



2C-7 Watershed Routing (Hydrograph Determination)

Watershed routing is used when the watershed basin has multiple subbasins and it is desired to add hydrographs together from each of the subbasins to determine the combined hydrograph at critical points. Common critical points are at control conveyance structures where an inflow hydrograph is required to route the discharges through structures. The most common structure where an inflow hydrograph is needed, is a stormwater detention basin. (See Section 2G-1 for detention basin design). Two methods for watershed routing are provided in this chapter: Modified Rational Method for Basin Routing and the Tabular Hydrograph TR-55 Method.

A. Modified Rational Method for basin routing

The Modified Rational Method can estimate peak flows at critical points in basins with numerous subbasins. The Modified Rational Method can give a triangular and trapezoidal hydrograph for determining storage volumes. This method is applicable for uniform areas up to 20 acres. It should be noted that this method has limitations, since it does not produce a true hydrograph, or recognize soil conditions. To assist the engineer in the calculations, there are numerous computer programs available, such as MODRAT, which is a Modified Rational Method program developed by the Los Angeles County Department of Public Works.

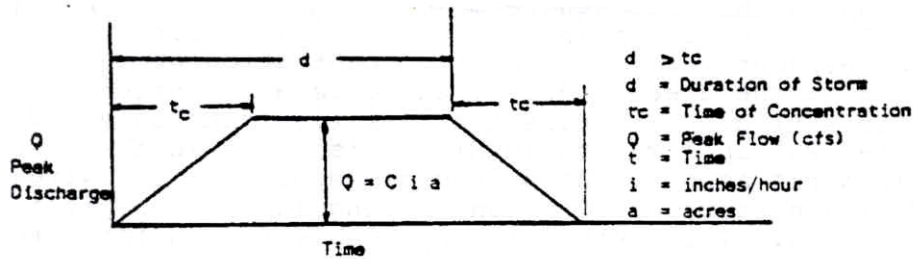
Theory: The area under a hydrograph equals the volume of runoff. For the Modified Rational Method, this area is equal to the peak discharge rate times the duration of the storm. A uniform rainfall intensity for the entire rainfall period is assumed here. This is highly unlikely. The Modified Rational Method recommends that a coefficient be used in order to account for the antecedent moisture conditions of storms greater than those with a 25-year recurrence intensity ($Q = ca \times c \times I \times a$). This attempts to predict a more realistic runoff volume, which is characteristic of major storms. The maximum product of $ca \times c$ cannot be greater than 1.

Recommended antecedent precipitation factors for the Rational Method

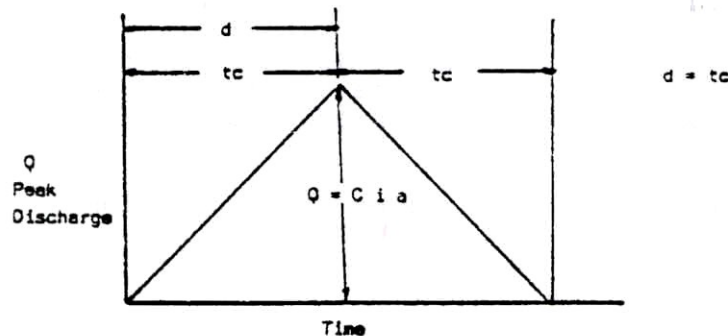
<i>Recurrence Interval (years)</i>	<i>Ca</i>
2-10	1.0
25	1.1
50	1.2
100	1.25

The time of concentration (t_c), which is the time of travel from the most remote point (in time of flow), determines the largest peak discharge. Therefore, there are two possible approximate hydrographs that can be used for runoff and storage requirements.

1. If the rainfall duration is greater than the t_c , then the approximate hydrograph is a trapezoid.



2. If the rainfall duration is equal to the t_c , assuming the t_c is the same as in the first case, then the approximate hydrograph is a triangle.



For storage volume determination using the Modified Rational Method, see Section 2G-1.

B. Tabular Hydrograph Method

The TR-55 Tabular Hydrograph Method is used for computing discharges from rural and urban areas, using the time of concentration (T_c) and travel time (T_t) from a subarea as inputs. The SCS TR-55 methodology can determine peak flows from areas of up to 5.5 sq. mi. (2000 acres); provide a hydrograph for times of concentration of up to 2 hours; and estimate the required storage for a specified outflow.

1. **Purpose of the Tabular Hydrograph Method.** This method can develop composite flood hydrographs at any point in a watershed by dividing the watershed into homogeneous subareas. In this manner, the method can estimate runoff from non-homogeneous watersheds; a common occurrence in developed urban areas. The method is especially applicable for estimating the effects of land use change in a portion of a watershed.
2. **Use of the Tabular Hydrograph Method.** The Tabular Hydrograph Method is based upon a series of unit discharge hydrographs that were developed by the Soil Conservation Service (SCS) in the late 1970's. These hydrographs, developed in tabular form, are expressed in csm/in (cubic feet of discharge per second per square mile of watershed per inch of runoff). A series of these unit discharge hydrographs is provided in Table 2 for a range of subarea T_c s from 0.1 hours to 2 hours and reach T_t s from 0 to 3 hours. Table 2 data is for a Type II rainfall distribution. Most of the United States (and all of Iowa) falls into this Type II rainfall distribution. Use of the Tabular Method is limited to: drainage areas of less than 2000 acres; travel times less than or equal to 3 hours; times of concentration less than or equal to 2 hours; and drainage areas of individual subareas that differ by less than a factor of five.
 - a. The input data needed to develop a flood hydrograph include:
 - 1) 24-hour rainfall (in)
 - 2) Appropriate rainfall distribution (I, IA, II, or III)

- 3) Curve Number (CN)
 - 4) Time of Concentration, T_c , (hr)
 - 5) Travel Time, T_t , (hr)
 - 6) Drainage area (mi^2).
- b. The process for developing a hydrograph using the Tabular Method is described below. The results of each step are recorded in Worksheet 1 in order to develop a summary of basic watershed data by subarea. The steps are as follows:
- 1) Subdivide the watershed into areas that are relatively homogeneous and have convenient routing reaches. Enter the name of each subarea in the first column.
 - 2) Determine the drainage areas of each subarea in square miles and enter the values in the Drainage Area, A_m , column.
 - 3) Calculate the Time of Concentration (T_c) for each reach in hours. (See Worksheet 3). Enter the values for each subarea in the T_c column.
 - 4) Determine the Travel Time (T_t) for each reach in hours. (See Worksheet 3). Record the values in the T_t column.
 - 5) Record the downstream reaches through which the runoff from each upstream area flows in the column labeled Downstream Subarea Names.
 - 6) Calculate the cumulative travel times, through each downstream reach, for each subarea to the point of interest and enter the result in the ΣT_t column.
 - 7) Determine the 24-hour rainfall depth (P) for the desired storm event. Enter the value in column P.
 - 8) Determine a weighted Curve Number (CN) for each subarea and enter in column CN.
 - 9) Calculate the total runoff (Q) in inches, for each subarea, computed from CN and rainfall (P) utilizing the SCS Runoff Equation:

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \quad \text{Equation 1}$$

where:

Q = Runoff (inches)

P = Rainfall (in)

S = Potential maximum retention after runoff begins (in)

and:

$$S = \frac{1000}{CN} - 10 \quad \text{Equation 2}$$

- 10) Multiply columns A_m and Q to determine the total volume of runoff for each subarea. Enter results in column A_mQ .
 - 11) Determine the Initial Abstraction (I_a). The Initial Abstraction is all losses before runoff begins. It includes water retained in surface depressions, water intercepted by vegetation, evaporation, and infiltration. I_a is highly variable but generally is correlated with soil and cover parameters. Through studies, I_a was found to correlate with the Curve Number as indicated in Table 5:
 - 12) Calculate I_a/P for each subarea and enter in the last column.
- c. Now that the drainage basin's subarea properties have been summarized in Worksheet 1, a composite flood hydrograph may be determined utilizing Worksheet 2 and the appropriate values from Table 2.

Table 1: I_a Values for Runoff Curve Numbers¹

Curve number	I_a	Curve number	I_a	Curve number	I_a	Curve number	I_a
40	3.000	55	1.636	70	0.857	85	0.353
41	2.878	56	1.571	71	0.817	86	0.326
42	2.762	57	1.509	72	0.778	87	0.299
43	2.651	58	1.448	73	0.740	88	0.273
44	2.545	59	1.390	74	0.703	89	0.247
45	2.444	60	1.333	75	0.667	90	0.222
46	2.348	61	1.279	76	0.632	91	0.198
47	2.255	62	1.226	77	0.597	92	0.174
48	2.167	63	1.175	78	0.564	93	0.151
49	2.082	64	1.125	79	0.532	94	0.128
50	2.000	65	1.077	80	0.500	95	0.105
51	1.922	66	1.030	81	0.469	96	0.083
52	1.846	67	0.985	82	0.439	97	0.062
53	1.774	68	0.941	83	0.410	98	0.041
54	1.704	69	0.899	84	0.381		

3. This begins by carrying the necessary information for each subarea from Worksheet 1 over to Worksheet 2 (T_c , ΣT_t , I_a/P , & A_mQ). Enter a consecutive series of hydrograph times from Table 2. Review the unit discharges in the tables for the various combinations of T_c and T_t and make a rough estimate of when the peak flow for the composite section will occur. This value should be in the middle of the time range entered in the worksheet.
4. For each subarea and hydrograph time, enter Table 2 for the appropriate values of T_c , T_t , and I_a/P and find the corresponding unit discharge in csm/in. Multiply this value by the value shown in the A_mQ column and record the result in the worksheet as the discharge for that subarea at the selected hydrograph time. Repeat this process for each hydrograph time and subarea. Upon completion, sum each of the time columns to obtain the composite hydrograph at the outlet.
5. Review the values for the composite hydrograph. Ensure that the values rise, reach a maximum, and then begin to fall to ensure that the time range selected includes the peak discharge.

¹ Source: TR-55: Urban Hydrology for Small Watersheds, USDA/NRCS

