

Referring to the following table, column 3 defines the unit hydrograph for a 0.5 mi² watershed area. The unit hydrograph is calculated by dividing each hydrograph runoff point in column 2 by the average precipitation, $P_{ave,excess}$, which is 1.18 in.

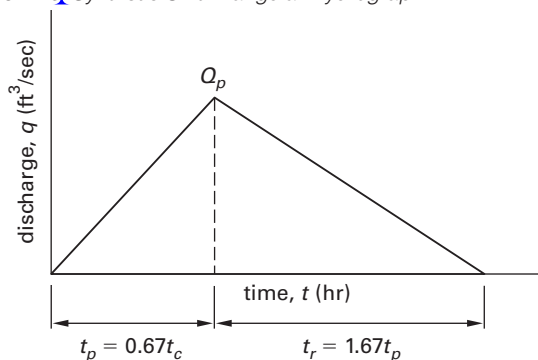
Column 4 defines the hydrograph coordinates for a 2.0 in storm in the watershed, which are calculated by multiplying the unit hydrograph runoff calculated in column 3 by the storm precipitation, 2.0 in.

time (hr)	1.18 in hydrograph runoff (ft ³ /sec)	unit hydrograph runoff (ft ³ /sec-in)	2.0 in hydrograph runoff (ft ³ /sec)
12.7	50	50/1.18 = 42.4	(42.4)(2.0) = 84.7
14	155	155/1.18 = 131.4	(131.4)(2.0) = 262.7
15.4	250	250/1.18 = 211.9	(211.9)(2.0) = 423.7
16	137	137/1.18 = 116.1	(116.2)(2.0) = 232.2
16.5	50	50/1.18 = 42.4	(42.4)(2.0) = 84.7

Synthetic Unit Triangular Hydrograph

In ungauged watersheds, *synthetic hydrographs* are used to design reservoirs and detention ponds and can be estimated using the *NRCS synthetic unit triangular hydrograph method* (see Fig. 1.11). The coordinates of the synthetic hydrograph are defined by the peak runoff, Q_p , time to peak runoff, t_p , and time of concentration, t_c .

Figure 1-10 Synthetic Unit Triangular Hydrograph



The *peak runoff* is the maximum rate of runoff flow. (See Sec. 1.11 for how to calculate peak runoff.) The time of concentration is the maximum time for runoff to travel from the farthest and uppermost point in a watershed downstream to the outlet point of the watershed. The storm duration is equal to the time of concentration for small watersheds (1 mi²). The ascending leg of the hydrograph is the *time to peak runoff*, t_p , as measured from the beginning of overland runoff hydrograph as defined in Fig. 1.11 and Eq. 1.6.

$$t_p = 0.67t_c \tag{1.6}$$

The receding leg of the hydrograph is measured after the time of peak runoff using Eq. 1.7.

$$t_r = 1.67t_p \tag{1.7}$$

Example 1.8

Define a synthetic unit triangular hydrograph where the peak runoff is estimated as 100 ft³/sec and the time of concentration is 1.5 hr.

Solution

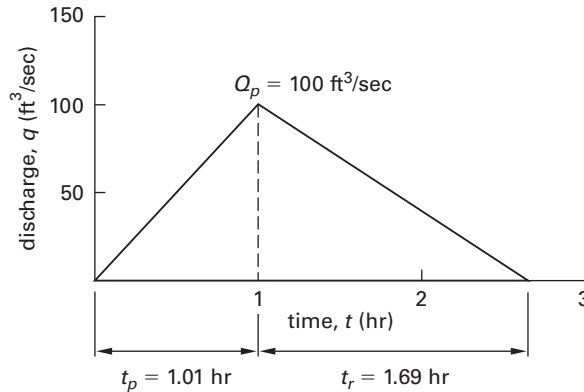
Plot the peak runoff at 100 ft³/sec. Use Eq. 1.6 to define the time for the ascending limb of the hydrograph as t_p , the time to peak runoff.

$$\begin{aligned} t_p &= 0.67t_c \\ &= (0.67)(1.5 \text{ hr}) \\ &= 1.01 \text{ hr} \end{aligned}$$

Using Eq. 1.7, define the time of the receding limb of the hydrograph.

$$\begin{aligned} t_r &= 1.67t_p \\ &= (1.67)(1.01 \text{ hr}) \\ &= 1.69 \text{ hr} \end{aligned}$$

Plot the synthetic unit triangular hydrograph as shown.



7. RESERVOIR VOLUME (RIPPL DIAGRAM)

The minimum required volume of a water tank or reservoir can be estimated by creating a *Rippl diagram* according to the following steps, and as illustrated in Ex. 1.9.

- step 1: Tabulate days of accumulation (column one) and the cumulative volume (column two).
- step 2: Plot cumulative volume (y -axis) versus time (x -axis).
- step 3: Determine the half-maximum accumulation and mark the point on the curve. The half-maximum

accumulation is the intersection of cumulative volume and time at the point where time is one-half of the total duration.

step 4: Draw a straight line through the origin and the half-maximum point and continue it through the top of the plotted cumulative volume curve. This is the average volume line.

step 5: Draw two lines parallel to the average volume line. The first line, tangent 1, runs through times earlier than the cumulative volume curve, except at the point that it touches the curve. Tangent 2 runs through times later than the cumulative volume curve, except at the point that it touches the curve.

step 6: Starting at the point where the lowest parallel line intersects the *x*-axis, draw a vertical line upward to intersect with the highest parallel line.

step 7: Starting at the intersection of the vertical line with the highest parallel line, draw a horizontal line to intersect the *y*-axis. The *minimum required volume* is given by that point.

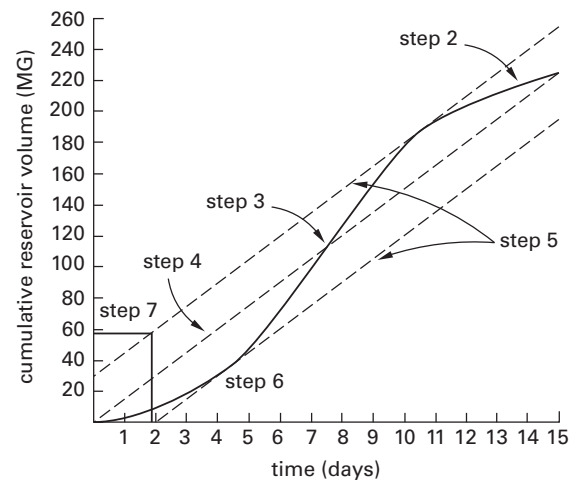
Example 1.9

Estimate the minimum required volume of a reservoir with a cumulative volume relationship as defined in the following table.

time (days)	cumulative volume (MG)	average volume (MG)	tangent 1 (MG)	tangent 2 (MG)
0	0	0	–	30
1	6	15	–	45
2	12	30	0	60
3	18	45	15	75
4	28	60	30	90
5	46	75	45	105
6	68	90	60	120
7	98	105	75	135
8	130	120	90	150
9	155	135	105	165
10	175	150	120	180
11	192	165	135	195
12	205	180	150	210
13	215	195	165	225
14	222	210	180	240
15	225	225	195	255

Solution

The data for step 1 is tabulated in the problem statement and plotted as a Rippl diagram, which is labeled with the associated step numbers. The minimum required volume is found in step 7 to be 60 MG.

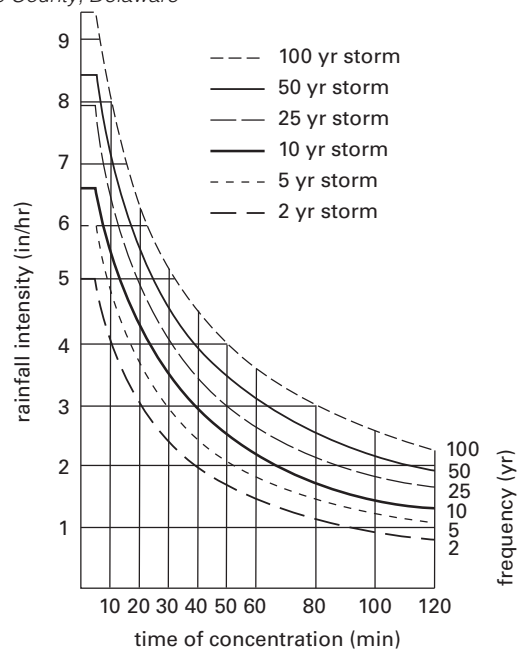


8. RAINFALL INTENSITY-DURATION-FREQUENCY RELATIONS

Intensity-Duration-Frequency Curves

Rainfall intensity, *i*, and storm duration (given by time of concentration, *t_c*) are related by *intensity-duration-frequency* (IDF) curves published by the USNWS, the United States Department of Agriculture (USDA), and local or state governments for specific geographic regions of the United States. Most state and local governments as well as the Departments of Transportation publish IDF curves in stormwater manuals. Figure 1.12 provides a typical IDF curve published by the USDA for New Castle County, Delaware.

Figure 1-11. Rainfall Intensity-Duration-Frequency Curve for New Castle County, Delaware



Adapted from *Surface Water Management Code*. 2007. USDA and New Castle County.

Figure 1-15 Computing Time of Concentration*

Project	By	Date
Location	Checked	Date
Check one: <input type="checkbox"/> Present <input type="checkbox"/> Developed Check one: <input type="checkbox"/> t_c <input type="checkbox"/> T_t through subarea Notes: Space for as many as two segments per flow type can be used for each worksheet. Include a map, schematic, or description of flow segments.		
Sheet flow (Applicable to t_c only)		
Segment ID		
1. Surface description (Table 1.12)		
2. Manning's roughness coefficient, n (Table 1.12) ...		
3. Flow length, L (total $L \leq 300$ ft)	ft	
4. Two year, 24 hour rainfall, P_2	in	
5. Land slope, S	ft/ft	
6. $t_{sf} = \frac{(0.007 \text{ hr})(nL)^{0.8}}{P_2^{0.5} S^{0.4}}$ Compute t_{sf}	hr	<input type="text"/> + <input type="text"/> = <input type="text"/>
Shallow concentrated flow		
Segment ID		
7. Surface description (paved or unpaved)		
8. Flow length, L	ft	
9. Watercourse slope, S	ft/ft	
10. Average velocity, v (Fig. 1.18)	ft/sec	
11. $t_{sc} = \frac{L}{v}$ Compute t_{sc}	hr	<input type="text"/> + <input type="text"/> = <input type="text"/>
Channel flow		
Segment ID		
12. Cross-sectional flow area, A_{ft^2}	ft ²	
13. Wetted perimeter, WP	ft	
14. Hydraulic radius, $R = \frac{A_{ft^2}}{WP}$, compute R	ft	
15. Channel slope, S	ft/ft	
16. Manning's roughness coefficient, n	ft/ft	
17. $v = \left(\frac{1.49}{n}\right) R^{2/3} \sqrt{S}$ Compute v	ft/sec	
18. Flow length, L	ft	
19. $t_{ch} = \frac{L}{v}$ Compute t_{ch}	hr	<input type="text"/> + <input type="text"/> = <input type="text"/>
20. Watershed or subarea, t_c (add t_{sf} , t_{sc} , and t_{ch} from steps 6, 11, and 19)	hr	<input type="text"/>

*TR-55 Worksheet 3 gives each time component as T_t . This book uses subscripts to differentiate between the component travel times. Reprinted from TR-55: Urban Hydrology for Small Watersheds. NRCS. Worksheet 3. 1986. USDA.

be calculated by prorating the coefficient by the amount of land cover and then dividing by the total watershed area. For example, in a watershed with two different areas of land use, the composite c_{total} value is

$$c_{total} = \frac{\sum c_i A_i}{\sum A_i} = \frac{c_1 A_1 + c_2 A_2}{A_1 + A_2} \quad 1.15$$

Once the time of concentration is calculated, select the rainfall intensity, i , from an IDF curve, such as the one in Fig. 1.12.

Example 1.12

Using Table 1.11, calculate the composite runoff coefficient for a 100 ac watershed occupied by 50 ac of single family residential, 25 ac of light industrial, and 25 ac of park land uses.