Appendix H Acceptable Hydrological Methods and Models

H.1 Acceptable Hydrologic Methods and Models

The following are the acceptable methodologies and computer models for estimating runoff hydrographs before and after development. These methods are used to predict the runoff response from given rainfall information and site surface characteristic conditions. The design storm frequencies used in all of the hydrologic engineering calculations will be based on design storms required in this guidebook unless circumstances make consideration of another storm intensity criterion appropriate:

- Urban Hydrology for Small Watersheds TR-55 (TR-55)
- Storage-Indication Routing
- HEC-1, WinTR-55, TR-20, and SWMM Computer Models
- Rational Method (limited to sites under five acres)

These methods are given as valid in principle, and are applicable to most stormwater management design situations in the District. Other methods may be used when the District reviewing authority approves their application.

Note: Of the above methods, TR-55 and SWMM allow for the easiest correlation of the benefits of retention BMPs used to meet the SWRv with peak flow detention requirements, and are therefore strongly recommended. Appendix A includes more information on using the General Retention Compliance Calculator to account for retention BMPs in calculating peak flow detention requirements.

The following conditions should be assumed when developing predevelopment, preproject, and post-development hydrology, as applicable:

- Predevelopment runoff conditions (used for the 2-year storm) shall be computed independent of existing developed land uses and conditions and shall be based on "Meadow in good condition" or better, assuming good hydrologic conditions and land with grass cover.
- Preproject runoff conditions (used for the 15-year storm) shall be based on the existing condition of the site
- Post-development shall be computed for future land use assuming good hydrologic and appropriate land use conditions. If a NRCS CN Method-based approach, such as TR-55, is used, this curve number may be reduced based upon the application of retention BMPs, as indicated in the General Retention Compliance Calculator (see Appendix A). This curve number reduction will reduce the required detention volume for a site, but it should not be used to reduce the size of conveyance infrastructure.

- The rainfall intensity - duration - frequency curve should be determined from the most recent version of the Hydrometeorological Design Studies Center's Precipitation Frequency Data Server (NOAA Atlas 14, Volume 2).
- Predevelopment time of concentration shall be based on the sum total of computed or estimated overland flow time and travel in natural swales, streams, creeks and rivers, but never less than six minutes.
- Post-development time of concentration shall be based on the sum total of the inlet time and travel time in improved channels or storm drains, but shall not be less than six minutes.
- Drainage areas exceeding 25 acres that are heterogeneous with respect to land use, soils, RCN or Time of Concentration (Tc) shall require a separate hydrological analysis for each sub-area.
- Hydrologic Soil Groups approved for use in the District are contained in the Soil Survey of the District of Columbia Handbook. Where the Hydrologic Soil Group is not available through the Soil Survey due to the listed soil type being "Urban Soils" or similar, a Hydrologic Soil Group of C shall be used.

H.2 Urban Hydrology for Small Watersheds TR-55

Chapter 6 of Urban Hydrology for Small Watersheds TR-55, Storage Volume for Detention Basins, or TR-55 shortcut procedure, is based on average storage and routing effects for many structures, and can be used for multistage outflow devices. Refer to TR-55 for more detailed discussions and limitations.

Information Needed

To calculate the required storage volume using TR-55, the predevelopment hydrology for the 2-year storm, and the preproject hydrology for the 15-year storm are needed, along with post-development hydrology for both the 2-year and 15-year storms. The predevelopment hydrology for the 2-year storm is based on natural conditions (meadow), and will determine the site's predevelopment peak rate of discharge, or allowable release rate, qo_2, for the 2-year storm, whereas the preproject hydrology for the 15-year storm is based on existing conditions, and will determine the site's preproject peak rate of discharge, or allowable release rate, qo_{15}, for the 15-year storm.

The post-development hydrology may be determined using the reduced curve numbers calculated in the General Retention Compliance Calculator (See Appendix A) or more detailed routing calculations. This will determine the site's post-development peak rate of discharge, or inflow for both the 2-year and 15-year storms, qi_2 and qi_{15}, respectively, and the site's post-developed runoff, Q_2 and Q_{15}, in inches. (Note that this method does not require a hydrograph.) Once the above parameters are known, the TR-55 Manual can be used to approximate the storage volume required for each design storm. The following procedure summarizes the TR-55 shortcut method.

Procedure

1. Determine the peak development inflows, qi_2 and qi_{15}, and the allowable release rates, $q_{o2}$and qo_{15}, from the hydrology for the appropriate design storm.

   Using the ratio of the allowable release rate, qo , to the peak developed inflow, qi , or qo/qi , for both the 2-year and 15-year design storms, use Figure H.1 (or Figure 6.1 in TR-55) to obtain the ratio of storage volume, Vs , to runoff volume, Vr , or Vs_2 /Vr_2 and Vs_{15} /Vr_{15} for Type II storms.

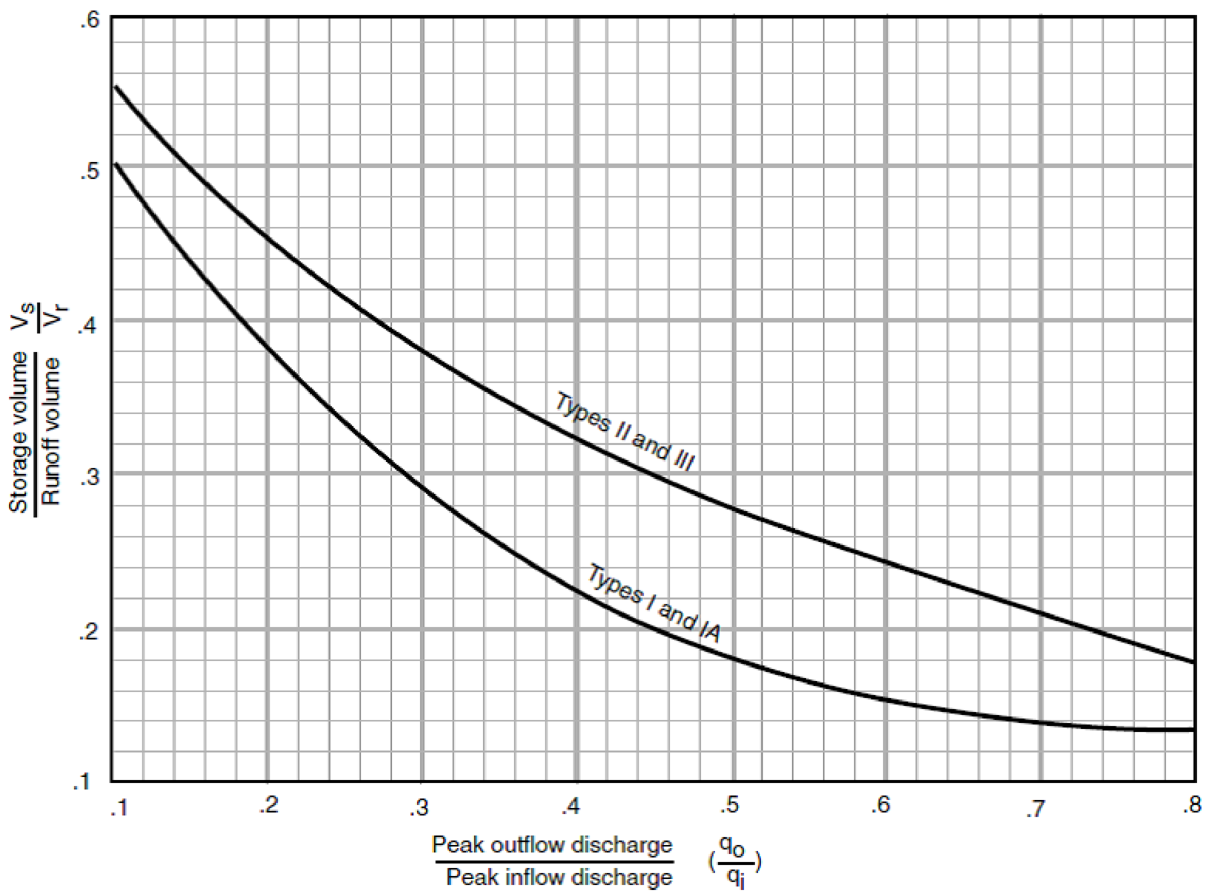

Figure H.1 Approximate detention basin routing for rainfall types I, IA, II and III.

2. Determine the runoff volumes, Vr_2 and Vr_{15}.

$$Vr_2 = 53.33 \text{ x } Q_2 \times Am$$

where:

53.33	=	conversion factor from in-mi^2 to acre-feet
Q_2	=	post-development runoff, in inches for the 2-year storm
Am	=	drainage area, in square miles

$$Vr15 = 53.33 \text{ x } Q_{15} \times Am$$

where:

53.33	=	conversion factor from in-mi^2 to acre-feet
Q_{15}	=	post-development runoff for the 15-year storm (in.)
Am	=	drainage area (mi^2)

3. Multiply the Vs /Vr ratios from Step 1 by the runoff volumes, Vr_2 and Vr_{15}, from Step 2, to determine the required storage volumes, Vs_2 and Vs_{15}, in acre-feet.

$$\left(\frac{Vs_2}{Vr_2}\right)Vr_2 = Vs_2$$

$$\left(\frac{Vs_{15}}{Vr_{15}}\right)Vr_{15} = Vs_{15}$$

Note: In most cases, Vs_{15} represents the total storage required for the 2-year storm and the 15-year storm, and the outflow, qo_{15}, includes the outflow q_{o2}. In some cases, Vs_{15} may be less than Vs_2. In these cases, the storage volume provided for the 2-year storm (Vs_2) may or may not be sufficient to meet the 15-year requirements, and must be checked via stage-storage curve analysis.

The design procedure presented above may be used with Urban Hydrology for Small Watersheds TR-55 Worksheet 6a. The worksheet includes an area to plot the stage-storage curve, from which actual elevations corresponding to the required storage volumes can be derived. The characteristics of the stage-storage curve are dependent upon the topography of the proposed storage practice and the outlet structure design (see Appendix G), and may be best developed using a spreadsheet or appropriate hydraulics software.

Limitations

This routing method is less accurate as the qo/qi ratio approaches the limits shown in Figure H.1. The curves in Figure H.1 depend on the relationship between available storage, outflow device, inflow volume, and shape of the inflow hydrograph. When storage volume (Vs) required is small, the shape of the outflow hydrograph is sensitive to the rate of the inflow hydrograph. Conversely, when Vs is large, the inflow hydrograph shape has little effect on the outflow hydrograph. In such instances, the outflow hydrograph is controlled by the hydraulics of the outflow device and the procedure therefore yields consistent results. When the peak outflow discharge (qo) approaches the peak inflow discharge (qi) parameters that affect the rate of rise of a hydrograph, such as rainfall volume, curve number, and time of concentration, become especially significant.

The procedure should not be used to perform final design if an error in storage of 25 percent cannot be tolerated. Figure H.1 is biased to prevent undersizing of outflow devices, but it may significantly overestimate the required storage capacity. More detailed hydrograph development and storage indication routing will often pay for itself through reduced construction costs.

H.3 Storage-Indication Routing

Storage-Indication Routing may be used to analyze storage detention practices. This approach requires that the inflow hydrograph be developed through one of the methods listed in this appendix (TR-55, WinTR-55, SWMM, etc.), as well as the required maximum outflows, q_{o2} and qo_{15}. Using the stage-discharge relationship for a given combination outlet devices, the detention volume necessary to achieve the maximum outflows can be determined.

H.4 HEC-1, WinTR-55, TR-20, and SWMM Computer Models

If the application of the above computer models is needed, the complete input data file and printout will be submitted with the stormwater management plans at the 85 percent submittal stage. Submission of stormwater management plans shall include the following computer model documentation:

- For all computer models, supporting computations prepared for the data input file shall be submitted with the stormwater management plans.
- Inflow-outflow hydrographs shall be computed for each design storm presented graphically, and submitted for all plans.
- Schematic (node) diagrams must be provided for all routings.

H.5 Rational Method

While this method is not recommended, as it cannot account for the retention/detention benefits of the BMPs applied on a site, this method will be permitted for use in a development of five acres or less. When applying this method, the following steps must be taken in the design consideration:

- In the case of more than one sub-drainage area, the longest time of concentration shall be selected.
- Individual sub-drainage flows shall not be summed to get the total flow for the watershed.
- The runoff coefficient, C, shall be a composite of the future site development conditions for all contributing areas to the discharge point. Runoff coefficient factors for typical District land uses are provided in Table H.1.
- The flow time in storm sewers shall be taken into account in computing the watershed time of concentration.
- The storm duration shall be dependent upon the watershed time of concentration.
- The storm intensity can be selected from the selected storm duration.

Table H.1 Runoff Coefficient Factors for Typical District of Columbia Land Uses

Zone	Predominant Use	Minimum Lot Dimensions		Runoff Coefficient C
		Width (ft)	Area (ft^2)	
R-1-A	One-family detached dwelling	75	7,500	0.60
R-1-B	One-family detached dwelling	50	5,000	0.65
R-2	One-family semi-detached dwelling	30	3,000	0.65
R-3	Row dwelling	20	2,000	0.70
R-4	Row dwelling	18	1,800	0.75
R-5-A	Low density apartment	–	–	0.70
R-5-B	Medium density apartment house	–	–	0.75
R-5-C	Medium high density apartment house	–	–	0.80
R-5-D	High density building	–	–	0.80
C	Commercial	–	–	0.85–0.95
M	General Industry	–	–	0.80–0.90
Park	Open green space	–	–	0.35

H.6 Stormwater Retention Volume Peak Discharge

The peak rate of discharge for individual design storms may be required for several different components of water quality BMP design. While the primary design and sizing factor for most stormwater retention BMPs is the design Stormwater Retention Volume (SWRv), several design elements will require a peak rate of discharge for specified design storms. The design and sizing of pretreatment cells, level spreaders, by-pass diversion structures, overflow riser structures, grass swales and water quality swale geometry, etc., all require a peak rate of discharge in order to ensure non-erosive conditions and flow capacity.

The peak rate of discharge from a drainage area can be calculated from any one of several calculation methods discussed in this appendix. The two most commonly used methods of computing peak discharges for peak runoff calculations and drainage system design are NRCS TR-55 Curve Number (CN) methods (NRCS TR-55, 1986) and the Rational Formula. The Rational Formula is highly sensitive to the time of concentration and rainfall intensity, and therefore should only be used with reliable Intensity-Duration-Frequency (IDF) curves or tables for the rainfall depth and region of interest (Claytor and Schueler, 1996). Unfortunately, there are no IDF curves available at this time for the 1.2-inch rainfall depth.

The NRCS CN methods are very useful for characterizing complex sub-watersheds and drainage areas and estimating the peak discharge from large storms (greater than two inches), but can significantly under estimate the discharge from small storm events (Claytor and Schueler, 1996). Since the Tv is based on a one-inch rainfall, this underestimation of peak discharge can lead to undersized diversion and overflow structures, potentially bypassing a significant volume of the design SWRv around the retention practice. Undersized overflow structures and outlet channels can cause erosion of the BMP conveyance features which can lead to costly and frequent maintenance.

In order to maintain consistency and accuracy, the following Modified CN Method is recommended to calculate the peak discharge for the SWRv 1.2-inch rain event. The method utilizes the Small Storm Hydrology Method (Pitt, 1994) and NRCS Graphical Peak Discharge Method (USDA 1986) to provide an adjusted curve number that is more reflective of the runoff volume from impervious areas within the drainage area. The design rainfall is a NRCS type II distribution so the method incorporates the peak rainfall intensities common in the eastern United States, and the time of concentration is computed using the method outlined in TR-55.

The following provides a step-by-step procedure for calculating the Stormwater Retention Volume peak rate of discharge (q_{pSWRv}):

Step 1: Calculate the adjusted curve number for the site or contributing drainage area.

The following equation is derived from the NRCS CN Method and is described in detail in the National Engineering Handbook Chapter 4: Hydrology (NEH-4), and NRCS TR-55 Chapter 2: Estimating Runoff:

$$CN = \frac{1000}{\left[10 + 5P + 10Q_a - 10\left(Q_a^2 + 1.25Q_aP\right)^{0.5}\right]}$$

where:

C	=	adjusted curve number
P	=	rainfall (in.), (1.2 in.)
Q_a	=	runoff volume (watershed inches), equal to SWRv divided by drainage area

Note: When using hydraulic/hydrologic model for sizing a retention BMP or calculating the SWRv peak discharge (), designers must use this modified CN for the drainage area to generate runoff equal to the SWRv for the 1.2-inch rainfall event.

Step 2: Compute the site or drainage area Time of Concentration (Tc).

TR-55 Chapter 3: Time of Concentration and Travel Time provides a detailed procedure for computing the Tc.

Step 3: Calculate the Stormwater Retention Volume peak discharge (qp_{SWRv})

Step 4: The qp_{SWRv} is computed using the following equation and the procedures outlined in TR-55, Chapter 4: Graphical Peak Discharge Method. Designers can also use WinTR-55 or an equivalent TR-55 spreadsheet to compute qp_{SWRv}:

- Read initial abstraction (I_a) from TR-55 Table 4.1 or calculate using I_a = 200/CN - 2
- Compute I_a/P (P = 1.0)
- Read the Unit Peak Discharge (q_u) from exhibit 4-II using Tc and I_a/P
- Compute the qp_{SWRv} peak discharge:

$$qp_{SWRv} = q_u \times A \times Qa$$

where:

qp_{SWRv}	=	Stormwater Retention Volume peak discharge (cfs)
q_u	=	unit peak discharge (cfs/mi^2/in.)
A	=	drainage area (mi^2)
Q_a	=	runoff volume (watershed inches = SWRv/A)

This procedure is for computing the peak flow rate for the 1.2-inch rainfall event. All other calculations of peak discharge from larger storm events for the design of drainage systems, culverts, etc., should use published curve numbers and computational procedures.

H.7 References

Claytor, R. and T. Schueler. 1996. Design of Stormwater Filtering Systems. Chesapeake Research Consortium and the Center for Watershed Protection. Ellicott City, MD. http://www.cwp.org/online-watershed-library?view=docman

Pitt, R., 1994, Small Storm Hydrology. University of Alabama - Birmingham. Unpublished manuscript. Presented at design of stormwater quality management practices. Madison, WI, May 17-19 1994.

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