


# **Watershed Hydrology**

## **Unit Hydrograph**

# Unit hydrograph

 A unit hydrograph is defined as the hydrograph of **direct runoff (DR)** resulting from **one unit depth (1 cm)** of rainfall excess occurring **uniformly** over the basin and at a uniform rate for a specified **duration (D hours)**.

 This method was first suggested by Sherman in 1932.

 Unit hydrograph relates direct runoff to the rainfall excess

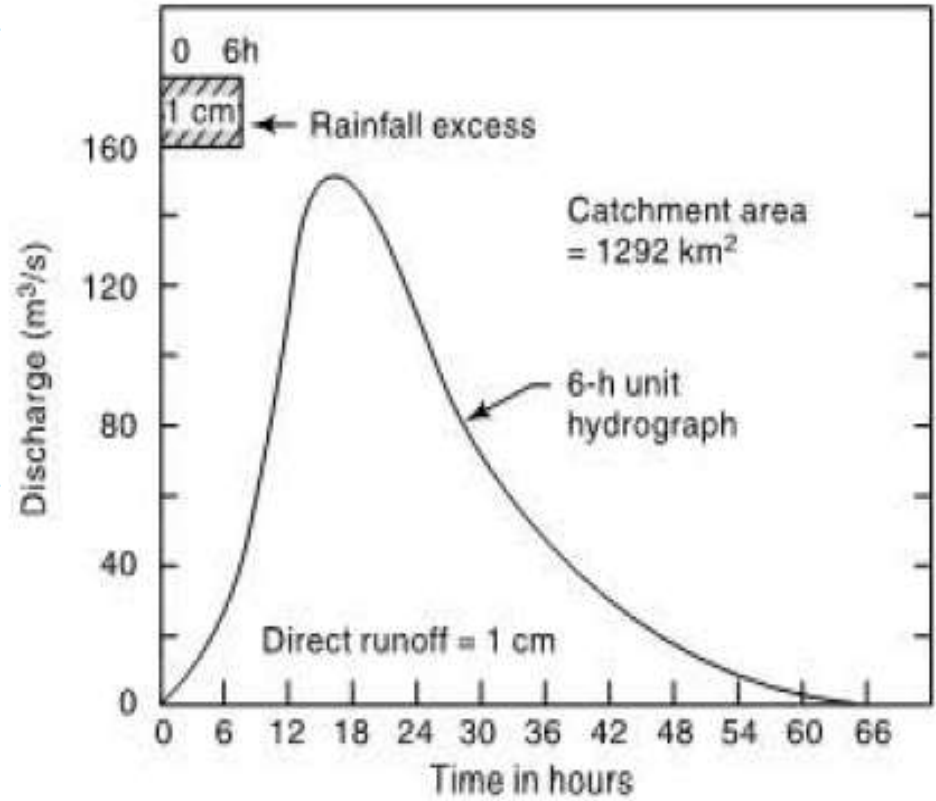
## **Application**

- Design of hydraulic structures
- Extension of flood-flow records
- Flood forecasting & warning system



# Assumption of Unit Hydrograph

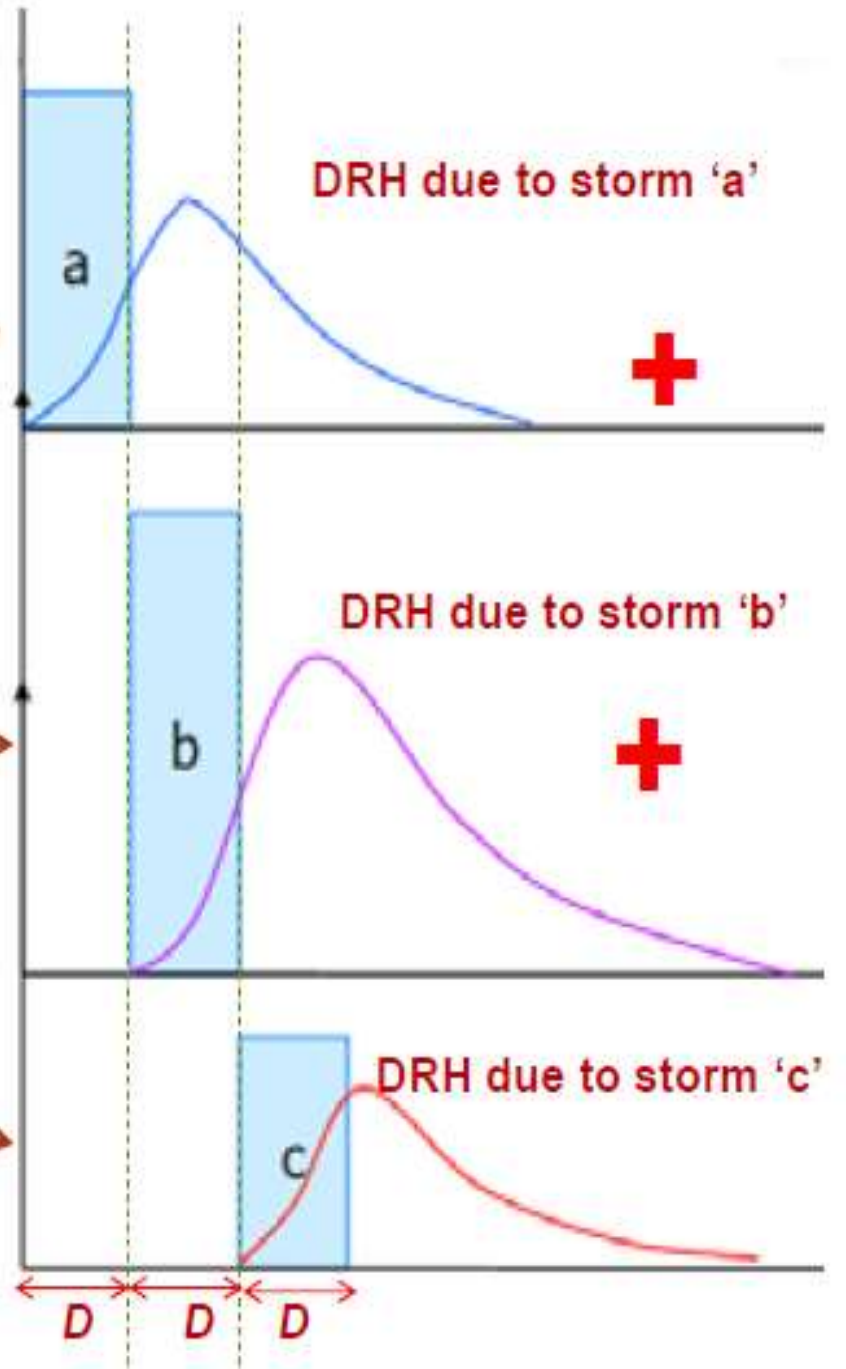
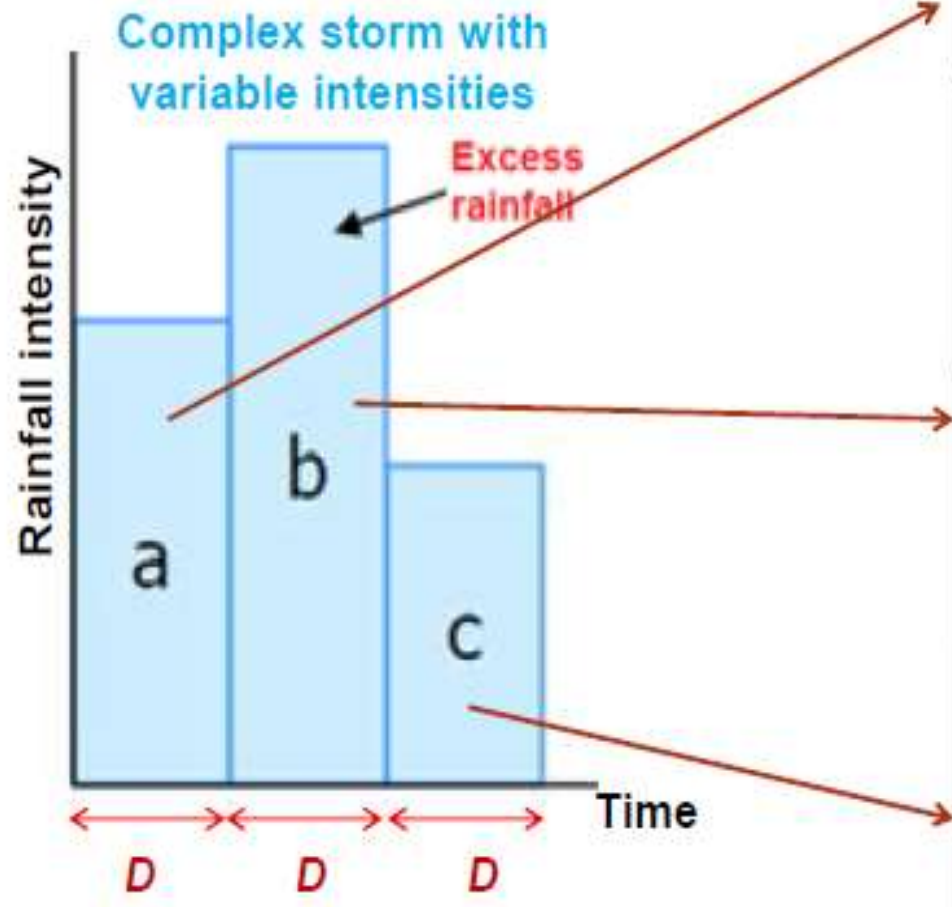
- **Time invariability of rainfall:** DRH for a given ER in a catchment is always same irrespective of when it occurs
- **Spatial invariability of rainfall:** Effective rainfall should be uniformly distributed over the whole catchment.
- **Time base of the DRH (i.e., the duration of DRH):** Depends only on the effective rainfall duration (D), and is independent of the magnitude of the effective rainfall intensity.

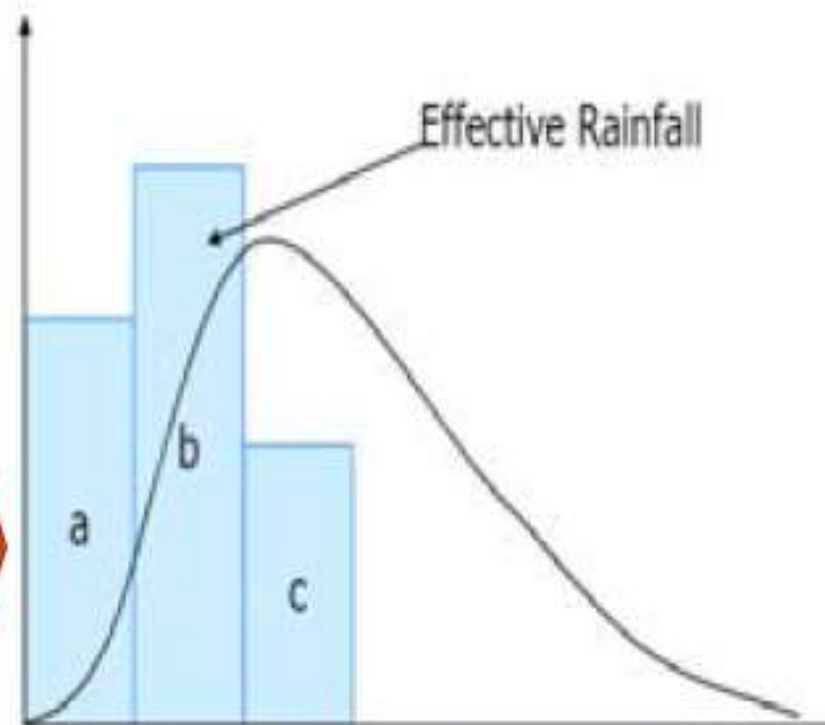
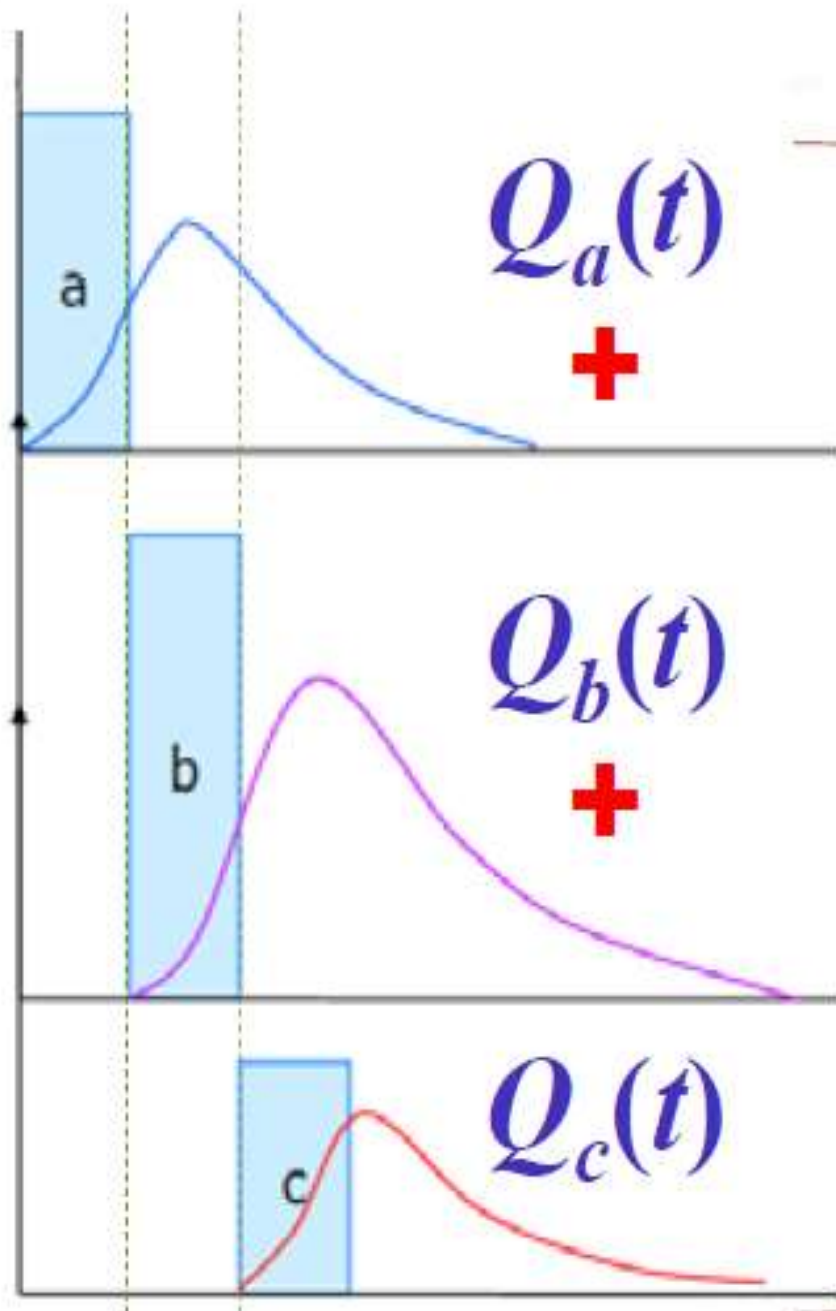


Typical 6-h Unit Hydrograph

- **Proportionality Principle:** DRH ordinates are proportional to the magnitude of effective rainfall intensity.
- **Time invariance principle:** Unit hydrograph (UH) reflects the basic effects of various **physical characteristics** of the basin, which do not change in time.
- **Linear response:** Linear response means if an input  $x_1(t)$  causes an output  $y_1(t)$  and an input  $x_2(t)$  causes an output  $y_2(t)$ , then an input  $x_1(t) + x_2(t)$  causes an output  $y_1(t) + y_2(t)$ .
- **Area limitation:** The **linear UH theory** can be applied only for a basin having drainage area between 200 ha - 5,00,000 ha (5000 km<sup>2</sup>).

# Principle of Superposition (for complex storms)





$$Q(t) = Q_a(t) + Q_b(t) + Q_c(t)$$

**Direct Runoff = DR due to storm 'a' +  
 DR due to storm 'b' + DR due to  
 storm 'c'**

## Problem

Given below are the ordinates of a 6-h unit hydrograph for a catchment. Calculate the ordinates of the DRH due to a rainfall excess of 3.5 cm occurring in 6h.

| Time (h) | UH ordinate (m <sup>3</sup> /s) |
|----------|---------------------------------|
| 0        | 0                               |
| 6        | 25                              |
| 12       | 50                              |
| 18       | 85                              |
| 24       | 100                             |
| 30       | 150                             |
| 36       | 120                             |
| 42       | 95                              |
| 48       | 75                              |
| 54       | 40                              |
| 60       | 20                              |
| 66       | 15                              |
| 72       | 0                               |

## Solution

| Time (h) | UH ordinate (m <sup>3</sup> /s) | Ordinate of 3.5 cm DRH (m <sup>3</sup> /s) |
|----------|---------------------------------|--|
| 0        | 0                               | 0  |
| 6        | 25                              | 87.5                                       |
| 12       | 50                              | 175  |
| 18       | 85                              | 297.5                                      |
| 24       | 100                             | 350  |
| 30       | 150                             | 525  |
| 36       | 120                             | 420  |
| 42       | 95                              | 332.5                                      |
| 48       | 75                              | 262.5                                      |
| 54       | 40                              | 140  |
| 60       | 20                              | 70   |
| 66       | 15                              | 52.5                                       |
| 72       | 0                               | 0  |



## Problem 2

Two storm each of 6-h duration and having rainfall excess values of 3.0 and 2.0 cm respectively occur successively. The 2cm ER rain follows the 3 cm rain. The 6h unit hydrograph for the catchment is the given in table. Calculate the resulting DRH.

| Time (h) | UH ordinate (m <sup>3</sup> /s) |
|----------|---------------------------------|
| 0        | 0                               |
| 3        | 25                              |
| 6        | 50                              |
| 9        | 85                              |
| 12       | 125                             |
| 15       | 160                             |
| 18       | 185                             |
| 21       | 160                             |
| 24       | 110                             |
| 27       | 60                              |
| 30       | 36                              |
| 33       | 25                              |
| 36       | 16                              |
| 39       | 8                               |
| 42       | 0                               |

| Time (h) | UH ordinate (m <sup>3</sup> /s) | Ordinate of 3cm DRH (col.2) x 3 (m <sup>3</sup> /s) | Ordinate of 2cm DRH (col.2 lagged by 6h) x 2 (m <sup>3</sup> /s) | Ordinate of 5cm DRH (col.3 +col.4) (m <sup>3</sup> /s) |
|----------|---------------------------------|---|--|--|
| Col 1    | Col 2                           | Col 3   | Col 4  | Col 5  |
| 0        | 0                               | 0   | -  | 0  |
| 3        | 25                              | 75  | -  | 75   |
| 6        | 50                              | 150   | 0  | 150  |
| 9        | 85                              | 255   | 50   | 305  |
| 12       | 125                             | 375   | 100  | 475  |
| 15       | 160                             | 480   | 170  | 650  |
| 18       | 185                             | 555   | 250  | 805  |
| 21       | 160                             | 480   | 320  | 800  |
| 24       | 110                             | 330   | 370  | 700  |
| 27       | 60                              | 180   | 320  | 500  |
| 30       | 36                              | 108   | 220  | 328  |
| 33       | 25                              | 75  | 120  | 195  |
| 36       | 16                              | 48  | 72   | 120  |
| 39       | 8                               | 24  | 50   | 74   |
| 42       | 0                               | 0   | 32   | 32   |
| 45       | 0                               | 0   | 16   | 16   |
| 48       | 0                               | 0   | 0  | 0  |

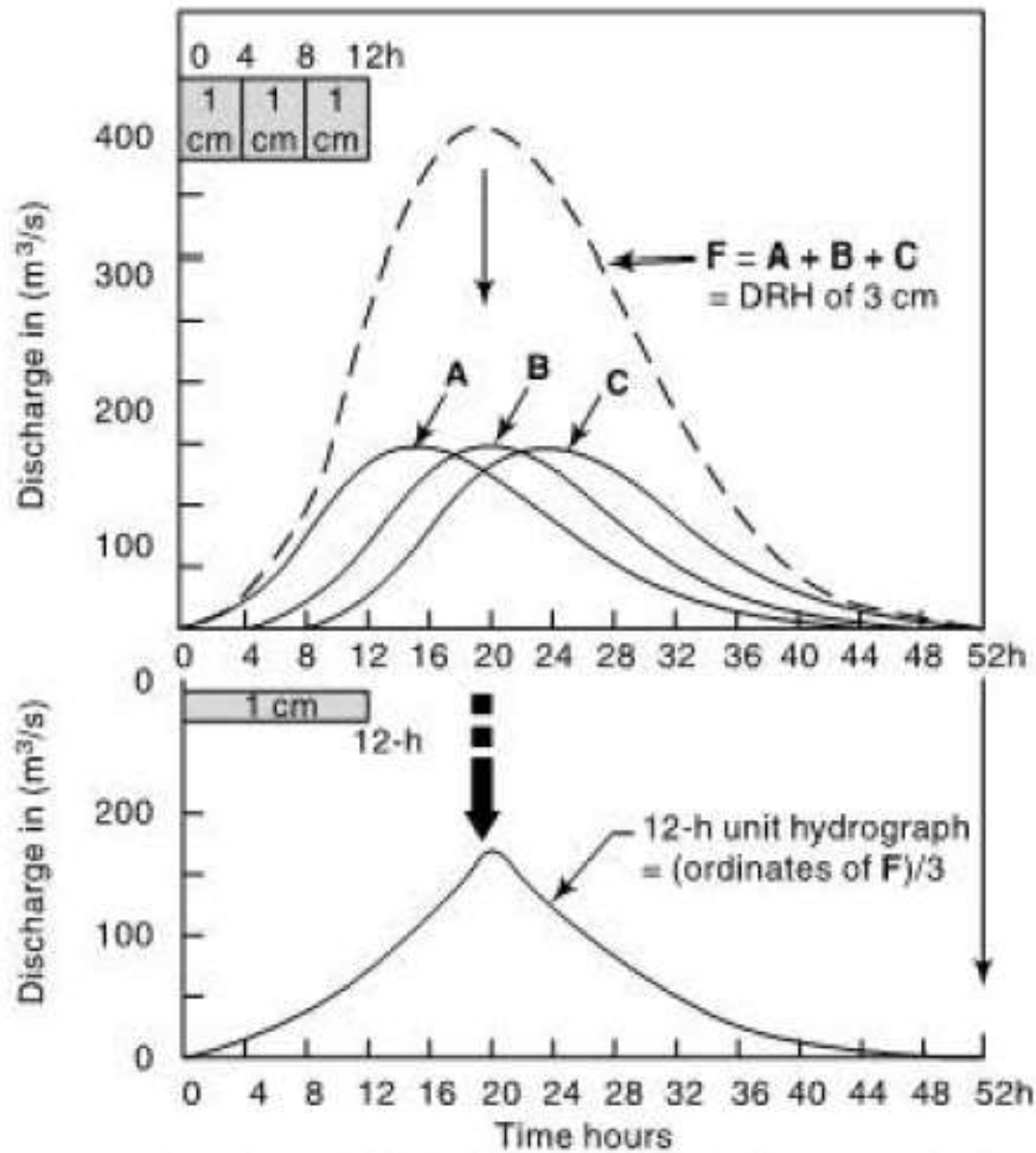
# Superposition Method

## Problem 3

Given the ordinates of a 4-h unit hydrograph as below. Derive the ordinates of a 12 h unit hydrograph for the same catchment.

| Time (h) | UH of 4 h ordinate<br>(m <sup>3</sup> /s) |
|----------|---|
| 0        | 0   |
| 4        | 20  |
| 8        | 80  |
| 12       | 130                                       |
| 16       | 150                                       |
| 20       | 130                                       |
| 24       | 90  |
| 28       | 52  |
| 32       | 27  |
| 36       | 15  |
| 40       | 5   |
| 44       | 0   |

| Time (h) | ordinate of 4 h UH<br>(m <sup>3</sup> /s) |                    |                    | DRH of 3cm in 12 h<br>(m <sup>3</sup> /s)<br>(col.3 +col.4+col.5) | Ordinate of<br>12-h UH<br>(m <sup>3</sup> /s)<br>(col. 5 /3) |
|----------|---|--------------------|--------------------|---|--|
|          | A   | B<br>Lagged by 4-h | C<br>Lagged by 8-h |   |  |
| Col 1    | Col 2                                     | Col 3              | Col 4              | Col 5   | Col 6  |
| 0        | 0   | -                  | -                  | 0   | 0  |
| 4        | 20  | 0                  | -                  | 20  | 6.7  |
| 8        | 80  | 20                 | 0                  | 100   | 33.3   |
| 12       | 130                                       | 80                 | 20                 | 230   | 76.7   |
| 16       | 150                                       | 130                | 80                 | 360   | 120.0  |
| 20       | 130                                       | 150                | 130                | 410   | 136.7  |
| 24       | 90  | 130                | 150                | 370   | 123.3  |
| 28       | 52  | 90                 | 130                | 272   | 90.7   |
| 32       | 27  | 52                 | 90                 | 169   | 56.3   |
| 36       | 15  | 27                 | 52                 | 94  | 31.3   |
| 40       | 5   | 15                 | 27                 | 47  | 15.7   |
| 44       | 0   | 5                  | 15                 | 20  | 6.7  |
| 48       |   | 0                  | 5                  | 5   | 1.7  |
| 52       |   |                    | 0                  | 0   | 0  |



Construction of a 12-h Unit Hydrograph from a 4-h Unit Hydrograph—

