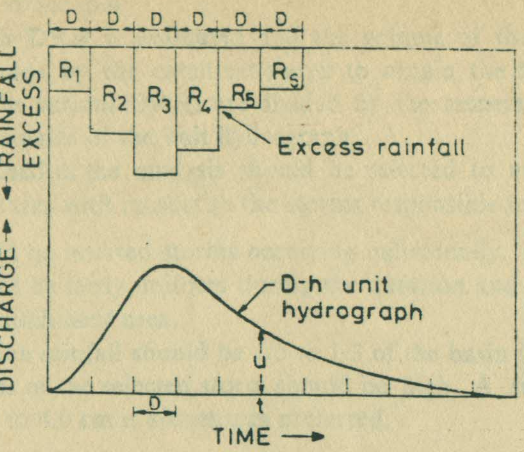

Fig. 6.10 DRH due to an ERH

Thus at any time t, the total direct runoff is

$$Q_t = \sum_{i=1}^{M} Q_i = \sum_{i=1}^{M} R_i \cdot u[t-(i-1)\,D] \tag{6.5}$$

The arithmetic calculations of Eq. (6.5) are best performed in a tabular manner as indicated in Examples 6.4 and 6.5. After deriving the nett DRH, the estimated base flow is then added to obtain the total flood hydrograph.

EXAMPLE 6.5 *The average storm rainfall values over a catchment in three successive 6-h intervals are known to be 3.5, 7.5 and 5.5 cm. The storm loss rate (ϕ index) for the catchment is estimated at 0.25 cm/h. Using the 6-h unit hydrograph ordinates of Example 6.4, estimate the direct-runoff hydrograph. If the base flow can be assumed to be 15 m³/s at the beginning and increasing by 2.0 m³/s every 12 h, till the end of the direct-runoff hydrograph, estimate the resulting flood hydrograph.*

The effective rainfall hyetograph is calculated as in the following table.

Interval	1st 6 hours	2nd 6 hours	3rd 6 hours
Rainfall depth (cm)	3.5	7.5	5.5
Loss @ 0.25 cm/h for 6 h	1.5	1.5	1.5
Effective rainfall (cm)	2.0	6.0	4.0

The direct runoff hydrograph is next calculated by the method of superposition as indicated in Table 6.4. The ordinates of the unit hydrograph are multiplied by the ER values successively. The second and third set of ordinates are advanced by 6 and 12 h respectively and the ordinates at a

TABLE 6.4 CALCULATION OF FLOOD HYDROGRAPH DUE TO A KNOWN ERH—EXAMPLE 6.5

Time	Ordinates of U.H	Col. 2 ×2.0	Col. 2 ×6.0 (Advanced by 6 h)	Col. 2 ×4.0 (Advanced by 12 h)	Ordinates of final DRH (Col. 3+4+5)	Base flow (m^3/s)	Ordinates of flood hydrograph (m^3/s) (Col. 6+7)
1	2	3	4	5	6	7	8
0	0	0	0	0	0	15	15
3	25	50	0	0	50	15	65
6	50	100	0	0	100	15	115
9	85	170	150	0	320	15	335
12	125	250	300	0	550	17	567
15	160	320	510	100	930	17	947
18	185	370	750	200	1320	17	1337
(21)	(172.5)	(345)	(960)	(340)	(1645)	(17)	(1662)
24	160	320	1110	500	1930	19	1949
(27)	(135)	(270)	(1035)	(640)	(1945)	19	1964
30	110	220	960	740	1920	19	1939
36	60	120	660	640	1420	21	1441
42	36	72	360	440	872	21	893
48	25	50	216	240	506	23	529
54	16	32	150	144	326	23	349
60	8	16	96	100	212	25	237
66	(2.7)	(5.4)	(48)	(64)	(117)	25	142
69	0	0	—	—	—	—	—
72		0	16	32	48	27	75
75		0	0	—	—	—	—
78		0	0	(10.8)	(11)	27	49
81				0	0	27	27
84						27	27

Note : Due to the unequal time intervals of unit hydrograph ordinates, a few entries, indicated in parentheses have to be interpolated to complete the table.

given time interval added. The base flow is then added to obtain the flood hydrograph Col. 8, Table 6.4.

6.7 DERIVATION OF UNIT HYDROGRAPHS

A number of isolated storm hydrographs caused by short spells of rainfall excess, each of approximately same duration [0.90 to 1.1 *D* h] are selected from a study of the continuously gauged runoff of the stream. For each of these surface hydrographs, the base flow is separated by adopting one of the methods indicated in Sec. 6.4.

The area under each DRH is evaluated and the volume of the direct runoff obtained is divided by the catchment area to obtain the depth of ER. The ordinates of the various DRHs are divided by the respective ER values to obtain the ordinates of the unit hydrograph.

Flood hydrographs used in the analysis should be selected to meet the following desirable features with respect to the storms responsible for them:

1. The storms should be isolated storms occurring individually.
2. The rainfall should be fairly uniform during the duration and should cover the entire catchment area.
3. The duration of the rainfall should be 1/5 to 1/3 of the basin lag.
4. The rainfall excess of the selected storm should be high. A range of ER values of 1.0 to 4.0 cm is sometimes preferred.

A number of unit hydrographs of a given duration are derived by the above method and then plotted on a common pair of axes as shown in Fig. 6.11. Because of rainfall variations both in space and time and due to some departures from the assumptions of the unit-hydrograph theory, the various unit hydrographs thus developed will not be identical. It is common practice to adopt a mean of such curves as the unit hydrograph of a given duration for the catchment. While deriving the mean curve, the average of peak flows and time to peaks are first calculated. Then a mean curve of best fit, judged by eye, is drawn through the averaged peak to close on an averaged base length. The volume of DRH is calculated and any departure from unity is corrected by adjusting the value of the peak. The averaged ERH of unit depth is customarily drawn in the plot of the unit hydrograph to indicate the type and duration of rainfall causing the unit hydrograph.

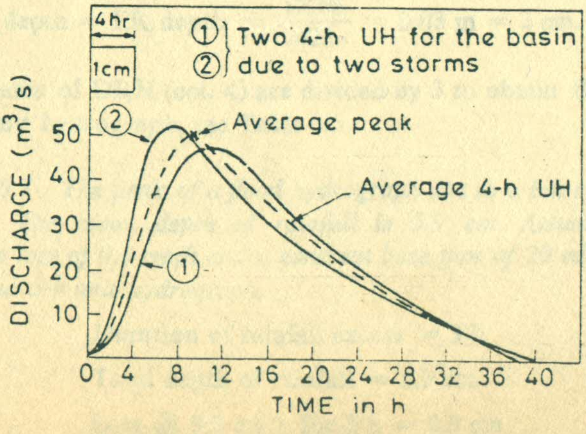

Fig. 6.11 Derivation of an average unit hydrograph

By definition the rainfall excess is assumed to occur uniformly over the catchment during duration D of a unit hydrograph. An ideal duration for a unit hydrograph is one wherein small fluctuations in the intensity of rainfall within this duration do not have any significant effects on the runoff. The catchment has a damping effect on the fluctuations of the rainfall intensity in the runoff-producing process and this damping is a function of the catchment area. This indicates that larger durations are admissible for larger catchments. By experience it is found that the duration of the unit hydrograph should not exceed 1/5 to 1/3 basin lag. For catchments of sizes larger than 250 km^2 the duration of 6 h is generally satisfactory.

EXAMPLE 6.6 *Following are the ordinates of a storm hydrograph of a river draining a catchment area of 423 km^2 due to a 6-h isolated storm. Derive the ordinates of a 6-h unit hydrograph for the catchment.*

Time from start of storm (h)	−6	0	6	12	18	24	30	36	42	48
Discharge (m^3/s)	10	10	30	87.5	115.5	102.5	85.0	71.0	59.0	47.5

Time from start of storm (h)	54	60	66	72	78	84	90	96	102
Discharge (m^3/s)	39.0	31.5	26.0	21.5	17.5	15.0	12.5	12.0	12.0

The storm hydrograph is plotted to scale (Fig. 6.12). Denoting the time from beginning of storm as t, by inspection of Fig. 6.12,

A = beginning of DRH $t = 0$

B = end of DRH $t = 90$ h [redacted]

P_i = point of inflection $t = 24$ h

Hence

$$N = (90 - 24) = 66 \text{ h} = 2.75 \text{ days}$$

By Eq. (6.4),

$$N = 0.83\,(423)^{0.2} = 2.78 \text{ days,}$$

However, $N = 2.75$ days is adopted for convenience. A straight line joining A and B is taken as the divide line for base-flow separation. The ordinates of DRH are obtained by subtracting the base flow from the ordinates of the storm hydrograph. The calculations are shown in Table 6.5

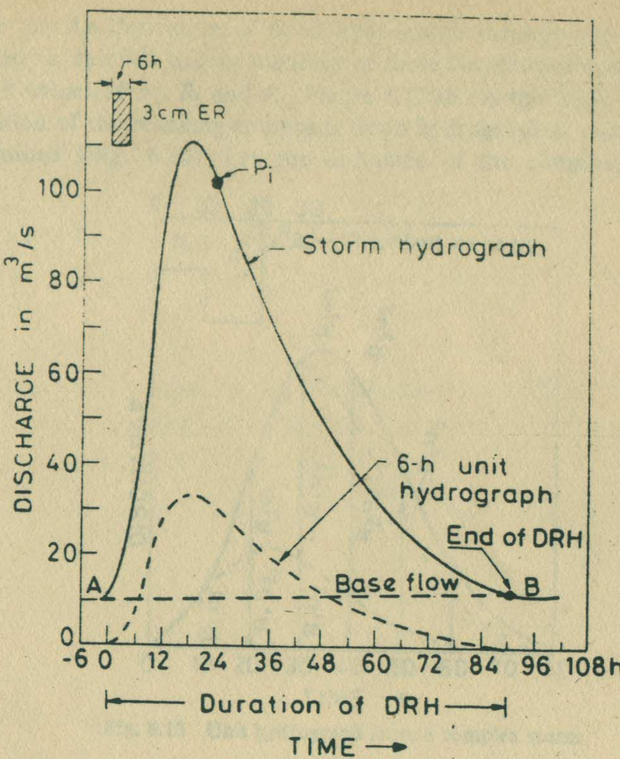

Fig. 6.12 Derivation of unit hydrograph from a storm hydrograph

Volume of DRH $= 60 \times 60 \times 6 \times$ (sum of DRH ordinates)

$= 60 \times 60 \times 6 \times 587 = 12.68$ Mm^3

Drainage area $= 423$ km^2 $= 423$ Mm^2

$$\text{Runoff depth} = \text{ER depth} = \frac{12.68}{423} = 0.03 \text{ m} = 3 \text{ cm.}$$

The ordinates of DRH (col. 4) are divided by 3 to obtain the ordinates of the 6-h unit hydrograph, see Table 6.5.

Example 6.7 *The peak of a flood hydrograph due to a 3-h effective storm is 270 m³/s. The mean depth of rainfall is 5.9 cm. Assuming an average infiltration loss of 0.3 cm/h and a constant base flow of 20 m³/s, estimate the peak of the 3-h unit hydrograph.*

Duration of rainfall excess = 3 h

Total depth of rainfall = 5.9 cm

Loss @ 0.3 cm/h for 3 h = 0.9 cm

Rainfall excess = 5.9 − 0.9 = 5.0 cm

TABLE 6.5 CALCULATION OF THE ORDINATES OF A 6-h UNIT HYDROGRAPH—EXAMPLE 6.6

Time from beginning of storm (h)	Ordinate of storm hydrograph (m^3/s)	Base flow (m^3/s)	Ordinate of DRH (m^3/s)	Ordinate of 6-h unit hydrograph (Col. 4 ÷ 3)
1	2	3	4	5
—6	10.0	10.0	0	0
0	10.0	10.0	0	0
6	30.0	10.0	20.0	6.7
12	87.5	10.5	77.0	25.7
18	111.5	10.5	101.0	33.7
24	102.5	10.5	92.0	30.7
30	85.0	11.0	74.0	24.7
36	71.0	11.0	60.0	20.0
42	59.0	11.0	48.0	16.0
48	47.5	11.5	36.0	12.0
54	39.0	11.5	27.5	9.2
60	31.5	11.5	20.0	6.6
66	26.0	12.0	14.0	4.6
72	21.5	12.0	9.5	3.2
78	17.5	12.0	5.5	1.8
84	15.0	12.5	2.5	0.8
90	12.5	12.5	0	0
96	12.0	12.0	0	0
102	12.0	12.0	0	0
			Sum = 587.0	195.7

Example 6.7 (*Contd.*)

Peak flow:

Peak of flood hydrograph = 270 m^3/s

Base flow = 200 m^3/s

Peak of DRH = 250 m^3/s

$$\text{Peak of 3-h unit hydrograph} = \frac{\text{peak of DRH}}{\text{rainfall excess}}$$

$$= \frac{250}{5.0} = 50 \text{ m}^3/\text{s}$$

Unit Hydrograph from a Complex Storm

When suitable simple isolated storms are not available, data from complex storms of long duration will have to be used in unit-hydrograph derivation. The problem is to decompose a measured composite flood hydrograph into its component DRHs and base flow. A common unit hydrograph of appropriate duration is assumed to exist. This problem is thus the