2C-1 General Information for Stormwater Hydrology

A. Introduction

Urban stormwater hydrology includes the information and procedures for estimating flow peaks, volumes, and time distributions of stormwater runoff. The analysis of these parameters is fundamental to the design of stormwater management facilities, such as storm drainage systems for conveyance of surface runoff and structural stormwater controls for quality and quantity. In the hydrologic analysis of a development site, there are a number of variable factors that affect the nature of stormwater runoff from the site. Some of the factors that must be considered include:

- Rainfall amount and storm distribution
- Drainage area size, shape, and orientation
- Ground cover and soil type
- Slopes of terrain and stream channel(s)
- Antecedent moisture condition
- Storage potential (floodplains, ponds, wetlands, reservoirs, channels, etc.)
- Watershed development potential
- Characteristics of the local drainage system

The typical hydrologic processes of interest in urban hydrology are related to:

- Precipitation and losses (rainfall abstractions)
- Determination of peak flow rate
- Determination of total runoff volume
- Runoff hydrograph (flow vs. time)
- Stream channel hydrograph routing and combining of flows
- Reservoir (storage) routing

The practice of urban stormwater hydrology is not an exact science. While the hydrologic processes are well-understood, the necessary equations and boundary conditions required to solve them are often quite complex. In addition, the required data is often not available. There are a number of empirical hydrologic methods that can be used to estimate runoff characteristics for a site or drainage subbasin; the methods presented in this section have been selected to support hydrologic site analysis for the design methods and procedures included in this manual:

- Rational method
- NRCS Urban Hydrology for Small Watersheds (TR-55, 1986; WINTR-55, 2003)
- U.S. Geological Survey (USGS) regression equations
- Small storm hydrology methods (water quality treatment volume – WQv and water quality capture volume calculations)
- Low-impact development (LID) hydrologic methods
- Water balance calculations

These methods have been included since the applications are well-documented in urban stormwater hydrology design practice, and have been verified for accuracy in duplicating local hydrologic estimates for a range of design storms. The applicable design equations, nomographs, and computer programs are readily available to support the methods.

Table 1 lists the hydrologic methods and circumstances for their use in various analysis and design applications. Table 2 includes some limitations on the use of several of the methods.

1. The Rational method is recommended for small, highly-impervious drainage areas, such as parking lots and roadways draining into inlets and gutters:

    a. Planning level calculations up to 160 acres.

    b. Detailed final design for peak runoff calculations of smaller homogeneous drainage areas of up to 60 acres.

2. The NRCS Urban Hydrology for Small Watersheds (WINTR-55) has wide application for existing and developing urban watersheds up to 2000 acres.

3. The USGS regression equations are recommended for drainage areas with characteristics within the ranges given for the equations. The USGS equations should be used with caution when there are significant storage areas within the drainage basin, or where other drainage characteristics indicate that general regression equations might not be appropriate.

Table 1: Applications of hydrologic methods

Method	Rational method	NRCS Method	USGS Equations	Water Quality Volume
Water quality volume (WQv)				✓
Channel protection volume (CPv)		✓		
Overbank flood protection (Qp_5)		✓	✓	
Extreme flood protection (Qf)		✓	✓	
Storage facilities		✓	✓	
Outlet structures		✓	✓	
Gutter flow and inlets	✓			
Storm sewer piping	✓	✓	✓	
Culverts	✓	✓	✓	
Small ditches	✓	✓	✓	
Open channels	✓	✓	✓	
Energy dissipation		✓	✓	

Table 2: Limitations of hydrologic methods

Method	Size Limitations	Comments
Rational	≤ 160 acres	Method can be used for estimating peak flows and the design of small site or subdivision storm sewer systems. *Should not be used for storage design.*
NRCS	0-2000 acres	Method can be used for estimating peak flows and hydrographs for all design applications. Can be used for low-impact development hydrologic analysis.
USGS regression		Method can be used for estimating peak flows for all design applications.
Water quality		Methods used for calculating the water quality volume (WQv): (1) Simplified method, (2) NRCS CN method, (3) water quality capture volume method.

B. Definitions

1. **Travel time (T_t) and time of concentration (T_c).** Travel time is the time it takes for water to travel from one location to another in a watershed. T_t is a component of the time of concentration, T_c, which is the time for runoff to travel from the hydraulically most distant point of the watershed to a point of interest within the watershed. T_c is computed by summing all the travel times for consecutive components of the drainage conveyance system.

2. **Infiltration.** Infiltration is the process through which precipitation enters the soil surface and moves through the upper soil profile.

3. **Depression storage.** Depression storage is the natural depressions within the ground surface and landscape that collect and store rainfall runoff, either temporarily or permanently.

4. **Interception.** Interception is the storage of rainfall on foliage and other intercepting surfaces, such as vegetated pervious areas, during a rainfall event.

5. **Rainfall excess.** After interception, depression storage, and infiltration have been satisfied, rainfall excess is the remaining water available to produce runoff.

6. **Hyetograph.** A hyetograph is a graph of the time distribution of rainfall over a watershed (rainfall intensity (in/hr) or volume vs. time).

7. **Hydrograph.** A hydrograph is a graph of the time distribution of runoff from a watershed.

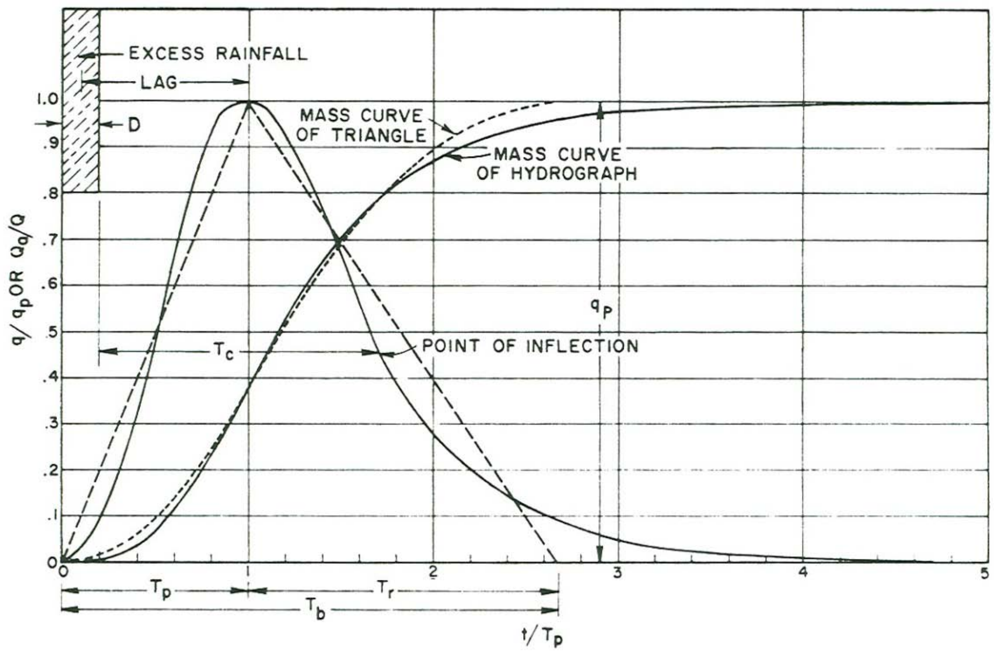
8. **Unit hydrograph.** The hydrograph resulting from 1 inch of rainfall excess generated uniformly over the watershed, at a uniform rate, for a specified period of time. There are several types of unit hydrographs. The use of unit hydrographs to create direct runoff hydrographs is discussed in more detail in Section 2C-7. An example of the NRCS dimensionless unit hydrograph and the relationships to the other components presented above is shown in Figure 1.

9. **Peak discharge.** The peak discharge (peak flow) is the maximum rate of flow of water passing a given point during or after a rainfall event (or snowmelt).

10. **Runoff volume.** The runoff volume represents the volume of rainfall excess generated from the watershed area. The runoff volume is often expressed in watershed-inches or acre-feet. The

runoff volume for a rainfall event can also be represented by the area under the runoff portion of the hydrograph.

Figure 1: NRCS dimensionless curvilinear unit hydrograph and equivalent triangular hydrograph



C. Concepts

The hydrologic concepts of interest with respect to the design of BMPs are closely related to the design objectives of the BMP. Design of BMPs can be focused on peak discharge control, volume control, water quality management, pollutant removal, groundwater recharge, thermal control, or a combination of two or more of these objectives. Each control objective has somewhat different hydrologic parameter requirements that will need to be addressed in the design of the BMP to achieve these objectives.

The addition of water quality considerations in the design of BMPs adds a new dimension to the hydrologic considerations for traditional BMP design. Prior to the introduction of water quality considerations, hydrologic design methods were focused on flood event hydrology focused on storms typically ranging from the 2-year (bank-full), 5-year to 10-year (storm drainage conveyance storm), to the 100-year (floodplain storm). Water quality considerations require a shift from flood events to annual rainfall volumes and the associated pollutant loads. Concepts such as the rainfall frequency spectrum and small storm hydrology become important when designing for water quality. These, along with traditional concepts, are summarized below.

1. **Large versus small storm hydrology.** Traditional practice in stormwater management has focused on flood events ranging from the 2-year to the 100-year storm. The increased emphasis on addressing the quality of urban stormwater has resulted in the realization that small storms (i.e. <1 to 1.5 inches of rainfall) dominate watershed hydrologic parameters typically associated with water quality management issues and BMP design. These small storms are responsible for most annual urban runoff and groundwater recharge. Likewise, with the exception of eroded sediment, they are responsible for most pollutant wash-off from urban surfaces. Therefore, the small storms are of most concern for the stormwater management objectives of ground water recharge, water quality resource protection, and thermal impacts control.
   Medium storms, defined as storms with a return frequency of 6 months to 2 years, are the dominant storms that determine the size and shape of the receiving streams. These storms are critical in the

design of BMPs that protect stream channels from accelerated erosion and degradation. For example, the problem with traditional detention BMPs is not the BMPs themselves, but the design guidance for BMP outlet flow control that usually does not take into account the geomorphologic character of the receiving stream.

The larger, more infrequent storms have traditionally been used for the design of stormwater conveyance facilities such as storm sewers and detention basins for peak discharge control; to prevent local overbank flooding on urban streams and flooding of structures located in the floodplains of stream channels. These storms have a return frequency of 2 years to 100 years. For traditional urban drainage design, the 2-year to 10-year storm events are termed “minor storms,” and those with a recurrence interval >10 years are called “major storms.” In this case, minor storms should not be confused with the concept of small storm hydrologic events as described above. Although the larger storms may contain significant pollutant loads for a single runoff event, the contribution to the annual average pollutant load is really quite small due to the infrequency of occurrence. In addition, longer periods of recovery are available to receiving waters between larger storm events.

Most rainfall events are much smaller than the design storms used for urban drainage models. In any given area, most frequently recurrent rainfall events are small (less than 1 inch of daily rainfall). Additional details and procedures are included in Section 2C-2.

A detailed discussion of small storm hydrology is presented in Section 2C-6.

2. **Rainfall frequency spectrum.** A rainfall frequency spectrum (RFS), defined as the distribution of all rainfall events (see example in Figure 4), is a useful tool placing in perspective many of the relevant hydrologic parameters. Represented in this distribution is the rainfall volume from all storm events ranging from the smallest, most frequent events in any given year; to the largest, most extreme events, such as the 100-year frequency event, over a long duration.

   The RFS consists of classes of frequencies, often broken down by return period ranges. Four principal classes are typically targeted for control by stormwater management practices. The two smallest, or most frequent, classes are often referred to as water quality storms, for which the control objectives are groundwater recharge, pollutant load reduction, and to some extent, control of channel-erosion-producing events. The two larger, or less frequent, classes are typically referred to as quantity storms, for which the control objectives are channel erosion control, overbank control, and flood control.

   The runoff volume is the most important hydrologic variable for water quality protection and design because water quality is a function of the capture and treatment of the mass load of pollutants. The runoff peak rate is the most important hydrologic variable for drainage system design and flooding analysis. Water quality facilities are designed to treat a specified quantity or volume of runoff for the full duration of a storm event, as opposed to accommodating only an instantaneous peak at the most severe portion of a storm event. To design effective BMPs and evaluate water quality impacts in urban watersheds, it is necessary to predict the following hydrologic processes:

   - Amount and distribution of rainfall volume
   - Amount of rainfall that contributes to runoff volume, i.e., rainfall volume minus abstractions

D. Methods of runoff estimation

The Rational method (see Section 2C-4) or approved alternatives may be used in both the minor and major storm runoff computations for relatively uniform basins in land use and topography, which generally have less than 160 acres (The American Society of Civil Engineers Water Environment Federation, "Design and Construction of Urban Stormwater Management Systems," 1992 edition, states that the Rational method is not recommended for drainage areas much larger than 100-200 acres).

The averaging of the significantly different land uses through the runoff coefficient of the Rational method should be minimized where possible. For basins that have multiple changes in land use and topography, or are larger than 160 acres, or both; the design storm runoff should be analyzed by other methods such as unit hydrographs or computer applications. These basins should be broken down into subbasins of like uniformity and routing methods applied to determine peak runoff at specified points. For drainage areas less than 160 acres and when routing is needed, the Modified Rational method is an acceptable method for drainage areas up to 20 acres.

If the Rational method is not used, TR-55, Urban Hydrology for Small Watersheds (NRCS) (see Section 2C-5), may be used for drainage areas up to 2000 acres. For areas larger than 2000 acres, TR-20 or an approved alternative may be used. When computer programs are used for design calculation, it is important to understand the assumptions and limits for the maximum and minimum drainage area or other limits before it is selected.