H.W: A storm of rainfall over catchment area 5 km^2 with duration of 12 hrs. The accumulated rainfall (mass curve) is given as;

Time (hr)	0	2	4	6	8	10	12
Acc. depth (cm)	0	0.5	2.5	5.0	6.5	7.5	9.3

The ϕ-index is equal to 0.4 cm/hr. Plot the hyetograph of effective rainfall (ER) and calculate the volume of direct runoff.

Unit Hydrograph الهيدروغراف القياسي

A unit hydrograph method was first suggested by Sherman in 1932 to predicting the flood hydrograph resulting from known storm.
ان مسألة التنبؤ بالهيدروغراف الفيضاني الناتج عن عاصفة مطرية معروفة كل الابعاد قد حظيت باهتمام كبير واقترحت عدة طرق لحل هذه المسألة وكان اكثرها شيوعاً هو طريقة الهيدروغراف القياسي التي اقترحها شيرمان عام وحظيت لاحقاً بعدة تحسينات
It has undergone many refinements since then.

Definition

It is the hydrograph of direct runoff resulting from one unit depth (1 cm) of rainfall excess occurring uniformly over the basin and at uniform rate for a specified duration D.
يعرف بأنه هيدروغراف السيح المباشر والناتج عن وحدة عمق (1 سم) للمطر الزائد تحت شكل منتظم وبشدة ثابتة خلال D فترة ثابتة.

The definition of U-H implies the following:

- the hydrograph represents the lumped response of the catchment to a unit rainfall excess of D-duration
  الهيدروغراف الفيضاني يمثل رد فعل الحوض للامطار الزائدة ذات الاستدامة D.
- The rainfall considered to have intensity of ER of (1/D) cm/hr for duration D-h.
- The distribution of the storm is considered to be uniform over catchment

Two basic assumptions were considered for unit-hydrograph theory:

1. time invariance ثبات الوقت
2. Linear response الاستجابة الخطية

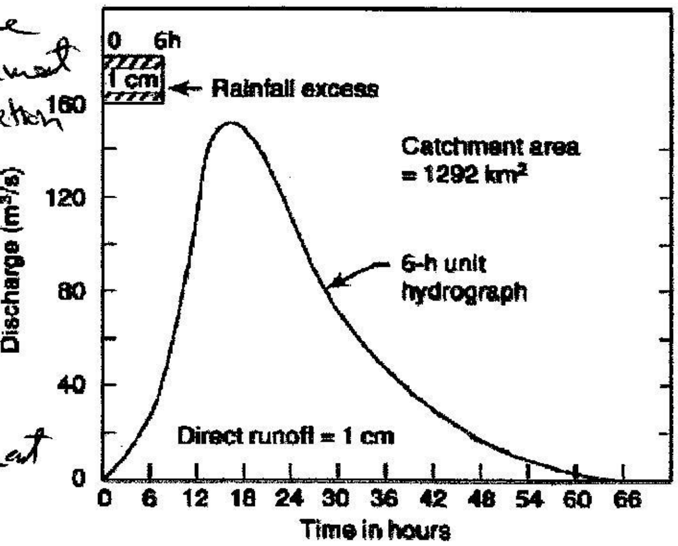

Fig. 13 Typical 6-h Unit Hydrograph

Note: Catchment area = 1292 km^2
Area under U-H = 12.92×10^6 m^3
what is the relation?

Example 4

Given below the ordinates of 6-h UH for a catchment. Calculate the ordinate of the DRH due to rainfall excess of 3.5 cm occurred in 6h.

Time (h)	0	3	6	9	12	15	18	24	30	36	42	48	54	60	69
UH ordinate (m^3/s)	0	25	50	85	125	160	185	160	110	60	36	25	16	8	0

Solution

The ordinates of DRH are obtained by multiplying the ordinates of UH by (3.5) as in table below. The interval of the table (col. 1) are not in any way related to rainfall excess duration and can be any convenient value.

Time (h)	Ordinate of 6-h unit hydrograph (m^3/s)	Ordinate of 3.5 cm DRH (m^3/s)
1	2	3
0	0	0
3	25	87.5
6	50	175.0
9	85	297.5
12	125	437.5
15	160	560.0
18	185	647.5
24	160	560.0
30	110	385.0
36	60	210.0
42	36	126.0
48	25	87.5
54	16	56.0
60	8	28.0
69	0	0

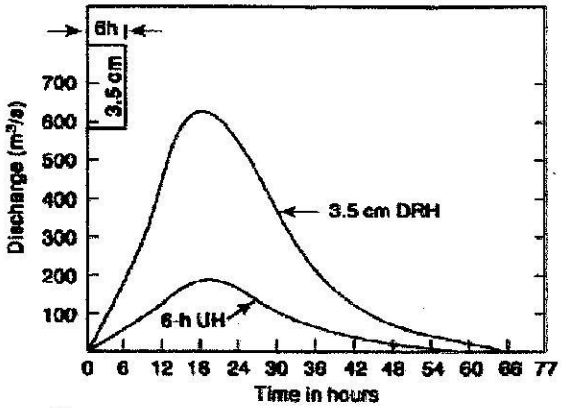

Fig. 14 — 3.5 cm DRH derived from 6-h Unit Hydrograph — Example 4

Example 5

Two storms of 6-h duration having excess values of 3.0 & 2.0 cm, respectively. The 2 cm ER follows the 3 cm rain. Use the UH of example 4 to calculate the DHR of the two storms.

Time (h)	Ordinate of 6-h UH (m^3/s)	Ordinate of 3-cm DRH (col. 2) × 3	Ordinate of 2-cm DRH (col. 2 lagged)	Ordinate of 5-cm DRH (col. 3 + 4)	Remarks
1	2	3	4	5	6
0	0	0	0	0	
3	25	75	0	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)	(172.5)	(517.5)	(320)	(837.5)	Interpolated value
24	160	480	370	850	
30	110	330	320	650	
36	60	180	220	400	
42	36	108	120	228	
48	25	75	72	147	
54	16	48	50	98	
60	8	24	32	56	
(66)	(2.7)	(8.1)	(16)	(24.1)	Interpolated value
69	0	0	(10.6)	(10.6)	Interpolated value
75	0	0	0	0	

Note: 1. The entries in col. 4 are shifted by 6 h in time relative to col. 2.
2. Due to unequal time interval of ordinates a few entries have to be interpolated.

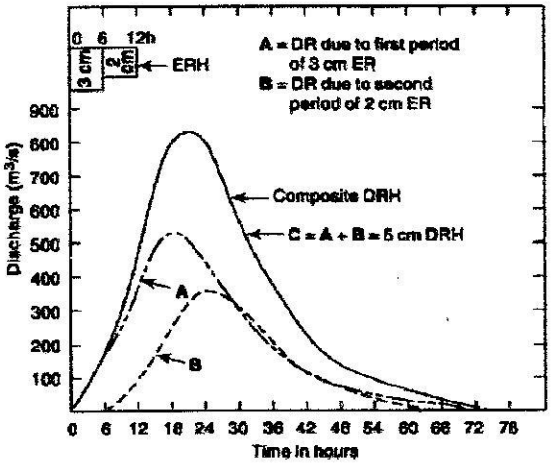

Fig. 15 — Principle of Superposition — Example 5

Application of UH

As followed in Example 5, if a sequence of M rainfall excess value $R_1, R_2, R_3, \ldots, R_M$ all of same duration D-h, the resulting DRH components can be written at t from the begining as; (U(t): coordinates of UH)

$Q_1 = R_1\, U(t)$ [DR due to R_1 at time(t)]

$Q_2 = R_2\, U(t-D)$ [DR due to R_2 at time $(t-D)$]

$Q_i = R_i\, U(t-(i-1)D)$

$Q_m = R_m\, U(t-(m-1)D)$

and thus; at any time(t), the total Componets of DR is:-

$$Q_t = \sum_{i=1}^{M} Q_i = \sum_{i=1}^{M} R_i U(t-(i-1)D)$$

thus;

$$\left.\begin{aligned} Q_1 &= R_1 u_1 \\ Q_2 &= R_2 u_1 + R_1 u_2 \\ Q_3 &= R_3 u_1 + R_2 u_2 + R_1 u_3 \end{aligned}\right\} \text{DRH} = Q_t$$

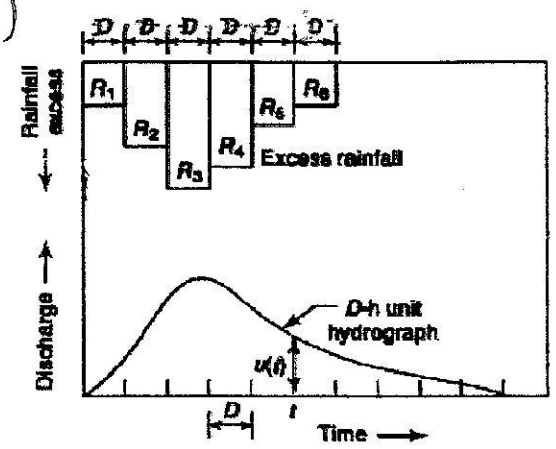

Fig. 16 DRH due to an ERH

Example 6

The ordinates of 6-h UH is given below :-

Time (h)	0	3	6	9	12	15	18	24	30	36	42	48	54	60	69
Ordinate of 6-h UH	0	25	50	85	125	160	185	160	110	60	36	25	16	8	0

Derive the flood hydrograph in the catchment due to the storm as;

Time from start of storm (h)	0	6	12	18
Accumulated rainfall (cm)	0	3.5	11.0	16.5

and the storm Loss of rate (ϕ-index) for the catchment is estimated as 0.25cm/hr. The baseflow was assumed to be 15 m^3/s at the begining and increasing by 2 m^3/s for every 12 hrs till the end of hydrograph.

Solution:

Interval	First 6-hrs.	Second 6-hrs.	Third 6-hrs.
Rainfall depth (cm)	3.5	11-3.5 = 7.5	16.5 - 11 = 5.5
Loss @ 2.5cm/hr for each 6 hrs.	1.5	1.5	1.5
Effective rainfall (cm)	2	6	4

Calculation of Flood Hydrograph due to a known *ERH* of example 6.

Time	Ordinates of UH	DRH due to 2 cm ER Col. 2 × 2.0	DRH due to 2 cm ER Col. 2 × 6.0 (Advanced by 6 h)	DRH due to 4 cm ER 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.

Derivation of Unit Hydrograph اشتقاق الهيدروغراف القياسي

The flood hydrograph used in the analysis should be selected to meet the following

- The storm must be isolated storm occurring individually.
- The rainfall should be fairly uniform through the duration over the entire catchment.
- The duration of rainfall ranged from ($\frac{1}{5}$ - $\frac{1}{3}$) of the basin Lag.
- The rainfall excess of the selected storm should be high (1-4 cm).

ملاحظة: للكابيات التي تزيد مساحتها عن 250 كم² فأن أمطار 6 - 8 كم تعد مقبولة.