CHAPTER 7: HYDROLOGY

For a stormwater-management design to be effective, it is necessary to develop an understanding of how much water will be running off a watershed and the rate at which the runoff will occur. This section of the guidebook will discuss various methods that are available to estimate the runoff and the peak flows. It is important to note that hydrology is a combination of "art" and science. Since many methods are available that will produce a discharge, there is no one method that is always "correct." This guidebook will focus on the methodologies that are used by the Michigan Department of Environmental Quality, Land and Water Management Division, Hydrologic Studies Unit (telephone # (517) 335-3176). Other methods will be mentioned; however, they will not be discussed in detail.

There are numerous variables that are required to compute flood flows using the various hydrologic methods. Two variables that would be required for the majority of the methods include **drainage area** and **precipitation.**

WATERSHED DELINEATION

A very important component of any hydrologic study or analysis is determining the amount of area that will be contributing runoff to the design point. The boundary of a watershed for surface water runoff will follow ridges or high points that separate one drainage basin from another (See figure 7.1).

An inaccurate boundary will result in inaccurate runoff volumes and peaks. Thus, it is critical to spend the time necessary to get the delineation as accurate as possible. The watershed boundary is drawn using the following considerations:

1. Obtain the most up-to-date topographic information, such as USGS quadrangle, aerial photographs, county or community topographic mapping, or storm -drain maps. In urban areas, the use of only a USGS quadrangle may result in significant errors in the delineation. Storm-drain maps and better topographic information is critical in urban areas.
2. Identify the main watercourse and all of its tributaries. Identify ridges and high points that outline the boundary of the watershed.
3. Water will flow perpendicularly to the contours on the topographic map.
4. The topographic contours point upstream when it crosses a watercourse.
5. In urban areas, street grades may define the drainage boundary.
6. Delineate areas that will be draining into depressions from which flow will not escape (natural retention areas). These depressions will have to be deep enough so water will be retained. Such drainage areas will be subtracted from the total drainage area as they will not contribute to the runoff. Care should be taken to make sure depressions are not filled or drained during development.
7. It is necessary to field check the delineation to determine if it is appropriate. It is possible that urbanization or drain projects may have changed the drainage patterns since the topographic map has been prepared. In some instances, the topographic map may not be adequate to accurately determine drainage boundaries due to the contour intervals on the map.
   In reference 1, the watershed delineations for 12 watersheds in the Denver area based solely on a topographic map were compared to field-verified delineations. It was found that the watershed area determined by a delineation based solely on a topographic map ranged from 5 times greater to 8 times less than the field-verified delineation.

These are obviously extreme examples; however, they point out the need for field checking watershed boundaries.

8. It is also recommended that the delineation consider the effects that future development may have on the watershed divide. Future development may alter the runoff patterns which may change the size and shape of the watershed.

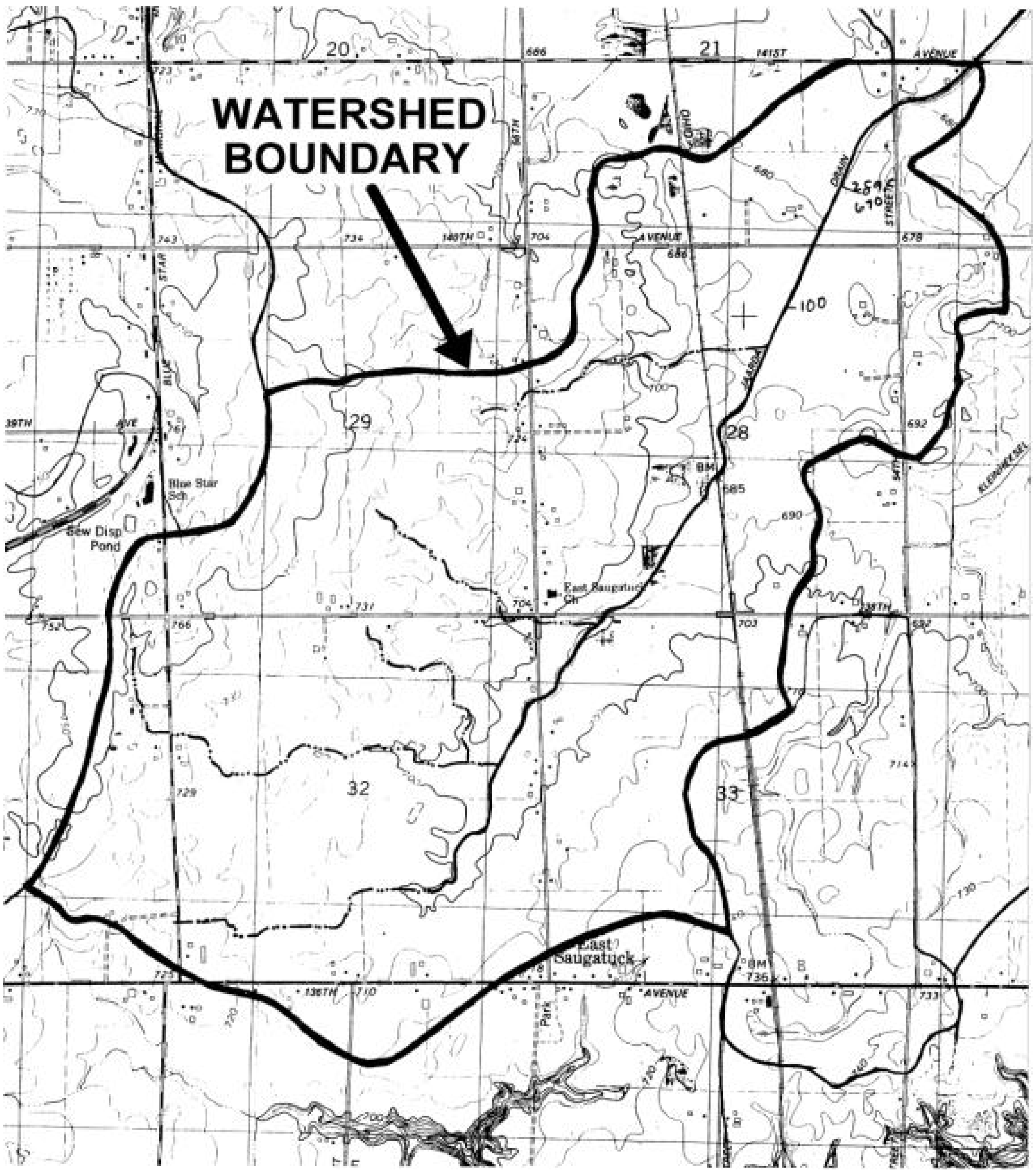


Figure 7.1 - Typical Watershed Delineation

Precipitation

The amount of precipitation that will be occurring in a watershed will be essential in determining the volume of runoff and flood peaks. The National Weather Service is the primary source of rainfall data. Technical Paper 40, “Rainfall Frequency Atlas of the United States" published by the National Weather Service (reference 50) contains expected rainfall durations ranging from 30 minutes to 24 hours, and for frequencies ranging from 1 to 100-year events. In 1990, the DEQ updated the rainfall frequencies for Michigan (reference 40).

Figure 7.3 gives the updated 100-year, 24-hour rainfall amounts for the state of Michigan. Appendix B lists other rainfall amounts for the State. It is suggested that future designs in Michigan utilize the updated rainfall data.

For large drainage areas (greater than 10 square miles), it may be necessary to make an adjustment to the rainfall as it is unlikely that the rainfall will be spread uniformly over a large drainage area. This guidebook is mostly concerned with smaller drainage areas, which will not require an adjustment to the rainfall. However, figure 7.2, does provide the adjustment to the rainfall that would be required for larger drainage areas.

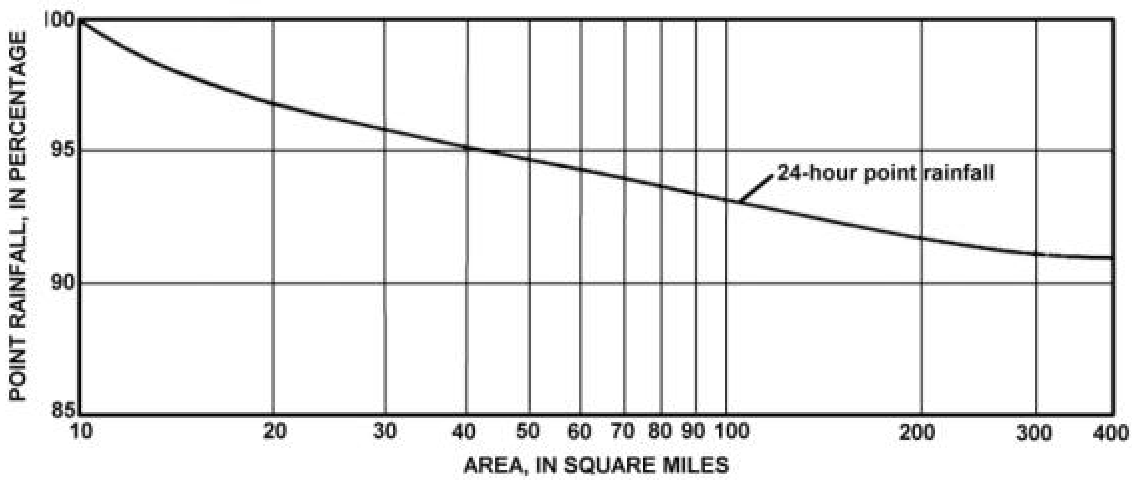


Figure 7.2 - Area-Depth Curve for Adjustment of Point Rainfall

(Adapted from U.S. Weather Bureau, 1961)

OVERVIEW OF HYDROLOGIC METHODS

It is not possible to discuss all of the hydrologic methods that are available to estimate runoff volumes and flood peaks. The methods can range from the rational method to computer models which provide a continuous hydrologic simulation. A survey by the American Public Works Association indicated that over 40 various hydrologic methods are currently in use around the Country. Listed below are some of the methods used by the Michigan Department of Environmental Quality:

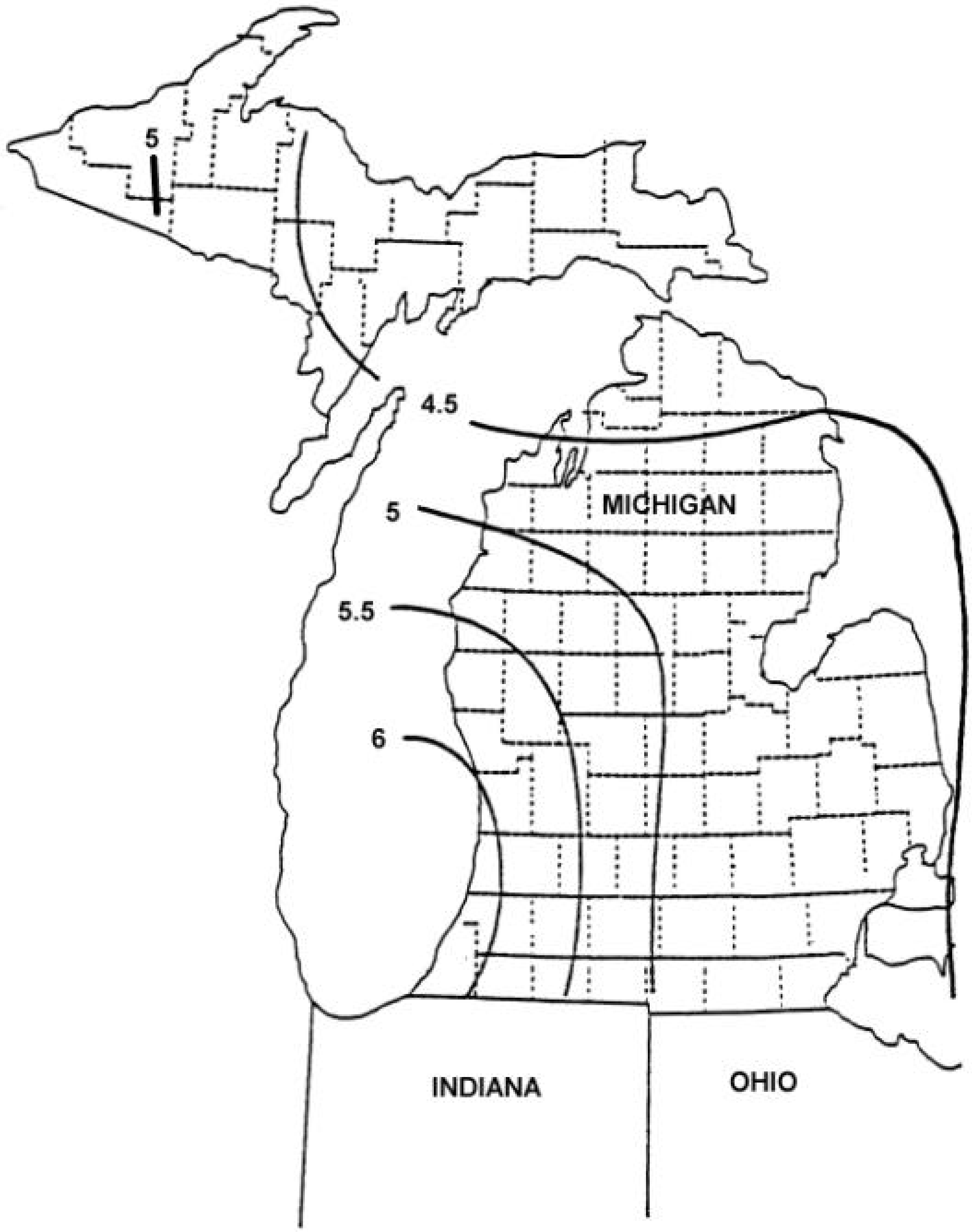


Figure 7.3 - 100-year, 24-hour Point Rainfall Depths, State of Michigan

(From MDNR 1991, Reference 40)

1. **Gaged Locations - Statistical Analysis**

The U.S. Geological Survey in cooperation with State agencies maintains about 145 continuous stream-flow gaging stations, and 48 crest-stage partial-record stations in Michigan. No matter how good the theoretical methods may be, there is no substitute for having information from actual flood events.

A statistical analysis of the gaging-station record provides a discharge-probability relationship for the watercourse at the gaging-station site. Such information can be obtained from either the U.S. Geological Survey (USGS), or from the Michigan Department of Environmental Quality, Land & Water Management Division, Hydrologic Studies Unit (telephone # (517) 335-3176).

In addition to obtaining discharge-probability relationships for gage sites, continuous recording gages will also provide a hydrograph at the site. The crest-stage recorders would only provide a peak stage.

Several of the drawbacks of using the gaging stations include:

1. Very few of the rivers and streams have gaging station information. Usually the gaging stations are located on watercourses that have a relatively large drainage area. The majority of the stormwater management designs will likely be on "ungaged" small watersheds.
2. Many of the gages have a relatively short record. Trying to estimate the 100-year flood flows may require extrapolation of the data, which may lead to potential error.
3. Funding reductions for the stream-gaging program has resulted in over 100 gaging-station sites being eliminated in the past 20 years. Thus, some records may be incomplete, and have missed substantial flood events.
4. Some of the watersheds that have gaging stations may have under-gone changes over the years. These changes may include urbanization and channel improvements. As a result, the records may not be homogeneous. In other words, the flows produced by the watershed for similar rainstorms may change over the years due to changes in the watershed or the river system. A statistical analysis may not produce reliable results.

If a stormwater-management study is to be prepared for a watershed, it is advisable to set up a gaging station and a rain-gage network to determine flow and runoff characteristics of the basin. The gage should be in for at least a year, and preferably more. The characteristics of the watershed, and how it responds to various runoff events, will be better understood the longer the gage is in place.

2. **Transfer Methods**

The transfer method uses the peak-flow information computed at a location and extrapolates the information upstream, downstream, or to a different watershed.

The transfer method is limited, as there is an assumption that the flows are a function of the size of the drainage area. If the basin characteristics change from the gage site to the design location, a transfer may not be appropriate. Of particular concern would include changes in land-use, soil type, channel slope, or storage (such as lakes, reservoir or valley storage). There is also the limitation that this method only computes peak flows.

3. **Regression Analysis (Regional Method)**

A regression analysis was developed by the USGS and the DEQ for Michigan (reference 18). The regression analysis is a regional method that allows the designer to compute a peak flow (100-year, 10-year, and etc.) when several physical variables are known. The regression is based upon an evaluation of gage sites throughout Michigan. The variables in the Michigan regression equation include:

basin area
precipitation
channel slope
slenderness ratio (stream length squared divided by the contributing drainage area)
forested area
mean snowfall depth
temperature
geological characteristics (such as clay, glacial till, moraines, glacial outwash, muck, etc.)

There are a couple of limitations on using the regression equation.

1. The equation is not applicable for areas that are either urbanized or where flow is regulated.
2. Caution should be used when the drainage area of a basin is less than 10 square miles.
3. The equation will only compute a peak flow.

4. **SCS Methodology as Adapted to Michigan by the DEQ**

The runoff curve number methodology developed by the Soil Conservation Service (SCS) was adapted to Michigan in a publication prepared by the DEQ (reference 39). The method has been subsequently updated in October 1991 (reference 40). If additional information is needed, it is suggested that references 40 and 49 be reviewed. The method is very straight forward, as it considers drainage area, rainfall data, land use, soil type, time of concentration, antecedent moisture content, and adjustments for swamps and ponding.

5. **SCS Technical Release 55 (TR-55)**

TR-55, Urban Hydrology for Small Watersheds (reference 46), provides simplified procedures to calculate runoff volumes, peak flows, hydrographs, and storage-volume requirements for detention ponds. The methods contained in TR-55 are primarily applicable for small urban/urbanizing watersheds and are also available in a computer-program format.

The methods used in TR-55 to compute the volume of runoff are the same as used in the UD-21 Methodology. The runoff is computed based on soil type, precipitation, and land use.

Under urbanized conditions the terms impervious and "connected" become much more important in regard to runoff. As noted earlier, impervious conditions would include roof-tops, parking lots, roadways, and etc. An impervious surface is "connected" to a drainage course if it drains directly into a drainage course. Table 7.1 shows the percent impervious for given urban land uses, and it also assumes that impervious surfaces are connected directly to the drainage courses. If the land use has a different percentage of impervious area, and/or has less than 100% of the impervious area connected to the drainage course, the TR-55 method includes a method to adjust the runoff curve number.

Table 7.1 - Percent Impervious Areas for Urban Land Uses

Land Use	Average Percent Impervious Area
streets and roads	98
Commercial and business	85 / 85
industrial	72
Residential lot 1/8 acre or less 1/4 acre 1/3 acre 1/2 acre 1 acre	65 38 30 25 20

6. **Computer Models**

Using one of the above methods, basin characteristics are developed and can be input into a computer model such as the Corps of Engineers HEC-1 (reference 44) and HEC-HMS (reference 52), or SCS TR-20 (reference 47). The computer models can generate, combine, and route the flood hydrographs. These computer programs that were once limited to "main-frame" computers are now run on personal computers. Once the basic watershed model is set up, it is possible to consider numerous scenarios and design configurations with minimal additional effort.

OTHER METHODS

In addition to the methods that are used by the DEQ, there are numerous other methods that are being used around the nation. Following is a listing of three other methods that are available:

1. **Rational Method**

Probably the most widely used (and sometimes misused) method for computing runoff volumes and peaks is the rational method (references 2, 4, & 36). The rational method was developed in 1889 as a method of sewer design for urban areas. The rational equation is defined by:

$$Q = CiA \tag{14}$$

where: **Q** - peak runoff in cfs
C - runoff coefficient
i - average intensity in inches/hour
A - Drainage area in acres

At first glance, the method looks very simple and straightforward. It is true that it is easy to get an "answer" from the equation, but how appropriate is the "answer"? There is a considerable amount of judgement involved in selecting the C coefficient which considers infiltration, land use, rainfall intensity, and depression storage. The average intensity, i, is a function of local precipitation, frequency-duration, and time of concentration. If the designer has considerable experience and is well aware of the methodology and its limitations the rational method can be applied to small drainage areas. The limitations on the size of the drainage area can range from 20 acres to 200 acres, depending on the complexity of the watershed (reference 2). For additional information on the rational method, it is suggested that reference 4 be used.

2. **Continuous Simulation**

Of the various methodologies available for analyzing the hydrology of a basin, a continuous simulation is by far the most complex. The analysis requires a continuous accounting of the soil moisture, evaporation, precipitation and runoff. This methodology requires extensive input data and computation time.

3. **Colorado Urban Hydrograph Procedure**

This method was originally developed in 1969 for the Denver Regional Council of Governments. The method will allow the designer to develop a unit hydrograph, and the design-storm hydrograph for the basin. The procedure requires the following information:

a) Rainfall data
b) Basin information: basin size, slope, soils, land use (pervious and impervious areas), detention storage, and depression storage
c) Data to correlate the model, such as past flooding or gaging station information

The method has been used in some Midwest areas with reasonable results. For more information on the method, it is suggested that reference 9 be obtained.

SCS METHODOLOGY

In the preceding pages, we have mentioned the various methods that are available to compute runoff volumes, peak flows, and in some instances hydrographs. In this section, the SCS methodology will be discussed in greater detail. In addition, an example problem will be worked. The methodology will require the following information:

Drainage Area

As discussed earlier, it is extremely important to have an accurate delineation of the watershed boundary.

Rainfall Data

Rainfall information is available from various sources, as noted earlier.

Land Use

The type of land use is critical in determining the amount of runoff that would be anticipated from a watershed. It was also discussed earlier that different land uses produce different runoff amounts. In an attempt to quantify the runoff potential for various land uses and soil

Table 7.2 - Runoff Curve Numbers for Selected Agricultural, Suburban, and Urban Land Use.

(antecedent moisture condition II, and $I_a = 0.2S$) (Reference 49)

Land Use	Treatment or practice	Hydrologic condition	Hydrologic Soil Groups A	B	C	D
Fallow	Straight row		77	81	88	91
Row crops	Straight row	Poor	72	81	88	91
	Straight row	Good	67	78	85	89
	Contoured	Poor	70	79	84	88
	Contoured	Good	65	75	82	86
	…and terraced	Poor	66	74	80	82
	…and terraced	Good	62	71	78	81
Small grain	Straight row	Poor	65	76	84	88
	Straight row	Good	63	75	83	87
	Contoured	Poor	63	74	82	85
	Contoured	Good	61	73	81	84
	…and terraced	Poor	61	72	79	82
	…and terraced	Good	59	70	78	81
Close-seeded	Straight row	Poor	66	77	85	89
legumes or	Straight row	Good	58	72	81	85
rotation	Contoured	Poor	64	75	83	85
meadow	Contoured	Good	55	69	78	83
	…and terraced	Poor	63	73	80	83
	…and terraced	Good	51	67	76	80
Pasture or		Poor	68	79	86	89
range		Fair	49	69	79	84
		Good	39	61	74	80
	Contoured	Poor	47	67	81	88
	Contoured	Fair	25	59	75	83
	Contoured	Good	6	35	70	79
Meadow			30	58	71	78
Woods		Poor	45	66	77	83
		Fair	36	60	73	79
		Good	25	55	70	77
Residential	1/8 acre or less lot size		77	85	90	92
	1/4 acre		61	75	83	87
	1/3 acre		57	72	81	86
	1/2 acre		54	70	80	85
	1 acre		51	68	79	84
Open spaces (parks, golf courses, cemeteries, etc.)						
Good condition: Grass cover > 75% of area			39	61	74	80
Fair condition: Grass cover 50-75% of area			49	69	79	84
Commercial or business area (85% impervious)			89	92	94	95
Industrial district (72% impervious)			81	88	91	93
Farmsteads			59	74	82	86
Paved areas (roads, driveways, parkind lots, roofs)			98	98	98	98
Water Surface (lakes, ponds, reservoirs, etc.)			100	100	100	100
Swamp At least 1/3 is open water			85	85	85	85
Swamp Vegetated			78	78	78	78

types, a value termed "runoff curve number" (RCN) was developed. Table 7.2 provides a listing of land use, soil type, and RCN.

Soil Type

As discussed earlier, different soil types have different infiltration capacities. The soils are broken down into four hydrologic categories: A, B, C, and D. Appendix C lists the hydrologic categories for the various soil types.

Soils that are classified as A soils have a high infiltration rate and a low runoff potential. These soils consist of well -drained sand and gravel.

B soils have a moderate infiltration rate. These soils are fine to moderately coarse in texture, including sandy loam, loam, and silt.

C soils have a slow infiltration rate. These soils are fine or finely textured, and include clay loam.

D soils have the slowest infiltration rate, and the highest runoff rate. The soils are mostly clay and have a high water table.

In some instances, a soil type may have more than one hydrologic classification. As an example, Kinross has a soil classification of D/A. This designation indicates that the soil would exhibit D tendencies if in its natural state. However, if the soil has been artificially drained, such as by tiling, the soil will act as an A soil.

Time of Concentration

Time of concentration (t_c), is the time it takes for a drop of water to travel from the farthest point of the watershed to the design point. The farthest point is based on travel time and not necessarily the longest distance. As an example, for a given distance, it will take longer for water to flow overland than it will to travel along a channel.

The smaller the time of concentration, the quicker flood flows can get to the design point and the higher the peak discharge. For a given watershed, if the time of concentration is reduced, the peak discharge will be increased. On large drainage basins, such as the Grand River, it may take days for the peak flows to reach the design point. While on a small, urbanized watershed, the time of concentration may be less than an hour.

An empirical formula has been developed to estimate the velocity of the flood flow which in turn can be used to determine the travel time (time of concentration).

$$V = KS^{0.5} \quad \text{(Reference 39)} \qquad (15)$$

where: **K** - coefficient depending on the type of channel
S - Slope expressed in percent
V - velocity in feet per second

The K coefficient has been determined for the three types of channels:

1. Small tributaries and swamps with channels. These channels are typically shown on topographic maps as solid or dashed blue lines. (K = 2.1)

2. Overland waterways which are well defined by elevation contours and do not have blue lines indicating a channel. This classification would also include swamps with channels (K = 1.2).
3. Sheet flow that is not well defined by el evation contours (K = 0.48).

By substituting the K values into equation 15, the following equations are obtained:

$$V = 2.1\ S^{0.5} \quad \text{(small tributaries and swamps w/channels)} \qquad (16)$$

$$V = 1.2\ S^{0.5} \quad \text{(waterways and swamps without channels)} \qquad (17)$$

$$V = .48\ S^{0.5} \quad \text{(sheet flow)} \qquad (18)$$

Once velocities are known, it possible to determine the travel time to a design point.

$$t_c = \text{Length} / V \times 3600 \qquad (19)$$

where: **t_c** - time of concentration
Length- distance, in feet, from the most dist ant point in the watershed
V - velocity, in feet per second
3600 - converts seconds to hours

In most situations, different flow types will be occurring as the water flows from the headwaters to the design point. As a result, it will be necessary to compute the t_c for each of the flow types, then add all of the t_c's together. In addition, if there is a significant change in slope, it would be necessary to break a flow type down further to reflect the slope change.

Example 7.1: Time of Concentration

Compute the time of concentration given the following information:

1. Small tributary length of 4000 feet of which, 3000 feet is at a slope of 0.2%, and 1000 feet is at a slope of 1%.
2. The waterway length is 800 feet at a slope of 2%.
3. The sheet flow length is 500 feet at a slope of 0.5%.

Flow Type	Length	Slope(%)	V(fps)*	tc(hrs.)**
Small tributary	3000	0.2	0.94	0.89
Small tributary	1000	1.0	2.10	0.13
Waterway	800	2.0	1.70	0.13
Sheet	500	0.5	0.34	0.41

The total t_c = 0.89 + 0.13 + 0.13 + 0.41 = **1.56 hrs**

* Note: V computed using equations 16, 17, and 18
** t_c = length / V x 3600, (3000/.94 x 3600) = .89 hrs

SURFACE RUNOFF

The major component of any stormwater management design is the amount of surface runoff (SRO). As discussed earlier, runoff will occur when the infiltration capacity of a soil is exceeded by the rainfall intensity. The runoff curve number (RCN) is used in the following equation to estimate the SRO:

$$SRO = \frac{(P-200/RCN+2)^2}{(P+800/RCN-8)} \qquad (20)$$

where: **SRO** - runoff, inches
P - rainfall, inches
RCN - runoff curve number, Table 7.2

Figure 7.4 provides a graphical solution of the above equation.

As an example, if a basin has a RCN of 74, and a total rainfall of 4.3 inches, the SRO is computed to be:

$$SRO = \frac{(4.3-200/74+2)^2}{(4.3+800/74-8)} = \frac{(3.60)^2}{(7.11)} = \quad 1.82 \text{ inches}$$

It is rare for a basin to have a single hydrologic soil type and land use. When a basin does contain more than one hydrologic soil type or land-use type, it will be necessary to break the basin up into soil types and land uses. Following is a suggested procedure determining the runoff from a basin with multiple land uses and soil types (figure 7.8 may be useful in this computation):

1. Determine the percentage of the hydrologic soil types throughout the basin.
2. Determine the different land uses that are present for each soil type. Then determine the percentage of each land use within each soil type.
3. Assign RCN and compute the runoff from each land use within each soil type. Add the runoff from each land use/soil type to determine the runoff from entire basin.
4. If an average RCN is needed for the entire basin, the total runoff volume is divided by the total drainage area to obtain an average runoff. Using the average runoff, and the precipitation, the graph in figure 7.6 can be used to determine an average RCN.

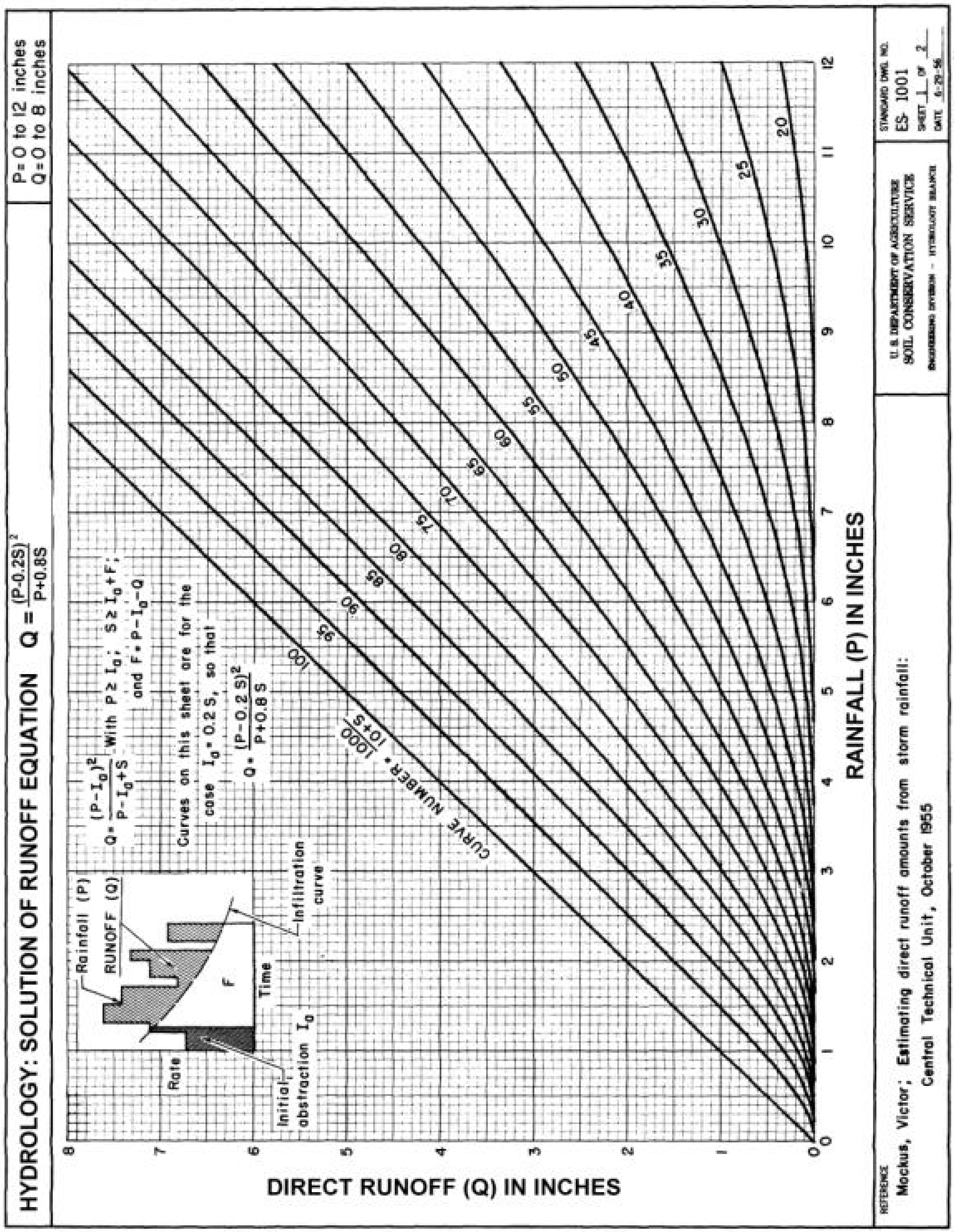


Figure 7.4 - Graphical Solution of Runoff Equation

(Source: Soil Conservation Service, reference 49)

Example 7.2: # Runoff Computations

Compute the runoff from a 1.1-square-mile basin which includes the following hydrologic soil types and land uses. The 100-year 24-hour rainfall is 5.1 inches.

1. B soils - 30%, of which 40% is forest, 40% is 1/2 acre residential, and 20% is parks.
2. C soils - 60%, of which 20% open space, 80% is 1/2 acre residential.
3. D soils - 10%, of which 100 % is meadow.

Soils			**Land Use**			**Runoff**		
Group	%	sq. mi.	Type	%	sq. mi.	RCN	r.o.	Sq. mi.-in.
B	30	0.33	forest res. park	40 40 20	0.132 0.132 0.066	70 70 61	2.11 2.11 1.43	0.279 0.279 0.094
C	60	0.66	open res.	20 80	0.132 0.528	74 80	2.44 2.98	0.322 1.573
D	10	0.11	meadow	100	0.11	71	2.19	0.241

The **total volume of runoff** is:

= 0.279 + 0.279 + 0.094 + 0.322 + 1.573 + 0.241

= **2.79 sq.mi-in**

The average runoff $= \dfrac{2.79 \text{ sq.mi.-in.}}{1.1 \text{ sq. mi.}} =$ **2.54 inches**

Using a precipitation of 5.1 inches and a runoff of 2.54 inches, an average RCN of 75 for the basin may be determined from Figure 7.4.

ANTECEDENT MOISTURE CONDITION

The antecedent moisture condition (AMC) of a soil is an index of the "wetness" of the soil. For the SCS methodology there are three levels of AMC:

1. **AMC-I** has the lowest runoff potential. The soils are relatively dry.
2. **AMC-II** is an average condition.
3. **AMC-III** occurs when the watershed is saturated, thus the runoff potential is the highest.

Table 7.3 lists the AMC groups based on the total 5 -day previous rainfall:

Table 7.3 - Total 5-day antecedent rainfall, inches

AMC Group	Dormant Season	Growing Season
I	less than 0.5	less than 1.4
II	0.5 to 1.11	1.4 to 2.1
III	over 1.1	over 2.1

(From reference 49)

A soil that is dry will produce less runoff than the same soil that is saturated. Most everyone knows of instances in which there has been a "100 -year" rainfall but not a 100-year flood. The moisture content plays a major role in affecting the amount of runoff that will occur.

Table 7.2 lists the RCN values for various land uses and soil types. These values are based on an AMC condition II. If a moisture content other than condition II exists, table 7.4 lists a method of modifying the RCN values to a condition I or III. For most design conditions, a type II condition would be used. However, if the hydrologic analysis is trying to match a past flood, it will be necessary to use the correct moisture condition that was present at the time of the flood event.

UNIT HYDROGRAPH PEAK

A unit hydrograph results when a 24-hour rainfall produces a 1-inch depth of runoff over the given drainage area (reference 4). The unit hydrograph will show the rates at which the runoff will occur from the watershed, for the 1-inch runoff. In theory, the unit hydrograph will be constant for a given duration storm. For runoff amounts other than 1 inch, the ordinates of the hydrograph are multiplied by the runoff amount.

Once the total runoff volume is computed using the procedure above, it is possible to compute the peak flow. The first step is to compute the unit hydrograph peak, $\mathbf{Q_p}$, in cfs/sq.mi.-inches. Figure 7.5 plots $\mathbf{Q_p}$ versus $\mathbf{t_c}$. The value of $\mathbf{Q_p}$ may also be computed using the following equation:

$$Q_p = 270.9\,(t_c)^{-0.81} \qquad (21)$$

This equation is applicable for 24-hour rainfall events, and for drainage areas of less than twenty square miles. For additional information on this procedure, it is suggested that the designer obtain reference 40 from the DEQ, Land and Water Management Division, Hydrologic Studies Unit (telephone # (517) 335-3176).

Once Q_p is obtained, it is possible to determine the design peak discharge from the following equation:

$$Q = Q_p \times SRO\ (\text{sq.-mi.-in.}) \qquad (22)$$

Table 7.4 - Curve Numbers for Different AMC Conditions

(Source: Soil Conservation Service, Reference 49)

Curve Number for:			Curve Number for:			Curve Number for:		
AMC Condition II	AMC Condition I	AMC Condition III	AMC Condition II	AMC Condition I	AMC Condition III	AMC Condition II	AMC Condition I	AMC Condition III
100	100	100	76	58	89	52	32	71
99	97	100	75	57	88	51	31	70
98	94	99	74	55	88	50	31	70
97	91	99	73	54	87	49	30	69
96	89	99	72	53	86	48	29	68
95	87	98	71	52	86	47	28	67
94	85	98	70	51	85	46	27	66
93	83	98	69	50	84	45	26	65
92	81	97	68	48	84	44	25	64
91	80	97	67	47	83	43	25	63
90	78	96	66	46	82	42	24	62
89	76	96	65	45	82	41	23	61
88	75	95	64	44	81	40	22	60
87	73	95	63	43	80	39	21	59
86	72	94	62	42	79	38	21	58
85	70	94	61	41	78	37	20	57
84	68	93	60	40	78	36	19	56
83	67	93	59	39	77	35	18	55
82	66	92	58	38	76	34	18	54
81	64	92	57	37	75	33	17	53
80	63	91	56	36	75	32	16	52
79	62	91	55	35	74	31	16	51
78	60	90	54	34	73			
77	59	89	53	33	72			

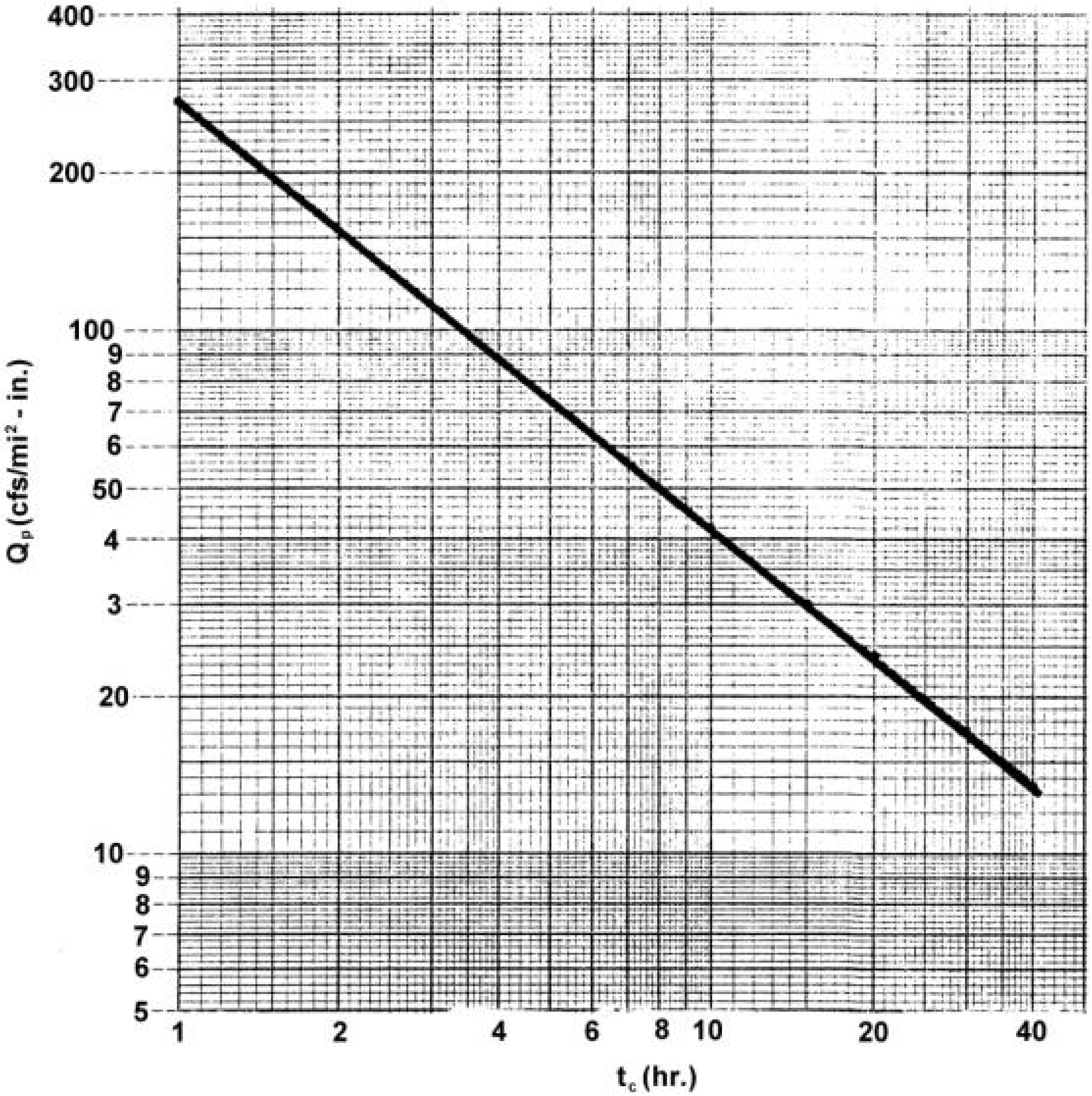


Figure 7.5 - Unit Hydrograph Peak, (Q_p) Versus Time of Concentration (t_c).

Example 7.3: Peak-Discharge Computation

Compute the peak discharge at the given design point, using the following information that had been computed in Example 7.1 and 7.2:

t_c = 1.56 hours (from example 7.1)

SRO = 2.79 sq.-mi.-in. (from example 7.2)

1. From equation 21:

   Q_p = 270.9 $(1.56)^{-0.81}$ = 189 cfs / sq.-mi.-in.

2. From equation 22:

   Q = 189 cfs / sq.mi.-inch x 2.79 sq.-mi.-in. = **527 cfs**

ADJUSTMENTS FOR SWAMPS AND PONDS

The methodology discussed so far has assumed that flow will continue downstream at a uniform rate and will not be stored. In basins where there is ponding or swampy areas, there is potential for temporary storage which will reduce flood peaks.

Table 7.5 provides swamp adjustment factors to be applied to the computed peak flow. The factors are a function of storm frequency, ratio of drainage area to storage area, and location of the storage area.

Example 7.4: Swamp Adjustment

If a watershed has a drainage area that contains 2% of swamp or ponding, which is located near the design point, the adjustment factor for a 100 -year storm would be 0.86 (from table 7.5). Thus, for the example above, the adjusted 100 -year peak flow would be:

Qpeak = 527 cfs x 0.86 = 453 cfs

Figure 7.6 is a form that may be used to determine time of concentration, volume of runoff, and peak flow.

Table 7.5 - Swamp Adjustment Factors

A. -- Ponding and swampy areas are at the design point

Ratio of drainage area to ponding and swampy area	Percentage of ponding and swampy area	Storm frequency (years) 2	5	10	25	50	100
500	00.2	0.92	0.94	0.95	0.96	0.97	0.98
200	00.5	0.86	0.87	0.88	0.90	0.92	0.93
100	01.0	0.80	0.81	0.83	0.85	0.87	0.89
050	02.0	0.74	0.75	0.76	0.79	0.82	0.86
040	02.5	0.69	0.70	0.72	0.75	0.78	0.82
030	03.3	0.64	0.65	0.67	0.71	0.75	0.78
020	05.0	0.59	0.61	0.63	0.67	0.71	0.75
015	06.7	0.57	0.58	0.60	0.64	0.67	0.71
010	10.0	0.53	0.54	0.56	0.60	0.63	0.68
005	20.0	0.48	0.49	0.51	0.55	0.59	0.64

B. -- Ponding and swampy areas are spread throughout the watershed or occur in central parts of the watershed.

Ratio of drainage area to ponding and swampy area	Percentage of ponding and swampy area	Storm frequency (years) 2	5	10	25	50	100
500	00.2	0.94	0.95	0.96	0.97	0.98	0.99
200	00.5	0.88	0.89	0.90	0.91	0.92	0.94
100	01.0	0.83	0.84	0.86	0.87	0.88	0.90
050	02.0	0.78	0.79	0.81	0.83	0.85	0.87
040	02.5	0.73	0.74	0.76	0.78	0.81	0.84
030	03.3	0.69	0.70	0.71	0.74	0.77	0.81
020	05.0	0.65	0.66	0.68	0.72	0.75	0.78
015	06.7	0.62	0.63	0.65	0.69	0.72	0.75
010	10.0	0.58	0.59	0.61	0.65	0.68	0.71
005	20.0	0.53	0.54	0.56	0.60	0.63	0.68
004	25.0	0.50	0.51	0.53	0.57	0.61	0.66

C. -- Ponding and swampy areas are located only in the upper reaches of the watershed.

Ratio of drainage area to ponding and swampy area	Percentage of ponding and swampy area	Storm frequency (years) 2	5	10	25	50	100
500	00.2	0.96	0.97	0.98	0.98	0.99	0.99
200	00.5	0.93	0.94	0.94	0.95	0.96	0.97
100	01.0	0.90	0.91	0.92	0.93	0.94	0.95
050	02.0	0.87	0.88	0.88	0.90	0.91	0.93
040	02.5	0.85	0.85	0.86	0.88	0.89	0.91
030	03.3	0.82	0.83	0.84	0.86	0.88	0.89
020	05.0	0.80	0.81	0.82	0.84	0.86	0.88
015	06.7	0.78	0.79	0.80	0.82	0.84	0.86
010	10.0	0.76	0.77	0.78	0.80	0.82	0.84
005	20.0	0.74	0.75	0.76	0.78	0.80	0.82

BY ____________________________ DATE ___________________ FILE NO. __________

WATERCOURSE ___________________________ COUNTY ______________________

DRAINAGE AREA _____________________ RECURRENCE INTERVAL _____________

FLOW TYPE | LENGTH | ELE (FT) | SLOPE(%) | VEL(fps) | tc(hrs)

Total tc, hrs. = _________________

SOILS **GROUP % sq. mi.**	LAND USE **Type % sq. mi. CN**	Hr. RF = Adj. RF **R.O.**	 **Sq. mi.-in.**	24 Hr. RF = Adj. RF **R.O.**	 **Sq. mi.-in.**
A					
B					
C					
D					
	Total sq. mi.-in.				
	Avg. R.O., in.				
	Comp. CN				
	Qp, cfs/sq. mi.-in				
	Q (R.O. x Qp)				
	Adj. factor				
	Q _________________				

Figure 7.6 - SCS Methodology Form

SCS METHODOLOGY TR-55

As noted in the overview, TR-55 was developed primarily for urban/urbanizing watersheds. Rather than try to duplicate all of the information that is contained in the TR-55 manual, it is suggested that the manual be obtained as a reference. Request "Urban Hydrology for Small Watersheds", Technical Release No. 55. from:

National Technical Information Service (NTIS)
U.S. Dept. of Commerce
5285 Port Royal Road
Springport, Virginia 22162
(703) 487-4600

There are some differences between the UD-21 method, discussed above, and TR-55 which include:

1. **RCN adjustment**

If the land use has a different percentage of impervious area or has less than 100% of the impervious area connected to the drainage course, then figures 7.7 & 7.8 may be used to adjust the RCN. These figures were taken directly from the TR-55 manual.

The following equations were used to develop the figures:

For **composite CN** with **connected impervious** areas.

$$CN_c = CN_p + (P_{imp}/100)(98\text{-}CN_p) \qquad (23)$$

where: CN_c - composite runoff curve number
CN_p - runoff curve number for the pervious area
P_{imp} - percent imperviousness

Example 7.5: RCN Adjustment

Given: A 1/2-acre residential lot, with B soils. The typical CN value for a 1/2-acre residential lot on B soils is 70. However, this assumes that the lot has 25% impervious area connected to the drainage course. If only 20% of the impervious area is connected, it is necessary to adjust the CN. The CN for the pervious portion of the lot is 61. (B soils, open space, good condition). The composite or adjusted CN is computed as follows:

$$CN_c = 61 + (20/100)(98\text{-}61) = \mathbf{68}$$

For **composite CN** with **unconnected impervious areas** and total impervious area less than 30%

$$CN_c = CN_p + (P_{imp}/100)(98\text{-}CN_p)(1 - 0.5R) \qquad (24)$$

where: **R** - unconnected impervious area/total impervious area

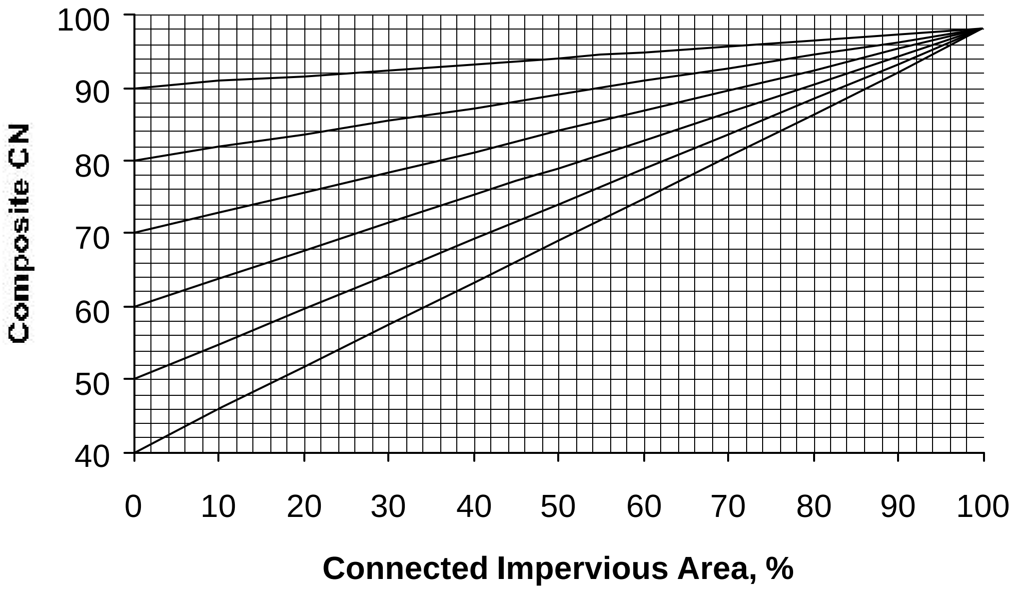


Figure 7.7 - Composite CN with connected impervious area

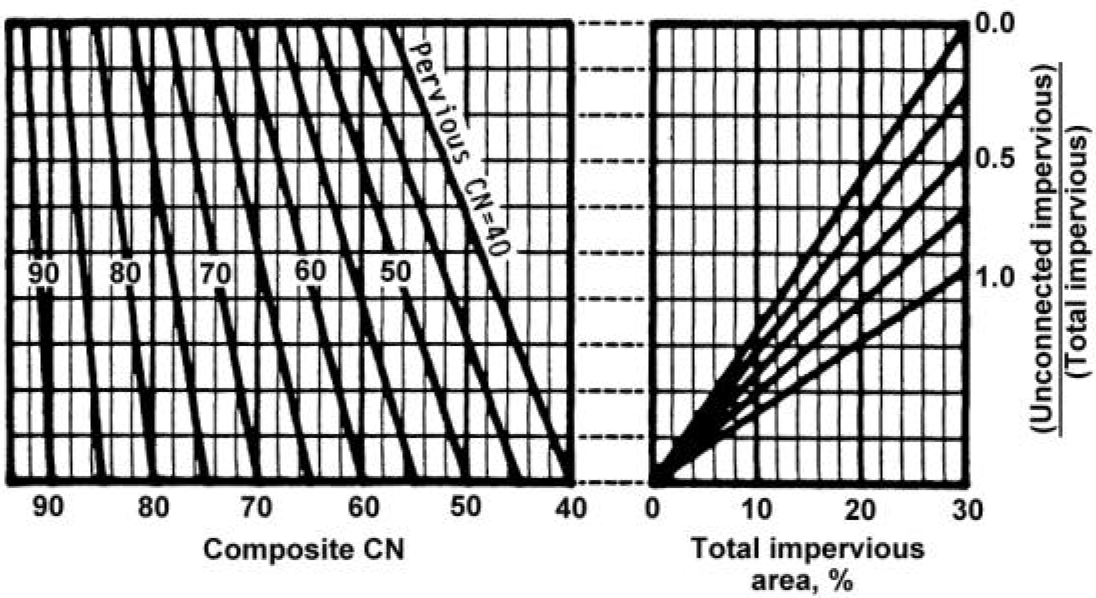


Figure 7.8 - Composite CN with unconnected impervious areas and total impervious area less than 30%.

(Source: Reference 46)

Example 7.6:

Given: A ½-acre residential lot on C soils, with 25% impervious area, of which 30% is connected to the drainage course (or 70% of impervious area is unconnected, which means R = 70/100 = 0.70). The CN value for the pervious portion of the lot is 74 (open space on C soils, good condition).

CN_c = 74 + (25/100)(98-74)(1 - 0.5(0.70)) = **78**

The average CN value for a 1/2-acre residential lot on C soil is 80. This example computed a CN of 78 when only 30% of the impervious area is connected to the drainage course.

It is interesting to note from these two examples how the curve number (and therefore the runoff) can be reduced by an on-site stormwater management technique such as **not** connecting the impervious areas with the drainage course. In other words, directing downspouts onto lawns and directing runoff from parking lots across grassed areas.

2. **Time of Concentration**

The method for computing the time of concentration in TR- 55 is somewhat different than was shown for the UD-21 method. The UD-21 method uses three simple formulas to determine velocity for channel, waterway and sheet flow. The UD-21 method does not have a good method for including the impact on the time of concentration as channel improvements (such as a drain improvements) are made.

The following equation taken from TR-55 provides an estimate of travel time for sheet flow:

$$T_t = \frac{.007(nL)^{0.8}}{(P_2)^{0.5}\, S^{0.4}} \qquad (25)$$

where:
- $\mathbf{T_t}$ - travel time, hours
- **n** - Manning's roughness coefficient
- **L** - flow length, feet,
- $\mathbf{P_2}$ - 2-year, 24-hour rainfall, inches
- **s** - slope of channel, ft/ft

Note: If flow length exceeds 300 feet, use figure 7.9.

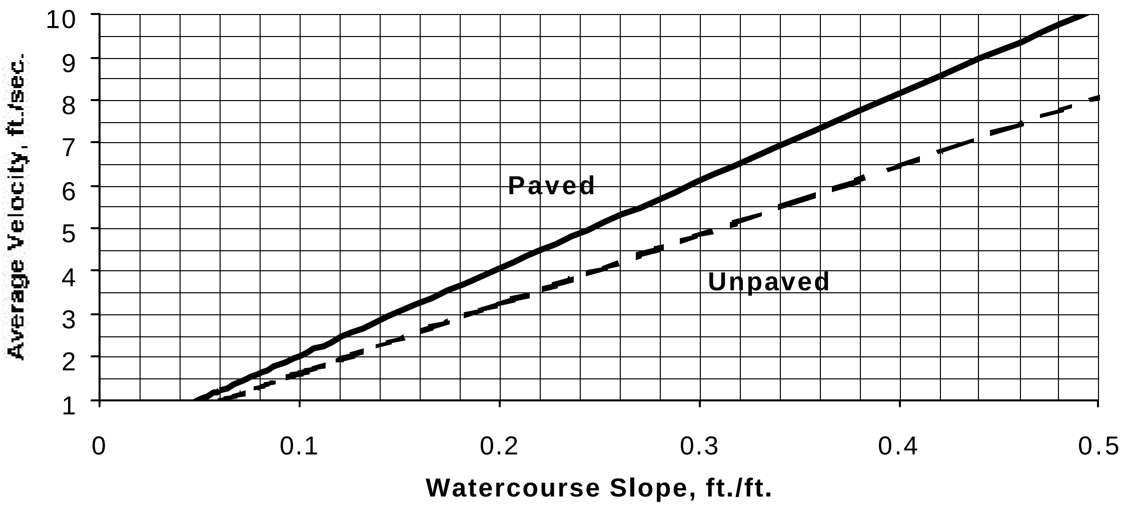


Figure 7.9 - Average velocities for estimating travel time for shallow concentrated flow.
(Source: Reference 46)

Figure 7.9 is from the TR-55 manual and provides an estimated velocity as a function of watercourse slope for shallow concentrated flow. Equations may also be used to determine the velocity of flow:

Unpaved watercourse: $V = 16.1345\ (s)^{0.5}$ (26)

Paved watercourse: $V = 20.3282\ (s)^{0.5}$ (27)

where: **V** - velocity in feet/sec
s - slope of watercourse in ft/ft

For open channels, the velocity of flow for bank-full conditions can be estimated using Manning's equation:

$$V = \frac{1.49\ r^{2/3} s^{1/2}}{n} \qquad (28)$$

where: **V** - velocity, ft/sec
r - hydraulic radius (area/wetted perimeter; wetted perimeter is the wetted surface of the channel)
s - hydraulic gradient (slope of channel) feet/feet
n – Manning's roughness coefficient

Example 7.7: Time of Concentration

Compute the time of concentration given the following information:

– Small tributary length of 4000 feet of which, 3000 feet is at a slope of 0.2%, & 1000 feet is at a slope of 1%. Use a hydraulic radius of 1.5 & a Manning's n value of 0.06.

– The waterway length is 800 feet, unpaved at a slope of 2%.

– The sheet flow length is 250 feet at a slope of 0.5%. Use P_2= 2.5 inches, and n = .15.

a) Compute velocity for the small tributary using equation (28):

$$V_1 = \frac{1.49\ (1.5)^{2/3}\ (0.002)^{½}}{0.06} \quad = 1.46 \text{ ft/sec}$$

$$V_2 = \frac{1.49\ (1.5)^{2/3}\ (0.01)^{½}}{0.06} \quad = 3.25 \text{ ft/sec}$$

b) Compute velocity for **shallow** concentrated flow using (26):

$$V = 16.1345\ (s)^{0.5} = 16.1345\ (0.02)^{0.5} \quad = 2.28 \text{ ft/sec}$$

c) Compute **travel time** for **sheet** flow using equation (25):

$$T_t = \frac{0.007(nL)^{0.8}}{(P_2)^{0.5}\ S^{0.4}} = \frac{.007\ (.15 \times 250)^{0.8}}{(2.5)^{0.5}\ (.005)^{0.4}} = 0.67 \text{ hrs.}$$

d) Determine the total time of concentration

Flow Type	Length	Slope (%)	V(fps)	tc (hours)
Small Trib	3000	0.2	1.46	0.57
Small Trib	1000	1.0	3.25	0.09
Waterway	800	2.0	2.28	0.10
Sheet	250	0.5	--	0.67

*t_c = length / V x 3600 = (3000/1.46 x 3600) = .57 hrs

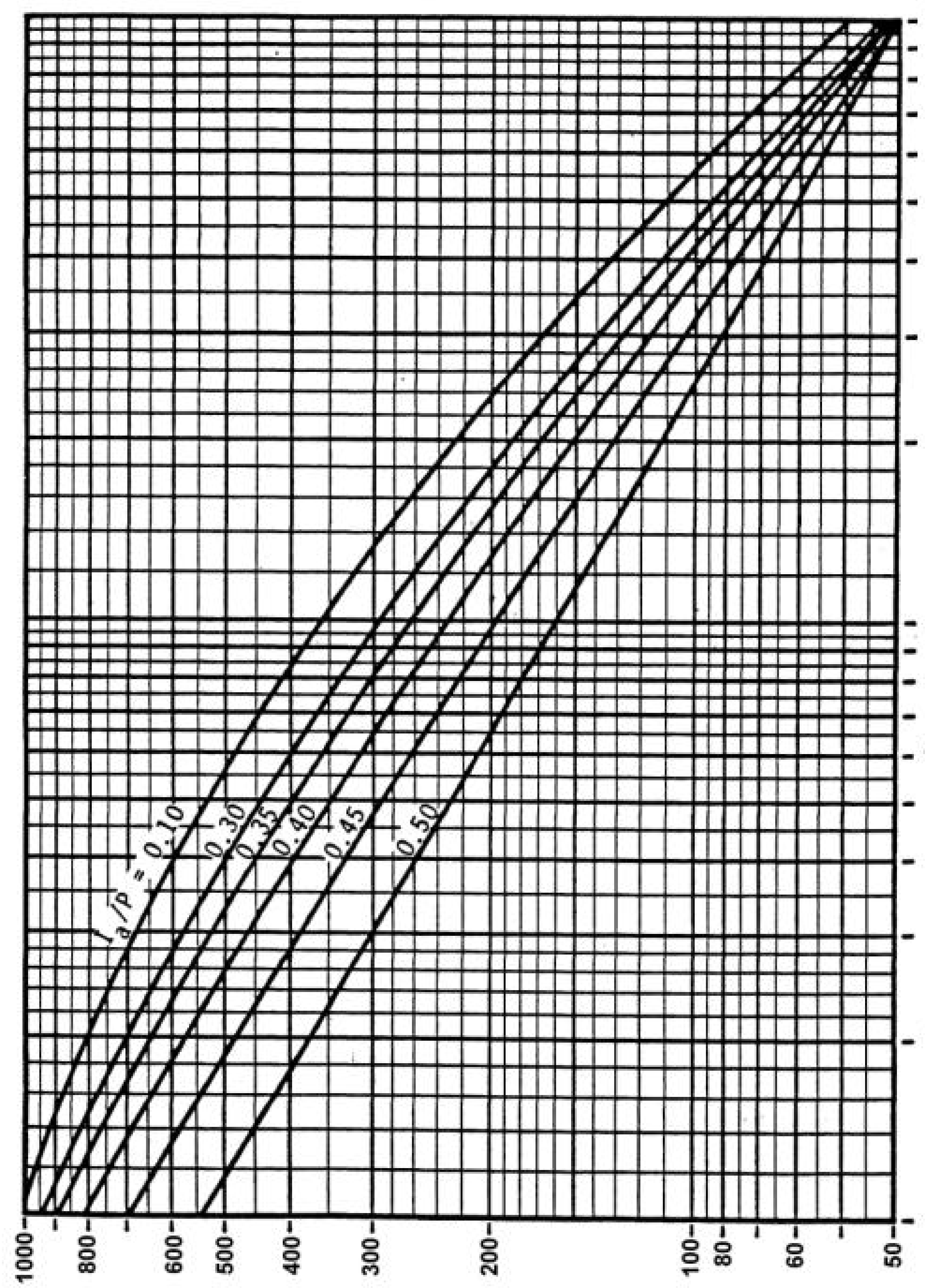
Total t_c = 0.57 + 0.09 + 0.10 + 0.67 = **1.43 hrs** .

3. **Unit Peak**

Once the time of concentration is determined, it is possible to compute the peak discharge using figure 7.10. From the figure, it can be seen that the peak discharge is a function of t_c and a ratio of Ia/P.

Ia - is the initial abstraction, or all the losses before runoff begins. (Such as infiltration, interception, and evaporation)
P - is the rainfall in inches

Table 7.6 gives **Ia** values for different runoff curve numbers. Once Ia is known, it is very straight forward to compute Ia/P, and then using figure 7.10, to compute the unit peak discharge:



Unit peak discharge (q_u), csm/in

Figure 7.10 – Unit Peak Discharge (q_u) SCS Type II Rainfall Distribution

(Source: reference 46)

Figure 7.10 - Unit Peak Discharge

Table 7.6 - Ia values for runoff curve numbers

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

Source: Reference 46, TR-55, Second Edition, June 1986

Example 7.7: The basin has a RCN of 75, a precipitation of 5.1 inches, Type II rainfall distribution, and 2.79 sq.mi-inches of runoff. The t_c is 1.43 hours, compute the unit peak discharge.

For a RCN = 75, from Table 7.6, the initial abstraction (Ia) is **.667 inches.**

Ia/P = 0.667/5.1 = 0.13

From figure 7.10, interpolating between Ia/P= 0.1 and 0.3, to Ia/P = 0.13, the unit peak discharge is **280** cfs/square mile-inch.

Just like the UD-21 method, the peak flow can be determined by using equation 22:

Q = Qp x surface runoff
= 280 cfs/sq.mi.-inch x 2.79 sq.mi.-inch
= **780 cfs**

4. Swamp and Pond Adjustment Factor

As in the UD-21 methodology, it is necessary to adjust the peak flow if there is ponding or swampy areas within the drainage basin. Table 7.5 that was used in the UD-21 method is also applicable to TR-55.

A sample work sheet for using the TR-55 graphical peak method is given in Figure 7.11.

Worksheet - Graphical Peak Method

Project _________________ By ____________________ Date _______

Location ________________ Checked _______________ Date _______

1. Pertinent Data:

Drainage area	A = ___________	$mi.^2$
Runoff Curve Number	RCN = ___________	
Time of Concentration	Tc = ___________	hr.
Pond and Swamp Areas	= ___________	percent

2. Frequency	yr.	___________	___________
3. Rainfall, P (24-hour), Appendix Cin.	in.	___________	___________
4. Initial Abstraction, Ia, Table 7.6	in.	___________	___________
5. Compute Ia/P			
6. Unit peak discharge, qu, Figure 7.12	csm/in	___________	___________
7. Runoff, Ro	in.	___________	___________
8. Pond and swamp adjustment factor, FP (Use table 7.5)		___________	___________
9. **Peak discharge**, qp (Where qp = qu A Ro Fp)	cfs	___________	___________

Figure 7.11 - Graphical Peak Discharge Method Worksheet

(Source: Reference 46, TR-55, Second Edition, June 1986)

5. Development of Hydrographs

Once the basin characteristics, runoff and peak flow have been determined, it is possible to develop a flood hydrograph for the basin. TR-55 contains a straightforward method of developing a portion of the hydrograph for a single sub-basin. For multiple sub-basins, it will be necessary to develop hydrographs for each of the sub- basins, route the hydrographs, and combine hydrographs. Thus, if more than one sub-basin is to be considered, it is suggested that references 44-, 46, 47 or 49 be used for guidance.

Figures 7.12 a-f contain tabulations of unit discharges as a function of time of concentration and travel time. For this guidebook, it will be assumed that only one sub-basin is being considered. The hydrograph that will be developed will be at the design point, as a result, the travel will be equal to 0. The travel time is considered when more than one sub-basin is being considered, and it is necessary to route the hydrographs to the design point. In addition, if the time of concentration exceeds 2 hours, one of the above references would have to be used.

Figure 7.12a - Tabular Hydrograph Unit Discharge (cfs/sq.mi-inch)
Type II Rainfall Distribution

TRAVEL TIME (HRs.)	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	24.0
				IA/P = 0.10											TC = 0.5 HR.												IA/P = 0.10					
0.00	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
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
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
0.30	13	18	24	35	43	60	97	170	378	382	446	448	401	270	171	114	83	66	56	46	40	34	31	27	24	22	20	19	17	15	12	0
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
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
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
1.00	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
1.50	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
2.00	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
2.50	2	3	4	5	5	6	6	7	8	8	9	9	10	12	15	18	24	36	66	150	244	278	171	87	52	39	33	29	23	20	15	11
3.00	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					
0.00	0	0	0	1	9	53	157	314	433	439	379	299	237	159	115	95	81	71	65	56	50	46	42	38	34	31	30	28	25	22	19	0
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
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
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
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
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
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
1.00	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
1.50	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
2.00	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
2.50	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
3.00	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					
0.00	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
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
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
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
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
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
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
1.00	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
1.50	0	0	0	0	0	0	0	0	0	0	0	0	0	2	16	50	97	136	154	145	121	89	75	64	58	54	49	45	41	37	29	10
2.00	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
2.50	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
3.00	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

Figure 7-12b - Tabular Hydrograph Unit Discharge (cfs/sq.mi-inch)
Type II Rainfall Distribution

TRAVEL TIME (HRs.)	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	24.0
				IA/P = 0.10											TC = 0.75 HR.												IA/P = 0.10					
0.00	13	18	24	36	46	68	115	194	294	380	424	410	369	252	172	123	93	74	61	49	41	35	31	27	24	22	20	19	17	15	12	0
0.10	13	17	23	34	42	59	97	162	250	337	395	405	381	279	191	135	100	79	65	51	42	36	31	28	25	22	21	19	17	15	12	0
0.20	11	15	20	28	32	39	52	82	135	211	295	362	391	351	255	178	127	95	75	57	46	38	32	29	26	23	21	20	17	15	12	0
0.30	11	14	19	26	30	36	47	70	113	179	256	326	379	360	277	196	140	103	80	60	48	38	33	29	26	23	21	20	18	15	12	0
0.40	10	12	16	22	25	28	33	42	61	96	151	221	291	367	336	255	182	131	98	69	54	42	34	30	27	24	22	20	18	16	12	0
0.50	9	12	16	21	24	27	31	39	53	82	128	190	258	358	343	274	200	144	106	74	56	43	35	30	27	24	22	20	18	16	12	0
0.75	8	10	13	17	18	21	23	26	31	39	55	82	122	230	314	329	281	217	161	104	72	51	38	33	29	26	23	21	19	16	12	1
1.00	6	8	10	13	14	15	17	19	21	23	27	32	42	89	177	272	319	303	249	163	105	66	45	36	31	27	24	22	19	17	13	3
1.50	4	6	7	9	10	10	11	12	14	15	16	18	20	27	46	90	163	241	295	275	204	119	66	45	35	31	27	24	20	18	13	7
2.00	3	4	5	6	7	7	8	9	9	10	11	12	13	16	20	28	48	89	151	245	274	213	115	65	44	35	30	27	22	19	14	10
2.50	1	2	3	4	4	5	5	6	6	7	7	8	5	10	12	14	17	24	37	86	170	260	219	127	71	47	36	31	24	20	16	11
3.00	1	1	2	3	3	3	4	4	4	5	5	5	6	7	8	10	11	14	17	30	64	157	247	205	122	70	46	36	27	22	17	12
				IA/P = 0.30											TC = 0.75 HR.												IA/P = 0.30					
0.00	0	0	0	0	1	6	30	86	174	266	326	348	328	246	181	138	110	92	79	66	57	49	44	40	36	32	31	29	26	23	19	0
0.10	0	0	0	0	0	1	4	22	65	137	223	292	329	303	228	170	131	106	89	73	61	52	46	41	37	33	31	29	26	23	19	0
0.20	0	0	0	0	0	0	3	15	48	108	185	256	305	321	245	184	141	112	93	75	63	53	46	42	37	34	31	30	27	23	19	0
0.30	0	0	0	0	0	0	2	11	36	84	151	221	277	308	260	199	152	120	98	78	65	54	47	42	38	34	31	30	27	23	19	0
0.40	0	0	0	0	0	0	0	1	8	27	65	122	188	286	301	243	187	144	114	87	71	57	48	43	39	35	32	30	27	24	19	1
0.50	0	0	0	0	0	0	0	1	6	20	50	98	158	263	292	254	200	155	122	91	74	59	49	44	40	35	32	30	27	24	19	1
0.75	0	0	0	0	0	0	0	0	0	2	8	23	51	140	231	269	253	211	167	119	90	68	53	46	42	37	34	31	28	25	19	2
1.00	0	0	0	0	0	0	0	0	0	0	0	1	4	29	96	156	249	261	231	169	120	84	61	50	44	40	36	33	29	26	20	5
1.50	0	0	0	0	0	0	0	0	0	0	0	0	0	1	8	34	91	163	220	241	197	131	83	61	50	44	40	35	31	27	21	12
2.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	11	36	85	174	226	200	127	82	60	49	44	39	32	29	22	17
2.50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	6	37	105	196	214	135	87	62	51	44	36	31	24	18
3.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	24	96	205	189	130	85	62	50	39	32	26	18
				IA/P = 0.50											TC = 0.75 HR.												IA/P = 0.50					
0.00	0	0	0	0	0	0	2	16	45	92	137	166	185	170	146	125	110	98	89	79	70	63	58	53	48	44	42	41	37	33	28	0
0.10	0	0	0	0	0	0	0	1	11	34	73	115	149	180	163	141	122	107	96	84	74	65	59	54	50	45	43	41	38	33	28	0
0.20	0	0	0	0	0	0	0	1	8	25	57	96	131	173	166	146	126	111	99	86	76	66	59	55	50	46	43	41	38	34	28	0
0.30	0	0	0	0	0	0	0	0	1	5	18	44	79	143	170	160	141	122	108	92	81	69	61	56	52	47	44	42	38	34	28	1
0.40	0	0	0	0	0	0	0	0	0	4	14	34	64	127	166	162	145	127	111	95	82	70	62	57	52	47	44	42	38	34	28	1
0.50	0	0	0	0	0	0	0	0	0	0	2	10	26	82	138	162	157	140	123	103	88	75	64	58	53	49	45	43	39	35	28	2
0.75	0	0	0	0	0	0	0	0	0	0	1	4	12	47	98	139	154	148	135	113	96	80	67	60	55	50	46	43	39	36	29	3
1.00	0	0	0	0	0	0	0	0	0	0	0	0	0	6	30	73	119	146	151	134	113	91	74	63	58	53	48	45	41	37	29	7
1.50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	9	30	66	105	143	143	117	90	73	63	57	52	48	42	39	30	18
2.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	11	30	77	121	137	114	88	72	63	57	52	44	40	32	25
2.50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	19	55	111	132	111	87	71	62	56	47	42	34	27
3.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	12	51	112	128	108	86	71	62	51	44	36	27

Figure 7-12c - Tabular Hydrograph Unit Discharge (cfs/sq.mi-inch)
Type II Rainfall Distribution

TRAVEL TIME (HRs.)	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	24.0
				IA/P = 0.10											TC = 1.0 HR.												IA/P = 0.10					
0.00	11	15	20	29	35	47	72	112	168	231	289	329	357	313	239	175	133	103	83	63	50	40	33	29	26	23	21	20	17	15	12	0
0.10	10	13	17	24	27	33	42	62	95	144	202	260	306	340	293	222	165	126	98	72	56	43	35	30	27	24	22	20	18	15	12	0
0.20	10	13	17	23	26	30	38	54	82	123	176	232	281	332	303	238	179	136	105	76	59	45	35	30	27	24	22	20	18	16	12	1
0.30	9	12	16	22	24	28	35	48	70	105	152	205	256	323	310	254	193	146	113	81	61	46	36	31	27	24	22	20	18	16	12	1
0.40	8	11	14	19	21	23	27	32	42	61	91	132	181	276	318	294	237	181	138	95	70	51	39	32	28	25	23	21	18	16	12	1
0.50	8	10	13	18	20	22	25	30	38	53	78	114	159	253	311	300	251	195	149	102	74	53	40	33	29	25	23	21	18	16	12	1
0.75	7	8	11	14	16	17	19	21	25	30	38	53	76	146	228	284	293	256	208	143	99	66	46	36	31	27	24	22	19	17	13	2
1.00	5	7	8	11	12	13	14	16	17	19	22	25	31	57	111	188	256	286	272	208	144	90	56	41	33	29	26	23	20	17	13	4
1.50	4	5	6	8	8	9	10	11	12	13	14	15	17	22	33	59	107	171	231	268	235	157	88	56	41	33	29	25	21	18	14	8
2.00	2	3	4	5	5	6	6	7	7	8	9	9	10	12	15	19	27	44	78	157	231	252	167	96	59	42	34	29	23	20	15	11
2.50	1	2	2	3	4	4	4	5	5	6	6	7	7	8	10	12	15	19	27	58	120	214	241	159	94	59	42	34	26	21	16	11
3.00	0	1	1	2	2	3	3	3	4	4	4	5	5	6	7	8	10	12	14	22	44	113	214	231	152	91	58	42	29	23	17	12
				IA/P = 0.30											TC = 1.0 HR.												IA/P = 0.30					
0.00	0	0	0	0	1	4	16	42	83	137	195	243	271	292	227	178	143	117	98	79	66	55	47	42	38	34	31	30	27	23	19	0
0.10	0	0	0	0	0	0	3	12	32	66	113	168	218	279	260	213	169	136	113	88	72	59	49	43	39	35	32	30	27	24	19	1
0.20	0	0	0	0	0	0	2	9	24	52	93	143	193	271	271	225	180	145	119	92	75	60	50	44	39	35	32	30	27	24	19	1
0.30	0	0	0	0	0	0	1	6	18	41	75	120	169	246	264	234	191	153	125	96	78	62	51	44	40	36	33	31	27	24	19	1
0.40	0	0	0	0	0	0	0	1	4	14	32	61	100	190	251	259	222	181	146	109	86	67	53	46	41	37	33	31	28	25	19	2
0.50	0	0	0	0	0	0	0	1	3	10	24	49	83	168	237	254	230	191	155	115	90	69	54	47	42	37	34	31	28	25	19	2
0.75	0	0	0	0	0	0	0	0	0	1	4	12	25	76	150	213	239	228	198	149	112	82	61	50	44	39	35	32	29	26	20	4
1.00	0	0	0	0	0	0	0	0	0	0	0	1	2	15	51	113	182	226	234	197	150	104	72	56	47	42	38	34	30	27	20	7
1.50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	18	51	104	162	220	210	158	102	71	56	47	42	37	31	28	22	13
2.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	5	20	49	121	187	209	152	100	70	55	47	41	34	29	23	17
2.50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	7	32	87	171	199	146	98	69	54	46	37	31	24	18
3.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	13	62	158	192	151	103	73	56	41	34	26	18
				IA/P = 0.50											TC = 1.0 HR.												IA/P = 0.50					
0.00	0	0	0	0	0	0	1	7	21	42	71	101	126	160	154	138	123	110	100	87	77	67	60	55	50	46	43	41	38	34	28	1
0.10	0	0	0	0	0	0	0	1	5	15	33	58	87	134	156	149	134	120	108	93	82	71	62	57	52	47	44	42	38	34	28	1
0.20	0	0	0	0	0	0	0	1	4	12	26	48	74	123	153	153	137	123	111	95	84	72	63	57	52	47	44	42	38	34	28	1
0.30	0	0	0	0	0	0	0	0	3	9	20	38	62	111	143	150	140	127	114	98	86	73	63	58	53	48	45	42	39	35	28	1
0.40	0	0	0	0	0	0	0	0	0	2	6	16	31	75	120	145	148	137	123	106	91	77	66	59	54	49	45	43	39	35	29	2
0.50	0	0	0	0	0	0	0	0	0	1	5	12	25	64	109	139	146	139	127	108	94	79	67	60	55	50	46	43	39	36	29	3
0.75	0	0	0	0	0	0	0	0	0	0	2	5	12	39	78	115	136	140	134	117	101	84	70	62	56	51	47	44	40	36	29	4
1.00	0	0	0	0	0	0	0	0	0	0	0	0	1	7	26	59	96	125	139	133	117	97	78	66	59	54	49	46	41	37	29	8
1.50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	9	26	54	86	123	133	119	95	77	66	59	54	49	43	39	31	17
2.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	10	25	64	104	129	116	93	76	65	58	53	45	41	33	24
2.50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	10	34	84	125	117	96	78	66	59	49	43	35	27
3.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	6	32	89	122	114	94	77	66	53	45	37	27

Figure 7-12d - Tabular Hydrograph Unit Discharge (cfs/sq.mi-inch)
Type II Rainfall Distribution

TRAVEL TIME (HRs.)	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	24.0
				IA/P = 0.10											TC = 1.25 HR.												IA/P = 0.10					
0.00	10	13	18	25	29	38	54	81	118	163	213	256	284	311	266	212	163	129	104	78	61	47	37	31	27	24	22	20	18	16	12	1
0.10	10	13	17	23	28	34	47	69	102	143	189	234	267	297	274	226	175	138	111	82	64	48	38	31	27	24	22	20	18	16	12	1
0.20	9	11	15	20	22	26	31	42	60	88	124	168	212	280	292	261	212	166	131	95	72	53	40	33	28	25	23	21	18	16	12	1
0.30	8	11	14	19	21	24	29	38	53	76	108	148	190	263	288	268	224	177	140	101	76	55	41	34	29	25	23	21	18	16	12	2
0.40	8	10	13	18	20	23	27	34	46	66	94	130	170	245	282	273	235	188	149	107	80	58	42	34	29	26	23	21	19	16	12	2
0.50	7	9	12	16	17	19	22	25	31	41	58	82	114	190	256	279	262	222	178	127	93	65	46	36	31	27	24	22	19	17	13	2
0.75	6	8	10	14	15	17	19	21	25	31	41	56	78	139	207	254	265	245	208	152	110	75	51	39	32	28	25	22	19	17	13	3
1.00	5	6	8	10	11	13	14	15	17	19	22	26	33	60	109	173	230	261	255	208	153	100	64	46	36	30	26	24	20	18	13	5
1.50	3	4	5	7	7	8	9	9	10	11	12	13	15	19	27	45	79	130	186	247	239	180	108	68	48	37	31	27	22	19	14	10
2.00	2	3	4	5	6	6	7	7	8	8	9	10	11	13	16	22	35	59	98	171	236	236	156	95	62	44	35	30	23	20	15	11
2.50	1	2	2	3	4	4	4	5	5	5	6	6	7	8	10	12	14	19	28	58	114	197	226	163	102	65	46	36	26	21	16	11
3.00	0	1	1	2	2	2	2	3	3	3	4	4	4	5	6	7	9	10	13	19	35	88	184	218	169	109	70	49	31	24	18	12
				IA/P = 0.30											TC = 1.25 HR.												IA/P = 0.30					
0.00	0	0	0	0	0	2	9	25	50	86	130	174	208	253	235	201	164	136	115	92	76	61	51	44	39	35	32	30	27	24	19	1
0.10	0	0	0	0	0	0	1	6	19	40	71	110	153	217	247	227	191	157	131	103	84	66	53	46	41	36	33	31	28	24	19	2
0.20	0	0	0	0	0	0	1	4	14	31	58	93	133	202	239	231	199	165	138	108	87	68	55	47	41	37	33	31	28	25	19	2
0.30	0	0	0	0	0	0	0	1	3	10	24	46	77	152	210	236	222	190	158	122	97	74	58	49	43	38	34	32	28	25	20	3
0.40	0	0	0	0	0	0	0	0	2	8	19	37	64	134	196	232	225	198	166	127	101	77	59	50	43	38	35	32	28	25	20	3
0.50	0	0	0	0	0	0	0	0	0	2	6	14	30	82	151	206	228	217	189	146	113	85	64	52	45	40	36	33	29	26	20	5
0.75	0	0	0	0	0	0	0	0	0	1	2	7	15	49	105	164	205	218	205	166	129	95	69	55	47	41	37	33	29	26	20	6
1.00	0	0	0	0	0	0	0	0	0	0	0	0	1	9	32	77	134	185	214	203	166	120	83	63	52	45	39	35	30	27	21	10
1.50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	11	33	72	121	184	203	171	117	82	62	51	44	39	32	29	22	15
2.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	7	21	67	132	194	174	123	86	64	52	45	35	31	24	18
2.50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	13	46	121	187	166	119	84	63	52	39	32	25	18
3.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	8	44	129	180	160	116	83	63	44	35	27	18
				IA/P = 0.50											TC = 1.25 HR.												IA/P = 0.50					
0.00	0	0	0	0	0	0	1	5	13	26	44	68	91	125	142	142	128	117	107	94	83	72	63	57	52	47	44	42	38	34	28	2
0.10	0	0	0	0	0	0	0	0	3	10	20	36	57	100	129	140	136	125	114	100	88	76	65	59	54	49	45	43	39	35	29	3
0.20	0	0	0	0	0	0	0	0	2	7	16	30	48	90	122	139	139	127	117	102	90	77	66	60	54	49	45	43	39	35	29	3
0.30	0	0	0	0	0	0	0	0	0	2	5	12	24	59	98	126	137	134	125	109	96	82	69	61	56	51	46	44	40	36	29	4
0.40	0	0	0	0	0	0	0	0	0	1	4	10	19	51	89	119	134	136	127	112	98	83	70	62	56	51	47	44	40	36	29	5
0.50	0	0	0	0	0	0	0	0	0	1	3	7	15	43	79	112	131	135	129	114	100	85	71	63	57	52	47	44	40	36	29	6
0.75	0	0	0	0	0	0	0	0	0	0	0	1	3	15	39	71	102	123	130	125	112	94	78	67	60	54	49	46	41	37	29	9
1.00	0	0	0	0	0	0	0	0	0	0	0	0	1	4	17	40	71	101	121	129	121	103	84	71	62	56	51	47	42	38	30	13
1.50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	10	26	51	92	119	125	105	86	72	63	57	52	44	40	32	23
2.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	11	35	72	112	122	103	85	71	63	56	47	42	34	26
2.50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	7	24	66	111	119	101	83	71	62	51	44	36	27
3.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	27	71	110	116	99	82	70	55	46	37	27

Figure 7.12 e - Tabular Hydrograph Unit Discharge (cfs/sq.mi-inch)
Type II Rainfall Distribution

TRAVEL TIME (HRs.)	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	24.0
				IA/P = 0.10											TC = 1.5 HR.												IA/P = 0.10					
0.00	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
0.10	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
0.20	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
0.30	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
0.40	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
0.50	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
0.75	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
1.00	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
1.50	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
2.00	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
2.50	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	57	60	44	30	23	17	12
3.00	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					
0.00	0	0	0	0	0	1	6	15	31	53	80	112	144	193	225	208	156	157	134	108	89	70	56	48	42	37	34	31	28	25	20	2
0.10	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
0.20	0	0	0	0	0	0	0	1	3	9	19	35	57	114	168	201	213	198	171	135	108	84	64	53	46	40	36	33	29	26	20	4
0.30	0	0	0	0	0	0	0	1	2	7	45	29	48	100	155	193	210	200	177	140	113	87	66	54	46	41	36	33	29	26	20	5
0.40	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
0.50	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
0.75	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
1.00	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
1.50	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
2.00	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
2.50	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
3.00	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					
0.00	0	0	0	0	0	0	0	3	8	16	27	42	59	92	115	128	130	121	112	100	90	78	67	60	55	50	46	43	39	35	29	4
0.10	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
0.20	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
0.30	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
0.40	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
0.50	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
0.75	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
1.00	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
1.50	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
2.00	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
2.50	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
3.00	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

Figure 7.12f - Tabular Hydrograph Unit Discharge (cfs/sq.mi-inch)
Type II Rainfall Distribution

TRAVEL TIME (HRs.)	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	24.0
				IA/P = 0.10											TC = 2.0 HR.												IA/P = 0.10					
0.00	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
0.10	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
0.20	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
0.30	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
0.40	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
0.50	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
0.75	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
1.00	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
1.50	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
2.00	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
2.50	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
3.00	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					
0.00	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
0.10	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
0.20	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
0.30	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
0.40	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
0.50	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
0.75	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
1.00	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
1.50	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
2.00	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
2.50	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
3.00	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					
0.00	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
0.10	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
0.20	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
0.30	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
0.40	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
0.50	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
0.75	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
1.00	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
1.50	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
2.00	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
2.50	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
3.00	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

Example 7.8: Develop a partial hydrograph using the following information that was computed above:

1. Time of concentration = 1.43 hours
2. Type II rainfall distribution
3. Runoff = 2.79 sq. mi.-inches
4. Ia/P = .13

The t_c of 1.43 is rounded to the nearest value, which is 1.5 hours. The Ia/P of 0.13 is between the values of 0.1 and 0.3 shown on Figure 7.12e. The following information is a result of interpolating between the values using the Ia/P of .13.

Tabular Unit Hydrograph, Type II Rainfall, Ia/P = 0.13

Hours	**q_u**	**Hours**	**q_u**	**Hours**	**q_u**	**Hours**	**q_u**
11.0	8	12.4	74	13.6	196	16.5	32
11.3	9	12.5	103	13.8	159	17.0	27
11.6	13	12.6	137	14.0	130	17.5	25
11.9	18	12.7	173	14.3	100	18.0	23
12.0	21	12.8	205	14.6	78	19.0	20
12.1	27	13.0	246	15.0	59	20.0	17
12.2	36	13.2	268	15.5	45	22.0	13
12.3	52	13.4	232	16.0	37	26.0	1

Note: **q_u** is in cfs/sq.mi-in
Q on hydrograph = (qu) x (vol. of runoff)

Figure 7.13 shows a plot of the hydrograph that would result from a runoff of 2.79 sq.mi.-in. As noted above, the Q on the hydrograph results from multiplying q_u by 2.79 sq. mi.-in. (total runoff). The hydrograph has been extrapolated for the time less than 11 hours. If this portion of the hydrograph were critical, it would have been necessary to use more comprehensive methods (references 46, 47 and 49).

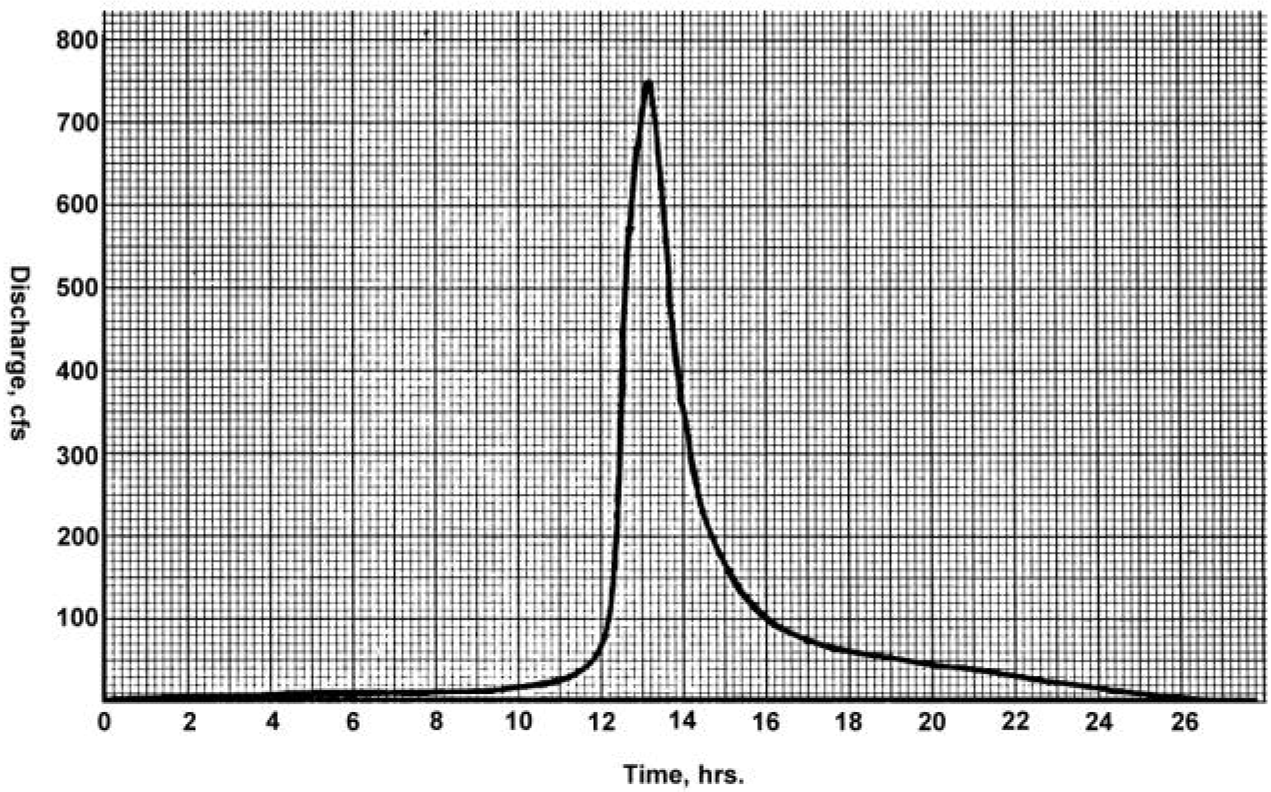


Figure 7.13 - Plot of Hydrograph for Example 7.8