CHAPTER 2

HYDROLOGY

2.1 HYDROLOGIC DESIGN POLICIES

2.1.1 Factors Affecting Flood Runoff

For all hydrologic analysis, the following factors shall be evaluated and included when they will have a significant effect on the final results.

Drainage Basin Characteristics
Size
Shape
Slope
Ground Cover
Land Use (Existing Conditions, Existing Zoning)
Geology
Soil Types
Surface Infiltration
Ponding and Storage
Watershed Development Potential (Future Land Use Plans)
Other Characteristics

Stream Channel Characteristics
Geometry and Configuration
Natural Controls
Artificial Controls
Channel Modifications
Aggradation – Degradation
Debris
Hydraulic roughness (Manning's *n*)
Slope
Other Characteristics

Flood Plain Characteristics
Slope
Vegetation
Alignment
Storage
Location of Structures
Obstructions to Flow
Other Characteristics

Meteorological Characteristics
Precipitation Amounts
Time Rate of Precipitation
Historical Flood Heights
Storm Frequency Events
Other Characteristics

2.1.2 Hydrologic Method

Many hydrologic methods are available. Recommended methods and the circumstances for their use are listed in Table 2-1. The recommended methods have been selected for use in the Charlotte-Mecklenburg area based on several considerations, including:

- Verification of their accuracy in duplicating local hydrological estimates of a range of design storms
- Availability of equations, nomographs, and computer programs for the methods
- Use and familiarity with the methods by local governments and consulting engineers

Table 2-1
Recommended Hydrologic Methods

Method	Size Limitations[1]	Comments
Rational (see Section 2.4)	0 – 200 Acres	Method can be used for estimating peak flows and the design of small sub-division type storm drainage systems.
NRCS Method (TR-55) (see Section 2.6)	0 – 2,000 Acres	Method can be used for estimating peak flows from developed areas.
HEC-1/HEC–HMS	None	Method can be used for estimating peak flows and hydrographs. Application of HEC-1 is limited by a maximum of 2,000 ordinates in the hydrograph, and of the particular hydrograph generation technique (NRCS Unit Hydrograph, Kinematic Wave, etc.) including the minimum time step interval expressed in the HEC-1 manual. Also, see section 2.1.4

[1]Size limitations refers to the sub-watershed size to the point where storm water management facility (i.e., culvert, inlet) is located

In using these methods, the procedures outlined in this chapter should be followed.

If other methods are used, they must first be calibrated to local conditions and tested for accuracy and reliability by the user. Third party computer software not identified in this table must be independently verified and calibrated to the recommended methods by the professional prior to its use. If other software is used, it will be compared to HEC-1/HEC-HMS to make sure it reproduces equivalent results. In addition to verifying results, complete source documentation for the software must be submitted for approval.

2.1.3 Storm Water Conveyance Design Policy

All storm water conveyances shall be designed based on fully developed land use conditions as shown on current County and City Land Use Plans and Zoning Maps or existing land use, whichever generates the higher runoff rate.

2.1.4 HEC-1 Limitations

The following are limitations of the HEC-1 model hydrograph generation routine using the NRCS unit dimensionless hydrograph. In addition to the items in the list, the user of the HEC-1 model must be knowledgeable of the limitations of the hydrologic and hydraulic methodologies which are being applied by the model.

- The computation interval must not be significantly less than the minimum rainfall increment on the “PH” record, otherwise a portion of the rainfall is lost because the program cannot perform the logarithmic interpolation necessary for the development of the complete hyetograph. Standard HEC-1 model input uses a 5-minute “worst” precipitation increment. Therefore, the model may not be used with a computation interval less than 5 minutes unless the rainfall hyetograph is input with “PC” or “PI” records. The computation interval, when multiplied by the number of hydrograph ordinates, must also be greater than the storm duration which is planned to be studied (6 hour, 24 hour, etc.). Not having the program set to allow the storm to run causes hydrographs to be inappropriately peaked due to the lack of necessary time to fit in the needed runoff hydrograph.

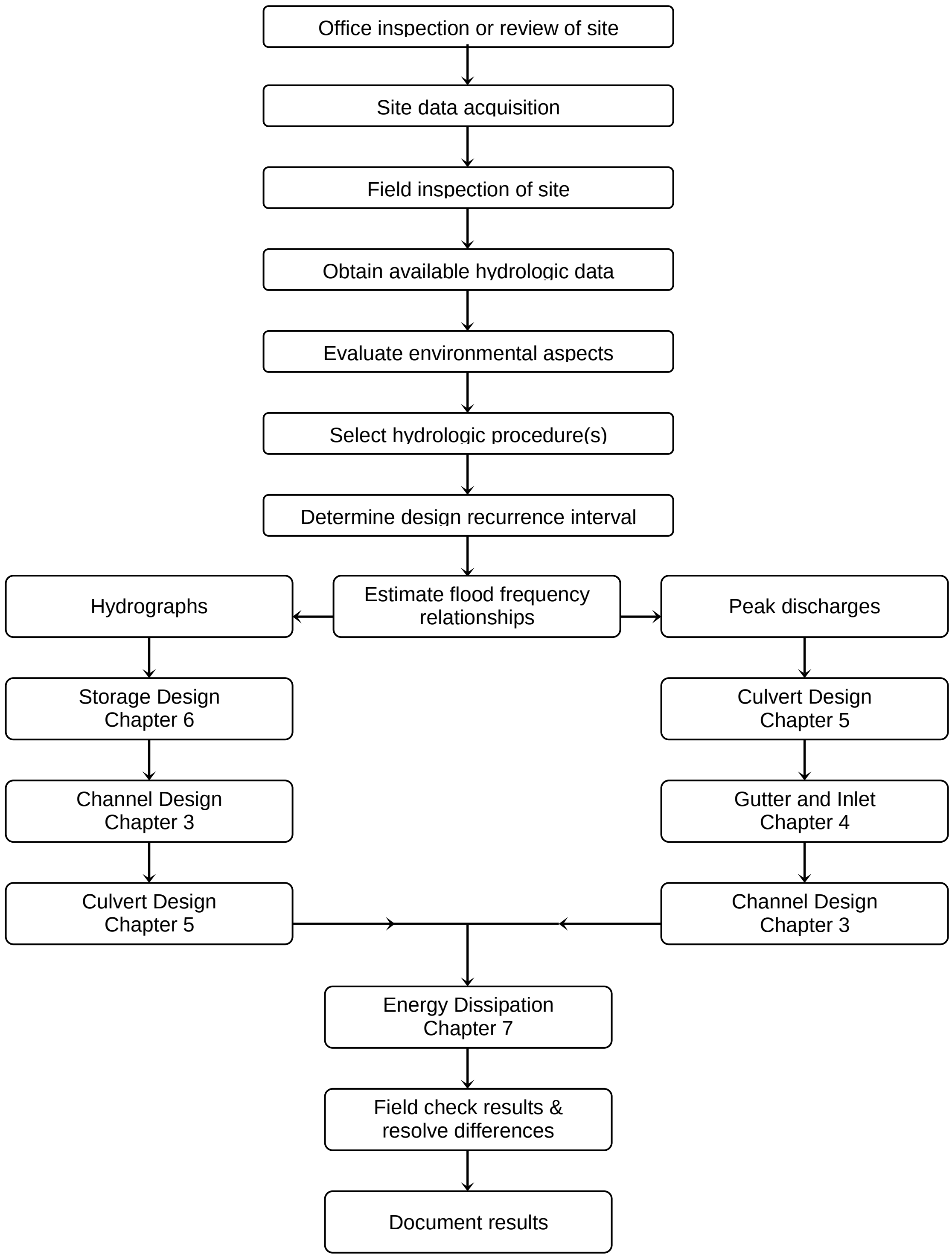
- The NRCS unit dimensionless hydrograph may not be used when the computation interval is greater than 0.29 times the lag time of the watershed. This limitation translates into a minimum time of concentration of 5.75 minutes which typically occurs in watersheds of 3 acres or less. The result of exceeding this limitation is that the resulting hydrograph may underestimate the peak flow by computing the peak flow values on either side of the peak of the hydrograph. However, the volume under the resulting hydrograph is correct and all volume computation such as detention storage is correct.

2.2 HYDROLOGIC ANALYSIS PROCEDURE FLOWCHART

2.2.1 Purpose and Use

The purpose of the hydrologic analysis procedure flowchart is to show the steps or elements which need to be completed for the hydrologic analysis, and the different designs that will use the hydrologic estimates.

2.2.2 Design Flowchart



2.3 DESIGN FREQUENCY

2.3.1 Design Frequencies

Description	***Design Storm***
Storm system pipes	10 year
Ditch systems	10 year
Culverts/Cross-drain (subdivision streets)	25 year
Culverts/Cross-drain (thoroughfare roads)	50 year
Culverts (over regulated floodways)	100 year
Culverts/Cross-drain (primary access streets)	No overtopping in 100 year
Usable and functionable part of structure or building (as defined in the Subdivision Ordinance)	100 year + 1 foot

2.3.2 Rainfall Intensity

The following rainfall intensities (Table 2-2) shall be used for all hydrologic analysis.

Table 2-2
Rainfall Intensities - Charlotte, North Carolina

Time		Recurrence interval (years)					
Hours	**Minutes**	**2**	**5**	**10**	**25**	**50**	**100**
0	**5**	5.03	6.30	7.03	8.21	9.00	9.92
	6	4.78	6.02	6.75	7.89	8.65	9.53
	7	4.55	5.76	6.49	7.59	8.32	9.17
	8	4.34	5.53	6.26	7.31	8.03	8.84
	9	4.16	5.32	6.04	7.06	7.75	8.54
	10	3.99	5.12	5.84	6.83	7.50	8.26
	15	3.33	4.35	5.03	5.87	6.46	7.11
	16	3.23	4.22	4.89	5.72	6.29	6.92
	17	3.13	4.10	4.77	5.57	6.13	6.74
	18	3.04	3.99	4.65	5.43	5.97	6.57
	19	2.96	3.89	4.53	5.30	5.83	6.41
	20	2.88	3.79	4.43	5.17	5.69	6.26
	21	2.80	3.70	4.32	5.05	5.56	6.12
	22	2.73	3.61	4.23	4.94	5.44	5.98
	23	2.66	3.53	4.14	4.83	5.32	5.85
	24	2.60	3.45	4.05	4.73	5.21	5.73
	25	2.54	3.37	3.96	4.63	5.10	5.61
	26	2.48	3.30	3.88	4.54	5.00	5.50
	27	2.43	3.23	3.81	4.45	4.90	5.39
	28	2.38	3.17	3.73	4.36	4.81	5.29
	29	2.33	3.11	3.66	4.28	4.72	5.19
	30	2.28	3.05	3.60	4.20	4.64	5.09
	40	1.90	2.57	3.05	3.56	3.93	4.32
	50	1.64	2.23	2.66	3.10	3.43	3.76
1	**60**	1.45	1.98	2.36	2.76	3.05	3.34
2	**120**	0.88	1.21	1.45	1.70	1.89	2.06
3	**180**	0.65	0.90	1.07	1.25	1.40	1.52
6	**360**	0.38	0.53	0.62	0.73	0.82	0.89
12	**720**	0.22	0.31	0.36	0.42	0.47	0.51
24	**1440**	0.13	0.18	0.20	0.24	0.27	0.29
P_{24} (inches – in.)		**3.12**	**4.32**	**4.80**	**5.76**	**6.48**	**6.96**

Table 2-2
Rainfall Intensities - Charlotte, North Carolina (continued)

IDF variables for equation:

$$\textbf{Intensity (I)} = \frac{a}{(t + b)^n} \qquad \textbf{(2.1)}$$

t = duration of rainfall (minutes - min)
I = intensity (inches/hour - in/hr)
a, b, n = storm fitting parameters

a	44.7516	61.3997	83.3331	97.3148	104.2990	116.4790
b	10	12	15	15	15	15
n	0.8070	0.8035	0.8256	0.8254	0.8179	0.8223

2.4 RATIONAL METHOD

2.4.1 Introduction

When using the rational method some precautions should be considered.

- In determining the C value (land use) for the drainage area, hydrologic analysis should take into account future land use changes. Drainage facilities shall be designed for future land use conditions as specified in the County and City Land Use Plans and Zoning Maps (or existing land use, whichever generates the higher runoff rate).
- Since the rational method uses a composite C value for the entire drainage area, if the distribution of land uses within the drainage basin will affect the results of hydrologic analysis, then the basin should be divided into two or more sub-drainage basins for analysis.
- The charts, graphs, and tables included in this section are given to assist the engineer in applying the rational method. The engineer should use good engineering judgment in applying these design aids and should make appropriate adjustments when specific site characteristics dictate that these adjustments are appropriate.

2.4.2 Runoff Equation

The rational formula estimates the peak rate of runoff at any location in a watershed as a function of the drainage area, runoff coefficient, frequency factor, and mean rainfall intensity for a duration equal to the time of concentration (the time required for water to flow from the most remote point of the basin to the location being analyzed). The rational formula is expressed as follows:

$$\mathbf{Q = C_f CIA} \qquad \textbf{(2.2)}$$

Where: Q = maximum rate of runoff (cubic feet/second - cfs)

C = runoff coefficient representing a ratio of runoff to rainfall

I = average rainfall intensity for a duration equal to the time of concentration (in/hr)

A = drainage area contributing to the design point location (acres)

C_f = frequency factor

The C_f values that can be used are listed in Table 2-3. The product of C_f multiplied by C shall not exceed 1.0.

Table 2-3
Frequency Factors for Rational Formula

Recurrence Interval (years)	C_f
2	1
10	1
25	1.1
50	1.2
100	1.25

2.4.3 Time of Concentration

Use of the rational formula requires the time of concentration (t_c) for each design point within the drainage basin. The duration of rainfall is then set equal to the time of concentration and is used to estimate the design average rainfall intensity (I) from Table 2-2. The time of concentration is interpreted as the longest time of flow from points on the watershed ridge to the point of interest. The most common method for determining time of concentration is outlined in section 2.6.5.

Although not commonly used, the Kirpich Equation is an acceptable method for calculating time of concentration.

$$\mathbf{t_c = 0.0078 \times \frac{L^{0.77}}{S^{0.385}}} \qquad \textbf{(2.3)}$$

Where: t_c = Time of Concentration (min)

L = Longest hydraulic flow length (foot - ft)

S = Surface slope (foot/foot - ft/ft)

This formula can be used to estimate the time of concentration for basins with well defined channels, for overland flow on grassed, concrete or asphalt surfaces, and for concrete channels. In the case where the flow is overland on grassed surfaces, multiply t_c by 2. For overland flow over concrete/asphalt surfaces or concrete channels, multiply the t_c by 0.4 and 0.2, respectively. Within the City of Charlotte, the Kirpich Equation can be used in the design of storm water conveyance systems. The Kirpich Equation cannot be used to design storm water control measures where a comparison of pre-development and post-development hydrology is necessary.

For each drainage area, flow length is determined from the inlet to the most hydrologically remote point in the tributary area. From a topographic map, the average slope is determined for the same distance. Other formulas or charts may be used to calculate overland flow time if approved by the City/County Engineering Departments. **Note: time of concentration cannot be less than 5 minutes.**

A common error should be avoided when calculating t_c. In some cases runoff from a portion of the drainage area which is highly impervious may result in a greater peak discharge than would occur if the entire area were considered. In these cases, adjustments can be made to the drainage area by disregarding those areas where flow time is too slow to add to the peak discharge.

2.4.4 Rainfall Intensity

The rainfall intensity (I) is the average rainfall rate in inches/hour for a duration equal to the time of concentration for a selected return period. Once a particular return period has been selected for design and a time of concentration calculated for the drainage area, the rainfall intensity can be determined from Rainfall-Intensity-Duration data given in Table 2-2. Straight-line interpolation can be used to obtain rainfall intensity values for storm durations between the values given in Table 2-2.

2.4.5 Runoff Coefficient

The runoff coefficient (C) is the variable of the rational method least susceptible to precise determination and requires judgment and understanding on the part of the design engineer. While engineering judgment will always be required in the selection of runoff coefficients, typical coefficients represent the integrated effects of many drainage basin parameters. Table 2-4 gives the recommended runoff coefficients for the Rational Method.

Table 2-4
Recommended Runoff Coefficient Values

Description of Area	Runoff Coefficient (C)
Lawns	0.30
Wooded	0.25
Streets	0.95
Gravel Areas	0.55
Drives, walks, roofs	0.95
Bare soils	0.45
Residential (including streets):	
Single-Family (Lot < 20,000 square feet - SF)	0.60
Single-Family (Lot > 20,000 square feet - SF)	0.50
Multi-family, Attached	0.70
Industrial:	
Light areas	0.70
Heavy areas	0.80
Office Parks	0.75
Shopping Centers	0.80

Note: The above runoff coefficients are valid for 2-year to 10-year storm frequencies only. Coefficients must be accompanied with a C_f factor when used for less frequent, higher intensity storms.

2.4.6 Composite Coefficients

It is often desirable to develop a composite runoff coefficient based on the percentage of different types of surfaces in the drainage areas. Composites can be made with the values from Table 2-4 by using percentages of different land uses. The composite procedure can be applied to an entire drainage area or to typical "sample" blocks as a guide to selection of reasonable values of the coefficient for an entire area.

It should be remembered that the rational method assumes that all land uses within a drainage area are uniformly distributed throughout the area. If it is important to locate a specific land use within the drainage area then another hydrologic method should be used where hydrographs can be generated and routed through the drainage area.

2.5 EXAMPLE PROBLEM - RATIONAL METHOD

Introduction

Following is an example problem which illustrates the application of the Rational Method to estimate peak discharges.

Problem

Preliminary estimates of the maximum rate of runoff are needed at the inlet to a culvert for a 25-year and 100-year return period.

Site Data

From a topographic map field survey, the area of the drainage basin upstream from the point in question is found to be 18 acres. In addition the following data were measured:

Flow Path
Average slope = 2.0%
Length of flow in well defined channel = 1,000 ft

Land Use

From existing land use maps, land use for the drainage basin was estimated to be:

Single Family (< 20,000 SF)	80%
Light Industrial	20%

Time of Concentration

Since this problem involves determining the flows for a storm water conveyance system, utilization of the conservative and simplistic Kirpich method may be appropriate:

Using Equation 2.3 with a flow length of 1,000 ft and slope of 2.0%

$$t_c = 0.0078 \times \frac{1{,}000^{0.77}}{0.02^{0.385}} = 7.2 \text{ minutes}$$

Rainfall Intensity

From Table 2-2, with a duration equal to 7.2 minutes, the intensity can be selected by interpolation.

I_{25} (25-year return period) = 7.53 in/hr
I_{100} (100-year return period) = 9.10 in/hr

Runoff Coefficient

A weighted runoff coefficient (C) for the total drainage area is determined in the following table by utilizing the values from Table 2-4.

Land Use	(1) Percent Of Total Land Area	(2) Runoff Coefficient	(3) Weighted Runoff Coefficient*
Residential (Single-Family, < 20,000 SF)	.80	.60	.48
Light Industrial	.20	.70	.14
Total Weighted Runoff Coefficient			.62

* *Column 3 equals column 1 multiplied by column 2.*

Peak Runoff

From the rational method equation 2.2:

$$Q_{25} = C_f CIA = 1.1 \times .62 \times 7.53 \text{ in/hr} \times 18 \text{ acres} = 92.4 \text{ cfs}$$
$$Q_{100} = C_f CIA = 1.25 \times .62 \times 9.10 \text{ in/hr} \times 18 \text{ acres} = 126.9 \text{ cfs}$$

These are the estimates of peak runoff for a 25-yr and 100-yr design storm for the given basin.

2.6 NRCS UNIT HYDROGRAPH

2.6.1 Introduction

The Natural Resources Conservation Service (NRCS) hydrologic method requires basic data similar to the Rational Method; drainage area, a runoff factor, time of concentration, and rainfall. The NRCS approach; however, is more sophisticated in that it also considers the time distribution of the rainfall, the initial rainfall losses to interception and depression storage, and an infiltration rate that decreases during the course of a storm. Details of the methodology can be found in the *NRCS National Engineering Handbook, Section 4*.

The NRCS method includes the following basic steps:

1. Determination of a composite curve number which represents and considers different land uses within the drainage area.

2. Calculation of time of concentration to the design point location.

3. Using the Type II rainfall distribution or the balanced storm distribution and peaking factor 484, total and excess rainfall amounts are determined.

4. Using the unit hydrograph approach, triangular and composite hydrographs are developed for the drainage area.

2.6.2 Equations and Concepts

The following discussion outlines the equation and basic concepts utilized in the NRCS method.

Drainage Area—the drainage area of a watershed is determined from topographic maps and field surveys. For large drainage areas it might be necessary to divide the area into sub-drainage areas to account for major land use changes, obtain analysis results at different points within drainage area, and route flows to design study points of interest.

Rainfall—The NRCS method applicable to the Charlotte-Mecklenburg area is based on a storm event which has a Type II time distribution. For example, the one-year 24-hour storm event is based on the distribution shown in Figure 2-1. Tables 2-5 through 2-10 show a center weighted balanced distribution for various 6-hour storm events to be used for the Charlotte-Mecklenburg area.

Rainfall-Runoff Equation—A relationship between accumulated rainfall and accumulated runoff was derived by NRCS from experimental plots for numerous soils and vegetative cover conditions. The following NRCS runoff equation is used to estimate direct runoff from 24-hour or 1-day storm rainfall. The equation is:

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \qquad \textbf{(2.4)}$$

Where: Q = accumulated direct runoff (inches)
P = accumulated rainfall or potential maximum runoff (inches)
I_a = initial abstraction including surface storage, interception, and infiltration prior to runoff (inches)
S = potential maximum soil retention (inches)

The empirical relationship used in the NRCS runoff equation for estimating I_a is :

$$I_a = 0.2S \qquad \textbf{(2.5)}$$

Substituting 0.2S for I_a in equation 2.4, the NRCS rainfall-runoff equation becomes:

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \qquad \textbf{(2.6)}$$

Where: S = (1,000/CN) – 10
CN = NRCS curve number (see section 2.6.3)

Figure 2-2 shows a graphical solution of this equation which enables the precipitation excess from a storm to be obtained if the total rainfall and watershed curve number are known. For example, 4.1 inches of direct runoff would result if 5.8 inches of rainfall occurs on a watershed with a curve number of 85.

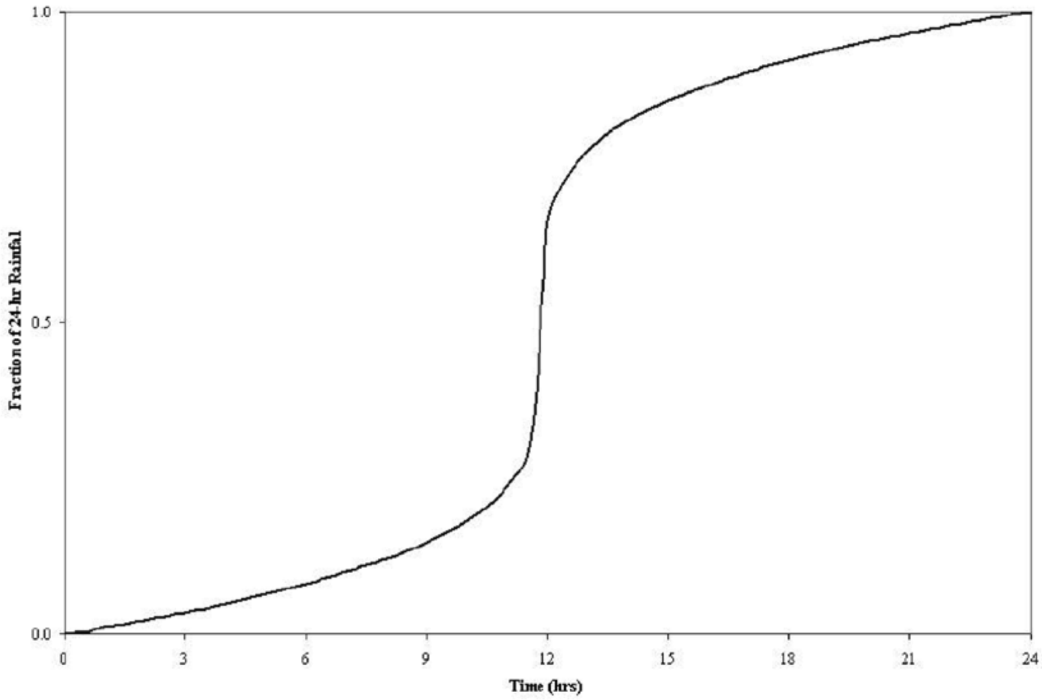


Figure 2-1 NRCS (SCS) Type II Rainfall Distribution
Source: http://www.seda-cog.org/union/lib/union/appendix_p_-_stormwater_tables_calculations,_cns.pdf

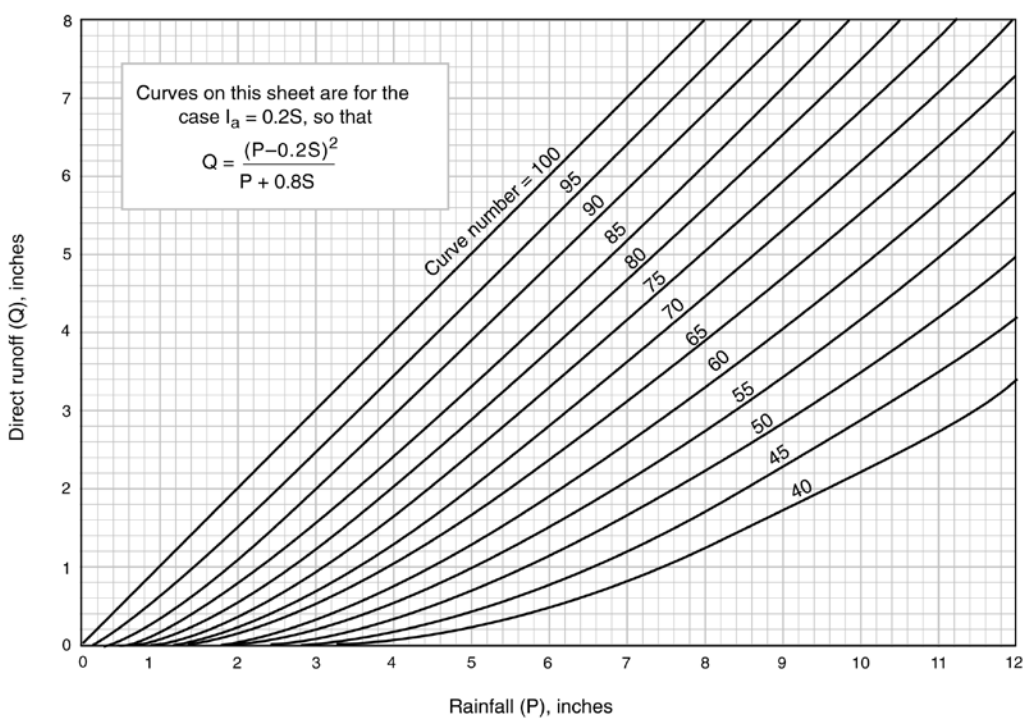


Figure 2-2 Solution of Runoff Equation
Source: ftp://ftp.wcc.nrcs.usda.gov/downloads/hydrology_hydraulics/tr55/tr55.pdf

Table 2-5
1-Year, 24-hour Precipitation Data

1-Year, 24-Hour Storm Event, 6-Minute Time Increment

IN	6									
PB	2.58									
PI	.0000	.0010	.0010	.0010	.0011	.0010	.0011	.0010	.0011	.0011
PI	.0011	.0011	.0011	.0011	.0012	.0011	.0012	.0011	.0012	.0012
PI	.0012	.0012	.0012	.0013	.0012	.0012	.0013	.0012	.0013	.0013
PI	.0013	.0013	.0013	.0013	.0014	.0013	.0014	.0014	.0013	.0014
PI	.0014	.0014	.0014	.0015	.0015	.0015	.0015	.0015	.0015	.0016
PI	.0016	.0016	.0016	.0017	.0017	.0016	.0018	.0017	.0017	.0018
PI	.0018	.0018	.0018	.0019	.0019	.0018	.0020	.0019	.0019	.0020
PI	.0020	.0020	.0020	.0021	.0021	.0021	.0021	.0021	.0021	.0022
PI	.0022	.0022	.0024	.0024	.0026	.0026	.0028	.0029	.0029	.0030
PI	.0032	.0032	.0032	.0032	.0032	.0032	.0033	.0034	.0036	.0038
PI	.0039	.0041	.0044	.0046	.0048	.0051	.0054	.0058	.0062	.0066
PI	.0070	.0077	.0086	.0096	.0106	.0115	.0238	.0476	.0764	.1371
PI	.0951	.0190	.0166	.0144	.0122	.0098	.0084	.0080	.0074	.0068
PI	.0064	.0060	.0056	.0054	.0052	.0048	.0046	.0044	.0042	.0040
PI	.0038	.0037	.0036	.0035	.0034	.0034	.0033	.0033	.0032	.0031
PI	.0030	.0030	.0029	.0028	.0027	.0027	.0026	.0026	.0025	.0024
PI	.0023	.0023	.0022	.0023	.0022	.0022	.0022	.0021	.0021	.0021
PI	.0021	.0020	.0020	.0020	.0019	.0020	.0019	.0019	.0018	.0018
PI	.0018	.0018	.0017	.0018	.0017	.0017	.0016	.0017	.0016	.0016
PI	.0015	.0016	.0015	.0015	.0015	.0014	.0014	.0014	.0013	.0014
PI	.0013	.0013	.0013	.0013	.0013	.0012	.0013	.0013	.0012	.0013
PI	.0012	.0013	.0012	.0013	.0012	.0012	.0013	.0012	.0012	.0012
PI	.0012	.0012	.0012	.0012	.0012	.0011	.0012	.0012	.0011	.0012
PI	.0011	.0012	.0011	.0012	.0011	.0011	.0012	.0011	.0011	.0011
PI	.0011	.0000								

Table 2-6
2-Year Precipitation Data

2-year, 6-Hour Balanced Storm Rainfall Distribution

Time Interval	5 min	15 min	1 hour	2 hour	3 hour	6 hour
Rainfall depth (in)	0.42	0.83	1.45	1.76	1.95	2.28

2-Year, 6-Hour Storm Event, 5-Minute Time Increment

PI	.000	.007	.007	.008	.008	.008	.008	.009	.009	.009
PI	.009	.009	.010	.010	.010	.011	.011	.011	.012	.012
PI	.014	.015	.016	.017	.018	.021	.022	.024	.026	.028
PI	.031	.044	.050	.058	.089	.115	.242	.420	.168	.100
PI	.064	,054	.047	.033	.029	.027	.025	.023	.021	.018
PI	.017	.016	.016	.015	.014	.012	.012	.011	.011	.010
PI	.010	.009	.009	.009	.009	.008	.008	.008	.008	.008
PI	.007	.007	.007	.000						

Table 2-7
10-Year Precipitation Data

10-Year, 6-Hour Balanced Storm Rainfall Distribution

Time Interval	5 min	15 min	1 hour	2 hour	3 hour	6 hour
Rainfall depth (in)	0.59	1.26	2.36	2.90	3.21	3.72

10-Year, 6-Hour Storm Event, 5-Minute Time Increment

PI	.000	.011	.011	.011	.012	.012	.012	.013	.013	.013
PI	.014	.014	.015	.015	.016	.016	.017	.018	.018	.023
PI	.024	.025	.026	.027	.029	.036	.039	.042	.045	.049
PI	.054	.079	.089	.103	.161	.201	.395	.590	.275	.177
PI	.112	.095	.084	.057	.051	.047	.043	.040	.038	.030
PI	.028	.027	.025	.024	.023	.019	.018	.017	.017	.016
PI	.016	.015	.015	.014	.014	.013	.013	.012	.012	.012
PI	.011	.011	.011	.000						

Table 2-8
25-Year Precipitation Data

25-Year, 6-Hour Balanced Storm Rainfall Distribution

Time Interval	5 min	15 min	1 hour	2 hour	3 hour	6 hour
Rainfall depth (in)	0.68	1.47	2.76	3.40	3.75	4.38

25-Year, 6-Hour Storm Event, 5-Minute Time Increment

PI	.000	.014	.014	.015	.015	.015	.016	.016	.016	.017
PI	.017	.018	.019	.019	.020	.020	.022	.022	.023	.026
PI	.027	.028	.029	.031	.033	.043	.046	.049	.053	.058
PI	.064	.093	.104	.120	.188	.234	.461	.680	.321	.207
PI	.131	.112	.098	.067	.061	.056	.051	.048	.045	.034
PI	.032	.030	.029	.027	.026	.023	.022	.021	.021	.020
PI	.019	.019	.018	.017	.017	.017	.017	.016	.015	.015
PI	.015	.014	.014	.000						

Table 2-9
50-Year Precipitation Data

50-Year, 6-Hour Balanced Storm Rainfall Distribution

Time Interval	5 min	15 min	1 hour	2 hour	3 hour	6 hour
Rainfall depth (in)	0.75	1.62	3.05	3.78	4.20	4.92

50-Year, 6-Hour Storm Event, 5-minute Time Increment

PI	.000	.016	.016	.016	.017	.018	.018	.019	.019	.019
PI	.020	.020	.021	.022	.022	.023	.024	.025	.026	.031
PI	.032	.034	.035	.037	.039	.050	.053	.056	.061	.066
PI	.073	.103	.116	.134	.208	.259	.508	.750	.354	.229
PI	.146	.124	.109	.077	.069	.063	.059	.055	.051	.040
PI	.038	.036	.034	.033	.031	.026	.025	.024	.024	.023
PI	.022	.021	.021	.020	.020	.019	.019	.018	.018	.017
PI	.017	.016	.016	.000						

Table 2-10
100-Year Precipitation Data

100-Year, 6-Hour Balanced Storm Rainfall Distribution

Time Interval	5 min	15 min	1 hour	2 hour	3 hour	6 hour
Rainfall depth (in)	0.83	1.77	3.34	4.12	4.56	5.34

100-Year, 6-Hour Storm Event, 5-Minute Time Increment

PI	.000	.017	.017	.018	.018	.019	.020	.020	.020	.021
PI	.022	.022	.023	.023	.024	.025	.026	.027	.028	.032
PI	.034	.035	.037	.039	.041	.053	.056	.060	.065	.071
PI	.078	.113	.126	.147	.226	.282	.555	.830	.386	.250
PI	.160	.136	.119	.082	.074	.068	.063	.058	.055	.042
PI	.040	.038	.036	.034	.033	.029	.027	.026	.025	.025
PI	.024	.023	.022	.022	.021	.021	.020	.020	.019	.019
PI	.018	.018	.017	.000						

2.6.3 Runoff Factor

The principal physical watershed characteristics affecting the relationship between rainfall and runoff are land use, land cover, soil types and land slope. The NRCS uses a combination of soil conditions and land-use (ground cover) to assign a runoff factor to an area. These runoff factors, called runoff curve numbers (CN), indicate the runoff potential of an area. The higher the CN, the higher is the runoff potential.

Soil properties influence the relationship between runoff and rainfall since soils have differing rates of infiltration. Based on infiltration rates, the NRCS has divided soils into four hydrologic soil groups as follows:

Group A - Soils having a low runoff potential due to high infiltration rates. These soils consist primarily of deep, well drained sand and gravels.

Group B - Soils having a moderately low runoff potential due to moderate infiltration rates. These soils consist primarily of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures.

Group C - Soils having moderately high runoff potential due to slow infiltration rates. These soils consist primarily of soils in which a layer exists near the surface that impedes the downward movement of water of soils with moderately fine to fine texture.

Group D - Soils having a high runoff potential due to very slow infiltration rates. These soils consist primarily of clays with high swelling potential, soils with permanently high water tables, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious parent material.

A list of soils for Charlotte and Mecklenburg County and their hydrologic classifications are presented in Table 2-11 below. Soil survey maps can be obtained from local NRCS offices.

Table 2-11
Hydrologic Soil Groups for Charlotte-Mecklenburg

Series Name	Hydrologic Group	Series Name	Hydrologic Group
Appling	B	Lignum	C
Cecil	B	Mecklenburg	C
Davidson	B	Monacan	C
Enon	C	Pacolet	B
Georgeville	B	Pits	D
Goldston	C	Vance	C
Helena	C	Wilkes	C
Iredell	D		

Consideration should be given to the effects of soil compaction due to development on the natural hydrologic soil group. If heavy equipment can be expected to compact the soil during construction or if grading will mix the surface and subsurface soils, appropriate changes should be made in the soil group selected. Also, runoff curve numbers vary with the antecedent soil moisture conditions. Average antecedent soil moisture conditions (AMC II) are recommended for all hydrologic analysis.

Table 2-12 gives recommended curve number values for a range of different land uses.

2.6.4 Modifications for Developed Conditions

Several factors, such as the percentage of impervious area and the means of conveying runoff from impervious areas to the drainage system, should be considered in computing CN for developed areas. For example, consider whether the impervious areas connect directly to the drainage system, or to lawns or other pervious areas where infiltration can occur.

The curve number values given in Table 2-12 on the following page are based on directly connected impervious area. An impervious area is considered directly connected if runoff from it flows directly into the drainage system. It is also considered directly connected if runoff from it occurs as concentrated shallow flow that runs over a pervious area and then into a drainage system.

It is possible that curve number values from developed areas could be reduced by not directly connecting impervious surfaces to the drainage system. For a discussion of connected and unconnected impervious areas and their effect on curve number values see Appendix A at the end of this chapter.

Table 2-12
Runoff Curve Numbers[1]

------------------------------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
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
Agricultural Lands					
Pasture, grassland or range (continuous for age for grazing)[4]					
Poor hydrologic condition		68	79	86	89
Fair hydrologic condition		49	69	79	84
Good hydrologic condition		39	61	74	80
Woods					
Poor hydrologic condition		45	66	77	83
Fair hydrologic condition		36	60	73	79
Good hydrologic condition		30	55	70	77
Developing urban areas					
Newly graded areas					
(pervious areas only, no vegetation)		77	86	91	94

1 Average runoff condition, and Ia = 0.2S.

2 The average percent impervious area shown was used to develop the composite CN's. Other assumptions are as follows: impervious areas area 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.

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 Poor: Forest litter, small trees, and brush are destroyed by heavy grazing or regular burning.
Fair: Woods are grazed but not burned, and some forest litter covers the soil.
Good: Woods are protected from grazing, and litter and brush adequately cover the soil.

Source: 210-VI-TR-55, Second Edition, June 1986

2.6.5 Travel Time Estimation

Travel time (T_t) is the time it takes water to travel from one location to another within a watershed through the various components of the drainage system. Time of concentration (t_c) is computed by summing all the travel times of consecutive components of the drainage conveyance system from the hydraulically most distant point of the watershed to the point of interest within the watershed.

Following is a discussion of related procedures and equations.

2.6.5.1 Travel Time

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

Travel time is the ratio of flow length to flow velocity:

$$\mathbf{T_t = \frac{L \times 0.0167}{V}} \qquad \textbf{(2.7)}$$

Where: T_t = travel time (min)
L = flow length (ft)
V = average velocity (feet/second - ft/s)

2.6.5.2 Time of Concentration

The time of concentration is the sum of T_t values for the various consecutive flow segments along the path extending from the hydraulically most distant point in the watershed to the point of interest.

$$\mathbf{t_c = T_{t1} + T_{t2} \ldots T_n} \qquad \textbf{(2.8)}$$

Where: t_c = time of concentration (hour - hr)
n = number of flow segments

2.6.5.3 Sheet Flow

Sheet flow is flow over plane surfaces. It occurs in the headwater of streams. With sheet flow, the friction value (Manning's *n*) is an effective roughness coefficient that includes the effect of raindrop impact; drag over the plane surface; obstacles such as litter, crop ridges, and rocks; and erosion and transportation of sediment. These *n* values are for very shallow flow depths of about 0.1 foot or so. Also please note, when designing a drainage system, the sheet flow path is not necessarily the same before and after development and grading operations have been completed. **Selecting sheet flow paths in excess of 100 feet in developed areas and 300 feet in undeveloped areas should be done only after careful consideration.**

For sheet flow less than 300 feet in undeveloped areas and less than 100 ft in developed areas use Manning's kinematic solution (Overton and Meadows 1976) to compute T_t:

$$\mathbf{T_t = \frac{0.42\,(nL)^{0.8}}{(P_2)^{1/2}(S)^{0.4}}} \qquad \textbf{(2.9)}$$

Where: T_t = travel time (min)
n = Manning's roughness coefficient, reference Table 2-13
L = flow length (ft)
P_2 = 2-year, 24 hour rainfall = 3.12 inches
S = slope of hydraulic grade line (land slope – ft/ft)

Substituting the constant rainfall amount the travel equation becomes:

$$T_t = \frac{0.238\,(nL)^{0.8}}{(S)^{0.4}} \quad (2.10)$$

Thus the final equations for paved and unpaved areas are:

Paved (n = .011)

$$T_t = 0.0065\,[(L)^{0.8} / (S)^{0.4}] \quad (2.11)$$

$$V = 2.56(S)^{0.4}(L)^{0.2} \quad (2.12)$$

Unpaved (n = .24)

$$T_t = 0.076\,[\,(L)^{0.8} / (S)^{0.4}\,] \quad (2.13)$$

$$V = 0.22(S)^{0.4}(L)^{0.2} \quad (2.14)$$

Where: V = Velocity (ft/s)
T_t = Travel time (min)

Table 2-13
Roughness Coefficients (Manning's *n*)[1] for Sheet Flow

Surface Description	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 grasses[2]	0.24
Bermuda grass	0.41
Range (natural)	0.13
Woods[3]	
Light underbrush	0.40
Dense underbrush	0.80

[1]The *n* values are a composite of information by Engman (1986).

[2]Includes species such as weeping lovegrass, bluegrass, buffalo grass, blue gamma grass, and native grass mixture.

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

Source: NRCS, TR-55, Second Edition, June 1986

2.6.5.4 Shallow Concentrated Flow

After a maximum of 300 feet in undeveloped areas or 100 feet in developed areas, sheet flow usually becomes shallow concentrated flow. Average velocities for estimating travel time for shallow concentrated flow can be computed using the following equations. These equations can also be used for slopes less than 0.005 ft/ft.

Unpaved $$V = 16.1345(S)^{1/2} \qquad (2.15)$$

Paved $$V = 20.3282(S)^{1/2} \qquad (2.16)$$

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

These two equations are based on the solution of Manning's equation with different assumptions for *n* (Manning's roughness coefficient) and r (hydraulic radius, ft). For unpaved areas, *n* is 0.05 and r is 0.4; for paved areas, *n* is 0.025 and r is 0.2.

After determining average velocity using equations 2.15 or 2.16, use equation 2.7 to estimate travel time for the shallow concentrated flow segment.

2.6.5.5 Channelized Flow

Open channel flow is assumed to begin where surveyed cross section information has been obtained, where channels are visible on aerial photographs, or where blue lines (indicating streams) appear on United States Geological Survey (USGS) quadrangle sheets. Flow within pipes and culverts not under pressure is considered closed channel flow. Manning's equation or water surface profile information can be used to estimate average flow velocity. Average flow velocity is usually determined for bank-full elevation. Manning's velocity for pipes assumes a fully flowing condition.

Manning's equation is $$V = \left[\frac{1.49\,(r)^{2/3}\,(s)^{1/2}}{n}\right] \qquad (2.17)$$

Where: V = average velocity (ft/s)
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 the hydraulic grade line (ft/ft)
n = Manning's roughness coefficient for open channel flow

After average velocity is computed using equation 2.17, T_t for the channel segment can be estimated using equation 2.7.

Velocity in channels should be calculated from the Manning's equation. Cross sections from all channels that have been field checked should be used in the calculations. This is particularly true of areas below dams or other flow control structures.

2.6.5.6 Reservoirs and Lakes

Sometimes it is necessary to estimate the velocity of flow through a reservoir or lake at the outlet of a watershed. This travel time is normally very small and can be assumed as zero. If the travel time through the reservoir or lake is important to the analysis then the hydrograph should be routed through the storage facility. A reservoir can have an impact in reducing peak flows which can be accounted for by routing.

2.6.5.7 Limitations

- Manning's kinematic solution should not be used for sheet flow longer than 300 feet in undeveloped areas and 100 feet in developed areas.

- For storm conveyance systems, carefully identify the appropriate hydraulic flow path to estimate t_c.

APPENDIX 2A
IMPERVIOUS AREA CALCULATIONS

2A.1 Urban Modifications

Several factors, such as the percentage of impervious area and the means of conveying runoff from impervious areas to the drainage system, should be considered in computing CN for urban areas. For example, consider whether the impervious areas connect directly to the drainage system, or to lawns or other pervious areas where infiltration can occur.

The curve number values given in Table 2-12 are based on directly connected impervious area. An impervious area is considered directly connected if runoff from it flows directly into the drainage system. It is also considered directly connected if runoff from it occurs as concentrated shallow flow that runs over pervious areas and then into a drainage system.

It is possible that curve number values from urban areas could be reduced by not directly connecting impervious surfaces to the drainage system. The following discussion will give some guidance for adjusting curve numbers for different types of impervious areas.

Connected Impervious Areas

Urban CN's given in Table 2-12 were developed for typical land use relationships based on specific assumed percentages of impervious area. These CN values were developed on the assumptions that:

(a) pervious urban areas are equivalent to pasture in good hydrologic condition, and

(b) impervious areas have a CN of 98 and are directly connected to the drainage system.

Some assumed percentages of impervious area are shown in Table 2-12.

If all the impervious area is directly connected to the drainage system, but the impervious area percentages or the pervious land use assumptions in Table 2-12 are not applicable, use figure 2A-1 to compute composite CN. For example, Table 2-12 gives a CN of 70 for a ½ acre lot in hydrologic soil, group B, with an assumed impervious area of 25 percent. However, if the lot has 20 percent impervious area and a pervious area CN of 61, the composite CN obtained from Figure 2A-1 is 68. The CN difference between 70 and 68 reflects the difference in percent impervious area.

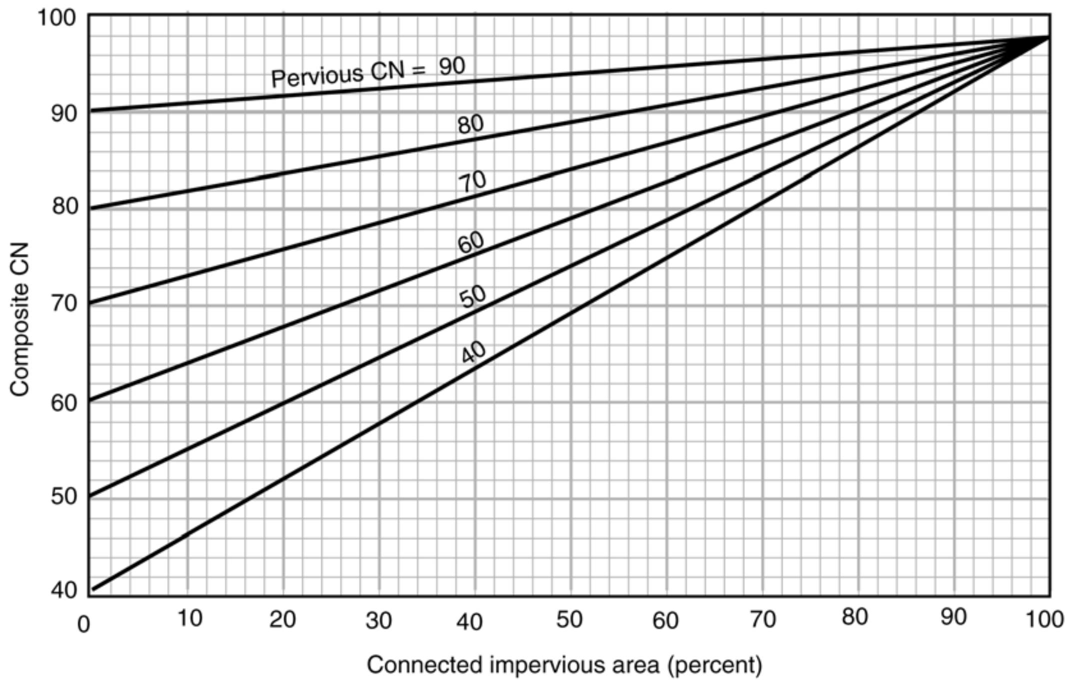


Figure 2A-1 Composite CN with Connected Impervious Area

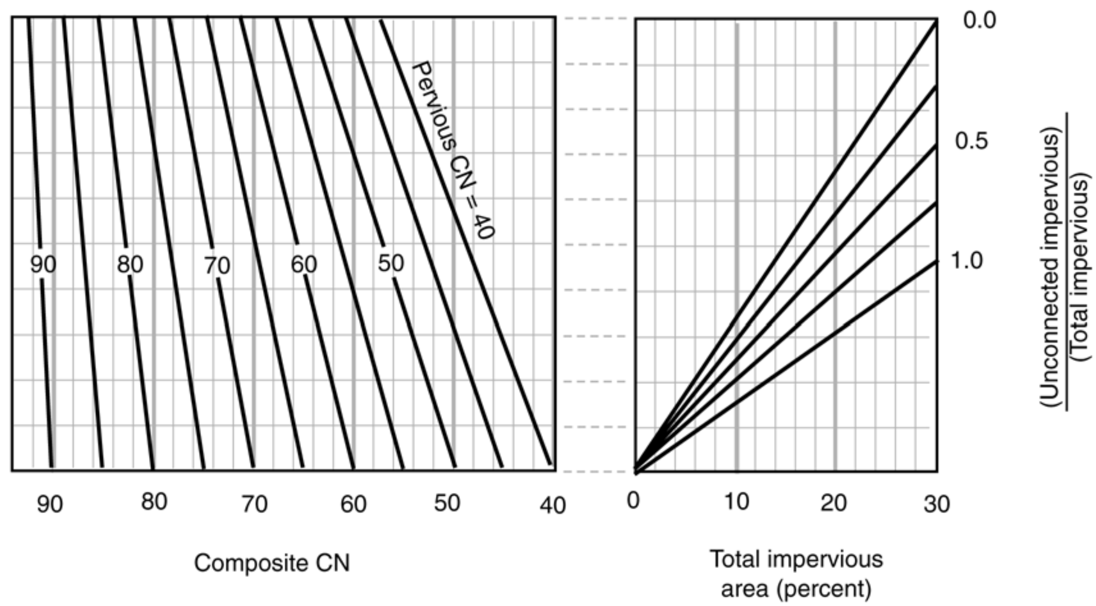


Figure 2A-2 Composite CN With Unconnected Impervious Area
(Total Impervious Area Less than 30%)
Source: ftp://ftp.wcc.nrcs.usda.gov/downloads/hydrology_hydraulicstr55/tr55.pdf

Unconnected Impervious Areas

Runoff from these areas is spread over a pervious area as sheet flow. To determine CN when all or part of the impervious area is not directly connected to the drainage system, (1) use Figure 2A-2 if total impervious area is less than 30 percent or (2) use Figure 2A-1 if the total impervious area is equal to or greater than 30 percent, because the absorptive capacity of the remaining pervious area will not significantly affect runoff.

When impervious area is less than 30 percent, obtain the composite CN by entering the right half of Figure 2A-2 with the percentage of total impervious area and the ratio of total unconnected impervious area to total impervious area. Then move left to the appropriate pervious CN and read down to find the composite CN. For example, for a ½ acre lot with 20 percent total impervious area (75 percent of which is unconnected) and pervious CN of 61, the composite CN from Figure 2A-2 is 66. If all of the impervious area is connected, the resulting CN (from Figure 2A-1) would be 68.

2A.2 Composite Curve Numbers

When a drainage area has more than one land use, a weighted composite curve number can be calculated and used in the analysis. It should be noted that when composite curve numbers are used, the analysis does not take into account the location of the specific land uses but rather sees the drainage area as a uniform land use represented by the composite curve number.

Composite curve numbers for a drainage area can be calculated by entering the required data into a table such as the example presented in Table 2A-1.

Table 2A-1
Composite Curve Numbers

Acreage	Land Use	Soil Type	Hydrologic Group	CN	Weighted CN (Acreage/Total Area) x (CN)
3.41	Pavement and Buildings	CuB/CeD2	B	98	41.10
1.70	Pavement and Buildings	EnD	C	98	20.49
0.65	Open Space—Good Condition	CeD2	B	61	4.88
0.78	Open Space—Good Condition	WuD	C	74	7.10
0.57	Woods—Good Condition	CeD2	B	55	3.86
1.02	Woods—Good Condition	EnD/WuD	C	70	8.78
8.13				CN_{post}=	86.21

The different land uses within the basin should represent a uniform hydrologic group represented by a single curve number. Any number of land uses can be included but if their spatial distribution is important to the hydrologic analysis the sub-basins should be developed and separate hydrographs developed and routed to the design point location.

APPENDIX 2B
ACCUMULATED PRECIPITATION DATA

2-Year, 6-Hour Storm

1 Minute Time Increment

Time (min.)	Accumulated Rainfall (in.)	Time (min.)	Accumulated Rainfall (in.)	Time (min.)	Accumulated Rainfall (in.)	Time (min.)	Accumulated Rainfall (in.)	Time (min.)	Accumulated Rainfall (in.)
0	0.0014	36	0.0576	72	0.1260	108	0.2214	144	0.3821
1	0.0029	37	0.0594	73	0.1282	109	0.2246	145	0.3882
2	0.0043	38	0.0610	74	0.1303	110	0.2279	146	0.3944
3	0.0058	39	0.0627	75	0.1325	111	0.2313	147	0.4007
4	0.0072	40	0.0645	76	0.1347	112	0.2347	148	0.4072
5	0.0087	41	0.0662	77	0.1369	113	0.2381	149	0.4138
6	0.0101	42	0.0680	78	0.1391	114	0.2416	150	0.4225
7	0.0116	43	0.0698	79	0.1413	115	0.2451	151	0.4313
8	0.0131	44	0.0715	80	0.1436	116	0.2486	152	0.4403
9	0.0146	45	0.0733	81	0.1459	117	0.2522	153	0.4495
10	0.0161	46	0.0751	82	0.1482	118	0.2558	154	0.4590
11	0.0176	47	0.0769	83	0.1505	119	0.2595	155	0.4687
12	0.0191	48	0.0787	84	0.1528	120	0.2636	156	0.4787
13	0.0206	49	0.0806	85	0.1552	121	0.2678	157	0.4889
14	0.0221	50	0.0824	86	0.1575	122	0.2720	158	0.4995
15	0.0237	51	0.0843	87	0.1599	123	0.2763	159	0.5104
16	0.0252	52	0.0861	88	0.1623	124	0.2806	160	0.5216
17	0.0267	53	0.0880	89	0.1647	125	0.2850	161	0.5332
18	0.0283	54	0.0899	90	0.1675	126	0.2894	162	0.5452
19	0.0299	55	0.0918	91	0.1703	127	0.2939	163	0.5577
20	0.0314	56	0.0937	92	0.1731	128	0.2985	164	0.5707
21	0.0330	57	0.0956	93	0.1759	129	0.3031	165	0.5879
22	0.0346	58	0.0976	94	0.1787	130	0.3078	166	0.6057
23	0.0362	59	0.0995	95	0.1816	131	0.3125	167	0.6243
24	0.0378	60	0.1015	96	0.1845	132	0.3174	168	0.6438
25	0.0394	61	0.1034	97	0.1874	133	0.3223	169	0.6642
26	0.0410	62	0.1054	98	0.1903	134	0.3273	170	0.6858
27	0.0426	63	0.1074	99	0.1933	135	0.3323	171	0.7086
28	0.0442	64	0.1094	100	0.1963	136	0.3375	172	0.7331
29	0.0459	65	0.1114	101	0.1993	137	0.3427	173	0.7655
30	0.0475	66	0.1135	102	0.2024	138	0.3480	174	0.8002
31	0.0492	67	0.1155	103	0.2055	139	0.3534	175	0.8444
32	0.0508	68	0.1176	104	0.2086	140	0.3590	176	0.8924
33	0.0525	69	0.1197	105	0.2117	141	0.3646	177	0.9458
34	0.0542	70	0.1218	106	0.2149	142	0.3703	178	1.0298
35	0.0559	71	0.1239	107	0.2181	143	0.3761	179	1.1138

2-Year, 6-Hour Storm

1 Minute Time Increment

Time (min.)	Accumulated Rainfall (in.)	Time (min.)	Accumulated Rainfall (in.)	Time (min.)	Accumulated Rainfall (in.)	Time (min.)	Accumulated Rainfall (in.)	Time (min.)	Accumulated Rainfall (in.)
180	1.1978	216	1.9078	252	2.0644	288	2.1579	324	2.2257
181	1.2818	217	1.9136	253	2.0676	289	2.1600	325	2.2274
182	1.3658	218	1.9192	254	2.0707	290	2.1621	326	2.2290
183	1.4162	219	1.9249	255	2.0739	291	2.1641	327	2.2307
184	1.4621	220	1.9303	256	2.0770	292	2.1662	328	2.2324
185	1.4983	221	1.9357	257	2.0800	293	2.1682	329	2.2340
186	1.5318	222	1.9410	258	2.0831	294	2.1703	330	2.2357
187	1.5631	223	1.9462	259	2.0861	295	2.1723	331	2.2373
188	1.5867	224	1.9513	260	2.0891	296	2.1743	332	2.2389
189	1.6089	225	1.9563	261	2.0928	297	2.1763	333	2.2405
190	1.6299	226	1.9612	262	2.0949	298	2.1783	334	2.2421
191	1.6498	227	1.9661	263	2.0979	299	2.1802	335	2.2437
192	1.6688	228	1.9709	264	2.1007	300	2.1822	336	2.2453
193	1.6870	229	1.9756	265	2.1036	301	2.1841	337	2.2469
194	1.7045	230	1.9803	266	2.1064	302	2.1861	338	2.2485
195	1.7178	231	1.9849	267	2.1092	303	2.1880	339	2.2501
196	1.7305	232	1.9894	268	2.1120	304	2.1899	340	2.2516
197	1.7428	233	1.9939	269	2.1147	305	2.1918	341	2.2532
198	1.7546	234	1.9983	270	2.1172	306	2.1936	342	2.2547
199	1.7660	235	2.0026	271	2.1196	307	2.1955	343	2.2563
200	1.7771	236	2.0069	272	2.1220	308	2.1974	344	2.2578
201	1.7878	237	2.0112	273	2.1244	309	2.1992	345	2.2593
202	1.7982	238	2.0154	274	2.1267	310	2.2011	346	2.2609
203	1.8083	239	2.0195	275	2.1291	311	2.2029	347	2.2624
204	1.8181	240	2.0232	276	2.1314	312	2.2047	348	2.2639
205	1.8273	241	2.0269	277	2.1337	313	2.2065	349	2.2654
206	1.8371	242	2.0305	278	2.1360	314	2.2083	350	2.2669
207	1.8462	243	2.0340	279	2.1382	315	2.2101	351	2.2684
208	1.8551	244	2.0375	280	2.1405	316	2.2118	352	2.2698
209	1.8638	245	2.0410	281	2.1427	317	2.2136	353	2.2713
210	1.8706	246	2.0445	282	2.1449	318	2.2154	354	2.2728
211	1.8771	247	2.0479	283	2.1471	319	2.2171	355	2.2742
212	1.8835	248	2.0512	284	2.1493	320	2.2188	356	2.5757
213	1.8898	249	2.0546	285	2.1515	321	2.2206	357	2.2771
214	1.8959	250	2.0579	286	2.1536	322	2.2223	358	2.2786
215	1.9020	251	2.0611	287	2.1558	323	2.2240	359	2.2800
								360	2.2800

10-Year, 6-Hour Storm

1 Minute Time Increment

Time (min.)	Accumulated Rainfall (in.)	Time (min.)	Accumulated Rainfall (in.)	Time (min.)	Accumulated Rainfall (in.)	Time (min.)	Accumulated Rainfall (in.)	Time (min.)	Accumulated Rainfall (in.)
0	0.0022	36	0.0887	72	0.1945	108	0.3469	144	0.6230
1	0.0044	37	0.0914	73	0.1979	109	0.3523	145	0.6336
2	0.0066	38	0.0940	74	0.2012	110	0.3577	146	0.6444
3	0.0089	39	0.0967	75	0.2046	111	0.3632	147	0.6554
4	0.0111	40	0.0994	76	0.2080	112	0.3687	148	0.6666
5	0.0134	41	0.1021	77	0.2114	113	0.3743	149	0.6781
6	0.0156	42	0.1048	78	0.2148	114	0.3799	150	0.6936
7	0.0179	43	0.1075	79	0.2183	115	0.3856	151	0.7094
8	0.0202	44	0.1102	80	0.2218	116	0.3914	152	0.7255
9	0.0225	45	0.1130	81	0.2253	117	0.3973	153	0.7420
10	0.0248	46	0.1158	82	0.2289	118	0.4032	154	0.7589
11	0.0271	47	0.1186	83	0.2325	119	0.4092	155	0.7763
12	0.0294	48	0.1214	84	0.2361	120	0.4164	156	0.7940
13	0.0317	49	0.1242	85	0.2397	121	0.4237	157	0.8122
14	0.0341	50	0.1271	86	0.2434	122	0.4311	158	0.8310
15	0.0364	51	0.1299	87	0.2471	123	0.4386	159	0.8502
16	0.0388	52	0.1328	88	0.2508	124	0.4461	160	0.8701
17	0.0412	53	0.1357	89	0.2546	125	0.4538	161	0.8906
18	0.0436	54	0.1386	90	0.2591	126	0.4615	162	0.9118
19	0.0460	55	0.1416	91	0.2636	127	0.4694	163	0.9338
20	0.0484	56	0.1445	92	0.2681	128	0.4774	164	0.9566
21	0.0508	57	0.1475	93	0.2727	129	0.4855	165	0.9876
22	0.0533	58	0.1505	94	0.2774	130	0.4936	166	1.0198
23	0.0557	59	0.1535	95	0.2820	131	0.5020	167	1.0531
24	0.0582	60	0.1565	96	0.2868	132	0.5104	168	1.0878
25	0.0606	61	0.1596	97	0.2915	133	0.5190	169	1.1240
26	0.0631	62	0.1627	98	0.2963	134	0.5276	170	1.1620
27	0.0636	63	0.1657	99	0.3012	135	0.5365	171	1.2021
28	0.0681	64	0.1689	100	0.3060	136	0.5454	172	1.2445
29	0.0707	65	0.1720	101	0.3110	137	0.5546	173	1.2976
30	0.0732	66	0.1751	102	0.3160	138	0.5638	174	1.3542
31	0.0758	67	0.1783	103	0.3210	139	0.5733	175	1.4281
32	0.0783	68	0.1815	104	0.3261	140	0.5829	176	1.5067
33	0.0809	69	0.1847	105	0.3312	141	0.5926	177	1.5919
34	0.0835	70	0.1880	106	0.3364	142	0.6026	178	1.7099
35	0.0861	71	0.1913	107	0.3416	143	0.6127	179	1.8279

10-Year, 6-Hour Storm

1 Minute Time Increment

Time (min.)	Accumulated Rainfall (in.)	Time (min.)	Accumulated Rainfall (in.)	Time (min.)	Accumulated Rainfall (in.)	Time (min.)	Accumulated Rainfall (in.)	Time (min.)	Accumulated Rainfall (in.)
180	1.9459	216	3.1144	252	3.3824	288	3.5315	324	3.6363
181	2.0639	217	3.1244	253	3.3876	289	3.5347	325	3.6389
182	2.1819	218	3.1343	254	3.3928	290	3.5380	326	3.6415
183	2.2635	219	3.1440	255	3.3979	291	3.5412	327	3.6440
184	2.3395	220	3.1535	256	3.4030	292	3.5444	328	3.6466
185	2.3982	221	3.1628	257	3.4080	293	3.5475	329	3.6492
186	2.4529	222	3.1720	258	3.4129	294	3.5507	330	3.6517
187	2.5045	223	3.1811	259	3.4178	295	3.5538	331	3.6542
188	2.5458	224	3.1900	260	3.4227	296	3.5569	332	3.6567
189	2.5847	225	3.1987	261	3.4275	297	3.5600	333	3.6592
190	2.6218	226	3.2073	262	3.4323	298	3.5630	334	3.6617
191	2.6572	227	3.2158	263	3.4370	299	3.5661	335	3.6642
192	2.6912	228	3.2242	264	3.4417	300	3.5691	336	3.6666
193	2.7240	229	3.2325	265	3.4464	301	3.5721	337	3.6691
194	2.7556	230	3.2406	266	3.4510	302	3.5751	338	3.6715
195	2.7788	231	3.2486	267	3.4556	303	3.5781	339	3.6739
196	2.8012	232	3.2565	268	3.4601	304	3.5810	340	3.6763
197	2.8227	233	3.2644	269	3.4646	305	3.5839	341	3.6787
198	2.8436	234	3.2721	270	3.4684	306	3.5868	342	3.6811
199	2.8638	235	3.2797	271	3.4721	307	3.5897	343	3.6835
200	2.8833	236	3.2872	272	3.4759	308	3.5926	344	3.6858
201	2.9023	237	3.2946	273	3.4795	309	3.5954	345	3.6882
202	2.9208	238	3.3020	274	3.4832	310	3.5983	346	3.6905
203	2.9388	239	3.3092	275	3.4868	311	3.6011	347	3.6929
204	2.9563	240	3.3152	276	3.4904	312	3.6039	348	3.6952
205	2.9734	241	3.3212	277	3.4940	313	3.6067	349	3.6975
206	2.9901	242	3.3271	278	3.4975	314	3.6094	350	3.6998
207	3.0065	243	3.3329	279	3.5011	315	3.6122	351	3.7021
208	3.0224	244	3.3387	280	3.5045	316	3.6149	352	3.7044
209	3.0381	245	3.3443	281	3.5080	317	3.6177	353	3.7066
210	3.0497	246	3.3499	282	3.5114	318	3.6204	354	3.7089
211	3.0611	247	3.3555	283	3.5148	319	3.6231	355	3.7111
212	3.0722	248	3.3610	284	3.5182	320	3.6257	356	3.7134
213	3.0831	249	3.3665	285	3.5216	321	3.6284	357	3.7156
214	3.0937	250	3.3718	286	3.5249	322	3.6310	358	3.7178
215	3.1041	251	3.3772	287	3.5282	323	3.6337	359	3.7200
								360	3.7200

50-Year, 6-Hour Storm

1 Minute Time Increment

Time (min.)	Accumulated Rainfall (in.)	Time (min.)	Accumulated Rainfall (in.)	Time (min.)	Accumulated Rainfall (in.)	Time (min.)	Accumulated Rainfall (in.)	Time (min.)	Accumulated Rainfall (in.)
0	0.0031	36	0.1257	72	0.2750	108	0.4847	144	0.8583
1	0.0063	37	0.1295	73	0.2797	109	0.4919	145	0.8725
2	0.0094	38	0.1332	74	0.2844	110	0.4992	146	0.8870
3	0.0126	39	0.1370	75	0.2891	111	0.5066	147	0.9018
4	0.0158	40	0.1408	76	0.2939	112	0.5141	148	0.9170
5	0.0189	41	0.1446	77	0.2987	113	0.5217	149	0.9324
6	0.0221	42	0.1484	78	0.3036	114	0.5293	150	0.9526
7	0.0254	43	0.1523	79	0.3084	115	0.5370	151	0.9733
8	0.0286	44	0.1562	80	0.3134	116	0.5449	152	0.9944
9	0.0319	45	0.1601	81	0.3183	117	0.5528	153	1.0159
10	0.0351	46	0.1640	82	0.3233	118	0.5608	154	1.0380
11	0.0384	47	0.1679	83	0.3283	119	0.5689	155	1.0606
12	0.0417	48	0.1719	84	0.3334	120	0.5787	156	1.0838
13	0.0450	49	0.1759	85	0.3385	121	0.5886	157	1.1076
14	0.0483	50	0.1799	86	0.3437	122	0.5986	158	1.1320
15	0.0517	51	0.1839	87	0.3489	123	0.6087	159	1.1571
16	0.0550	52	0.1880	88	0.3542	124	0.6190	160	1.1830
17	0.0584	53	0.1921	89	0.3594	125	0.6294	161	1.2098
18	0.0618	54	0.1962	90	0.3655	126	0.6399	162	1.2374
19	0.0652	55	0.2004	91	0.3717	127	0.6506	163	1.2660
20	0.0686	56	0.2045	92	0.3778	128	0.6614	164	1.2957
21	0.0720	57	0.2087	93	0.3841	129	0.6723	165	1.3363
22	0.0755	58	0.2129	94	0.3903	130	0.6834	166	1.3783
23	0.0790	59	0.2172	95	0.3967	131	0.6947	167	1.4219
24	0.0825	60	0.2215	96	0.4031	132	0.7061	168	1.4672
25	0.0860	61	0.2258	97	0.4095	133	0.7177	169	1.5145
26	0.0895	62	0.2301	98	0.4160	134	0.7294	170	1.5640
27	0.0930	63	0.2344	99	0.4226	135	0.7414	171	1.6161
28	0.0966	64	0.2388	100	0.4292	136	0.7535	172	1.6714
29	0.1002	65	0.2432	101	0.4359	137	0.7658	173	1.7400
30	0.1038	66	0.2477	102	0.4427	138	0.7783	174	1.8130
31	0.1074	67	0.2522	103	0.4495	139	0.7911	175	1.9086
32	0.1110	68	0.2567	104	0.4564	140	0.8040	176	2.0101
33	0.1147	69	0.2612	105	0.4634	141	0.8172	177	2.1198
34	0.1183	70	0.2658	106	0.4704	142	0.8307	178	2.2698
35	0.1220	71	0.2704	107	0.4775	143	0.8443	179	2.4198

50-Year, 6-Hour Storm

1 Minute Time Increment

Time (min.)	Accumulated Rainfall (in.)	Time (min.)	Accumulated Rainfall (in.)	Time (min.)	Accumulated Rainfall (in.)	Time (min.)	Accumulated Rainfall (in.)	Time (min.)	Accumulated Rainfall (in.)
180	2.5698	216	4.0852	252	4.4480	288	4.6535	324	4.8014
181	2.7198	217	4.0988	253	4.4551	289	4.6581	325	4.8051
182	2.8698	218	4.1121	254	4.4621	290	4.6626	326	4.8087
183	2.9751	219	4.1252	255	4.4690	291	4.6671	327	4.8124
184	3.0734	220	4.1380	256	4.4758	292	4.6716	328	4.8160
185	3.1490	221	4.1507	257	4.4826	293	4.6761	329	4.8196
186	3.2197	222	4.1631	258	4.4893	294	4.6805	330	4.8232
187	3.2864	223	4.1753	259	4.4960	295	4.6849	331	4.8268
188	3.3401	224	4.1873	260	4.5026	296	4.6893	332	4.8303
189	3.3908	225	4.1992	261	4.5092	297	4.6936	333	4.8338
190	3.4392	226	4.2109	262	4.5156	298	4.6980	334	4.8374
191	3.4854	227	4.2224	263	4.5221	299	4.7022	335	4.8409
192	3.5298	228	4.2337	264	4.5284	300	4.7065	336	4.8443
193	3.5726	229	4.2449	265	4.5347	301	4.7107	337	4.8478
194	3.6139	230	4.2559	266	4.5410	302	4.7149	338	4.8512
195	3.6442	231	4.2668	267	4.5472	303	4.7191	339	4.8547
196	3.6733	232	4.2775	268	4.5533	304	4.7233	340	4.8581
197	3.7014	233	4.2881	269	4.5594	305	4.7274	341	4.8615
198	3.7286	234	4.2985	270	4.5648	306	4.7315	342	4.8649
199	3.7549	235	4.3089	271	4.5700	307	4.7356	343	4.8682
200	3.7804	236	4.3191	272	4.5753	308	4.7396	344	4.8716
201	3.8052	237	4.3291	273	4.5804	309	4.7437	345	4.8749
202	3.8293	238	4.3391	274	4.5856	310	4.7477	346	4.8782
203	3.8528	239	4.3489	275	4.5907	311	4.7516	347	4.8815
204	3.8757	240	4.3571	276	4.5957	312	4.7556	348	4.8848
205	3.8980	241	4.3651	277	4.6008	313	4.7595	349	4.8881
206	3.9198	242	4.3731	278	4.6057	314	4.7635	350	4.8913
207	3.9411	243	4.3810	279	4.6107	315	4.7673	351	4.8946
208	3.9620	244	4.3888	280	4.6156	316	4.7712	352	4.8978
209	3.9824	245	4.3965	281	4.6204	317	4.7751	353	4.9010
210	3.9981	246	4.4041	282	4.6253	318	4.7789	354	4.9042
211	4.0134	247	4.4116	283	4.6301	319	4.7827	355	4.9074
212	4.0283	248	4.4190	284	4.6348	320	4.7865	356	4.9106
213	4.0430	249	4.4264	285	4.6395	321	4.7902	357	4.9137
214	4.0574	250	4.4337	286	4.6442	322	4.7940	358	4.9169
215	4.0714	251	4.4409	287	4.6489	323	4.7977	359	4.9200
								360	4.9200