6.0 Introduction

This chapter summarizes methodology for determining rainfall and runoff for the design of stormwater management facilities in the City. This methodology can be used to generate hydrology for the full spectrum of design storms, ranging from water quality (WQ) storms (which are smaller and more frequent) all the way to 100-year year storm events. References to the UDFCD Manual are made throughout this chapter, however where criteria in this chapter conflict with those in the UDFCD Manual, those included in this chapter supercede those in the UDFCD Manual. The review of all planning submittals will be based on the criteria presented herein.

6.1 Design Rainfall

Rainfall data to be used is based on the *NOAA Atlas 14 Precipitation-Frequency Atlas of the United States, Volume 8-Midwestern States (NOAA Atlas 14), published in 2013.* https://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html

The 1-hour point rainfall values in Table 6-1 form the basis for the following rainfall analysis. These values were obtained from NOAA Atlas 14 at a location near Arapahoe Road and Havana Street in the City of Centennial. Although different values may be obtained in different parts of the SEMSWA jurisdiction, they are not likely to differ significantly from the values in Table 6-1 based on the 90% confidence intervals reported in NOAA Atlas 14. The design engineer may use NOAA Atlas 14 results for other locations, however design submittals must include documentation of the NOAA Atlas 14 results for that location. The Rainfall chapter of the UDFCD Manual provides additional discussion on the use of rainfall data obtained from the NOAA Atlas 14.

TABLE 6-1
1-HOUR POINT RAINFALL VALUES FOR USE IN SEMSWA JURISIDICTION (INCHES)

2-Year	5-Year	10-Year	50-Year	100-Year
0.855	1.12	1.36	2.01	2.33

6.1.1 Intensity-Duration Curves. Rainfall intensity-duration curves for use with the Rational Method can be found on Figure 6-1 at the end of this chapter. These curves were developed using methods described in the UDFCD Manual.

6.1.2 Temporal Distribution and Spatial Adjustments for CUHP. Refer to the Rainfall Chapter of the UDFCD Manual for procedures to calculate the temporal distribution and depth reduction factor adjustments for CUHP modeling.

6.2 Selecting a Method to Estimate Runoff

Two primary methods for estimating storm runoff, peak flow rates and total volumes are used.

- Rational Method

- CUHP/EPA SWMM

The Rational Method is a simpler approach generally used for smaller sub-watersheds where hydrograph information is not required. CUHP and SWMM are computer models that are typically run sequentially; CUHP generates runoff hydrographs from individual subwatersheds and SWMM combines and routes individual hydrographs through channels and detention basins. Additional information on the CUHP and SWMM computer programs is provided in the UDFCD Manual.

Table 6-2 compares the Rational Method with CUHP/SWMM and provides information useful for selecting one of the approaches for a particular project. Additional information on each method is provided in Sections 6.3 and 6.4.

TABLE 6-2
APPLICABILITY HYDROLOGICAL METHODS

Watershed Size (acres)	Is Rational Method Applicable?	Is CUHP/SWMM5 Applicable?
0 to 90	Yes	Yes
90 to 160	Yes	Yes
160 to 3,000	No	Yes[1]
Greater than 3,000	No	Yes[1]
[1] – Subdividing into smaller subcatchments (130 acres or less) and routing the resulting hydrographs using SWMM may be needed to accurately model a subcatchment with areas of different soil types or percentages of imperviousness		

As shown in Table 6-2, either the Rational Method or CUHP/SWMM may be used for urbanized watersheds up to 100 acres in area and rural watersheds up to 160 acres in area. The following considerations may direct the user to one or the other of these methods.

- If no detention facilities are planned or if detention facilities are to be sized using simplified methods shown in Chapter 13, hydrograph information is not required and the Rational Method would be the simpler of the two methods.
- If detention facilities are to be sized based on hydrograph routing, or if hydrograph information is desired for any other reason, CUHP/SWMM must be used.
- If more detailed information on time to peak, duration of flow, rainfall losses, or infiltration is desired, CUHP/SWMM offers this information.

Regardless of the method used, the maximum sub-watershed size shall be approximately 130-acres in accordance with UDFCD master planning guidelines. This is to reduce discrepancies in peak flow predictions between master plan hydrology and flow estimates based on single sub-watersheds significantly larger than 130-acres.

6.3 Rational Method

The Rational Method is used to determine runoff peak discharges for urbanized watersheds up to 100 acres in area and rural watersheds up to 160 acres in area (see Table 6-2). All Rational Method design calculations shall be completed using the UD-

Rational spreadsheet which can be found at the UDFCD website, www.udfcd.org. Results from the Rational Method calculations shall be included with the drainage report submittal. Refer to the Runoff Chapter of the UDFCD Manual for detailed explanations of the Rational Method, including assumptions behind its use and its limitations.

6.3.1 Rational Method Equation. The Rational Method is based on the direct relationship between rainfall and runoff, and is expressed by the following equation:

$$Q = CIA$$

In which:

Q = the maximum rate of runoff (cubic feet per second [cfs])

C = the runoff coefficient that is the ratio between the runoff volume from an area and the average rainfall depth over a given duration for that area

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

A = basin area (acres)

6.3.2 Time of Concentration (t_c). Refer to the Runoff Chapter of the UDFCD Manual for explanations of how to calculate the time of concentration.

6.3.3 Rainfall Intensity (I). The average rainfall intensity (I), in inches per hour, for a storm duration equal to the time of concentration can be found in Figure 6-1.

6.3.4 Runoff Coefficient (C). Refer to the Runoff Chapter of the UDFCD Manual for explanations of how to estimate the runoff coefficient. <u>The one exception to the procedures outlined in the UDFCD Manual is</u>:

- *The runoff coefficient for all gravel surfaces in an urban area (drives, storage areas, walks, etc.) need to be considered 100% impervious*.

6.3.5 Basin Area (A). Refer to the Runoff Chapter of the UDFCD Manual for explanations of how to delineate basin areas.

6.4 CUHP/SWMM5

6.4.1 CUHP. The Colorado Urban Hydrograph Procedure (CUHP) is a hydrologic analysis method based upon the Snyder's unit hydrograph principle. It has been calibrated by UDFCD for this region using local simulations of rainfall-runoff data collected over an eight-year period in the 1970's. Table 6-2 provides information to help the designer determine if CUHP is appropriate for a particular project and watershed area.

Procedures, assumptions, and equations used for a CUHP computer model shall conform to the protocols described in the Runoff Chapter of the UDFCD Manual. The CUHP program users' manual (distributed by UDFCD) may also be used for reference.

6.4.2 EPA SWMM. The EPA Stormwater Management Model (SWMM) is used to route the hydrographs generated by CUHP through conveyance and storage facilities located within a drainage basin. Large watersheds may be divided into smaller sub-watersheds that contain a number of different conveyance and storage elements. SWMM will add and combine the hydrographs from sub-watersheds and conveyance elements as the flow proceeds downstream. The UDFCD Manual may be used as a reference for this software and the latest version of SWMM may be downloaded from the EPA' website, https://www.epa.gov/water-research/storm-water-management-model-swmm.

6.5 Other Hydrologic Methods

6.5.1 Published Hydrologic Information. The UDFCD has prepared Major Drainageway Planning Reports, Outfall Systems Planning Reports and/or Flood Hazard Area Delineation Reports that contain hydrologic studies for most of the major drainageways and watersheds within the UDFCD boundaries. These reports contain information regarding peak flow and runoff volume at numerous design points within the study watersheds. These studies, available at the UDFCD, contain information about watershed and sub-watershed boundaries, soil types, percent imperviousness, and rainfall. If there are published flow rate values available from the UDFCD for any drainageway of interest, these values shall be used for design unless there are compelling reasons to use other values or approaches. Use of other values shall be approved in writing by SEMSWA in advance of any related design work.

Published hydrologic information for major drainageways can also be found in Federal Emergency Management Agency (FEMA) Flood Insurance Studies (FIS). For all FEMA related projects, the FEMA hydrologic data shall be consulted. Flow rates published in FEMA FIS studies typically represent existing conditions at the time the study was completed and generally do not incorporate any future development. SEMSWA's policy is to analyze and design stormwater facilities based on future development flow rates; therefore, FEMA flow rates shall not be used for design without the written approval of SEMSWA.

6.5.2 Statistical Methods. In some situations, statistical analysis of measured stream flow data provides an acceptable means of determining design runoff rates. Statistical analyses are to be limited to drainageways with a long period of flow data (30-year minimum) that had no significant changes occur in land-uses within the tributary watershed during the flow record. Statistical methods may be useful in calibrating a hydrologic model for existing development conditions, but are not suited for estimating the flow for expected future watershed development conditions.

6.6 Runoff Reduction Associated with Minimizing Directly Connected Impervious Area

Imperviousness and runoff coefficients for the 5-year and smaller, more frequent storms may be reduced for sites that incorporate grass buffers and swales to minimize directly connected impervious area (MDCIA), as described in Volume 3 of the UDFCD Manual.

The UDFCD Manual includes several different methods for estimating runoff volume reduction. Below is a brief description of each method and how it generally would be applied in stormwater design/modeling. Refer to Volume 3 of the UDFCD Manual for additional details regarding these methods.

1. **MDCIA Level 1 and Level 2**: This method is primarily used for larger scale modeling where the exact values of directly connected impervious area (DCIA), unconnected impervious area (UIA), separate pervious area (SPA) and receiving pervious area (RPA) are not known. The procedure is explained in the Quantifying Volume Reduction chapter of the UDFCD Manual. Using qualitative descriptions of the application of runoff-reducing practices in a development, the user determines if Level 1 or Level 2 descriptions apply to their project. If so, the effective imperviousness of the basin can be estimated using associated figures and/or using CUHP. The effective imperviousness values can be applied to CUHP and/or used in other calculations that are dependent on imperviousness (e.g. Water Quality Capture Volume).

2. **Quantifying Runoff Reduction**: This method is primarily used for site-scale modeling where values of DIA, UIA, SPA and RPA can be estimated and where runoff reduction will be achieved using grass swales and buffers. The procedure is explained in Fact Sheet T-0 in the Treatment BMP chapter of the UDFCD Manual and calculations can be performed using the UD-BMP software. The results of this procedure can be used to reduce or eliminate the volume of Water Quality Capture Volume required downstream.

6.7 Additional Criteria and Policies

The following are additional criteria that pertain to on-site and off-site flow analysis.

1. All on-site flow analysis shall consider the fully developed condition of the site.
2. All off-site flow analysis shall consider fully developed conditions of both on-site and off-site areas.

The following are additional criteria that pertain to consideration of detention benefits in off-site flow analysis.

1. Detention benefits can only be considered for publicly owned/operated facilities or facilities with adequate assurances for long term operation and maintenance that are recognized by SEMSWA.
2. If off-site areas are undeveloped, it may be assumed that they will be required to release at historic rates when they develop, unless they are in a watershed with regional detention.
3. In all cases, the developers must consult with the watershed master plan (if one exists) and conform to that master plan.

FIGURE 6-1
RAINFALL INTENSITY-DURATION CURVE
CITY OF CENTENNIAL, COLORADO