2C-2 Rainfall and Runoff Analysis

A. Introduction

1. The first step in any hydrologic analysis is an estimation of the rainfall that will fall on the site for a given time period. The amount of rainfall can be quantified with the following characteristics:

   a. **Duration (hours).** Length of time over which rainfall (storm event) occurs.

   b. **Depth (inches).** Total amount of rainfall occurring during the storm duration.

   c. **Intensity (inches per hour).** Depth divided by the duration.

2. A design event is used as a basis for determining the design of a new urban storm water management project or evaluating an existing project. It is presumed that the project will function properly if it can accommodate the design event at full capacity. For economic reasons, some risk of failure is allowed in selection of the design event. This risk is usually related to return period.

3. The frequency of a rainfall event is the recurrence interval of storms having the same duration and volume (depth). This can be expressed either in terms of exceedence probability or return period.

   a. **Exceedence probability.** Probability that a storm event having the specified duration and volume will be exceeded in one given time period, typically one year.

   b. **Return period.** Average length of time between events that have the same duration and volume.

   Thus, if a storm event with a specified duration and volume has a 1% chance of occurring in any given year, then it has an exceedence probability of 0.01, and a return period of 100 years.

Urban stormwater projects are designed based on storm runoff, so a runoff event must be selected for design. However, runoff data are usually not available to determine the discharge-return period or runoff volume-return period for design. Rainfall data is available in various formats for a number of gauge stations across Iowa.

Summary data can be accessed at: http://mesonet.agron.iastate.edu/climodat/index.phtml. Hourly (TD3240) and 15-minute (TD3260) rainfall data are available from the National Climate Data Center: http://www.ncdc.noaa.gov/oa/ncdc.html for the National Weather Service Coop recording gauge stations in Iowa. Most all of the Coop stations in Iowa have a minimum of 60 years of hourly rainfall data, and many have 100 years on record. A rainfall record is converted to runoff using a rainfall-runoff model. Two methods are available: a continuous simulation approach, and the single-event design storm approach. For the continuous simulation method, a chronological record of rainfall for the area of interest is used as input to a rainfall-runoff model of the urban watershed being considered. The output can then be used as a chronological record of runoff to determine the maximum runoff peak and total volume for a selected design period. The Storm Water Management Model (SWMM v.5, EPA) and HEC-HMS (Hydraulic Engineering Center, USACE) are examples of models with continuous simulation capability. Both of these programs are available as public domain software programs. The software programs define the format for importing the rainfall data.

In the single-event design storm method, a rainfall record is analyzed to obtain a rainfall-return period relationship. Next, the storm event corresponding to a design return period is identified as the design storm. This design storm is then used as input to a mathematical rainfall-runoff model (i.e. Rational method, NRCS WINTR-55), and the resulting output is adopted as the design runoff (peak rate and/or volume). The single-event design storm method is the most commonly-used method for smaller urban catchments and urban developments. For assessment of larger urban stormwater systems (>1 mi^2) and regional detention basins, a continuous simulation method is recommended.

The design storm can be described as a return period, rainfall depth, average rainfall intensity, rain duration, or a time distribution of rainfall. Rainfall intensity refers to the time rate of rainfall (in/hr). The intensity will vary over the duration of the event, and a plot of rainfall intensity vs. time is called a hyetograph. The total depth of rainfall is the depth to which the rain would accumulate if it stayed in place where it fell. The average intensity is the total rainfall depth divided by the storm duration. Rain intensity will exhibit spatial variation, but is usually not considered for small urban watersheds (< 2000 acres).

The selection of the return period for design will depend on the relative importance of the facility being designed, cost (economics), desired level of protection, and damages resulting from a failure. Typical design return periods for storm sewer conveyance in Iowa (inlets and piping) vary from 2-10 years, with 5 years being most common. For culverts, design periods of 25-50 years are typical, depending on the type and level of service for the roadway. For detention basins, 25-100 years are common. Additional specific design storm criteria for stormwater quality and quantity management are covered in later sections of this manual.

The design storm duration also depends on the type of project. For peak discharge design of urban storm sewers and culverts, the design storm should be the one that results in the largest peak discharge for a given return period. For urban areas with a mix of pervious and impervious area, as the imperviousness increases, the time of concentration will decrease, and the peak runoff rate will increase. The shorter T_c will result in a higher rainfall intensity, and will give the highest peak discharge. As will be covered later in the Rational method for determining peak runoff rate, duration, and subsequently the rainfall intensity used for input, is dependent on the time of concentration for the catchment configuration. For storm sewer design, a minimum duration of 5 minutes is typically specified.

For development of runoff hydrographs using unit hydrograph methods, a storm duration much longer than than the time of concentration is selected. For the NRCS methods for unit hydrograph development, the duration of the storm will be almost twice the time of concentration. For the design of detention basins, the duration of the storm should be that which yields the highest storage requirement. The duration then becomes a function of the relative size of the detention basin, the watershed size, and the outlet configuration, and will be much longer than the duration used for peak discharge determination. This is of particular note when the Modified Rational method is used to size detention basin volume, particularly for catchment sizes more than 15-20 acres.

As described later in this manual, the design storm for management of stormwater quality is defined as the rainfall depth representing the 90% cumulative probability annual rainfall depth – this is the depth of rainfall that represents 90% of the rainfall events, based on a cumulative occurrence frequency. These will be the rainfall events with a recurrence interval of 3-4 months and generally will be less than 1.25 inches in depth. This water quality design storm is used to determine the water quality volume (WQv) for sizing stormwater quality BMPs. Additional details are provided in section 2C-6. The water quality design storm depth is determined using a cumulative frequency analysis of 24-hour precipitation event totals for the period of record for a local area. The rainfall events with a depth of less than 0.1 inches are excluded from the analysis, since these very seldom produce measurable runoff. The individual events are then grouped by depth intervals of 0.2 inches, and the frequency of depth occurrence tabulated to determine the cumulative rainfall depth occurrence until all of the rainfall events in the period of record are included. The smaller rainfall events are more frequent (smaller return period) while the larger storms more infrequent (smaller number) and have a larger return period.

For example, 90% of the annual rainfall events recorded at the NWS Coop rainfall gauge in Ames, Iowa for the period of record from 1960-2006, are less than or equal to 1.25 inches (computation based only on those rainfall events that generate measurable runoff; rainfall events less than 0.1 inch were subtracted from the total for calculation of occurrence frequency. For all rainfall events in the total period of record (100 years for most stations in Iowa), the 90% occurrence depth is 1 inch or less.

A rainfall analysis for the NWS Coop gauge on the southwest edge of Ames was performed for the period of record 1960-2006. The results are summarized in Table 1. Rainfall data for all of the NWS Coop sites in Iowa is available from the National Climate Data Center (NCDC) http://lwf.ncdc.noaa.gov/oa/climate/climatedata.html. The data is available in 24-hour totals recorded at 15-minute and 1-hour intervals. The frequency analysis is completed by first identifying the individual rainfall events by a separation interval (in this case, 6 hours). This means that each rainfall event is separated from the next measurable rainfall by the selected interval. The individual rainfall events are then grouped into discrete depth categories, as shown in the tabulated data for Ames. The number of events in each depth category are totaled, and the depth class total is divided by the total number of rainfall events for the period of record. For the 1960-2006 period of record, there were 3,362 events with more than 0.1 inches of precipitation. Rainfall depths less than 0.1 inches usually do not produce any measurable runoff, so when these events are subtracted from the total, there are 1,999 rainfall events with greater 0.1 inches depth. The cumulative frequency is computed by dividing the cumulative number of events at each depth category by the total number of events (1,999) to provide a percent frequency of occurrence for each depth range.

For the Ames data, 90.6% of the rainfall events (greater than 0.1 inch) had a depth of 1.25 inches or less. This is termed the "90% cumulative occurrence frequency," and is the rainfall depth recommended for determining the WQv for Iowa. Also note, for the rainfall frequency for Ames, that the average annual rainfall for the period 1960-2006 was 31.58 inches, and the mean rainfall depth (P_6) is 0.62 inches. The mean rainfall depth, P_6, is used in the calculation of the water quality capture volume (WQCV) for sizing extended detention storage for water quality improvement. The WQv is one of the unified sizing criteria discussed in Part 2B and used throughout this manual for the sizing of stormwater quality BMPs. The method for WQCV is discussed in more detail in Section 2C-6.

Table 1: Rainfall summary for Ames, IA for the period 1960-2006

Rainfall Depth - inches	Number of Events	Cumulative Frequency	Annual Rainfall in Frequency Class	Cumulative Percent of Annual Average Rainfall
0.01 - 0.10	1363		2.30	
0.11 - 0.25	651	32.57%	2.98	
0.26 - 0.50	596	62.38%	5.66	
0.51 - 0.75	262	75.49%	4.21	
0.76 - 1.00	182	84.59%	4.08	
1.01 - 1.25	120	**90.60%**	3.47	69.7%
1.26 - 1.50	73	94.25%	2.57	78.4%
1.51 - 1.75	37	96.10%	1.56	83.8%
1.76 - 2.00	32	97.70%	1.52	**89.0%**
2.01 - 3.00	35	99.45%	2.14	96.3%
3.01 - 4.00	8	99.85%	0.70	98.7%
4.01 - 5.00	1	99.90%	0.11	99.0%
5.01 - 6.00	2	100.00%	0.28	100.0%
> 6.00	0			
		Annual Average Precipitation	**31.58**	
Total Events > 0.01	**3362**			
Total events > 0.10	**1999**	**Mean Storm Depth**	**0.62-inches**	

B. Rainfall frequency analysis

Additional frequency analysis techniques are used to develop relationships between the average intensity, storm duration, and return period from rainfall data. Often, the rainfall depth is used in place of the average intensity. To establish the importance of the relationship between average intensity, duration, and frequency, the U.S. Weather Bureau compiled data for development of Intensity-Duration-Frequency (I-D-F) curves based on historic rainfall data for most localities across the country. Herschfield (1961) developed these relationships for the entire US, and the data was published in the National Weather Service Technical Paper 40 (TP40) publication. The Rainfall Frequency Atlas of the Midwest – Bulletin 71 (Huff and Angell, 1992), published by the Midwest Climate Center and the Illinois Water Survey, includes rainfall depth, duration, and return period frequency analysis in tabular format for the nine climate districts in Iowa (Figure 1). The Bulletin 71 summary data are provided in both rainfall depth and rainfall intensity in Tables 2 and 3 respectively. The Bulletin 71 data includes the additional rainfall data for the additional period or record since 1960, and is recommended as the primary source for single-event design procedures.

Figure 1: Climatic Sectional Codes for Iowa*

01 - Northwest	04 - West Central	07 - Southwest
02 - North Central	05 – Central	08 - South Central
03 - Northeast	06 - East Central	09 - Southeast

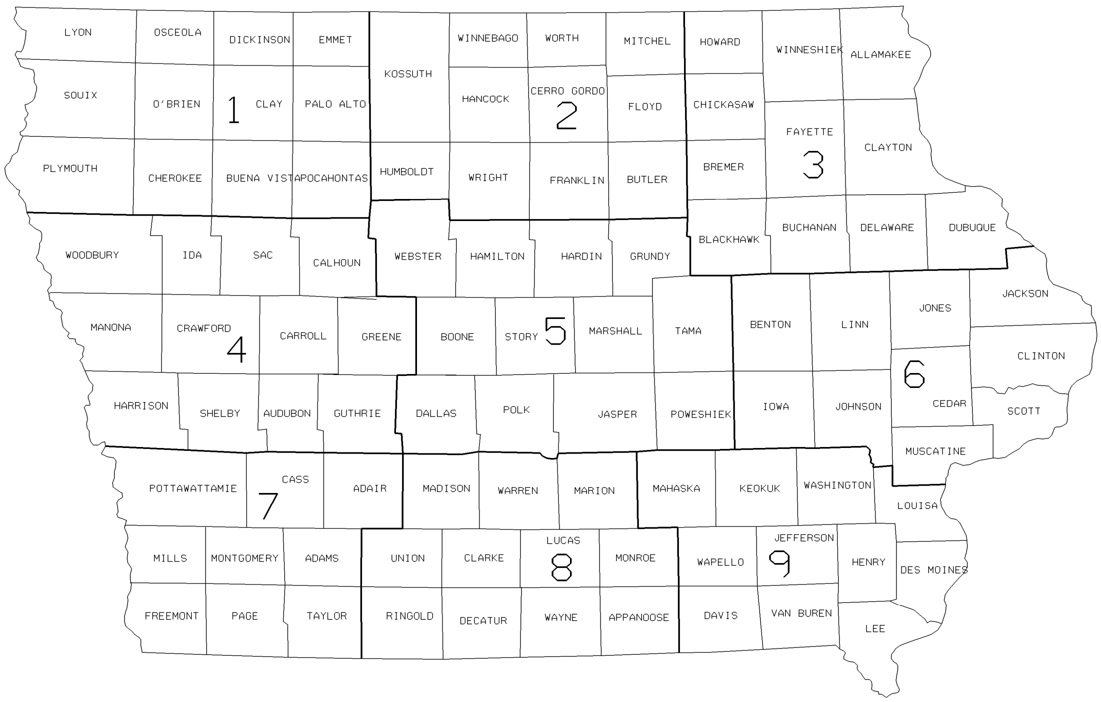


Table 2: Sectional mean rainfall amounts for storm periods of 5 minutes to 10 days and recurrence intervals of 3 months to 100 years in Iowa (see Figure 2, Iowa Map)

Rainfall (inches) for given recurrence interval T, return period, years

*Section	Duration	3-mo	4-mo	6-mo	1-yr	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr
01	10-day	2.39	2.75	3.24	4.05	4.81	5.84	6.70	8.02	9.11	10.31
01	5-day	1.90	2.15	2.49	3.11	3.77	4.68	5.43	6.61	7.60	8.75
01	72-hr	1.66	1.88	2.18	2.72	3.33	4.21	4.99	6.07	7.12	8.23
01	48-hr	1.55	1.73	2.00	2.50	3.01	3.81	4.52	5.60	6.53	7.52
01	24-hr	1.42	1.55	1.80	2.22	2.75	3.50	4.14	5.11	5.97	6.92
01	18-hr	1.34	1.46	1.69	2.09	2.59	3.29	3.89	4.80	5.61	6.50
01	12-hr	1.24	1.35	1.56	1.93	2.39	3.05	3.60	4.45	5.19	6.02
01	6-hr	1.06	1.16	1.34	1.66	2.06	2.62	3.11	3.83	4.48	5.19
01	3-hr	0.91	0.99	1.15	1.42	1.76	2.24	2.65	3.27	3.82	4.43
01	2-hr	0.83	0.90	1.04	1.29	1.59	2.03	2.40	2.96	3.46	4.01
01	1-hr	0.67	0.73	0.84	1.04	1.29	1.64	1.95	2.40	2.81	3.25
01	30-min	0.52	0.57	0.66	0.82	1.02	1.30	1.53	1.89	2.21	2.56
01	15-min	0.38	0.42	0.49	0.60	0.74	0.95	1.12	1.38	1.61	1.87
01	10-min	0.30	0.33	0.38	0.47	0.58	0.73	0.87	1.07	1.25	1.45
01	5-min	0.17	0.19	0.22	0.27	0.33	0.42	0.50	0.61	0.72	0.83
02	10-day	2.37	2.73	3.21	4.01	5.04	6.26	7.32	8.93	10.37	11.40
02	5-day	2.10	2.37	2.75	3.44	4.13	5.05	5.80	7.00	8.03	9.28
02	72-hr	1.74	1.97	2.29	2.86	3.53	4.45	5.15	6.33	7.30	8.30
02	48-hr	1.66	1.84	2.14	2.67	3.30	4.11	4.78	5.80	6.67	7.67
02	24-hr	1.51	1.65	1.91	2.36	2.98	3.72	4.38	5.33	6.14	7.07
02	18-hr	1.42	1.55	1.80	2.22	2.80	3.50	4.12	5.01	5.77	6.65
02	12-hr	1.31	1.43	1.66	2.06	2.59	3.24	3.80	4.64	5.34	6.15
02	6-hr	1.13	1.24	1.43	1.77	2.24	2.79	3.29	4.00	4.61	5.30
02	3-hr	0.97	1.06	1.22	1.51	1.91	2.38	2.80	3.41	3.93	4.52
02	2-hr	0.88	0.96	1.11	1.37	1.73	2.16	2.54	3.09	3.56	4.10
02	1-hr	0.71	0.78	0.90	1.11	1.40	1.75	2.06	2.51	2.89	3.32
02	30-min	0.56	0.61	0.70	0.87	1.10	1.38	1.62	1.97	2.27	2.62
02	15-min	0.41	0.45	0.52	0.64	0.80	1.00	1.18	1.44	1.66	1.91
02	10-min	0.32	0.35	0.41	0.50	0.63	0.78	0.92	1.12	1.29	1.48
02	5-min	0.18	0.20	0.23	0.28	0.36	0.45	0.53	0.64	0.74	0.85
03	10-day	2.49	2.87	3.38	4.22	5.04	6.17	7.07	8.29	9.20	10.19
03	5-day	2.03	2.29	2.66	3.32	3.94	4.86	5.64	6.84	7.75	8.77
03	72-hr	1.74	1.97	2.29	2.86	3.44	4.33	5.14	6.19	7.00	7.84
03	48-hr	1.61	1.79	2.07	2.59	3.20	4.02	4.69	5.62	6.34	7.09
03	24-hr	1.48	1.62	1.88	2.32	2.91	3.67	4.31	5.11	5.73	6.36
03	18-hr	1.40	1.53	1.77	2.18	2.74	3.45	4.05	4.80	5.39	5.98
03	12-hr	1.29	1.41	1.64	2.02	2.53	3.19	3.75	4.45	4.99	5.53
03	6-hr	1.11	1.22	1.41	1.74	2.18	2.75	3.23	3.83	4.30	4.77
03	3-hr	0.95	1.04	1.20	1.48	1.86	2.35	2.76	3.27	3.67	4.07
03	2-hr	0.86	0.94	1.09	1.35	1.69	2.13	2.50	2.96	3.32	3.69
03	1-hr	0.70	0.76	0.88	1.09	1.37	1.72	2.03	2.40	2.69	2.99
03	30-min	0.55	0.60	0.70	0.86	1.08	1.36	1.59	1.89	2.12	2.35
03	15-min	0.40	0.44	0.51	0.63	0.79	0.99	1.16	1.38	1.55	1.72
03	10-min	0.31	0.34	0.40	0.49	0.61	0.77	0.91	1.07	1.20	1.34
03	5-min	0.18	0.20	0.23	0.28	0.35	0.44	0.52	0.67	0.69	0.76

Source: Bulletin 71, *Rainfall Frequency Atlas of the Midwest*, 1992

Table 2 (continued): Sectional mean rainfall amounts for storm periods of 5 minutes to 10 days and recurrence intervals of 3 months to 100 years in Iowa (see Figure 2, Iowa Map)

Rainfall (inches) for given recurrence interval T, return period, years

*Section	Duration	3-mo	4-mo	6-mo	1-yr	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr
04	10-day	2.59	2.99	3.51	4.39	5.22	6.31	7.16	8.24	9.21	10.27
04	5-day	2.11	2.39	2.77	3.46	4.06	4.94	5.74	7.04	8.13	9.27
04	72-hr	1.79	2.02	2.34	2.93	3.51	4.37	5.13	6.28	7.26	8.46
04	48-hr	1.67	1.86	2.15	2.69	3.16	3.97	4.71	5.86	6.81	7.82
04	24-hr	1.59	1.74	2.01	2.48	2.94	3.64	4.30	5.27	6.08	7.00
04	18-hr	1.49	1.63	1.89	2.33	2.76	3.42	4.04	4.95	5.72	6.58
04	12-hr	1.38	1.51	1.75	2.16	2.56	3.17	3.74	4.58	5.29	6.09
04	6-hr	1.19	1.30	1.51	1.86	2.20	2.73	3.23	3.95	4.56	5.25
04	3-hr	1.02	1.11	1.29	1.59	1.88	2.33	2.75	3.37	3.89	4.48
04	2-hr	0.92	1.01	1.17	1.44	1.71	2.11	2.49	3.06	3.53	4.06
04	1-hr	0.75	0.82	0.95	1.17	1.38	1.71	2.02	2.48	2.86	3.29
04	30-min	0.59	0.64	0.75	0.92	1.09	1.35	1.59	1.95	2.25	2.59
04	15-min	0.43	0.47	0.54	0.67	0.79	0.98	1.16	1.42	1.64	1.89
04	10-min	0.33	0.36	0.42	0.52	0.62	0.76	0.90	1.11	1.28	1.47
04	5-min	0.19	0.21	0.24	0.30	0.35	0.44	0.52	0.63	0.73	0.84
05	10-day	2.64	3.05	3.58	4.48	5.20	6.22	7.22	8.61	9.66	10.88
05	5-day	2.11	2.39	2.77	3.46	4.05	4.94	5.72	6.92	7.98	9.18
05	72-hr	1.77	2.00	2.32	2.90	3.47	4.41	5.16	6.22	7.06	8.12
05	48-hr	1.64	1.82	2.11	2.64	3.13	3.93	4.67	5.75	6.52	7.33
05	24-hr	1.52	1.67	1.93	2.38	2.91	3.64	4.27	5.15	5.87	6.61
05	18-hr	1.43	1.57	1.81	2.24	2.74	3.42	4.01	4.84	5.52	6.21
05	12-hr	1.32	1.45	1.68	2.07	2.53	3.17	3.71	4.48	5.11	5.75
05	6-hr	1.15	1.25	1.45	1.79	2.18	2.73	3.20	3.86	4.40	4.96
05	3-hr	0.97	1.06	1.23	1.52	1.86	2.33	2.73	3.30	3.76	4.23
05	2-hr	0.88	0.97	1.12	1.38	1.69	2.11	2.48	2.99	3.40	3.83
05	1-hr	0.72	0.78	0.91	1.12	1.37	1.71	2.01	2.42	2.76	3.11
05	30-min	0.56	0.62	0.71	0.88	1.08	1.35	1.58	1.91	2.17	2.45
05	15-min	0.41	0.45	0.52	0.64	0.79	0.98	1.15	1.39	1.58	1.78
05	10-min	0.32	0.35	0.41	0.50	0.61	0.76	0.90	1.08	1.23	1.39
05	5-min	0.19	0.20	0.23	0.29	0.35	0.44	0.51	0.62	0.70	0.79
06	10-day	2.57	2.96	3.49	4.36	5.21	6.27	7.12	8.25	9.27	10.35
06	5-day	2.20	2.48	2.88	3.60	4.12	4.89	5.61	6.70	7.75	9.00
06	72-hr	1.84	2.08	2.41	3.01	3.59	4.53	5.31	6.42	7.35	8.42
06	48-hr	1.61	1.79	2.08	2.60	3.21	4.15	5.05	6.02	6.87	7.83
06	24-hr	1.54	1.68	1.94	2.40	3.06	3.84	4.44	5.42	6.25	7.13
06	18-hr	1.45	1.58	1.83	2026	2.88	3.61	4.17	5.09	5.88	6.70
06	12-hr	1.34	1.46	1.69	2.09	2.66	3.34	3.86	4.72	5.44	6.20
06	6-hr	1.15	1.26	1.46	1.60	2.30	2.88	3.33	4.07	4.69	5.35
06	3-hr	0.99	1.08	1.25	1.54	1.96	2.46	2.84	3.47	4.00	4.56
06	2-hr	0.89	0.97	1.13	1.39	1.77	2.23	2.58	3.14	3.62	4.14
06	1-hr	0.72	0.79	0.92	1.13	1.44	1.80	2.09	2.55	2.94	3.35
06	30-min	0.57	0.62	0.72	0.89	1.13	1.42	1.64	2.01	2.31	2.64
06	15-min	0.42	0.45	0.53	0.65	0.83	1.04	1.20	1.46	1.69	1.93
06	10-min	0.32	0.35	0.41	0.50	0.64	0.81	0.93	0.14	1.31	1.50
06	5-min	0.19	0.20	0.23	0.29	0.37	0.46	0.53	0.65	0.75	0.86

Table 2 (continued): Sectional mean rainfall amounts for storm periods of 5 minutes to 10 days and recurrence intervals of 3 months to 100 years in Iowa (see Figure 2, Iowa Map)

Rainfall (inches) for given recurrence interval T, return period, years

*Section	Duration	3-mo	4-mo	6-mo	1-yr	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr
07	10-day	2.76	3.18	3.74	4.67	5.47	6.54	7.53	9.00	10.25	11.66
07	5-day	2.17	2.45	2.84	3.55	4.26	5.30	6.20	7.59	8.71	9.86
07	72-hr	1.94	2.19	2.54	3.18	3.85	4.79	5.56	6.78	7.80	8.99
07	48-hr	1.84	2.05	2.38	2.97	3.53	4.38	5.11	6.19	7.09	8.04
07	24-hr	1.77	1.93	2.24	2.76	3.22	3.93	4.57	5.56	6.45	7.28
07	18-hr	1.66	1.81	2.10	2.59	3.03	3.69	4.30	5.23	6.06	6.84
07	12-hr	1.54	1.68	1.94	2.40	2.80	3.42	3.98	4.48	5.61	6.33
07	6-hr	1.32	1.45	1.68	2.07	2.41	2.95	3.43	4.17	4.84	5.46
07	3-hr	1.13	1.24	1.43	1.77	2.06	2.52	2.92	3.56	4.13	4.66
07	2-hr	1.02	1.12	1.30	1.60	1.87	2.28	2.65	3.22	3.74	4.22
07	1-hr	0.83	0.91	1.05	1.30	1.51	1.85	2.15	2.61	3.03	3.42
07	30-min	0.65	0.71	0.83	1.02	1.19	1.45	1.69	2.06	2.39	2.69
07	15-min	0.48	0.52	0.61	0.75	0.87	1.06	1.23	1.50	1.74	1.97
07	10-min	0.37	0.41	0.47	0.58	0.68	0.83	0.96	1.17	1.35	1.53
07	5-min	0.21	0.23	0.27	0.33	0.39	0.47	0.55	0.67	0.77	0.87
08	10-day	2.74	3.16	3.72	4.65	5.45	6.61	7.57	8.99	10.09	11.04
08	5-day	2.17	2.45	2.84	3.55	4.32	5.37	6.26	7.64	8.78	9.99
08	72-hr	1.88	2.13	2.46	3.08	3.67	4.68	5.64	6.90	7.96	9.24
08	48-hr	1.74	1.93	2.24	2.80	3.39	4.30	5.06	6.28	7.35	8.60
08	24-hr	1.60	1.75	2.03	2.50	3.11	3.87	4.65	5.78	6.73	7.74
08	18-hr	1.50	1.64	1.90	2.35	2.92	3.64	4.37	5.43	6.33	7.28
08	12-hr	1.39	1.52	1.76	2.17	2.71	3.37	4.05	5.03	5.86	6.73
08	6-hr	1.20	1.32	1.52	1.88	2.33	2.90	3.49	4.34	5.05	5.80
08	3-hr	1.02	1.12	1.30	1.60	1.99	2.48	2.98	3.70	4.31	4.95
08	2-hr	0.93	1.01	1.17	1.45	1.80	2.24	2.70	3.35	3.90	4.49
08	1-hr	0.75	0.82	0.95	1.17	1.46	1.82	2.19	2.72	3.16	3.64
08	30-min	0.60	0.65	0.75	0.93	1.15	1.43	1.72	2.14	2.49	2.86
08	15-min	0.44	0.48	0.55	0.68	0.84	1.04	1.26	1.56	1.82	2.09
08	10-min	0.33	0.36	0.42	0.52	0.65	0.81	0.98	1.21	1.41	1.63
08	5-min	0.19	0.21	0.24	0.30	0.37	0.46	0.56	0.69	0.81	0.93
09	10-day	2.64	3.04	3.58	4.47	5.44	6.50	7.35	8.45	9.33	10.42
09	5-day	2.13	2.41	2.79	3.49	4.31	5.45	6.32	7.60	8.69	9.95
09	72-hr	1.82	2.06	2.38	2.98	3.79	4.87	5.74	6.95	7.88	8.98
09	48-hr	1.73	1.93	2.23	2.79	3.50	4.46	5.20	6.35	7.32	8.40
09	24-hr	1.60	1.75	2.03	2.50	3.14	4.03	4.67	5.67	6.58	7.59
09	18-hr	1.50	1.64	1.90	2.35	2.95	3.79	4.39	5.33	6.19	7.13
09	12-hr	1.39	1.52	1.76	2.17	2.73	3.51	4.06	4.93	5.72	6.60
09	6-hr	1.20	1.32	1.52	1.88	2.36	3.02	3.50	4.25	4.93	5.69
09	3-hr	1.02	1.12	1.30	1.60	2.01	2.58	2.99	3.63	4.21	4.86
09	2-hr	0.93	1.01	1.17	1.45	1.82	2.34	2.71	3.29	3.82	4.40
09	1-hr	0.75	0.82	0.95	1.17	1.48	1.89	2.19	2.66	3.09	3.57
09	30-min	0.60	0.65	0.75	0.93	1.16	1.49	1.73	2.10	2.43	2.81
09	15-min	0.44	0.48	0.55	0.68	0.85	1.09	1.26	1.53	1.78	2.05
09	10-min	0.33	0.36	0.42	0.52	0.66	0.85	0.98	1.19	1.38	1.59
09	5-min	0.19	0.21	0.24	0.30	0.38	0.48	0.56	0.68	0.79	0.91

Table 3: Sectional mean rainfall intensity for storm periods of 5 minutes to 10 days and recurrence intervals of 2 years to 100 years in Iowa (see Figure 2, Iowa Map)

Rainfall (inches) for given recurrence interval T, return period, years

*Section	Duration	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr
01	10-day	0.02	0.02	0.03	0.03	0.04	0.04
01	5-day	0.03	0.04	0.05	0.06	0.06	0.07
01	72-hr	0.05	0.06	0.07	0.08	0.10	0.11
01	48-hr	0.06	0.08	0.09	0.12	0.14	0.16
01	24-hr	0.12	0.15	0.17	0.21	0.25	0.29
01	18-hr	0.14	0.18	0.22	0.27	0.31	0.36
01	12-hr	0.20	0.25	0.30	0.37	0.43	0.50
01	6-hr	0.34	0.44	0.52	0.64	0.75	0.87
01	3-hr	0.59	0.75	0.88	1.09	1.27	1.48
01	2-hr	0.80	1.02	1.20	1.48	1.73	2.01
01	1-hr	1.29	1.64	1.95	2.40	2.81	3.25
01	30-min	2.40	2.60	3.06	3.78	4.42	5.12
01	15-min	2.96	3.80	4.48	5.52	6.44	7.48
01	10-min	3.48	4.38	5.22	6.42	7.50	8.70
01	5-min	3.96	5.04	6.00	7.32	8.64	9.96
02	10-day	0.02	0.03	0.03	0.04	0.04	0.05
02	5-day	0.03	0.04	0.05	0.06	0.07	0.08
02	72-hr	0.05	0.06	0.07	0.09	0.10	0.12
02	48-hr	0.07	0.09	0.10	0.12	0.14	0.16
02	24-hr	0.12	0.16	0.18	0.22	0.26	0.30
02	18-hr	0.16	0.19	0.23	0.28	0.32	0.37
02	12-hr	0.22	0.27	0.32	0.39	0.45	0.51
02	6-hr	0.37	0.47	0.55	0.67	0.77	0.88
02	3-hr	0.64	0.79	0.93	1.14	1.31	1.51
02	2-hr	0.87	1.08	1.27	1.55	1.78	2.05
02	1-hr	1.40	1.75	2.06	2.51	2.89	3.32
02	30-min	2.20	2.76	3.24	3.94	4.54	5.24
02	15-min	3.20	4.00	4.72	5.76	6.64	7.64
02	10-min	3.78	4.68	5.52	6.72	7.74	8.88
02	5-min	4.32	5.40	6.36	7.68	8.88	10.20
03	10-day	0.02	0.03	0.03	0.04	0.04	0.04
03	5-day	0.03	0.04	0.05	0.06	0.07	0.07
03	72-hr	0.05	0.06	0.07	0.09	0.10	0.11
03	48-hr	0.07	0.08	0.10	0.12	0.13	0.15
03	24-hr	0.12	0.15	0.18	0.21	0.24	0.27
03	18-hr	0.15	0.19	0.23	0.27	0.30	0.33
03	12-hr	0.21	0.27	0.31	0.37	0.42	0.46
03	6-hr	0.36	0.46	0.54	0.64	0.72	0.80
03	3-hr	0.62	0.78	0.92	1.09	1.22	1.36
03	2-hr	0.85	1.07	1.25	1.48	1.66	1.85
03	1-hr	1.37	1.72	2.03	2.40	2.69	2.99
03	30-min	2.16	2.72	3.18	3.78	4.24	4.70
03	15-min	3.16	3.96	4.64	5052	6.20	6.88
03	10-min	3.66	4.62	5.46	6.42	7.20	8.04
03	5-min	4.20	5.28	6.24	8.04	8.28	9.12

Source: Bulletin 71, *Rainfall Frequency Atlas of the Midwest*, 1992

Table 3 (continued): Sectional mean rainfall intensity for storm periods of 5 minutes to 10 days and recurrence intervals of 2 years to 100 years in Iowa (see Figure 2, Iowa Map)

Rainfall (inches) for given recurrence interval T, return period, years

*Section	Duration	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr
04	10-day	0.02	0.03	0.03	0.03	0.04	0.04
04	5-day	0.03	0.04	0.05	0.06	0.07	0.08
04	72-hr	0.05	0.06	0.07	0.09	0.10	0.12
04	48-hr	0.07	0.08	0.10	0.12	0.14	0.16
04	24-hr	0.12	0.15	0.18	0.22	0.25	0.29
04	18-hr	0.15	0.19	0.22	0.28	0.32	0.37
04	12-hr	0.21	0.26	0.31	0.38	0.44	0.51
04	6-hr	0.37	0.46	0.54	0.66	0.76	0.88
04	3-hr	0.63	0.78	0.92	1.12	1.23	1.49
04	2-hr	0.86	1.06	1.25	1.53	1.77	2.03
04	1-hr	1.38	1.71	2.02	2.48	2.86	3.29
04	30-min	2.18	2.70	3.18	3.90	4.50	5.18
04	15-min	3.16	3.92	4.64	5.68	6.56	7.56
04	10-min	3.72	4.56	5.40	6.66	7.68	8.82
04	5-min	4.20	5.28	6.24	7.56	8.76	10.08
05	10-day	0.02	0.03	0.03	0.04	0.04	0.05
05	5-day	0.03	0.04	0.05	0.06	0.07	0.08
05	72-hr	0.05	0.06	0.07	0.09	0.10	0.11
05	48-hr	0.06	0.08	0.10	0.12	0.14	0.15
05	24-hr	0.12	0.15	0.18	0.22	0.25	0.28
05	18-hr	0.15	0.19	0.22	0.27	0.31	0.34
05	12-hr	0.21	0.26	0.31	0.37	0.43	0.48
05	6-hr	0.36	0.46	0.53	0.64	0.73	0.83
05	3-hr	0.62	0.78	0.91	1.10	1.25	1.41
05	2-hr	0.85	1.06	1.24	1.50	1.70	1.92
05	1-hr	1.37	1.71	2.01	2.42	2.76	3.11
05	30-min	2.16	2.70	3.16	3.82	4.34	4.90
05	15-min	3.16	3.92	4.60	5.56	6.32	7.12
05	10-min	3.66	4.56	5.40	6.48	7.38	8.34
05	5-min	4.20	5.28	6.12	7.44	8.40	9.48
06	10-day	0.02	0.03	0.03	0.03	0.04	0.04
06	5-day	0.03	0.04	0.05	0.06	0.07	0.08
06	72-hr	0.05	0.06	0.07	0.09	0.10	0.12
06	48-hr	0.07	0.09	0.11	0.13	0.14	0.16
06	24-hr	0.13	0.16	0.19	0.23	0.26	0.30
06	18-hr	0.16	0.20	0.23	0.28	0.33	0.37
06	12-hr	0.22	0.28	0.32	0.39	0.45	0.52
06	6-hr	0.38	0.48	0.56	0.68	0.78	0.89
06	3-hr	0.65	0.82	0.95	1.16	1.33	1.52
06	2-hr	0.89	1.12	1.29	1.57	1.81	2.07
06	1-hr	1.44	1.80	2.09	2.55	2.94	3.35
06	30-min	2.26	2.84	3.28	4.02	4.62	5.28
06	15-min	3.32	4.16	4.80	5.84	6.76	7.72
06	10-min	3.84	4.86	5.58	6.84	7.86	9.00
06	5-min	4.44	5.52	6.36	7.80	9.00	10.32

Table 3 (continued): Sectional mean rainfall intensity for storm periods of 5 minutes to 10 days and recurrence intervals of 2 years to 100 years in Iowa (see Figure 2, Iowa Map)

Rainfall (inches) for given recurrence interval T, return period, years

*Section	Duration	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr
07	10-day	0.02	0.03	0.03	0.04	0.04	0.05
07	5-day	0.04	0.04	0.05	0.06	0.07	0.08
07	72-hr	0.05	0.07	0.08	0.09	0.11	0.13
07	48-hr	0.07	0.09	0.11	0.13	0.15	0.17
07	24-hr	0.13	0.16	0.19	0.23	0.27	0.30
07	18-hr	0.17	0.21	0.24	0.29	0.34	0.38
07	12-hr	0.23	0.29	0.33	0.37	0.47	0.53
07	6-hr	0.40	0.49	0.57	0.70	0.81	0.91
07	3-hr	0.69	0.84	0.97	1.19	1.38	1.55
07	2-hr	0.94	1.14	1.33	1.61	1.87	2.11
07	1-hr	1.51	1.85	2.15	2.61	3.03	3.42
07	30-min	2.38	2.90	3.38	4.12	4.78	5.38
07	15-min	3.48	4.24	4.92	6.00	6.96	7.88
07	10-min	4.08	4.98	5.76	7.02	8.10	9.18
07	5-min	4.68	5.64	6.60	8.04	9.24	10.44
08	10-day	0.02	0.03	0.03	0.04	0.04	0.05
08	5-day	0.04	0.05	0.05	0.06	0.07	0.08
08	72-hr	0.05	0.07	0.08	0.10	0.11	0.13
08	48-hr	0.07	0.09	0.11	0.13	0.15	0.18
08	24-hr	0.13	0.16	0.19	0.24	0.28	0.32
08	18-hr	0.16	0.20	0.24	0.30	0.35	0.40
08	12-hr	0.23	0.28	0.34	0.42	0.49	0.56
08	6-hr	0.39	.048	0.58	0.72	0.84	0.97
08	3-hr	0.66	0.83	0.99	1.23	1.44	1.65
08	2-hr	0.90	1.12	1.35	1.68	1.95	2.25
08	1-hr	1.46	1.82	2.19	2.72	3.16	3.64
08	30-min	2.30	2.86	3.44	4.28	4.98	5.72
08	15-min	3.36	4.16	5.04	6.24	7.28	8.36
08	10-min	3.90	4.86	5.88	7.26	8.46	9.78
08	5-min	4.44	5.52	6.72	8.28	9.72	11.16
09	10-day	0.02	0.03	0.03	0.04	0.04	0.04
09	5-day	0.04	0.05	0.05	0.06	0.07	0.08
09	72-hr	0.05	0.07	0.08	0.10	0.19	0.13
09	48-hr	0.07	0.09	0.11	0.13	0.15	0.18
09	24-hr	0.13	0.17	0.20	0.24	0.27	0.32
09	18-hr	0.16	0.21	0.24	0.30	0.34	0.40
09	12-hr	0.23	0.29	0.34	0.41	0.48	0.55
09	6-hr	0.39	0.50	0.58	0.71	0.82	0.95
09	3-hr	0.67	0.86	1.00	1.21	1.40	1.62
09	2-hr	0.91	1.17	1.36	1.65	1.91	2.20
09	1-hr	1.48	1.89	2.19	2.66	3.09	3.57
09	30-min	2.32	2.98	3.46	4.20	4.86	5.62
09	15-min	3.40	4.36	5.04	6.12	7.12	8.20
09	10-min	3.96	5.10	5.88	7.14	8.28	9.54
09	5-min	4.56	5.76	6.72	8.16	9.48	10.92

The Rational method uses the I-D-F curves or rainfall depth/duration frequency transforms directly, while the NRCS methods generalize the rainfall data taken from the I-D-F curves and create rainfall distributions for various regions of the country. Rainfall intensity-duration-and-return period frequency data are provided in tabular format in Table 4 for the nine climate districts in Iowa. The data in Table 2 can be used directly in the Rational method once the T_c for the catchment and the critical duration have been determined. The initial task for the designer is to determine which combinations of storm durations and intensities are appropriate to use in a hydrologic analysis for a typical urban development. Working within the limitations of the procedures described later in this section, small drainage areas in an urban setting can be accurately modeled using either NRCS or the Rational methods. The methods are empirical, and the designer must stay within the bounds of the assumptions and restrictions relevant to the method being used. The belief that the short, very intense storm generates the greatest need for stormwater management often leads designers to use the Rational method for stormwater management design, since this method is based on short-duration storms. However, the NRCS 24-hour storm is also appropriate for short duration storms since it includes short storm intensities within the 24-hour distribution.

The selection of an appropriate time distribution for the design rainfall event must also be considered. The design objective is to select a runoff event of a particular frequency. A particular rainfall frequency may not always produce a runoff event with an identical frequency – i.e., a smaller rainfall depth occurring in a very short period may actually produce a larger peak runoff than a larger rainfall event spread more uniformly over the event duration. As the size of the watershed decreases and the imperviousness increases, the selection of the distribution becomes critical. Larger and less impervious watersheds will often attenuate the large pulses of rainfall and smooth out the runoff hydrographs. This rainfall distribution criterion is inherent in the governing assumption in the Rational method that the duration be equal to the time of concentration, and the watershed be fairly homogeneous in land use.

C. NRCS 24-hour storm distribution

The NRCS 24-hour storm distribution curve was derived from the National Weather Bureau's Rainfall Frequency Atlases of compiled data for areas less than 400 square miles, for durations up to 24 hours, and for frequencies from 1 to 100 years. Data analysis resulted in four regional distributions:

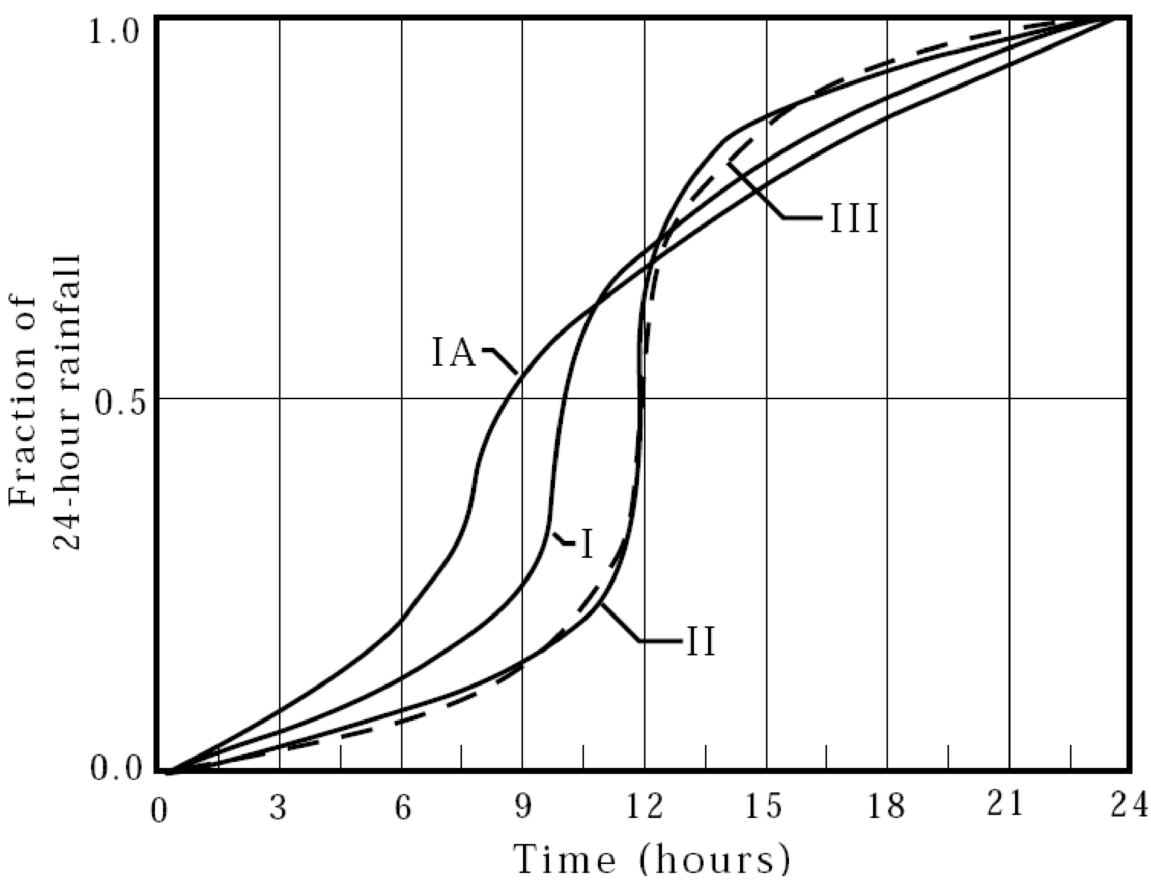
- Type I and Ia for use in Hawaii, Alaska, and the coastal side of the Sierra Nevada and Cascade Mountains in California, Washington, and Oregon
- Type II distribution for most of the remainder of the United States (including Iowa)
- Type III for the Gulf of Mexico and Atlantic coastal areas. The Type III distribution represents the potential impact of tropical storms which can produce large 24-hour rainfall amounts.

Iowa and all of the upper Midwest fall under the Type II rainfall distribution. For a more detailed description of the development of dimensionless rainfall distributions, refer to the USDA Soil Conservation Service's National Engineering Handbook (NRCS NEH), Part 630, Section 4 - http://www.info.usda.gov/CED/.

The NRCS 24-hour storm distributions are based on the generalized rainfall depth-duration-frequency relationships collected for rainfall events lasting from 30 minutes up to 24 hours. Working in 30-minute increments, the rainfall depths are arranged with the maximum rainfall depth assumed to occur in the middle of the 24-hour period. The next largest 30-minute incremental depth occurs just after the maximum depth; the third largest rainfall depth occurs just prior to the maximum depth, etc. This continues with each decreasing 30-minute incremental depth until the smaller increments fall at the beginning and end of the 24-hour rainfall (see Figure 2).

The length of the most intense rainfall period contributing to the peak runoff rate is related to the time of concentration (T_c) for the watershed. In a hydrograph created with NRCS procedures, the duration of rainfall that directly contributes to the peak is about 170 percent of the T_c. For example, the most intense 8.5-minute rainfall period would contribute to the peak discharge for a watershed with a T_c of 5 minutes; the most intense 8.5-hour period would contribute to the peak for a watershed with a 5-hour T_c. To avoid the use of different sets of rainfall intensities for each drainage area size, a set of synthetic rainfall distributions having "nested" rainfall intensities was developed. The set maximizes the rainfall intensities by incorporating selected short duration intensities within those needed for longer durations at the same probability level. For the size of the drainage areas for which NRCS usually provides assistance, a storm period of 24 hours was chosen for the synthetic rainfall distributions. The 24-hour storm, while longer than that needed to determine peaks for these drainage areas, is appropriate for determining runoff volumes. Therefore, a single storm duration and associated synthetic rainfall distribution can be used to represent not only the peak discharges, but also the runoff volumes for a range of drainage area sizes.

Figure 2: NRCS 24-hour rainfall distributions



Source: NRCS, 1986

The NRCS Urban Hydrology for Small Watersheds (WINTR-55) prompts the user to enter the rainfall distribution type (I, Ia, II, or III), and then computes the direct surface runoff volume in inches and the peak runoff rate using the applicable 24-hour rainfall distribution.

There are numerous excellent texts and handbooks that describe the use of rainfall data to generate a design storm for the design of drainage systems (e.g., ASCE, 1994; Chow, 1964; NRCS, 1985). For low-impact development (LID) hydrology, a unique approach has been developed to determine the design storm based on the basic philosophy of LID. This approach is described in Section 2C-8.

Rainfall abstractions include the physical processes of interception of rainfall by vegetation, evaporation from land surfaces and the upper soil layers, transpiration by plants, infiltration of water into soil surfaces, and storage of water in surface depressions. Although these processes can be evaluated individually, simplified hydrologic modeling procedures typically consider the combined effect of the various components of rainfall abstraction. The rainfall abstraction can be estimated as a depth of water (inches) over the total area of the site. This depth effectively represents the portion of rainfall that does not contribute to surface runoff. The portion of rainfall that is not abstracted by interception, infiltration, or depression storage is termed the excess rainfall or runoff. The rainfall abstraction may change depending on the configuration of the site development plan. Of particular concern is the change in impervious cover. Impervious areas prevent infiltration of water into soil surfaces, effectively decreasing the rainfall abstraction and increasing the resulting runoff. Post-development conditions, characterized by higher imperviousness, significantly decrease the overall rainfall abstraction, resulting not only in higher excess surface runoff volume, but also a rapid accumulation of rainwater on land surfaces.

In the Rational method the runoff coefficient “C” determines the amount of rainfall converted to runoff (Section 2C-4). In the NRCS method, a curve number “CN” is used to determine the direct runoff volume and rate based on the land use and soil type. The NRCS runoff curve number (CN) method is described in detail in NRCS NEH-4, and a summary is provided in Section 2C-5.