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.

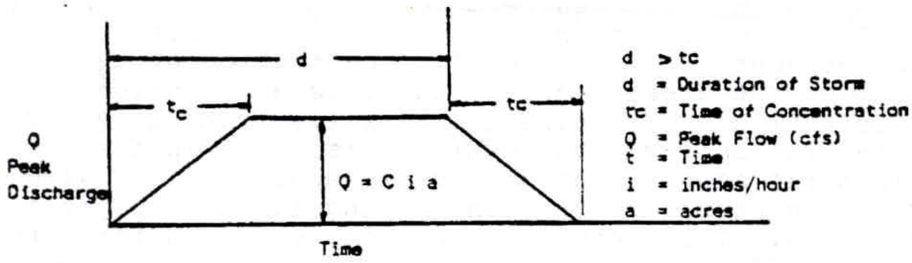
Theory: The area under a hydrograph equals the volume of runoff. For the Modified Rational Method, this area is equal to the peak discharge rate times the duration of the storm. A uniform rainfall intensity for the entire rainfall period is assumed here. This is highly unlikely. The Modified Rational 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 X c X I X a). This attempts to predict a more realistic runoff volume, which is characteristic of major storms. The maximum product of ca X c cannot be greater than 1.

Recommended antecedent precipitation factors for the Rational Method

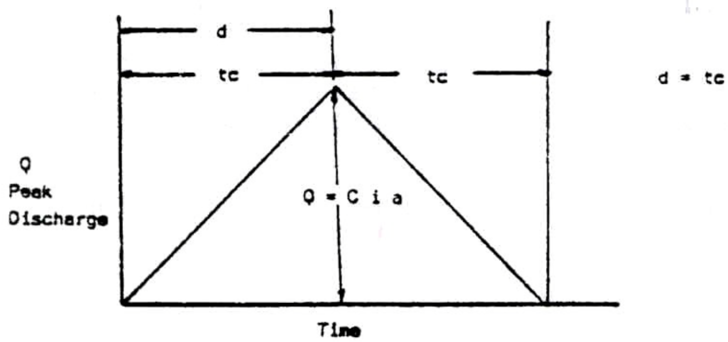
Recurrence Interval (years)	*Ca*
2-10	1.0
25	1.1
50	1.2
100	1.25

The time of concentration (tc), 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 tc, then the approximate hydrograph is a trapezoid.



2. If the rainfall duration is equal to the tc, assuming the tc 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_cs from 0.1 hours to 2 hours and reach T_ts 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 $\Sigma\ T_t$ 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:

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

where:
Q = Runoff (inches)
P = Rainfall (in)
S = Potential maximum retention after runoff begins (in)

and:

$$S = \frac{1000}{CN} - 10$$ **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 1.
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.
   1) 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.
   2) 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.
   3) 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.

Table 1: I_a Values for Runoff Curve Numbers[1]

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		

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

Worksheet 1: Subarea Properties[2]

Project				Location				By		Date	
Check one: ☐ Present ☐ Developed				Frequency (yr)				Checked		Date	
Subarea name	Drainage area A_m (mi^2)	Time of concen-tration T_c (hr)	Travel time through subarea T_t (hr)	Downstream subarea names	Travel time summation to outlet ΣT_t (hr)	24-hr rain-fall P (in)	Runoff curve number CN	Runoff Q (in)	A_mQ (mi^2—in)	Initial abstraction I_a (in)	I_a/P

[2] Source: TR-55: Urban Hydrology for Small Watersheds, USDA/NRCS.

Worksheet 2: Composite Hydrograph Development [3]

Project			Location							By				Date		
Check one: ☐ Present ☐ Developed			Frequency (yr)							Checked				Date		
Subarea name	Basic watershed data used 1/				Select and enter hydrograph times in hours from exhibit 5-II 2/											
	Subarea T_c (hr)	ΣT_t to outlet (hr)	I_a/P	A_mQ (mi^2—in)												
					Discharges at selected hydrograph times 3/ (cfs)											
Composite hydrograph at outlet																

1/ Worksheet 5a. Rounded as needed for use with exhibit 5.
2/ Enter rainfall distribution type used.
3/ Hydrograph discharge for selected times is A_mQ multiplied by tabular discharge from appropriate exhibit 5.

[3] Source: TR-55: Urban Hydrology for Small Watersheds, USDA/NRCS

Table 2: Tabular Hydrograph Unit Discharges (csm/in) for Type II Rainfall Distribution[4]

HYDROGRAPH TIME (HOURS)

IA/P = 0.10 * * * TC = 0.1 HR * * *

TRVL TIME (hr)	11.0	11.3	11.6	11.9	12.0	12.1	12.2	12.3	12.4	12.5	12.6	12.7	12.8	13.0	13.2	13.4	13.6	13.8	14.0	14.3	14.6	15.0	15.5	16.0	16.5	17.0	17.5	18.0	19.0	20.0	22.0	26.0
0.0	24	34	53	334	647	1010	623	217	147	123	104	86	76	66	57	51	46	42	38	34	32	29	26	23	21	20	19	18	15	13	12	0
.10	21	29	43	134	267	520	847	701	378	224	157	122	98	75	64	56	50	45	41	36	33	30	27	24	21	20	19	18	16	13	12	0
.20	18	25	35	61	110	215	418	704	702	486	312	209	151	94	73	62	54	49	44	38	34	31	28	25	22	21	19	18	16	14	12	0
.30	17	23	33	56	92	174	337	582	662	545	389	269	190	109	79	65	56	50	45	39	35	32	29	25	22	21	20	18	16	14	12	0
.40	15	20	28	41	51	78	142	272	478	601	563	447	328	172	104	76	63	55	49	42	37	33	29	26	23	21	20	19	17	14	12	0
.50	14	19	26	39	47	68	117	220	392	531	553	482	380	209	121	84	67	57	51	43	38	33	30	27	23	21	20	19	17	14	12	0
.75	12	15	21	29	33	38	49	73	126	224	343	432	464	385	252	156	103	76	62	50	43	36	31	28	25	22	21	19	17	15	12	0
1.0	9	12	15	21	23	26	29	33	40	55	86	148	238	406	434	317	205	130	89	62	50	41	34	30	27	24	22	20	18	16	12	0
1.5	7	8	10	14	15	16	18	20	22	25	29	34	45	101	220	339	373	320	234	131	80	53	40	34	30	27	24	21	19	17	12	2
2.0	4	6	7	9	9	10	11	12	13	15	16	18	20	25	37	72	150	252	336	312	216	109	58	42	34	30	27	24	20	18	13	8
2.5	3	4	5	6	7	7	8	8	9	10	11	12	13	16	19	25	39	75	142	262	308	229	108	58	41	34	30	27	22	19	14	11
3.0	1	2	3	4	4	5	5	6	6	7	7	8	8	10	12	14	17	22	31	76	169	288	236	122	64	43	35	30	24	20	16	11

IA/P = 0.30 * * * TC = 0.1 HR * * *

TRVL TIME (hr)	11.0	11.3	11.6	11.9	12.0	12.1	12.2	12.3	12.4	12.5	12.6	12.7	12.8	13.0	13.2	13.4	13.6	13.8	14.0	14.3	14.6	15.0	15.5	16.0	16.5	17.0	17.5	18.0	19.0	20.0	22.0	26.0
0.0	0	0	0	154	568	936	524	217	172	149	126	107	97	86	76	69	63	58	53	48	46	42	38	34	31	30	28	27	24	20	19	0
.10	0	0	0	19	109	415	762	603	346	230	176	143	119	96	84	74	68	62	57	50	47	44	40	35	32	30	29	27	24	21	19	0
.20	0	0	0	0	13	77	302	609	605	432	297	217	167	115	94	81	73	66	60	53	48	45	41	37	33	31	29	28	25	21	19	0
.30	0	0	0	0	9	54	219	479	563	476	357	263	199	129	99	85	75	68	62	54	49	45	41	37	33	31	29	28	25	21	19	0
.40	0	0	0	0	0	6	38	159	372	500	484	399	309	183	123	96	82	73	66	58	51	46	42	38	34	31	30	28	25	22	19	0
.50	0	0	0	0	0	4	27	115	287	429	465	421	346	213	138	103	86	76	68	59	52	47	43	39	34	32	30	29	25	22	19	0
.75	0	0	0	0	0	0	1	10	46	132	246	338	381	341	243	165	119	94	80	67	58	50	45	41	37	33	31	29	26	23	19	0
1.0	0	0	0	0	0	0	0	1	4	22	69	149	241	357	331	246	170	122	96	76	64	54	47	42	38	34	32	30	27	24	19	0
1.5	0	0	0	0	0	0	0	0	0	0	0	1	4	41	142	258	310	285	224	142	97	71	55	47	43	39	35	32	29	25	20	4
2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	10	49	130	221	279	255	182	108	70	55	47	42	38	34	30	27	20	11
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	14	52	119	224	256	193	107	70	55	47	42	38	32	28	22	17
3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	9	52	141	240	199	117	74	56	48	43	35	30	24	18

IA/P = 0.50 * * * TC = 0.1 HR * * *

TRVL TIME (hr)	11.0	11.3	11.6	11.9	12.0	12.1	12.2	12.3	12.4	12.5	12.6	12.7	12.8	13.0	13.2	13.4	13.6	13.8	14.0	14.3	14.6	15.0	15.5	16.0	16.5	17.0	17.5	18.0	19.0	20.0	22.0	26.0
0.0	0	0	0	0	70	539	377	196	171	154	134	117	108	99	89	83	77	72	67	61	59	56	51	46	43	42	40	38	34	30	28	0
.10	0	0	0	0	47	375	376	256	199	169	146	126	114	102	92	85	79	73	68	62	59	56	52	47	43	42	40	38	34	30	28	0
.20	0	0	0	0	0	31	260	338	283	227	189	160	138	112	99	90	83	77	72	64	60	57	53	48	44	42	41	39	35	30	28	0
.30	0	0	0	0	0	0	21	180	285	284	246	208	176	131	110	97	88	82	76	68	62	59	54	50	45	43	41	39	36	31	28	0
.40	0	0	0	0	0	0	14	125	232	266	253	223	192	142	115	100	91	83	77	69	63	59	55	50	45	43	41	40	36	31	28	0
.50	0	0	0	0	0	0	9	86	183	239	248	231	205	154	122	104	93	85	79	71	64	59	55	51	46	43	41	40	36	32	28	0
.75	0	0	0	0	0	0	3	31	87	147	190	211	213	184	147	121	103	92	84	75	67	61	57	52	47	44	42	40	37	32	28	0
1.0	0	0	0	0	0	0	0	0	1	13	45	92	141	205	197	165	134	112	98	84	75	65	59	55	50	46	43	41	38	34	28	0
1.5	0	0	0	0	0	0	0	0	0	0	0	2	9	51	118	170	183	167	143	111	92	77	65	59	54	50	45	43	39	35	28	2
2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	15	51	103	148	168	156	127	96	76	65	58	54	49	45	41	37	29	12
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	9	31	69	131	159	140	101	78	66	59	54	50	43	39	31	24
3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	11	46	101	151	134	99	77	65	59	54	45	41	33	26

RAINFALL TYPE = II * * * TC = 0.1 HR * * * SHEET 1 OF 10

[4] Source: TR-55: Urban Hydrology for Small Watersheds, USDA/NRCS