

**Supporting Handout to Chapter 2 (CAHE, 9<sup>th</sup> Edition)**

**CWR5535C – Advanced Modeling Applications**

**in Water Resources Engineering**

**Spring 2024**

**Main References:**

**Professor H. R. Fuentes Personal Notes, 2024**

**Gupta, R. S., Hydrology & Hydraulic Systems, Waveland Press, Inc.,**

**ISBN: 1-4786-3091-4, Long Grove, IL, 2017**

# Precipitation - Runoff Relationship

Importance: a) Hydrologic/Hydraulic Design  
 b) " " " Analysis

<u>Method</u> (approach, "model")	<u>Complexity</u> <u>Level</u>	<u>Assumptions</u>	<u>Limitations</u> (Examples)
Rational "Formula" ( $Q = C_f C_i A$ )			$A < 1 \text{ mi}^2$ (Robutson et al., 1998) $A < 0.015 - 4.6 \text{ mi}^2$ (Other references) - Small watersheds - Sheet etc.
NRC S [in Technical Release TR-55 (1975, 1986)]			$A < 5 - 10 \text{ mi}^2$ (Robutson et al., 1998) Conservative if storm is of long duration
Unit Hydrograph - Based on actual data (actual hydrographs) - Synthetic			$A < 40 - 50 \text{ mi}^2$ (Thunderstorms) $A < 2,000 - 3,000 \text{ mi}^2$ (Frontal storms)



United States  
Department of  
Agriculture

Natural  
Resources  
Conservation  
Service

Conservation  
Engineering  
Division

Technical  
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June 1986

# Urban Hydrology for Small Watersheds

## TR-55

To show bookmarks which navigate through the document.

Click the show/hide navigation pane button  , and then

click the bookmarks tab. It will navigate you to the contents,

chapters, rainfall maps, and printable forms.

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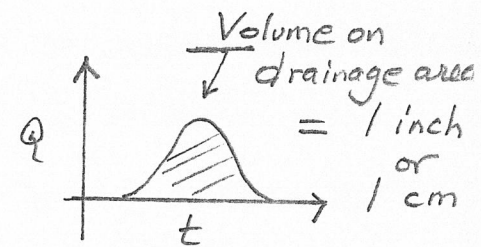
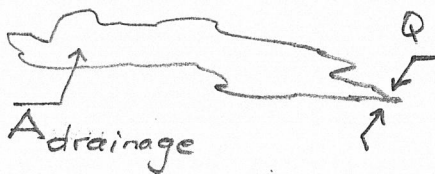
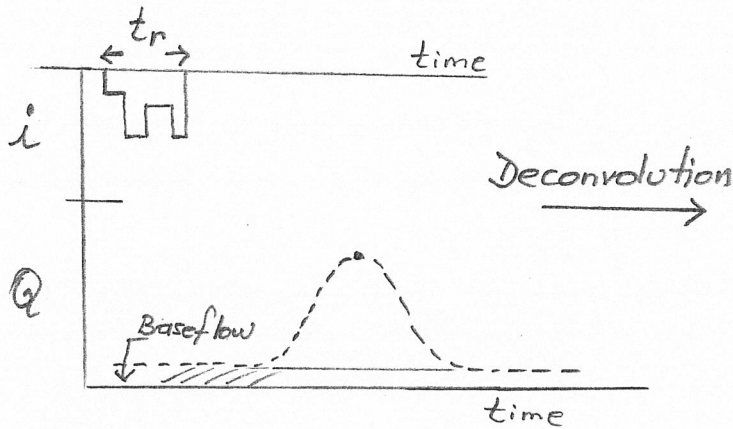
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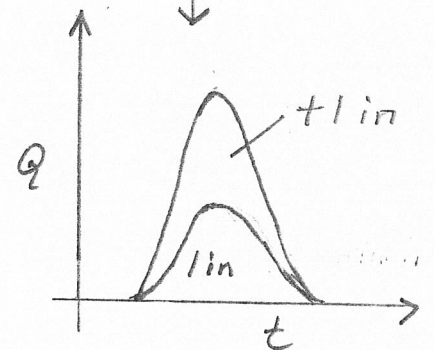
# UNIT HYDROGRAPH

## Development & Application

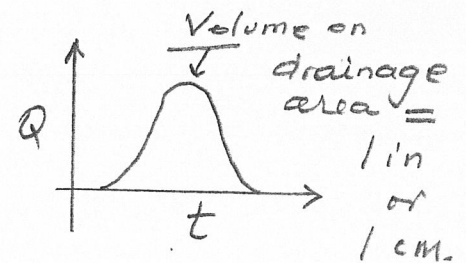
a) From actual hydrographs:



↓ Convolution



↑ Convolution

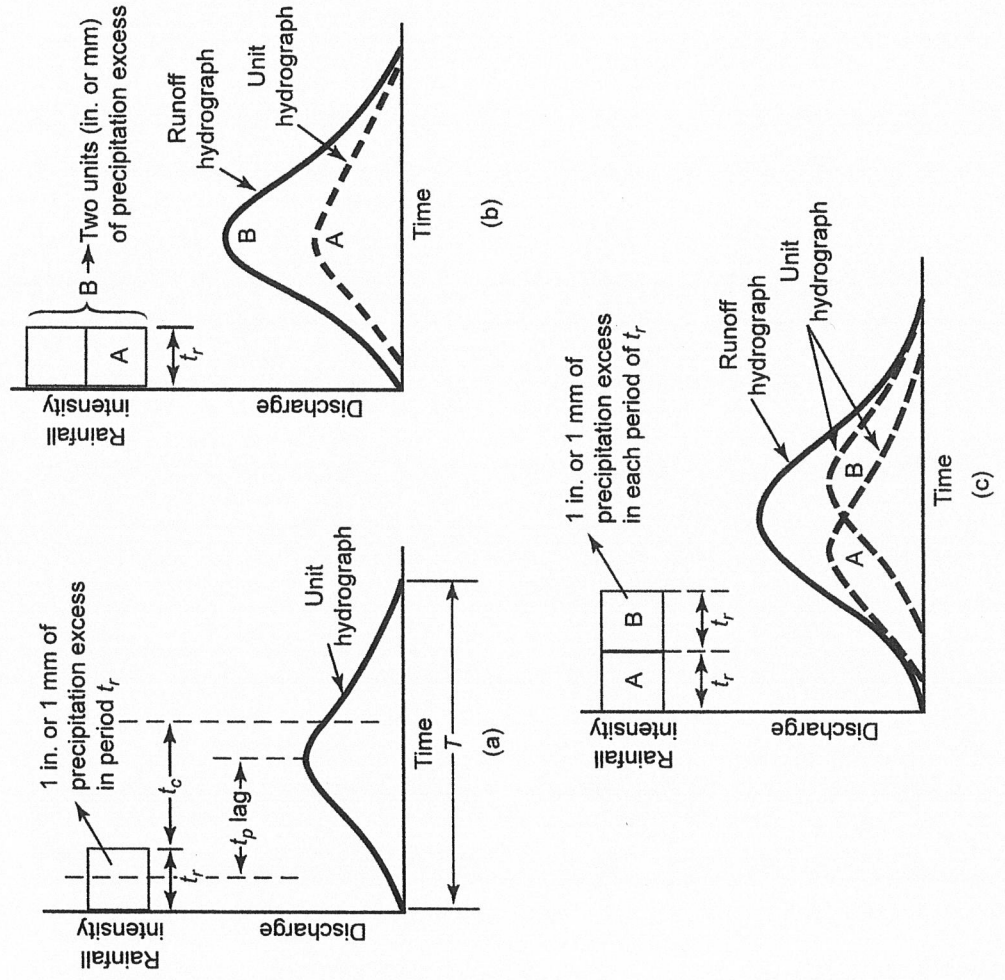


b) Synthetic Unit Hydrographs  
(develop based on drainage area characteristics)

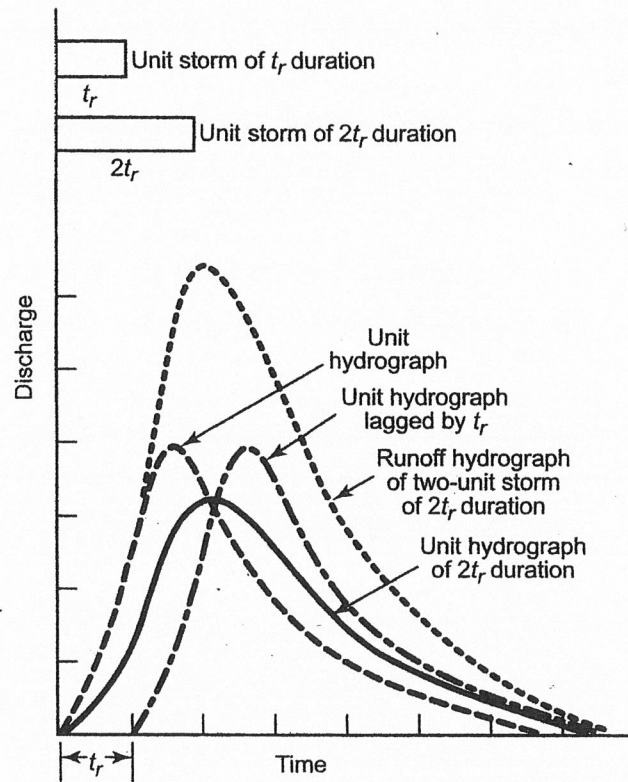
Examples: Snyder's UH  
NRCS' UH

# UH Basic Principles

**Figure 9.9** Principles of the unit hydrograph: (a) unit hydrograph; (b) runoff hydrograph for two units of precipitation of duration  $t_r$ ; (c) runoff hydrograph from unit precipitation for two consecutive periods of duration  $t_r$ .



**Figure 9.15** Lagging procedure to convert unit hydrograph duration.



$$\text{UH of } nt_r \text{ duration} = \frac{\text{sum of } n, \text{ UH of } t_r \text{ duration each lagged by } t_r \text{ time}}{n} \quad [L^3T^{-1}] \quad (9.8)$$



**EXAMPLE 9.5**

The following unit hydrograph results from a 2-hour storm. Determine the hourly ordinates of a 6-hour unit hydrograph.

Time (hr)	0	1	2	3	4	5	6
Q (m <sup>3</sup> /s)	0	1.42	8.50	11.30	5.66	1.45	0

**SOLUTION** See Table 9.8.

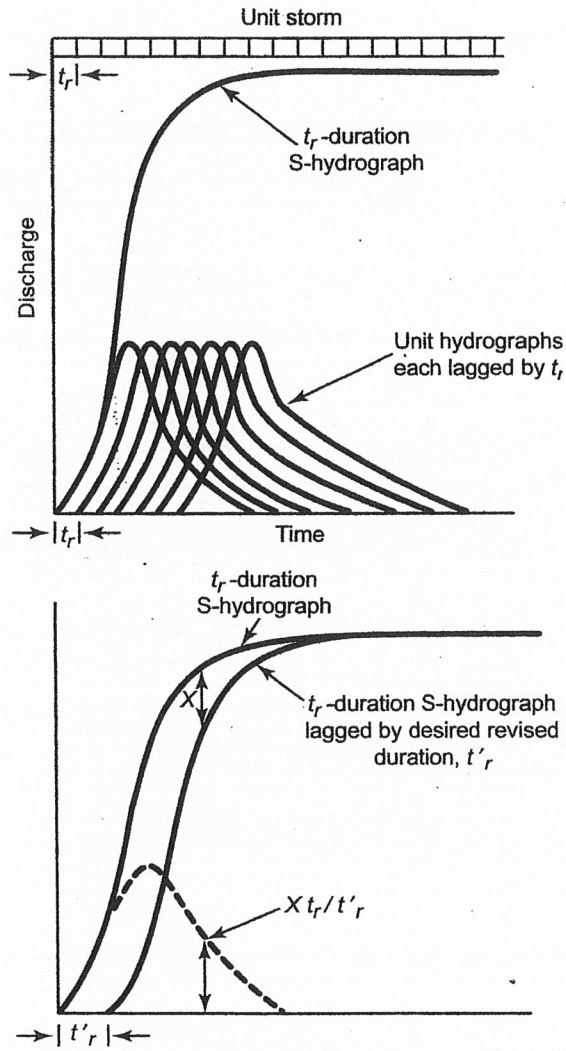
$$t_r = 2 \text{ hr}$$

$$n = \frac{6\text{-hr duration}}{2\text{-hr duration}} = 3$$

**Table 9.8 Conversion of Unit Hydrograph Duration by Lagging**

(1)	(2)	(3) (4) (5)			(6)	(7)
Time (hr)	2-hr Unit Hydrograph (m <sup>3</sup> /s)	Three 2-hr Hydrographs Each Lagged by 2 hr			Total	6-hr Unit Hydrograph (m <sup>3</sup> /s) (col. 6/3.0)
		1 × UH	1 × UH	1 × UH		
0	0	0			0	0
1	1.42	1.42			1.42	0.47
2	8.50	8.50	0		8.50	2.83
3	11.30	11.30	1.42		12.72	4.24
4	5.66	5.66	8.50	0	14.16	4.72
5	1.45	1.45	11.30	1.42	14.17	4.72
6	0	0	5.66	8.50	14.16	4.72
7			1.45	11.30	12.75	4.25
8			0	5.66	5.66	1.89
9				1.45	1.45	0.48
10				0	0	0

**Figure 9.16** Illustration of the S-curve.



**EXAMPLE 9.6**

Solve Example 9.5 by the S-curve method.

**SOLUTION** Computations are shown in Table 9.10.

**Table 9.10 Computation of 2-Hour S-Curve and 6-Hour Unit Hydrograph**

(1) Time (hr)	(2) 2-hr Unit Hydrograph (m <sup>3</sup> /s)	(3) S-Curve Addition	(4) 2-hr S-Curve	(5) 2-hr S-Curve Lagged by 6-hr	(6) S-Curve Difference	(7) 6-hr Unit Hydrograph (col. 6 × 2/6)
0	0	+0	→ 0		0	0
1	1.42	+0	→ 1.42		1.42	0.47
2	8.50	+0	→ 8.50		8.50	2.83
3	11.30	+1.42	→ 12.72		12.72	4.24
4	5.66	+8.50	→ 14.16		14.16	4.72
5	1.45	+12.72	→ 14.17		14.17	4.72
6	0	14.16	→ 14.16	0	14.16	4.72
7		14.17	→ 14.17	1.42	12.75	4.25
8		14.16	→ 14.16	8.50	5.66	1.89
9		14.17	→ 14.17	12.72	1.45	0.48
10		14.16	→ 14.16	14.16	0	0
11		14.17	→ 14.17	14.17	0	0

## Two Synthetic Unit Hydrographs

---

### 9.11.1 Snyder's Method

The four parameters—lag time, peak flow, time base, and standard duration—of rainfall excess for the unit hydrograph have been related to the physical geometry of the basin by the following relations:

$$t_p = C_t (LL_C)^{0.3} \quad \text{[unbalanced]} \quad (9.9)$$

$$Q_p = \frac{C_p A}{t_p} \quad \text{[unbalanced]} \quad (9.10)$$

$$T = 3 + \frac{t_p}{8} \quad \text{[T]} \quad (9.11)$$

$$t_D = \frac{t_p}{5.5} \quad \text{[T]} \quad (9.12)$$

When the duration of rainfall excess,  $t_r$ , is other than the standard duration,  $t_D$ , the following adjustments in lag time and peak discharge are made:

$$t_{pR} = t_p + 0.25 (t_r - t_D) \quad \text{[T]} \quad (9.13)$$

$$Q_{pR} = Q_p \frac{t_p}{t_{pR}} \quad \text{[L}^3\text{T}^{-1}] \quad (9.14)$$

where

$t_D$  = standard duration of rainfall excess, hours

$t_r$  = duration of rainfall excess other than standard duration adopted in the study, hours

$t_p$  = lag time from midpoint of rainfall excess duration,  $t_D$ , to peak of the unit hydrograph, hours

$t_{pR}$  = lag time from midpoint of duration,  $t_r$ , to the peak of the unit hydrograph, hours

$T$  = time base of unit hydrograph, days

$Q_p$  = peak flow for standard duration,  $t_D$

$Q_{pR}$  = peak flow for duration,  $t_r$

$L_C$  = stream mileage from the outlet to a point opposite the basin centroid

$L$  = stream mileage from the outlet to the upstream limits of the basin

$A$  = drainage area,  $\text{mi}^2$  or  $\text{km}^2$

$C_t$  = coefficient representing slope of the basin;

varies from 1.8 to 2.2 for distance in miles, or from 1.4 to 1.7 for distance in kilometers;

Taylor and Schwarz state that  $C_t$  equals  $0.6/\sqrt{S}$  for distance in miles,  $S$  being the basin slopes

$C_p$  = coefficient indicating the storage capacity;

varies from 360 to 440 for English units, and from 0.15 to 0.19 for metric units

If the ungaged basin and the gaged basin are located in close proximity to each other within a region, the coefficients  $C_t$  and  $C_p$  are computed from the data of the gaged basin. The coefficients so obtained are used in the preceding equations to construct the unit hydrograph for the ungaged basin. Otherwise, generalized values are used for the coefficients.

A unit hydrograph is sketched, from the lag time, peak discharge, and time base computed from eqs. (9.9) through (9.14), to represent a unit runoff amount (area under the graph). Equation (9.11) usually gives long base length for small to medium basins. The following Corps of Engineers formulas give additional assistance in plotting time width,  $W_{50}$ , in hours, at the discharge point equal to 50% of the peak discharge, and the width,  $W_{75}$ , in hours, at the discharge point equal to 75% of the peak flow.

$$W_{50} = \frac{770A^{1.08}}{Q_{pR}^{1.08}} \quad (\text{English units}) \quad [\text{unbalanced}] \quad (9.15a)$$

or

$$W_{50} = \frac{0.23A^{1.08}}{Q_{pR}^{1.08}} \quad (\text{metric units}) \quad [\text{unbalanced}] \quad (9.15b)$$

and

$$W_{75} = \frac{440A^{1.08}}{Q_{pR}^{1.08}} \quad (\text{English units}) \quad [\text{unbalanced}] \quad (9.16a)$$

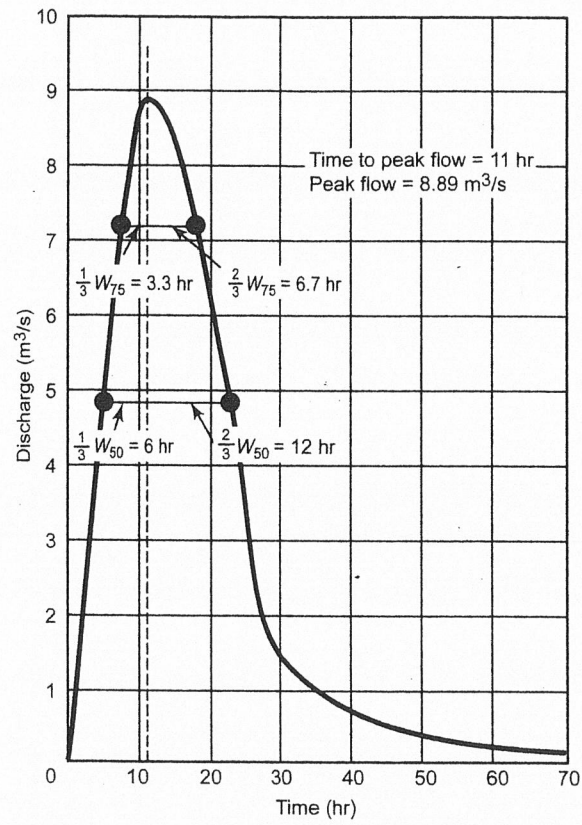
or

$$W_{75} = \frac{0.13A^{1.08}}{Q_{pR}^{1.08}} \quad (\text{metric units}) \quad [\text{unbalanced}] \quad (9.16b)$$

In eqs. (9.15a) and (9.16a),  $A$  is in  $\text{mi}^2$  and  $Q$  in cfs, and in eqs. (9.15b) and (9.16b),  $A$  is in  $\text{km}^2$  and  $Q$  in  $\text{m}^3/\text{s}$ .

As a rule of thumb, the widths  $W_{50}$  and  $W_{75}$  are proportioned each side of the unit hydrograph peak in the ratio 1:2, with the short side on the left of the synthetic unit hydrograph.

**Figure 9.17** Synthetic unit hydrograph by Snyder's method.



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**EXAMPLE 9.7**

For a basin of 500 km<sup>2</sup> having  $L = 25$  km and  $L_C = 10$  km, derive the 4-hour unit hydrograph. Assume that  $C_t = 1.6$  and  $C_p = 0.16$ .

**SOLUTION**

1.  $t_r = 4$  hr (given). From eq. (9.9),

$$t_p = 1.6(25 \times 10)^{0.3} = 8.38 \text{ hr}$$

2. From eq. (9.10),

$$Q_p = \frac{0.16(500)}{8.38} = 9.55 \text{ m}^3/\text{s}$$

3. From eq. (9.11),

$$T = 3 + \frac{8.38}{8} = 4.05 \text{ days or } 97 \text{ hr}$$

4. From eq. (9.12),

$$t_D = \frac{8.38}{5.5} = 1.5 \text{ hr}$$

5. From eq. (9.13),

$$t_{pR} = 8.38 + 0.25(4 - 1.5) = 9 \text{ hr}$$

6. From eq. (9.14),

$$Q_{pR} = \frac{9.55(8.38)}{9.0} = 8.89 \text{ m}^3/\text{s}$$

7. Time from beginning to peak,

$$P_r = \frac{t_r}{2} + t_{pR} = 2 + 9 = 11 \text{ hr}$$

8. From eq. (9.15b),

$$W_{50} = \frac{0.23(500)^{1.08}}{(8.89)^{1.08}} = 18 \text{ hr}$$

9. From eq. (9.16b),

$$W_{75} = \frac{0.13(500)^{1.08}}{(8.89)^{1.08}} = 10 \text{ hr}$$

The unit hydrograph has been sketched in Figure 9.17.

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### 9.11.2 Natural Resources Conservation Service (NRCS) Method

The NRCS employs an average dimensionless hydrograph developed from an analysis of a large number of unit hydrographs from field data of various-sized basins in different geographic locations.

This dimensionless hydrograph has its ordinate values of discharge expressed as the dimensionless ratio with the peak discharge and its abscissa values of time interval as the dimensionless ratio with the period of rise (time from beginning to the peak flow). The ratios for the NRCS dimensionless unit hydrograph are given in Table 9.11.

The unit hydrograph ordinates for different time periods can be obtained from Table 9.11. However, to use this table, the values of  $P_r$  and  $Q_p$  are required, which are computed as follows:

$$Q_p = \frac{484A}{P_r} \text{ (English units) [unbalanced]} \quad (9.17a)$$

or

$$Q_p = \frac{0.208A}{P_r} \text{ (metric units) [unbalanced]} \quad (9.17b)$$

$$P_r = \frac{t_r}{2} + t_p \text{ [T]} \quad (9.18)$$

The time lag,  $t_p$ , is computed by eq. (9.9) or by a regional empirical relation, or by the NRCS equation involving the NRCS curve number.

**Table 9.11 Ratios for the NRCS Dimensionless Unit Hydrograph**

Time Ratio, $t/P_r$	Hydrograph Discharge Ratio, $(Q/Q_p)$
0	0
0.1	0.030
0.2	0.100
0.3	0.190
0.4	0.310
0.5	0.470
0.6	0.660
0.7	0.820
0.8	0.930
0.9	0.990
1.0	1.000
1.1	0.990
1.2	0.930
1.3	0.860
1.4	0.780
1.5	0.680
1.6	0.560
1.8	0.390
2.0	0.280
2.2	0.207
2.4	0.147
2.6	0.107
2.8	0.077
3.0	0.055
3.5	0.025
4.0	0.011
4.5	0.005
5.0	0.000

Source: NRCS (formerly Soil Conservation Service), 1972.

Handwritten notes on the table:

- Next to 0.3: *Eg. 9.18* with a downward arrow pointing to 0.310.
- Next to 0.470: *Ex. =  $t_{0.5}/P_r \therefore t_{0.5} = 0.5 \times P_r$*
- Next to 0.470: *0.470 =  $Q/Q_p \therefore Q = 0.470 Q_p$*
- Next to 0.470: *Eg. 9.17b* with a downward arrow pointing to 0.470.

---

**EXAMPLE 9.8**

Solve Example 9.7 by the NRCS method.

**SOLUTION**

1.  $t_p = 8.38$  hr, from eq. (9.9) computed in Example 9.7.
2. From eq. (9.18),  $P_r = 4/2 + 8.38 = 10.38$  hr  $\approx 10.5$  hr.
3. From eq. (9.17b),

$$Q_p = \frac{0.208(500)}{10.5} = 9.90 \text{ m}^3/\text{s}$$

4. Using Table 9.11, the hydrograph ordinates are given in Table 9.12.
- 

**Table 9.12 Synthetic Unit Hydrograph by NRCS Method**

(1)	(2) <sup>a</sup>	(3)	(4) <sup>b</sup>
$t/P_r$	$t$ (hr)	$Q/Q_p$ (from Table 9.11)	$Q$ (m <sup>3</sup> /s)
0	0	0	0
0.2	2.1	0.100	0.99
0.5	5.25	0.470	4.65
0.8	8.4	0.930	9.21
1.0	10.5	1.00	9.90
1.5	15.75	0.680	6.73
2.0	21.0	0.280	2.77
3.0	31.5	0.055	0.54
4.0	42.0	0.011	0.11
5.0	52.5	0.000	0.00

<sup>a</sup> Col. 2 = col. 1  $\times P_r$

<sup>b</sup> Col. 4 = col. 3  $\times Q_p$

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**STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION**



# **DRAINAGE MANUAL**

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**OFFICE OF DESIGN, DRAINAGE SECTION    JANUARY 2015**  
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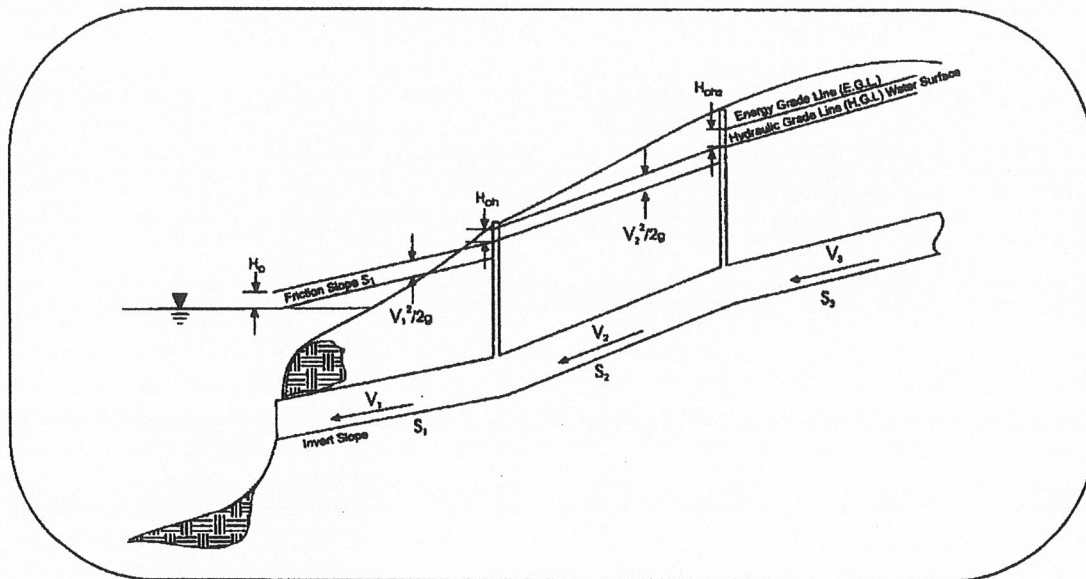


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