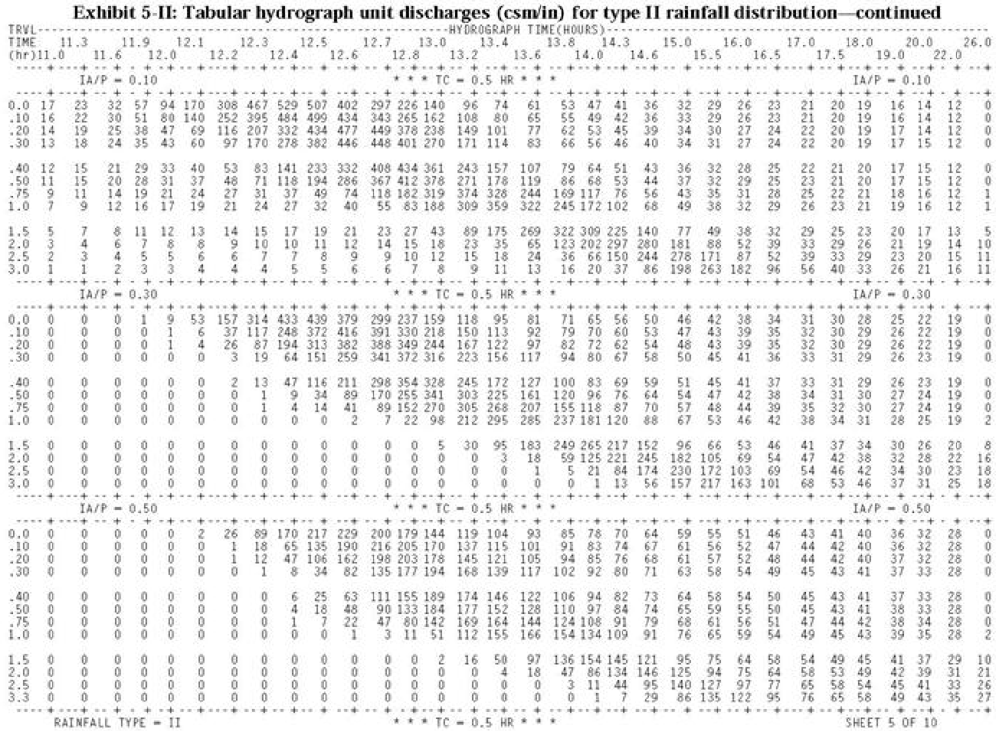


Exhibit 5-II: Tabular hydrograph unit discharges (csm/in) for type II rainfall distribution—continued

TRVL TIME (hr) / HYDROGRAPH TIME(HOURS)

IA/P = 0.10 * * * TC = 0.5 HR * * * IA/P = 0.10

TRVL TIME (hr)	11.0	11.3	11.6	11.9	12.0	12.1	12.2	12.3	12.4	12.5	12.6	12.7	12.8	13.0	13.2	13.4	13.6	13.8	14.0	14.3	14.6	15.0	15.5	16.0	16.5	17.0	17.5	18.0	19.0	20.0	22.0	26.0
0.0	17	23	32	57	94	170	308	467	529	507	402	297	226	140	96	74	61	53	47	41	36	32	29	26	23	21	20	19	16	14	12	0
.10	16	22	30	51	80	140	252	395	484	499	434	343	265	162	108	80	65	55	49	42	36	33	29	26	23	21	20	19	16	14	12	0
.20	14	19	25	38	47	69	116	207	332	434	477	449	378	238	149	101	77	62	53	45	39	34	30	27	24	22	20	19	17	14	12	0
.30	13	18	24	35	43	60	97	170	278	382	446	448	401	270	171	114	83	66	56	46	40	34	31	27	24	22	20	19	17	15	12	0
.40	12	15	21	29	33	40	53	83	141	233	332	408	434	361	243	157	107	79	64	51	43	36	32	28	25	22	21	20	17	15	12	0
.50	11	15	20	28	31	37	48	71	118	194	286	367	412	378	271	178	119	86	68	53	44	37	32	29	25	23	21	20	17	15	12	0
.75	9	11	14	19	21	24	27	31	37	49	74	118	182	319	374	328	244	169	117	76	56	43	35	31	28	25	22	21	18	16	12	1
1.0	7	9	12	16	17	19	21	24	27	32	40	55	83	188	309	359	322	245	172	102	68	49	38	32	29	26	23	21	19	16	12	1
1.5	5	7	8	11	12	13	14	15	17	19	21	23	27	43	89	175	269	322	309	225	140	77	49	38	32	29	25	23	20	17	13	5
2.0	3	4	6	7	8	8	9	10	10	11	12	14	15	18	23	35	65	123	202	297	280	181	88	52	39	33	29	26	21	19	14	10
2.5	2	3	4	5	5	6	6	7	7	8	9	9	10	12	15	18	24	36	66	150	244	278	171	87	52	39	33	29	23	20	15	11
3.0	1	1	2	3	3	4	4	4	5	5	6	6	7	8	9	11	13	16	20	37	86	198	263	182	96	56	40	33	26	21	16	11

IA/P = 0.30 * * * TC = 0.5 HR * * * IA/P = 0.30

TRVL TIME (hr)	11.0	11.3	11.6	11.9	12.0	12.1	12.2	12.3	12.4	12.5	12.6	12.7	12.8	13.0	13.2	13.4	13.6	13.8	14.0	14.3	14.6	15.0	15.5	16.0	16.5	17.0	17.5	18.0	19.0	20.0	22.0	26.0
0.0	0	0	0	1	9	53	157	314	433	439	379	299	237	159	118	95	81	71	65	56	50	46	42	38	34	31	30	28	25	22	19	0
.10	0	0	0	0	1	6	37	117	248	372	416	391	330	218	150	113	92	79	70	60	53	47	43	39	35	32	30	29	26	22	19	0
.20	0	0	0	0	1	4	26	87	194	313	382	388	349	244	167	122	97	82	72	62	54	48	43	39	35	32	30	29	26	22	19	0
.30	0	0	0	0	0	0	3	19	64	151	259	341	372	316	223	156	117	94	80	67	58	50	45	41	36	33	31	29	26	23	19	0
.40	0	0	0	0	0	0	2	13	47	116	211	298	354	328	245	172	127	100	83	69	59	51	45	41	37	33	31	29	26	23	19	0
.50	0	0	0	0	0	0	0	1	9	34	89	170	255	341	303	225	161	120	96	76	64	54	47	42	38	34	31	30	27	24	19	0
.75	0	0	0	0	0	0	0	1	4	14	41	89	152	270	305	268	207	155	118	87	70	57	48	44	39	35	32	30	27	24	19	0
1.0	0	0	0	0	0	0	0	0	0	0	2	7	22	98	212	295	285	237	181	120	88	67	53	46	42	38	34	31	28	25	19	2
1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	5	30	95	183	249	265	217	152	96	66	53	46	41	37	34	30	26	20	8
2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	18	59	125	221	245	182	105	69	54	47	42	38	32	28	22	16
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	5	21	84	174	230	172	103	69	54	46	42	34	30	23	18
3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	13	56	157	217	163	101	68	53	46	37	31	25	18

IA/P = 0.50 * * * TC = 0.5 HR * * * IA/P = 0.50

TRVL TIME (hr)	11.0	11.3	11.6	11.9	12.0	12.1	12.2	12.3	12.4	12.5	12.6	12.7	12.8	13.0	13.2	13.4	13.6	13.8	14.0	14.3	14.6	15.0	15.5	16.0	16.5	17.0	17.5	18.0	19.0	20.0	22.0	26.0
0.0	0	0	0	0	0	2	26	89	170	217	229	200	179	144	119	104	93	85	78	70	64	59	55	51	46	43	41	40	36	32	28	0
.10	0	0	0	0	0	0	1	18	65	135	190	216	205	170	137	115	101	91	83	74	67	61	56	52	47	44	42	40	36	32	28	0
.20	0	0	0	0	0	0	1	12	47	106	162	198	203	178	145	121	105	94	85	76	68	61	57	52	48	44	42	40	37	32	28	0
.30	0	0	0	0	0	0	0	1	8	34	82	135	177	194	168	139	117	102	92	80	71	63	58	54	49	45	43	41	37	33	28	0
.40	0	0	0	0	0	0	0	0	6	25	63	111	155	189	174	146	122	106	94	82	73	64	58	54	50	45	43	41	37	33	28	0
.50	0	0	0	0	0	0	0	0	4	18	48	90	133	184	177	152	128	110	97	84	74	65	59	55	50	45	43	41	38	33	28	0
.75	0	0	0	0	0	0	0	0	1	7	22	47	80	142	169	164	144	124	108	91	79	68	61	56	51	47	44	42	38	34	28	0
1.0	0	0	0	0	0	0	0	0	0	0	1	3	11	51	112	155	166	154	134	109	91	76	65	59	54	49	45	43	39	35	28	2
1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	2	16	50	97	136	154	145	121	95	75	64	58	54	49	45	41	37	29	10
2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	18	47	86	134	146	125	94	75	64	58	53	49	42	39	31	21
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	11	44	95	140	127	97	77	65	58	54	45	41	33	26
3.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	7	29	86	135	122	95	76	65	58	49	43	35	27

RAINFALL TYPE = II * * * TC = 0.5 HR * * * SHEET 5 OF 10

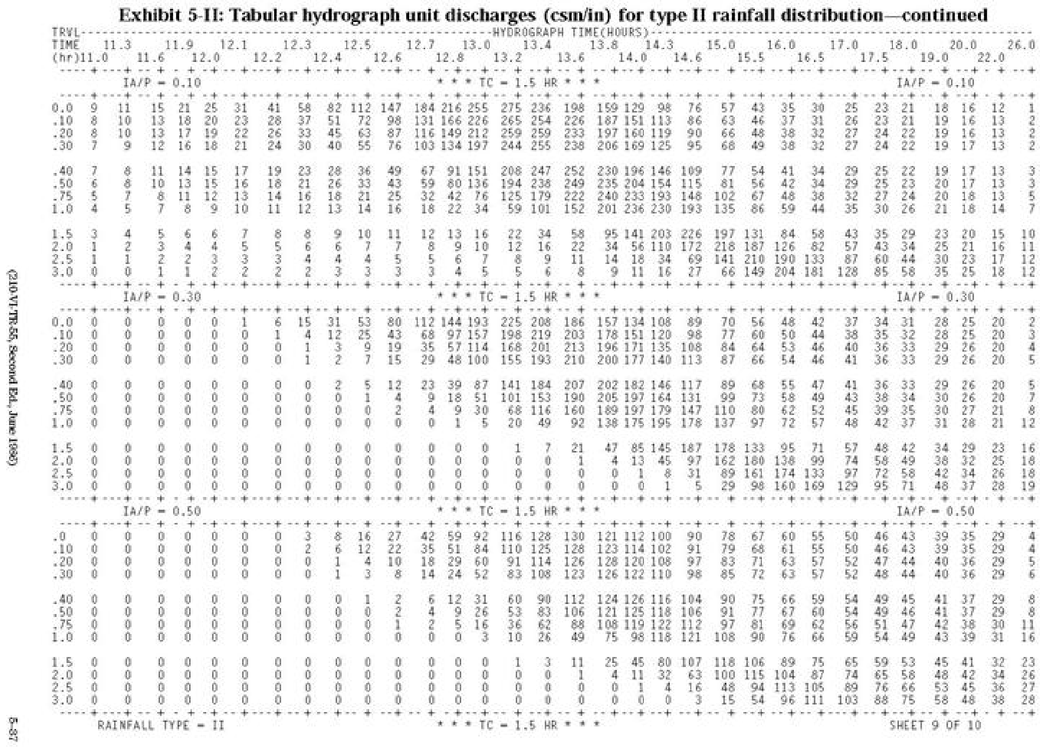


Exhibit 5-II: Tabular hydrograph unit discharges (csm/in) for type II rainfall distribution—continued

HYDROGRAPH TIME(HOURS)

IA/P = 0.10 * * * TC = 1.5 HR * * * IA/P = 0.10

TRVL TIME (hr)	11.0	11.3	11.6	11.9	12.0	12.1	12.2	12.3	12.4	12.5	12.6	12.7	12.8	13.0	13.2	13.4	13.6	13.8	14.0	14.3	14.6	15.0	15.5	16.0	16.5	17.0	17.5	18.0	19.0	20.0	22.0	26.0
0.0	9	11	15	21	25	31	41	58	82	112	147	184	216	255	275	236	198	159	129	98	76	57	43	35	30	25	23	21	18	16	12	1
.10	8	10	13	18	20	23	28	37	51	72	98	131	166	226	265	254	226	187	151	113	86	63	46	37	31	26	23	21	19	16	13	2
.20	8	10	13	17	19	22	26	33	45	63	87	116	149	212	259	259	233	197	160	119	90	66	48	38	32	27	24	22	19	16	13	2
.30	7	9	12	16	18	21	24	30	40	55	76	103	134	197	244	255	238	206	169	125	95	68	49	38	32	27	24	22	19	17	13	2
.40	7	8	11	14	15	17	19	23	28	36	49	67	91	151	208	247	252	230	196	146	109	77	54	41	34	29	25	22	19	17	13	3
.50	6	8	10	13	15	16	18	21	26	33	43	59	80	136	194	238	249	235	204	154	115	81	56	42	34	29	25	23	20	17	13	3
.75	5	7	8	11	12	13	14	16	18	21	25	32	42	76	125	179	222	240	233	193	148	102	67	48	38	32	27	24	20	18	13	5
1.0	4	5	7	8	9	10	11	12	13	14	16	18	22	34	59	101	152	201	236	230	193	135	86	59	44	35	30	26	21	18	14	7
1.5	3	4	5	6	6	7	8	8	9	10	11	12	13	16	22	34	58	95	141	203	226	197	131	84	58	43	35	29	23	20	15	10
2.0	1	2	3	4	4	5	5	6	6	7	7	8	9	10	12	16	22	34	56	110	172	218	187	126	82	57	43	34	25	21	16	11
2.5	1	1	2	2	3	3	3	4	4	4	5	5	6	7	8	9	11	14	18	34	69	141	210	190	133	87	60	44	30	23	17	12
3.0	0	0	1	1	2	2	2	2	3	3	3	3	4	5	5	6	8	9	11	16	27	66	149	204	181	128	85	58	35	25	18	12

IA/P = 0.30 * * * TC = 1.5 HR * * * IA/P = 0.30

TRVL TIME (hr)	11.0	11.3	11.6	11.9	12.0	12.1	12.2	12.3	12.4	12.5	12.6	12.7	12.8	13.0	13.2	13.4	13.6	13.8	14.0	14.3	14.6	15.0	15.5	16.0	16.5	17.0	17.5	18.0	19.0	20.0	22.0	26.0
0.0	0	0	0	0	0	1	6	15	31	53	80	112	144	193	225	208	186	157	134	108	89	70	56	48	42	37	34	31	28	25	20	2
.10	0	0	0	0	0	0	1	4	12	25	43	68	97	157	198	219	203	178	151	120	98	77	60	50	44	38	35	32	28	25	20	3
.20	0	0	0	0	0	0	0	1	3	9	19	35	57	114	168	201	213	196	171	135	108	84	64	53	46	40	36	33	29	26	20	4
.30	0	0	0	0	0	0	0	1	2	7	15	29	48	100	155	193	210	200	177	140	113	87	66	54	46	41	36	33	29	26	20	5
.40	0	0	0	0	0	0	0	0	2	5	12	23	39	87	141	184	207	202	182	146	117	89	68	55	47	41	36	33	29	26	20	5
.50	0	0	0	0	0	0	0	0	0	1	4	9	18	51	101	153	190	205	197	164	131	99	73	58	49	43	38	34	30	26	20	7
.75	0	0	0	0	0	0	0	0	0	0	2	4	9	30	68	116	160	189	197	179	147	110	80	62	52	45	39	35	30	27	21	8
1.0	0	0	0	0	0	0	0	0	0	0	0	0	1	5	20	49	92	138	175	195	178	137	97	72	57	48	42	37	31	28	21	12
1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	7	21	47	85	145	187	178	133	95	71	57	48	42	34	29	23	16
2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	13	45	97	162	180	138	99	74	58	49	38	32	25	18
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	8	31	89	161	174	133	97	72	58	42	34	26	18
3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	5	29	98	160	169	129	95	71	48	37	28	19

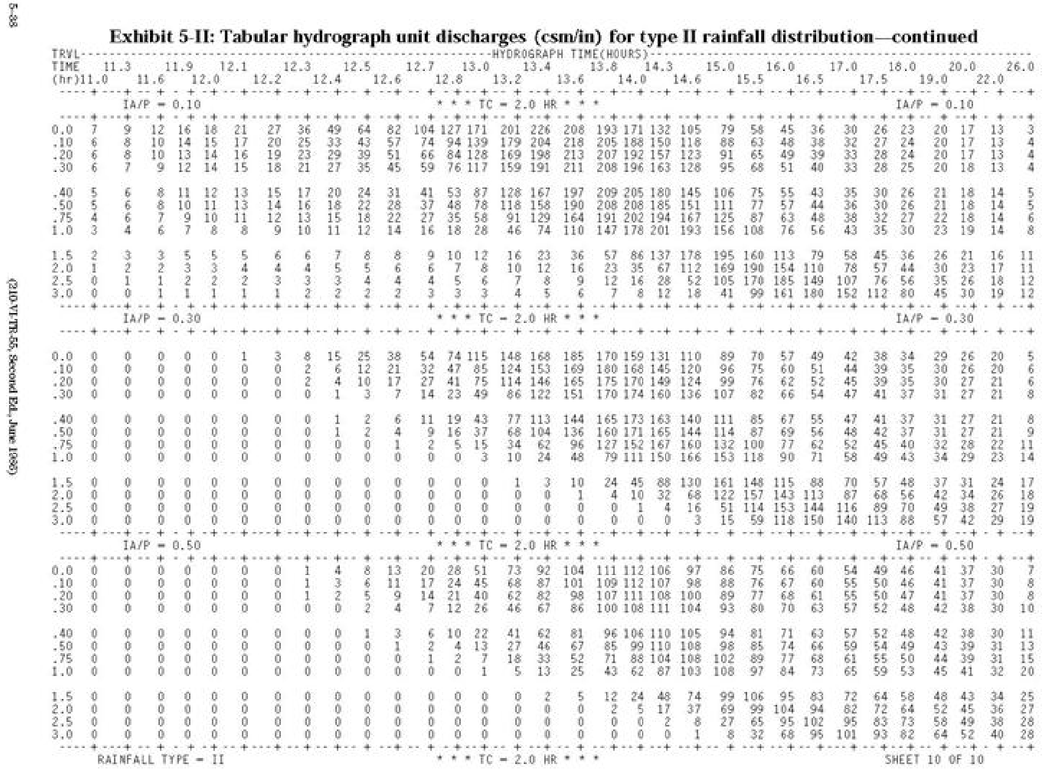
IA/P = 0.50 * * * TC = 1.5 HR * * * IA/P = 0.50

TRVL TIME (hr)	11.0	11.3	11.6	11.9	12.0	12.1	12.2	12.3	12.4	12.5	12.6	12.7	12.8	13.0	13.2	13.4	13.6	13.8	14.0	14.3	14.6	15.0	15.5	16.0	16.5	17.0	17.5	18.0	19.0	20.0	22.0	26.0
.0	0	0	0	0	0	0	0	3	8	16	27	42	59	92	116	128	130	121	112	100	90	78	67	60	55	50	46	43	39	35	29	4
.10	0	0	0	0	0	0	0	2	6	12	22	35	51	84	110	125	128	123	114	102	91	79	68	61	55	50	46	43	39	35	29	4
.20	0	0	0	0	0	0	0	0	1	4	10	18	29	60	91	114	126	128	120	108	97	83	71	63	57	52	47	44	40	36	29	5
.30	0	0	0	0	0	0	0	0	1	3	8	14	24	52	83	108	123	126	122	110	98	85	72	63	57	52	48	44	40	36	29	6
.40	0	0	0	0	0	0	0	0	0	1	2	6	12	31	60	90	112	124	126	116	104	90	75	66	59	54	49	45	41	37	29	8
.50	0	0	0	0	0	0	0	0	0	0	2	4	9	26	53	83	106	121	125	118	106	91	77	67	60	54	49	46	41	37	29	8
.75	0	0	0	0	0	0	0	0	0	0	1	2	5	16	36	62	88	108	119	122	112	97	81	69	62	56	51	47	42	38	30	11
1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	10	26	49	75	98	118	121	108	90	76	66	59	54	49	43	39	31	16
1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	11	25	45	80	107	118	106	89	75	65	59	53	45	41	32	23
2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	11	32	63	100	115	104	87	74	65	58	48	42	34	26
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	16	48	94	113	105	89	76	66	53	45	36	27
3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	15	54	96	111	103	88	75	58	48	38	28

RAINFALL TYPE = II * * * TC = 1.5 HR * * * SHEET 9 OF 10

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

5-87



5-38

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

Exhibit 5-II: Tabular hydrograph unit discharges (csm/in) for type II rainfall distribution—continued

HYDROGRAPH TIME(HOURS)

IA/P = 0.10 * * * TC = 2.0 HR * * * IA/P = 0.10

TRVL TIME (hr)	11.0	11.3	11.6	11.9	12.0	12.1	12.2	12.3	12.4	12.5	12.6	12.7	12.8	13.0	13.2	13.4	13.6	13.8	14.0	14.3	14.6	15.0	15.5	16.0	16.5	17.0	17.5	18.0	19.0	20.0	22.0	26.0
0.0	7	9	12	16	18	21	27	36	49	64	82	104	127	171	201	226	208	193	171	132	105	79	58	45	36	30	26	23	20	17	13	3
.10	6	8	10	14	15	17	20	25	33	43	57	74	94	139	179	204	218	205	188	150	118	88	63	48	38	32	27	24	20	17	13	4
.20	6	8	10	13	14	16	19	23	29	39	51	66	84	128	169	198	213	207	192	157	123	91	65	49	39	33	28	24	20	17	13	4
.30	6	7	9	12	14	15	18	21	27	35	45	59	76	117	159	191	211	208	196	163	128	95	68	51	40	33	28	25	20	18	13	4
.40	5	6	8	11	12	13	15	17	20	24	31	41	53	87	128	167	197	209	205	180	145	106	75	55	43	35	30	26	21	18	14	5
.50	5	6	8	10	11	13	14	16	18	22	28	37	48	78	118	158	190	208	208	185	151	111	77	57	44	36	30	26	21	18	14	5
.75	4	6	7	9	10	11	12	13	15	18	22	27	35	58	91	129	164	191	202	194	167	125	87	63	48	38	32	27	22	18	14	6
1.0	3	4	6	7	8	8	9	10	11	12	14	16	18	28	46	74	110	147	178	201	193	156	108	76	56	43	35	30	23	19	14	8
1.5	2	3	3	5	5	5	6	6	7	8	8	9	10	12	16	23	36	57	86	137	178	195	160	113	79	58	45	36	26	21	16	11
2.0	1	2	2	3	3	4	4	4	5	5	6	6	7	8	10	12	16	23	35	67	112	169	190	154	110	78	57	44	30	23	17	11
2.5	0	1	1	2	2	2	3	3	3	4	4	4	5	6	7	8	9	12	16	28	52	105	170	185	149	107	76	56	35	26	18	12
3.0	0	0	1	1	1	1	1	2	2	2	2	3	3	3	4	5	6	7	8	12	18	41	99	161	180	152	112	80	45	30	19	12

IA/P = 0.30 * * * TC = 2.0 HR * * * IA/P = 0.30

TRVL TIME (hr)	11.0	11.3	11.6	11.9	12.0	12.1	12.2	12.3	12.4	12.5	12.6	12.7	12.8	13.0	13.2	13.4	13.6	13.8	14.0	14.3	14.6	15.0	15.5	16.0	16.5	17.0	17.5	18.0	19.0	20.0	22.0	26.0
0.0	0	0	0	0	0	1	3	8	15	25	38	54	74	115	148	168	185	170	159	131	110	89	70	57	49	42	38	34	29	26	20	5
.10	0	0	0	0	0	0	0	2	6	12	21	32	47	85	124	153	169	180	168	145	120	96	75	60	51	44	39	35	30	26	20	6
.20	0	0	0	0	0	0	0	2	4	10	17	27	41	75	114	146	165	175	170	149	124	99	76	62	52	45	39	35	30	27	21	6
.30	0	0	0	0	0	0	0	0	1	3	7	14	23	49	86	122	151	170	174	160	136	107	82	66	54	47	41	37	31	27	21	8
.40	0	0	0	0	0	0	0	0	1	2	6	11	19	43	77	113	144	165	173	163	140	111	85	67	55	47	41	37	31	27	21	8
.50	0	0	0	0	0	0	0	0	1	2	4	9	16	37	68	104	136	160	171	165	144	114	87	69	56	48	42	37	31	27	21	9
.75	0	0	0	0	0	0	0	0	0	0	1	2	5	15	34	62	96	127	152	167	160	132	100	77	62	52	45	40	32	28	22	11
1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	10	24	48	79	111	150	166	153	118	90	71	58	49	43	34	29	23	14
1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	10	24	45	88	130	161	148	115	88	70	57	48	37	31	24	17
2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	10	32	68	122	157	143	113	87	68	56	42	34	26	18
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	16	51	114	153	144	116	89	70	49	38	27	19
3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	15	59	118	150	140	113	88	57	42	29	19

IA/P = 0.50 * * * TC = 2.0 HR * * * IA/P = 0.50

TRVL TIME (hr)	11.0	11.3	11.6	11.9	12.0	12.1	12.2	12.3	12.4	12.5	12.6	12.7	12.8	13.0	13.2	13.4	13.6	13.8	14.0	14.3	14.6	15.0	15.5	16.0	16.5	17.0	17.5	18.0	19.0	20.0	22.0	26.0
0.0	0	0	0	0	0	0	0	1	4	8	13	20	28	51	73	92	104	111	112	106	97	86	75	66	60	54	49	46	41	37	30	7
.10	0	0	0	0	0	0	0	1	3	6	11	17	24	45	68	87	101	109	112	107	98	88	76	67	60	55	50	46	41	37	30	8
.20	0	0	0	0	0	0	0	1	2	5	9	14	21	40	62	82	98	107	111	108	100	89	77	68	61	55	50	47	41	37	30	8
.30	0	0	0	0	0	0	0	0	0	2	4	7	12	26	46	67	86	100	108	111	104	93	80	70	63	57	52	48	42	38	30	10
.40	0	0	0	0	0	0	0	0	0	1	3	6	10	22	41	62	81	96	106	110	105	94	81	71	63	57	52	48	42	38	30	11
.50	0	0	0	0	0	0	0	0	0	0	1	2	4	13	27	46	67	85	99	110	108	98	85	74	66	59	54	49	43	39	31	13
.75	0	0	0	0	0	0	0	0	0	0	0	1	2	7	18	33	52	71	88	104	108	102	89	77	68	61	55	50	44	39	31	15
1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	5	13	25	43	62	87	103	108	97	84	73	65	59	53	45	41	32	20
1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	5	12	24	48	74	99	106	95	83	72	64	58	48	43	34	25
2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	5	17	37	69	99	104	94	82	72	64	52	45	36	27
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	8	27	65	95	102	95	83	73	58	49	38	28
3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	8	32	68	95	101	93	82	64	52	40	28

RAINFALL TYPE = II * * * TC = 2.0 HR * * * SHEET 10 OF 10

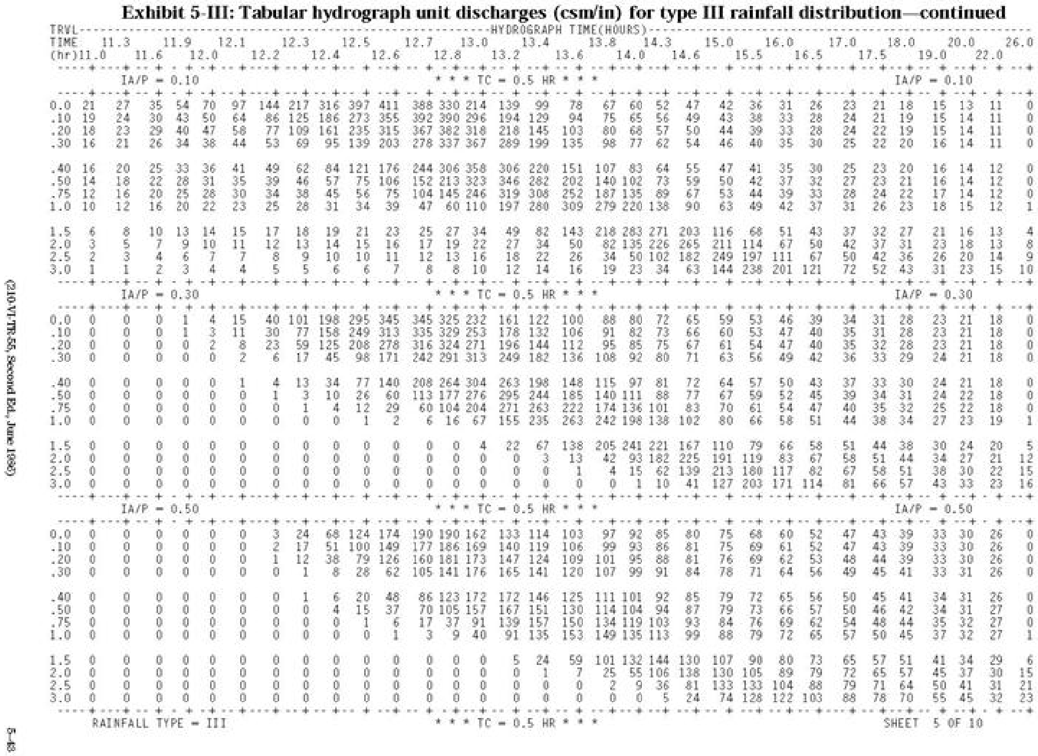


Exhibit 5-III: Tabular hydrograph unit discharges (csm/in) for type III rainfall distribution—continued

HYDROGRAPH TIME(HOURS)

IA/P = 0.10 * * * TC = 0.5 HR * * *

TRVL TIME (hr)	11.0	11.3	11.6	11.9	12.0	12.1	12.2	12.3	12.4	12.5	12.6	12.7	12.8	13.0	13.2	13.4	13.6	13.8	14.0	14.3	14.6	15.0	15.5	16.0	16.5	17.0	17.5	18.0	19.0	20.0	22.0	26.0
0.0	21	27	35	54	70	97	144	217	316	397	411	388	330	214	139	99	78	67	60	52	47	42	36	31	26	23	21	18	15	13	11	0
.10	19	24	30	43	50	64	86	125	186	273	355	392	390	296	194	129	94	75	65	56	49	43	38	33	28	24	21	19	15	14	11	0
.20	18	23	29	40	47	58	77	109	161	235	315	367	382	318	218	145	103	80	68	57	50	44	39	33	28	24	22	19	15	14	11	0
.30	16	21	26	34	38	44	53	69	95	139	203	278	337	367	289	199	135	98	77	62	54	46	40	35	30	25	22	20	16	14	11	0
.40	16	20	25	33	36	41	49	62	84	121	176	244	306	358	306	220	151	107	83	64	55	47	41	35	30	25	23	20	16	14	12	0
.50	14	18	22	28	31	35	39	46	57	75	106	152	213	323	346	282	202	140	102	73	59	50	42	37	32	27	23	21	16	14	12	0
.75	12	16	20	25	28	30	34	38	45	56	75	104	145	246	319	308	252	187	135	89	67	53	44	39	33	28	24	22	17	14	12	0
1.0	10	12	16	20	22	23	25	28	31	34	39	47	60	110	197	280	309	279	220	138	90	63	49	42	37	31	26	23	18	15	12	1
1.5	6	8	10	13	14	15	17	18	19	21	23	25	27	34	49	82	143	218	283	271	203	116	68	51	43	37	32	27	21	16	13	4
2.0	3	5	7	9	10	11	12	13	14	15	16	17	19	22	27	34	50	82	135	226	265	211	114	67	50	42	37	31	23	18	13	8
2.5	2	3	4	6	7	7	8	9	10	10	11	12	13	16	18	22	26	34	50	102	182	249	197	111	67	50	42	36	26	20	14	9
3.0	1	1	2	3	4	4	5	5	6	6	7	8	8	10	12	14	16	19	23	34	63	144	238	201	121	72	52	43	31	23	15	10

IA/P = 0.30 * * * TC = 0.5 HR * * *

TRVL TIME (hr)	11.0	11.3	11.6	11.9	12.0	12.1	12.2	12.3	12.4	12.5	12.6	12.7	12.8	13.0	13.2	13.4	13.6	13.8	14.0	14.3	14.6	15.0	15.5	16.0	16.5	17.0	17.5	18.0	19.0	20.0	22.0	26.0
0.0	0	0	0	1	4	15	40	101	198	295	345	345	325	232	161	122	100	88	80	72	65	59	53	46	39	34	31	28	23	21	18	0
.10	0	0	0	1	3	11	30	77	158	249	313	335	329	253	178	132	106	91	82	73	66	60	53	47	40	35	31	28	23	21	18	0
.20	0	0	0	0	2	8	23	59	125	208	278	316	324	271	196	144	112	95	85	75	67	61	54	47	40	35	32	28	23	21	18	0
.30	0	0	0	0	0	2	6	17	45	98	171	242	291	313	249	182	136	108	92	80	71	63	56	49	42	36	33	29	24	21	18	0
.40	0	0	0	0	0	1	4	13	34	77	140	208	264	304	263	198	148	115	97	81	72	64	57	50	43	37	33	30	24	21	18	0
.50	0	0	0	0	0	0	1	3	10	26	60	113	177	276	295	244	185	140	111	88	77	67	59	52	45	39	34	31	24	22	18	0
.75	0	0	0	0	0	0	0	1	4	12	29	60	104	204	271	263	222	174	136	101	83	70	61	54	47	40	35	32	25	22	18	0
1.0	0	0	0	0	0	0	0	0	0	1	2	6	16	67	155	235	263	242	198	138	102	80	66	58	51	44	38	34	27	23	19	1
1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	4	22	67	138	205	241	221	167	110	79	66	58	51	44	38	30	24	20	5
2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	13	42	93	182	225	191	119	83	67	58	51	44	34	27	21	12
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	15	62	139	213	180	117	82	67	58	51	38	30	22	15
3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	10	41	127	203	171	114	81	66	57	43	33	23	16

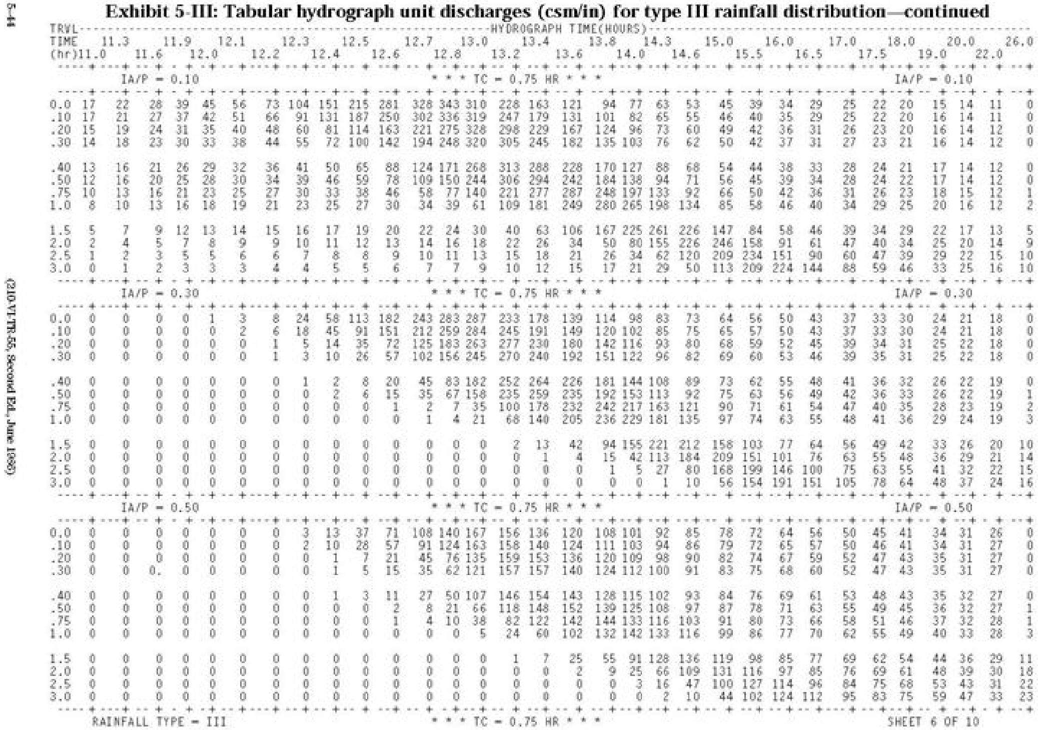
IA/P = 0.50 * * * TC = 0.5 HR * * *

TRVL TIME (hr)	11.0	11.3	11.6	11.9	12.0	12.1	12.2	12.3	12.4	12.5	12.6	12.7	12.8	13.0	13.2	13.4	13.6	13.8	14.0	14.3	14.6	15.0	15.5	16.0	16.5	17.0	17.5	18.0	19.0	20.0	22.0	26.0
0.0	0	0	0	0	0	0	3	24	68	124	174	190	190	162	133	114	103	97	92	85	80	75	68	60	52	47	43	39	33	30	26	0
.10	0	0	0	0	0	0	2	17	51	100	149	177	186	169	140	119	106	99	93	86	81	75	69	61	52	47	43	39	33	30	26	0
.20	0	0	0	0	0	0	1	12	38	79	126	160	181	173	147	124	109	101	95	88	81	76	69	62	53	48	44	39	33	30	26	0
.30	0	0	0	0	0	0	0	1	8	28	62	105	141	176	165	141	120	107	99	91	84	78	71	64	56	49	45	41	33	31	26	0
.40	0	0	0	0	0	0	0	1	6	20	48	86	123	172	172	146	125	111	101	92	85	79	72	65	56	50	45	41	34	31	26	0
.50	0	0	0	0	0	0	0	0	4	15	37	70	105	157	167	151	130	114	104	94	87	79	73	66	57	50	46	42	34	31	27	0
.75	0	0	0	0	0	0	0	0	0	1	6	17	37	91	139	157	150	134	119	103	93	84	76	69	62	54	48	44	35	32	27	0
1.0	0	0	0	0	0	0	0	0	0	0	1	3	9	40	91	135	153	149	135	113	99	88	79	72	65	57	50	45	37	32	27	1
1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	24	59	101	132	144	130	107	90	80	73	65	57	51	41	34	29	6
2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	7	25	55	106	138	130	105	89	79	72	65	57	45	37	30	15
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	9	36	81	133	133	104	88	79	71	64	50	41	31	21
3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	24	74	128	122	103	88	78	70	55	45	32	23

RAINFALL TYPE = III * * * TC = 0.5 HR * * * SHEET 5 OF 10

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

5-48



5-44

Exhibit 5-III: Tabular hydrograph unit discharges (csm/in) for type III rainfall distribution—continued

TRVL TIME (hr)	HYDROGRAPH TIME(HOURS)																														
	11.0	11.3	11.6	11.9	12.0	12.1	12.2	12.3	12.4	12.5	12.6	12.7	12.8	13.0	13.2	13.4	13.6	13.8	14.0	14.3	14.6	15.0	15.5	16.0	16.5	17.0	17.5	18.0	19.0	20.0	22.0	26.0
IA/P = 0.10 * * * TC = 0.75 HR * * * IA/P = 0.10																															
0.0	17	22	28	39	45	56	73	104	151	215	281	328	343	310	228	163	121	94	77	63	53	45	39	34	29	25	22	20	15	14	11	0
.10	17	21	27	37	42	51	66	91	131	187	250	302	336	319	247	179	131	101	82	65	55	46	40	35	29	25	22	20	16	14	11	0
.20	15	19	24	31	35	40	48	60	81	114	163	221	275	328	298	229	167	124	96	73	60	49	42	36	31	26	23	20	16	14	12	0
.30	14	18	23	30	33	38	44	55	72	100	142	194	248	320	305	245	182	135	103	76	62	50	42	37	31	27	23	21	16	14	12	0
.40	13	16	21	26	29	32	36	41	50	65	88	124	171	268	313	288	228	170	127	88	68	54	44	38	33	28	24	21	17	14	12	0
.50	12	16	20	25	28	30	34	39	46	59	78	109	150	244	306	294	242	184	138	94	71	56	45	39	34	28	24	22	17	14	12	0
.75	10	13	16	21	23	25	27	30	33	38	46	58	77	140	221	277	287	248	197	133	92	66	50	42	36	31	26	23	18	15	12	1
1.0	8	10	13	16	18	19	21	23	25	27	30	34	39	61	109	181	249	280	265	198	134	85	58	46	40	34	29	25	20	16	12	2
1.5	5	7	9	12	13	14	15	16	17	19	20	22	24	30	40	63	106	167	225	261	226	147	84	58	46	39	34	29	22	17	13	5
2.0	2	4	5	7	8	9	9	10	11	12	13	14	16	18	22	26	34	50	80	155	226	246	158	91	61	47	40	34	25	20	14	9
2.5	1	2	3	5	5	6	6	7	8	8	9	10	11	13	15	18	21	26	34	62	120	209	234	151	90	60	47	39	29	22	15	10
3.0	0	1	2	3	3	3	4	4	5	5	6	7	7	9	10	12	15	17	21	29	50	113	209	224	144	88	59	46	33	25	16	10
IA/P = 0.30 * * * TC = 0.75 HR * * * IA/P = 0.30																															
0.0	0	0	0	0	1	3	8	24	58	113	182	243	283	287	233	178	139	114	98	83	73	64	56	50	43	37	33	30	24	21	18	0
.10	0	0	0	0	0	2	6	18	45	91	151	212	259	284	245	191	149	120	102	85	75	65	57	50	43	37	33	30	24	21	18	0
.20	0	0	0	0	0	0	1	5	14	35	72	125	183	263	277	230	180	142	116	93	80	68	59	52	45	39	34	31	25	22	18	0
.30	0	0	0	0	0	0	1	3	10	26	57	102	156	245	270	240	192	151	122	96	82	69	60	53	46	39	35	31	25	22	18	0
.40	0	0	0	0	0	0	0	1	2	8	20	45	83	182	252	264	226	181	144	108	89	73	62	55	48	41	36	32	26	22	19	0
.50	0	0	0	0	0	0	0	0	2	6	15	35	67	158	235	259	235	192	153	113	92	75	63	56	49	42	36	33	26	22	19	1
.75	0	0	0	0	0	0	0	0	0	0	1	2	7	35	100	178	232	242	217	163	121	90	71	61	54	47	40	35	28	23	19	2
1.0	0	0	0	0	0	0	0	0	0	0	0	1	4	21	68	140	205	236	229	181	135	97	74	63	55	48	41	36	29	24	19	3
1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	13	42	94	155	221	212	158	103	77	64	56	49	42	33	26	20	10
2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	15	42	113	184	209	151	101	76	63	55	48	36	29	21	14
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	5	27	80	168	199	146	100	75	63	55	41	32	22	15
3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	10	56	154	191	151	105	78	64	48	37	24	16
IA/P = 0.50 * * * TC = 0.75 HR * * * IA/P = 0.50																															
0.0	0	0	0	0	0	0	0	3	13	37	71	108	140	167	156	136	120	108	101	92	85	78	72	64	56	50	45	41	34	31	26	0
.10	0	0	0	0	0	0	0	2	10	28	57	91	124	163	158	140	124	111	103	94	86	79	72	65	57	50	46	41	34	31	27	0
.20	0	0	0	0	0	0	0	0	1	7	21	45	76	135	159	153	136	120	109	98	90	82	74	67	59	52	47	43	35	31	27	0
.30	0	0	0.	0	0	0	0	0	1	5	15	35	62	121	157	157	140	124	112	100	91	83	75	68	60	52	47	43	35	31	27	0
.40	0	0	0	0	0	0	0	0	1	3	11	27	50	107	146	154	143	128	115	102	93	84	76	69	61	53	48	43	35	32	27	0
.50	0	0	0	0	0	0	0	0	0	0	2	8	21	66	118	148	152	139	125	108	97	87	78	71	63	55	49	45	36	32	27	1
.75	0	0	0	0	0	0	0	0	0	0	1	4	10	38	82	122	142	144	133	116	103	91	80	73	66	58	51	46	37	32	28	1
1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	24	60	102	132	142	133	116	99	86	77	70	62	55	49	40	33	28	3
1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	7	25	55	91	128	136	119	98	85	77	69	62	54	44	36	29	11
2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	9	25	66	109	131	116	97	85	76	69	61	48	39	30	18
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	16	47	100	127	114	96	84	75	68	53	43	31	22
3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	10	44	102	124	112	95	83	75	59	47	33	23

RAINFALL TYPE = III * * * TC = 0.75 HR * * * SHEET 6 OF 10

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

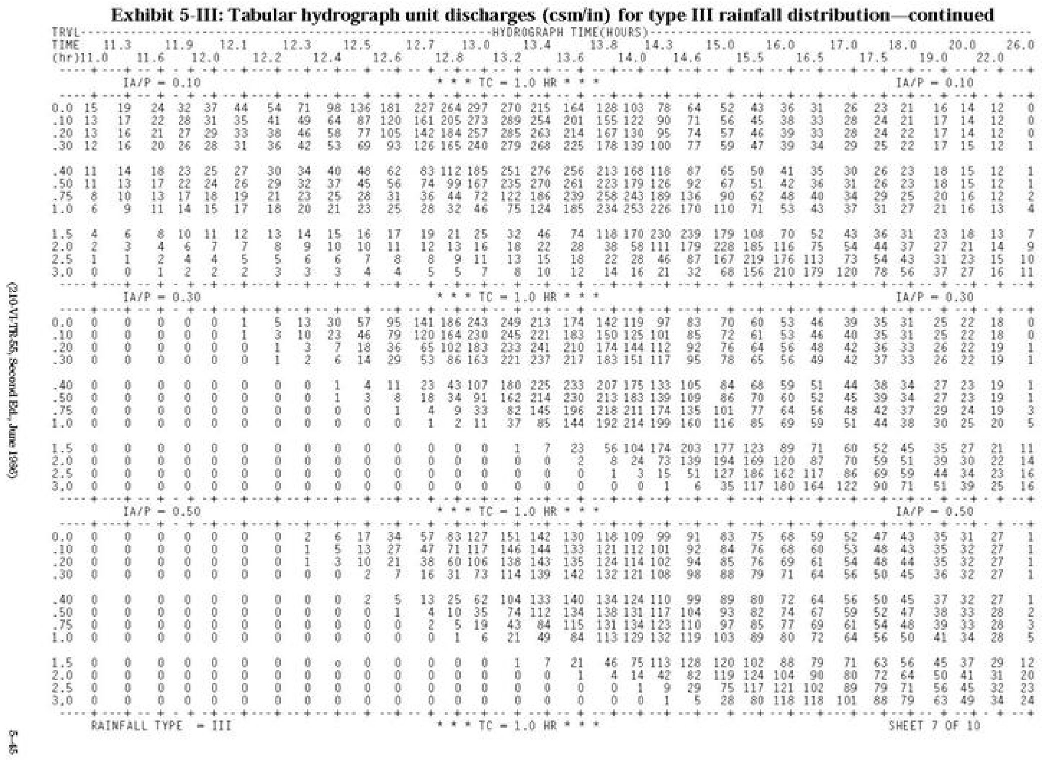


Exhibit 5-III: Tabular hydrograph unit discharges (csm/in) for type III rainfall distribution—continued

HYDROGRAPH TIME(HOURS)

IA/P = 0.10   * * * TC = 1.0 HR * * *   IA/P = 0.10

TRVL TIME (hr)	11.0	11.3	11.6	11.9	12.0	12.1	12.2	12.3	12.4	12.5	12.6	12.7	12.8	13.0	13.2	13.4	13.6	13.8	14.0	14.3	14.6	15.0	15.5	16.0	16.5	17.0	17.5	18.0	19.0	20.0	22.0	26.0
0.0	15	19	24	32	37	44	54	71	98	136	181	227	264	297	270	215	164	128	103	78	64	52	43	36	31	26	23	21	16	14	12	0
.10	13	17	22	28	31	35	41	49	64	87	120	161	205	273	289	254	201	155	122	90	71	56	45	38	33	28	24	21	17	14	12	0
.20	13	16	21	27	29	33	38	46	58	77	105	142	184	257	285	263	214	167	130	95	74	57	46	39	33	28	24	22	17	14	12	0
.30	12	16	20	26	28	31	36	42	53	69	93	126	165	240	279	268	225	178	139	100	77	59	47	39	34	29	25	22	17	15	12	1
.40	11	14	18	23	25	27	30	34	40	48	62	83	112	185	251	276	256	213	168	118	87	65	50	41	35	30	26	23	18	15	12	1
.50	11	13	17	22	24	26	29	32	37	45	56	74	99	167	235	270	261	223	179	126	92	67	51	42	36	31	26	23	18	15	12	1
.75	8	10	13	17	18	19	21	23	25	28	31	36	44	72	122	186	239	258	243	189	136	90	62	48	40	34	29	25	20	16	12	2
1.0	6	9	11	14	15	17	18	20	21	23	25	28	32	46	75	124	185	234	253	226	170	110	71	53	43	37	31	27	21	16	13	4
1.5	4	6	8	10	11	12	13	14	15	16	17	19	21	25	32	46	74	118	170	230	239	179	108	70	52	43	36	31	23	18	13	7
2.0	2	3	4	6	7	7	8	9	10	10	11	12	13	16	18	22	28	38	58	111	179	228	185	116	75	54	44	37	27	21	14	9
2.5	1	1	2	4	4	5	5	6	6	7	8	8	9	11	13	15	18	22	28	46	87	167	219	176	113	73	54	43	31	23	15	10
3.0	0	0	1	2	2	2	3	3	3	4	4	5	5	7	8	10	12	14	16	21	32	68	156	210	179	120	78	56	37	27	16	11

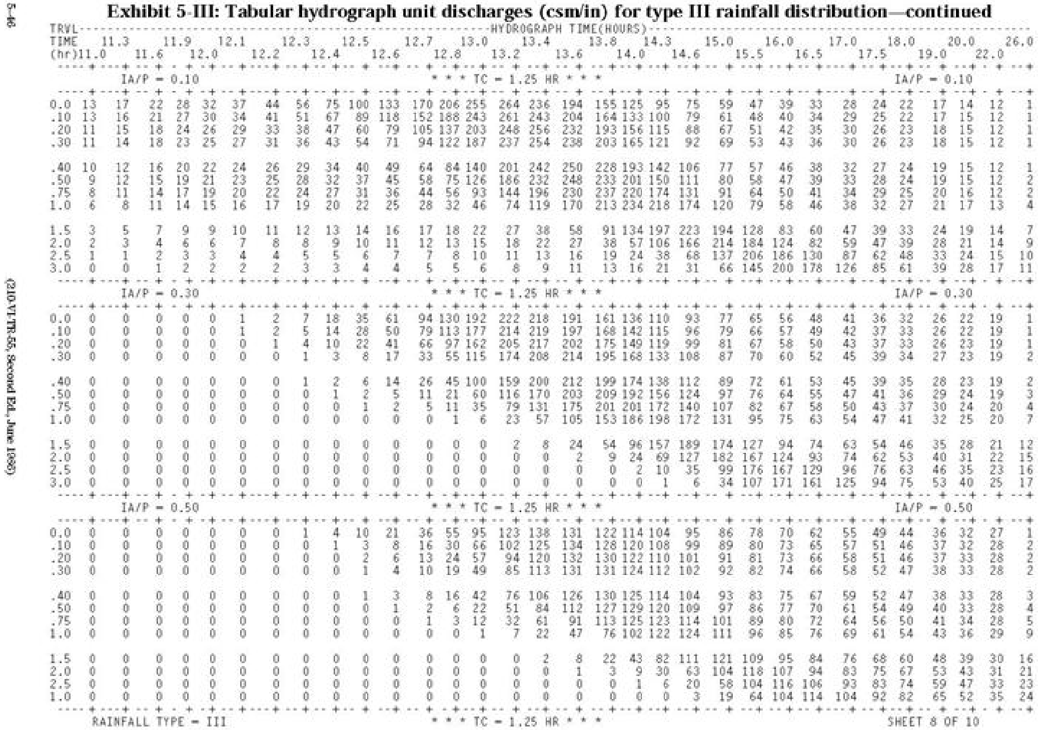
IA/P = 0.30   * * * TC = 1.0 HR * * *   IA/P = 0.30

TRVL TIME (hr)	11.0	11.3	11.6	11.9	12.0	12.1	12.2	12.3	12.4	12.5	12.6	12.7	12.8	13.0	13.2	13.4	13.6	13.8	14.0	14.3	14.6	15.0	15.5	16.0	16.5	17.0	17.5	18.0	19.0	20.0	22.0	26.0
0.0	0	0	0	0	0	1	5	13	30	57	95	141	186	243	249	213	174	142	119	97	83	70	60	53	46	39	35	31	25	22	18	0
.10	0	0	0	0	0	1	3	10	23	46	79	120	164	230	245	221	183	150	125	101	85	72	61	53	46	40	35	31	25	22	18	0
.20	0	0	0	0	0	0	1	3	7	18	36	65	102	183	233	241	210	174	144	112	92	76	64	56	48	42	36	33	26	22	19	1
.30	0	0	0	0	0	0	1	2	6	14	29	53	86	163	221	237	217	183	151	117	95	78	65	56	49	42	37	33	26	22	19	1
.40	0	0	0	0	0	0	0	0	1	4	11	23	43	107	180	225	233	207	175	133	105	84	68	59	51	44	38	34	27	23	19	1
.50	0	0	0	0	0	0	0	0	1	3	8	18	34	91	162	214	230	213	183	139	109	86	70	60	52	45	39	34	27	23	19	1
.75	0	0	0	0	0	0	0	0	0	0	1	4	9	33	82	145	196	218	211	174	135	101	77	64	56	48	42	37	29	24	19	3
1.0	0	0	0	0	0	0	0	0	0	0	0	1	2	11	37	85	144	192	214	199	160	116	85	69	59	51	44	38	30	25	20	5
1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	7	23	56	104	174	203	177	123	89	71	60	52	45	35	27	21	11
2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	8	24	73	139	194	169	120	87	70	59	51	39	30	22	14
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	15	51	127	186	162	117	86	69	59	44	34	23	16
3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	6	35	117	180	164	122	90	71	51	39	25	16

IA/P = 0.50   * * * TC = 1.0 HR * * *   IA/P = 0.50

TRVL TIME (hr)	11.0	11.3	11.6	11.9	12.0	12.1	12.2	12.3	12.4	12.5	12.6	12.7	12.8	13.0	13.2	13.4	13.6	13.8	14.0	14.3	14.6	15.0	15.5	16.0	16.5	17.0	17.5	18.0	19.0	20.0	22.0	26.0
0.0	0	0	0	0	0	0	0	2	6	17	34	57	83	127	151	142	130	118	109	99	91	83	75	68	59	52	47	43	35	31	27	1
.10	0	0	0	0	0	0	0	1	5	13	27	47	71	117	146	144	133	121	112	101	92	84	76	68	60	53	48	43	35	32	27	1
.20	0	0	0	0	0	0	0	1	3	10	21	38	60	106	138	143	135	124	114	102	94	85	76	69	61	54	48	44	35	32	27	1
.30	0	0	0	0	0	0	0	0	0	2	7	16	31	73	114	139	142	132	121	108	98	88	79	71	64	56	50	45	36	32	27	1
.40	0	0	0	0	0	0	0	0	0	2	5	13	25	62	104	133	140	134	124	110	99	89	80	72	64	56	50	45	37	32	27	1
.50	0	0	0	0	0	0	0	0	0	0	1	4	10	35	74	112	134	138	131	117	104	93	82	74	67	59	52	47	38	33	28	2
.75	0	0	0	0	0	0	0	0	0	0	0	2	5	19	43	84	115	131	134	123	110	97	85	77	69	61	54	48	39	33	28	3
1.0	0	0	0	0	0	0	0	0	0	0	0	0	1	6	21	49	84	113	129	132	119	103	89	80	72	64	56	50	41	34	28	5
1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	7	21	46	75	113	128	120	102	88	79	71	63	56	45	37	29	12
2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	14	42	82	119	124	104	90	80	72	64	50	41	31	20
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	9	29	75	117	121	102	89	79	71	56	45	32	23
3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	5	28	80	118	118	101	88	79	63	49	34	24

RAINFALL TYPE = III   * * * TC = 1.0 HR * * *   SHEET 7 OF 10



5–46

Exhibit 5-III: Tabular hydrograph unit discharges (csm/in) for type III rainfall distribution—continued

TRVL TIME (hr) — HYDROGRAPH TIME (HOURS)

IA/P = 0.10 * * * TC = 1.25 HR * * * IA/P = 0.10

TRVL TIME (hr)	11.0	11.3	11.6	11.9	12.0	12.1	12.2	12.3	12.4	12.5	12.6	12.7	12.8	13.0	13.2	13.4	13.6	13.8	14.0	14.3	14.6	15.0	15.5	16.0	16.5	17.0	17.5	18.0	19.0	20.0	22.0	26.0
0.0	13	17	22	28	32	37	44	56	75	100	133	170	206	255	264	236	194	155	125	95	75	59	47	39	33	28	24	22	17	14	12	1
.10	13	16	21	27	30	34	41	51	67	89	118	152	188	243	261	243	204	164	133	100	79	61	48	40	34	29	25	22	17	15	12	1
.20	11	15	18	24	26	29	33	38	47	60	79	105	137	203	248	256	232	193	156	115	88	67	51	42	35	30	26	23	18	15	12	1
.30	11	14	18	23	25	27	31	36	43	54	71	94	122	187	237	254	238	203	165	121	92	69	53	43	36	30	26	23	18	15	12	1
.40	10	12	16	20	22	24	26	29	34	40	49	64	84	140	201	242	250	228	193	142	106	77	57	46	38	32	27	24	19	15	12	1
.50	9	12	15	19	21	23	25	28	32	37	45	58	75	126	186	232	248	233	201	150	111	80	58	47	39	33	28	24	19	15	12	2
.75	8	11	14	17	19	20	22	24	27	31	36	44	56	93	144	196	230	237	220	174	131	91	64	50	41	34	29	25	20	16	12	2
1.0	6	8	11	14	15	16	17	19	20	22	25	28	32	46	74	119	170	213	234	218	174	120	79	58	46	38	32	27	21	17	13	4
1.5	3	5	7	9	9	10	11	12	13	14	16	17	18	22	27	38	58	91	134	197	223	194	128	83	60	47	39	33	24	19	14	7
2.0	2	3	4	6	6	7	8	8	9	10	11	12	13	15	18	22	27	38	57	106	166	214	184	124	82	59	47	39	28	21	14	9
2.5	1	1	2	3	3	4	4	5	5	6	7	7	8	10	11	13	16	19	24	38	68	137	206	186	130	87	62	48	33	24	15	10
3.0	0	0	1	2	2	2	2	3	3	4	4	5	5	6	8	9	11	13	16	21	31	66	145	200	178	126	85	61	39	28	17	11

IA/P = 0.30 * * * TC = 1.25 HR * * * IA/P = 0.30

TRVL TIME (hr)	11.0	11.3	11.6	11.9	12.0	12.1	12.2	12.3	12.4	12.5	12.6	12.7	12.8	13.0	13.2	13.4	13.6	13.8	14.0	14.3	14.6	15.0	15.5	16.0	16.5	17.0	17.5	18.0	19.0	20.0	22.0	26.0
0.0	0	0	0	0	0	1	2	7	18	35	61	94	130	192	222	218	191	161	136	110	93	77	65	56	48	41	36	32	26	22	19	1
.10	0	0	0	0	0	1	2	5	14	28	50	79	113	177	214	219	197	168	142	115	96	79	66	57	49	42	37	33	26	22	19	1
.20	0	0	0	0	0	0	1	4	10	22	41	66	97	162	205	217	202	175	149	119	99	81	67	58	50	43	37	33	26	23	19	1
.30	0	0	0	0	0	0	0	1	3	8	17	33	55	115	174	208	214	195	168	133	108	87	70	60	52	45	39	34	27	23	19	2
.40	0	0	0	0	0	0	0	1	2	6	14	26	45	100	159	200	212	199	174	138	112	89	72	61	53	45	39	35	28	23	19	2
.50	0	0	0	0	0	0	0	0	1	2	5	11	21	60	116	170	203	209	192	156	124	97	76	64	55	47	41	36	29	24	19	3
.75	0	0	0	0	0	0	0	0	0	1	2	5	11	35	79	131	175	201	201	172	140	107	82	67	58	50	43	37	30	24	20	4
1.0	0	0	0	0	0	0	0	0	0	0	0	0	1	6	23	57	105	153	186	198	172	131	95	75	63	54	47	41	32	25	20	7
1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	8	24	54	96	157	189	174	127	94	74	63	54	46	35	28	21	12
2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	9	24	69	127	182	167	124	93	74	62	53	40	31	22	15
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	10	35	99	176	167	129	96	76	63	46	35	23	16
3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	6	34	107	171	161	125	94	75	53	40	25	17

IA/P = 0.50 * * * TC = 1.25 HR * * * IA/P = 0.50

TRVL TIME (hr)	11.0	11.3	11.6	11.9	12.0	12.1	12.2	12.3	12.4	12.5	12.6	12.7	12.8	13.0	13.2	13.4	13.6	13.8	14.0	14.3	14.6	15.0	15.5	16.0	16.5	17.0	17.5	18.0	19.0	20.0	22.0	26.0
0.0	0	0	0	0	0	0	0	1	4	10	21	36	55	95	123	138	131	122	114	104	95	86	78	70	62	55	49	44	36	32	27	1
.10	0	0	0	0	0	0	0	0	1	3	8	16	30	66	102	125	134	128	120	108	99	89	80	73	65	57	51	46	37	32	28	2
.20	0	0	0	0	0	0	0	0	0	2	6	13	24	57	94	120	132	130	122	110	101	91	81	73	66	58	51	46	37	33	28	2
.30	0	0	0	0	0	0	0	0	0	1	4	10	19	49	85	113	131	131	124	112	102	92	82	74	66	58	52	47	38	33	28	2
.40	0	0	0	0	0	0	0	0	0	1	3	8	16	42	76	106	126	130	125	114	104	93	83	75	67	59	52	47	38	33	28	3
.50	0	0	0	0	0	0	0	0	0	0	1	2	6	22	51	84	112	127	129	120	109	97	86	77	70	61	54	49	40	33	28	4
.75	0	0	0	0	0	0	0	0	0	0	0	1	3	12	32	61	91	113	125	123	114	101	89	80	72	64	56	50	41	34	28	5
1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	7	22	47	76	102	122	124	111	96	85	76	69	61	54	43	36	29	9
1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	8	22	43	82	111	121	109	95	84	76	68	60	48	39	30	16
2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	9	30	63	104	118	107	94	83	75	67	53	43	31	21
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	6	20	58	104	116	106	93	83	74	59	47	33	23
1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	19	64	104	114	104	92	82	65	52	35	24

RAINFALL TYPE = III * * * TC = 1.25 HR * * * SHEET 8 OF 10

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

Appendix 3-B. Rainfall Distribution for the US (from TR-55, SCS, and TP-40)