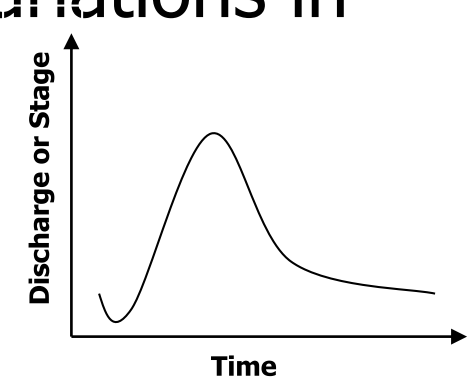
Methods for Estimation of Runoff

- Empirical formulae and tables
- Estimating losses
- Infiltration method
- Rational method
- SCS Curve number
- Unit hydrograph method
- Synthetic unit hydrograph

HYDROGRAPH

Hydrograph

- Graphical representation of variations in discharge or stage with time



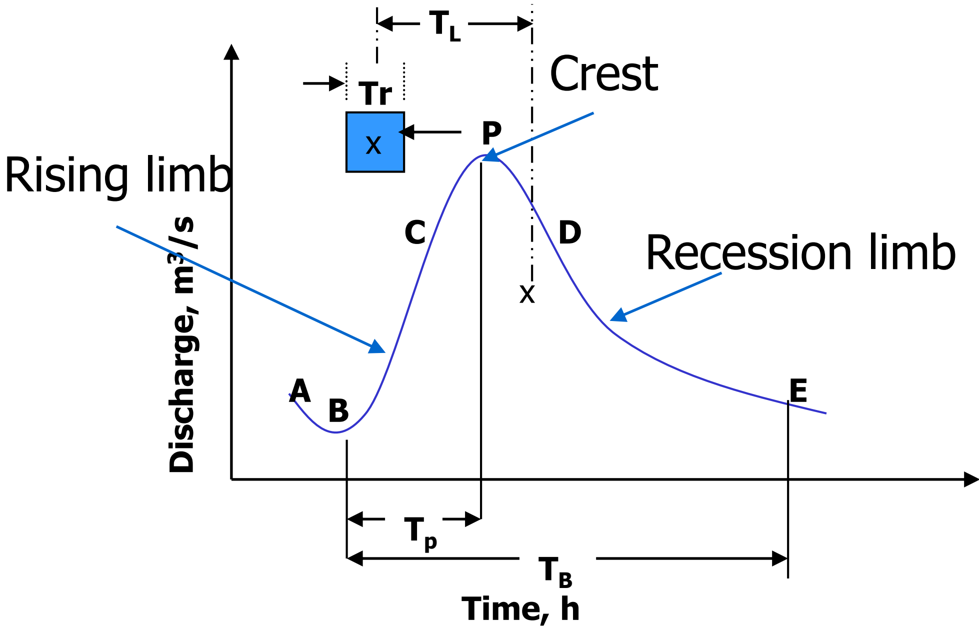
- Hydrograph resulting from an isolated storm
  - Typically a single peaked skewed distribution of discharge
  - Known as Storm Hydrograph, Flood Hydrograph or simply Hydrograph

Elements of a Flood Hydrograph

Time base of hydrograph (T_B) –time from the beginning to the end of the direct runoff.

Lag time (T_L) – time difference between the center of mass of net rainfall and center of mass of runoff.

Time to peak (T_p) – time difference between the beginning of direct runoff (point B in fig.) to peak.



Rainfall duration (T_r) – effective rainfall duration, which causes direct runoff.

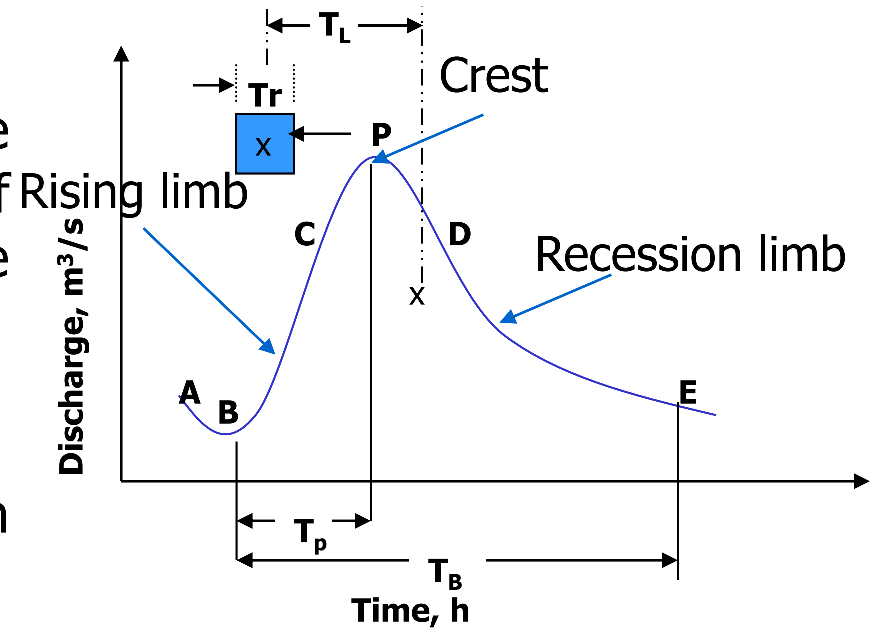
Hydrograph characteristic

❖ **Rising Limb (BC):**

- represents the increase in discharge due to the gradual building up of storage in channels and over the catchment surface.

❖ **Crest segment (CD):**

- most important part of hydrograph as it contains the peak flow.



❖ **Recession limb (DE):**

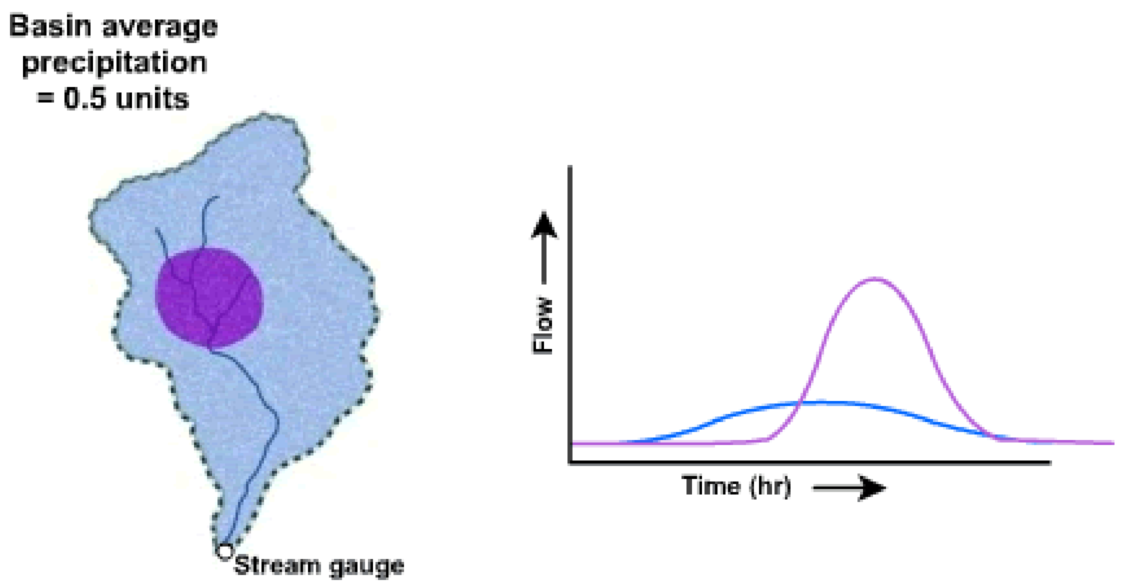
- Represents withdrawal of water from the storage within the basin.
- independent of storm characteristics since begins only after the rainstorm is over

Factors Affecting Hydrograph

- **Climatic factors** ⇨
  - Storm characteristics – *intensity, duration, magnitude and movement of storm*
  - Initial losses
  - Evapotranspiration

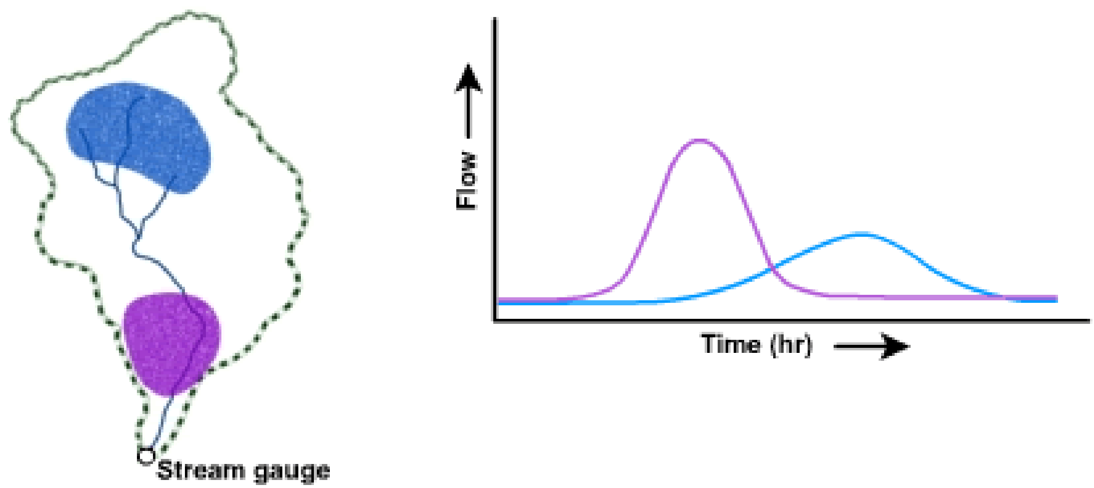
- **Physiographic factors** ⇨
  - Basin characteristics – *shape, size, slope, elevation, and drainage density*
  - Infiltration characteristics
  - Channel characteristics – *cross-section, roughness and storage capacity.*

Uniform Coverage vs. Intense Bull's-Eye for Same Basin-Averaged Rainfall



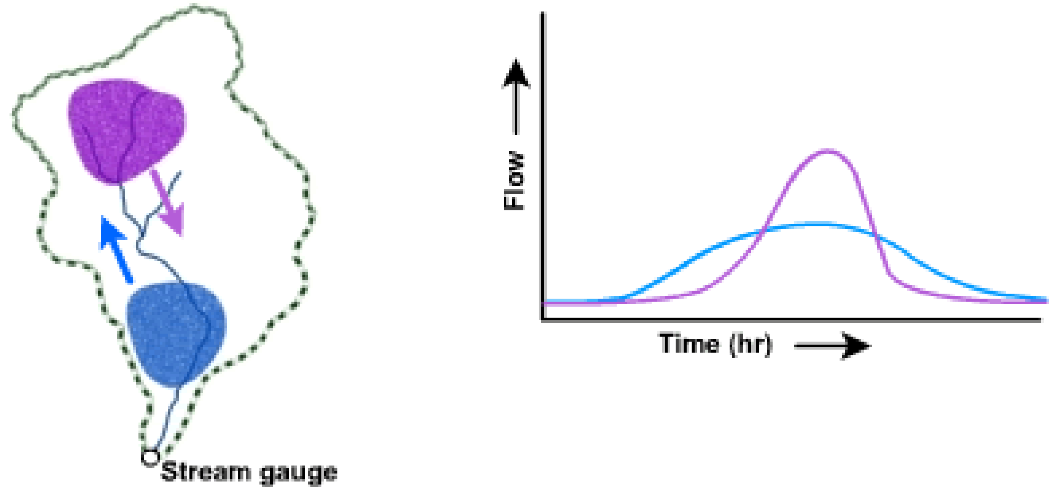
- ◉ Compare uniform coverage to intense bull's-eye
- ○ Uniform rainfall coverage
- ○ Intense rainfall bull's-eye

Upstream vs. Downstream Rainfall Locations for Same Basin-Averaged Rainfall



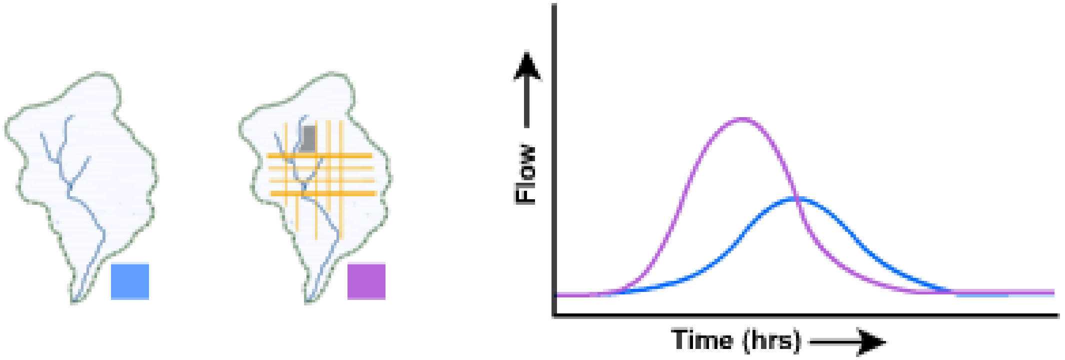
- ◉ Compare upstream and downstream locations
- ○ Upstream location of rainfall
- ○ Downstream location of rainfall

Upstream vs. Downstream Movement of Storm for Same Basin-Averaged Rainfall



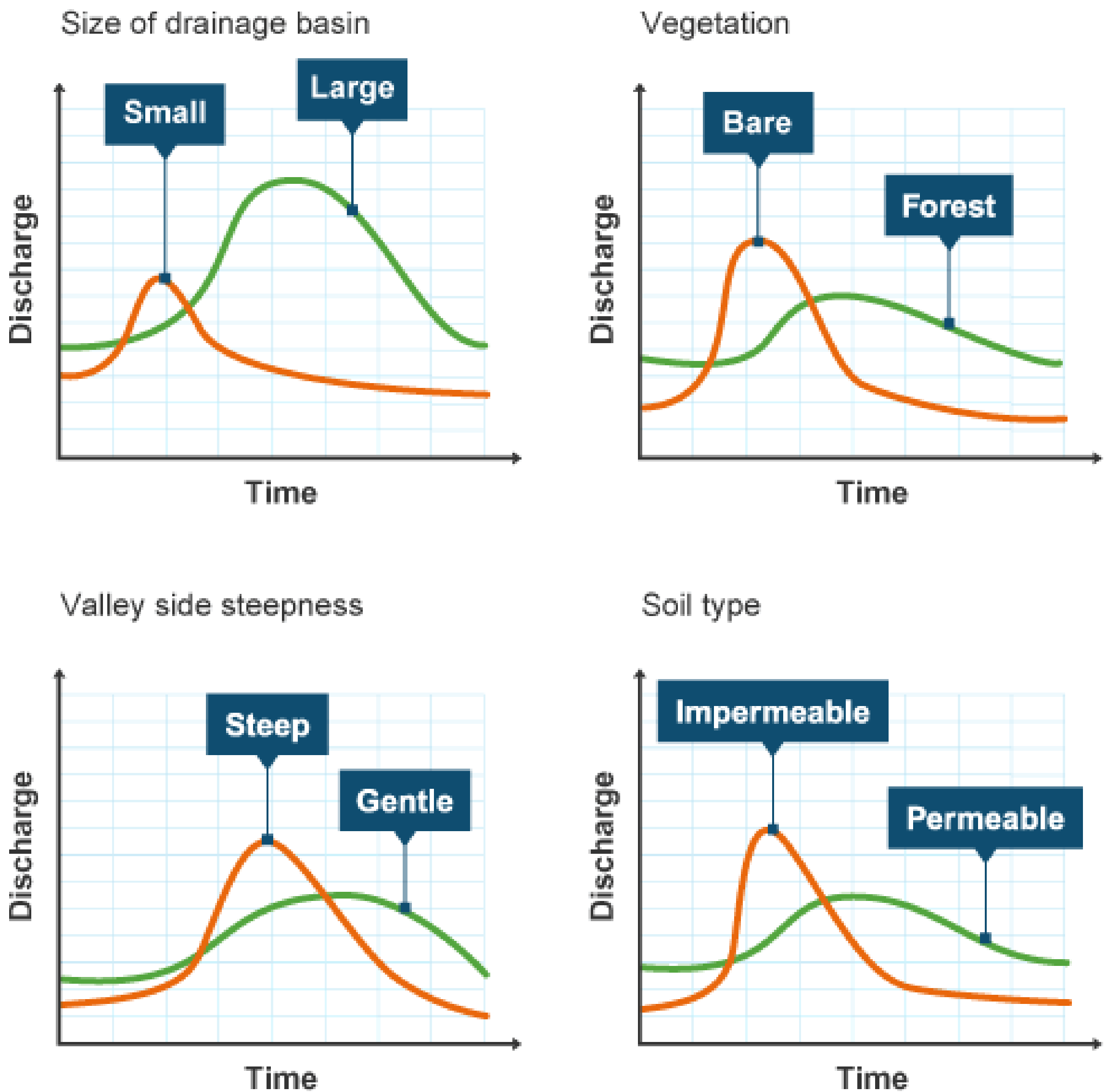
- ◉ Compare upstream to downstream movement
- ○ Upstream movement
- ○ Downstream movement

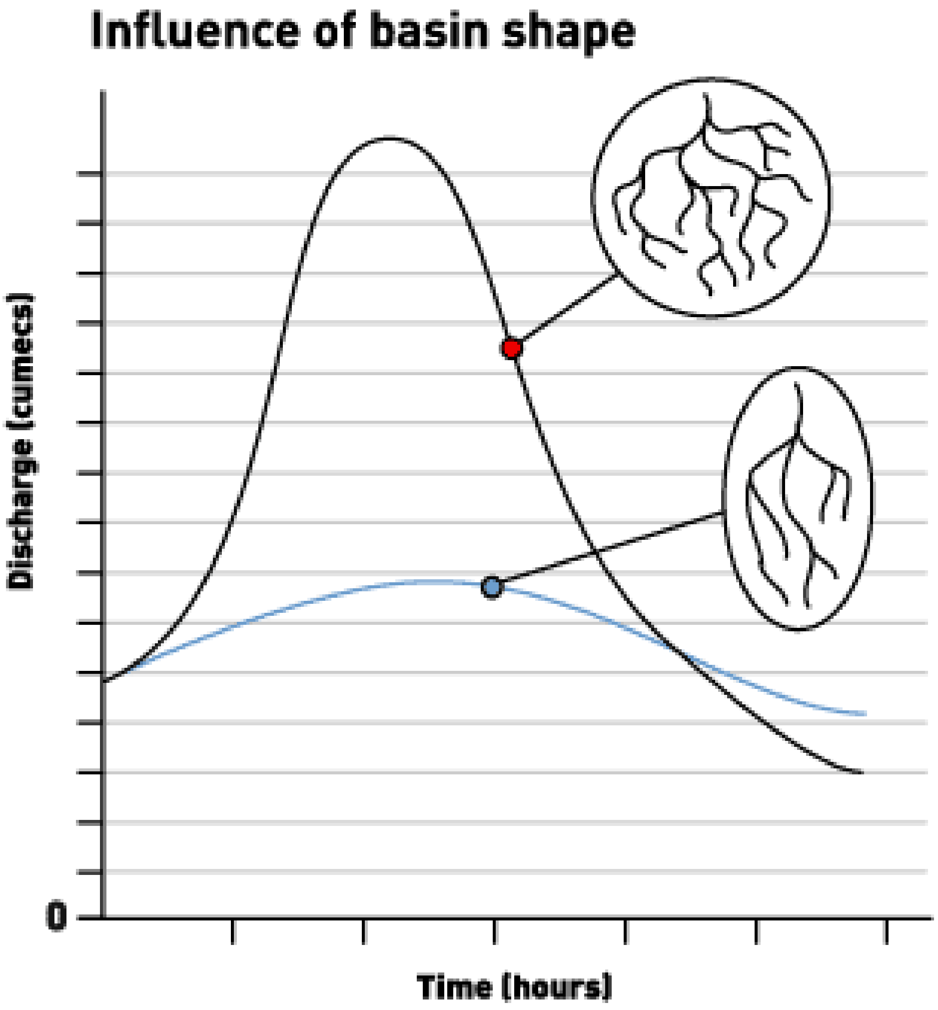
Urban vs. Non-Urban for Same Basin-Averaged Rainfall



For uniform rain coverage:

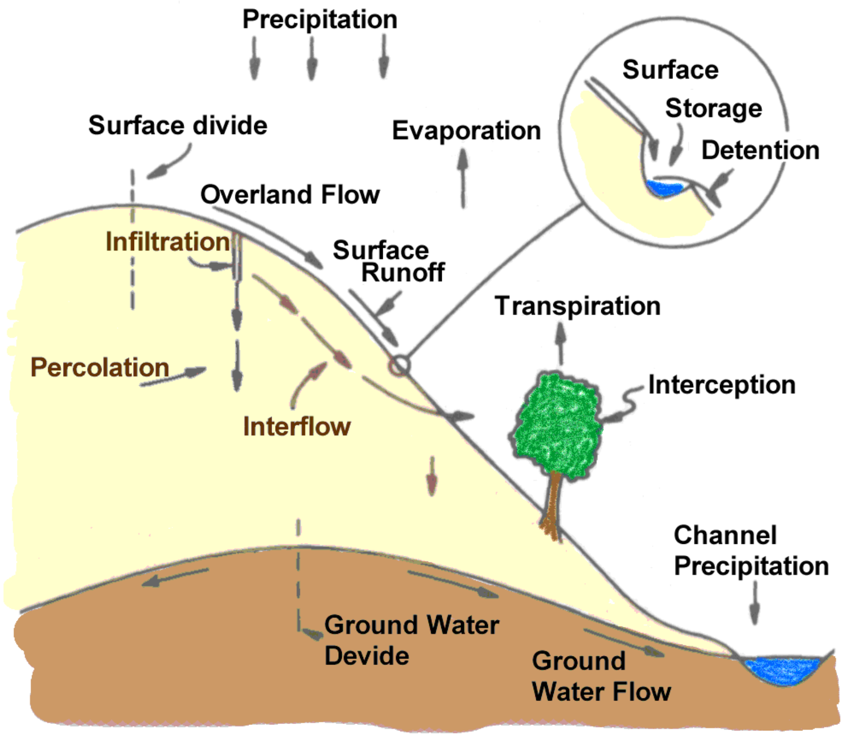
- ◉ Compare non-urban vs. urbanized
- ○ Non-urban
- ○ Urbanized


Size of drainage basin
Small
Large
Discharge
Time
Vegetation
Bare
Forest
Discharge
Time
Valley side steepness
Steep
Gentle
Discharge
Time
Soil type
Impermeable
Permeable
Discharge
Time


Influence of basin shape
Discharge (cumecs)
0
Time (hours)

Hydrograph Analysis or Baseflow Separation

- Division of a storm hydrograph into direct runoff hydrograph (DRH) and ground water runoff hydrograph or base flow is known as hydrograph separation or base-flow separation.



Total Runoff = Direct runoff + Groundwater runoff (baseflow)
Direct runoff = Overland flow + interflow

Hydrograph Analysis or Baseflow Separation

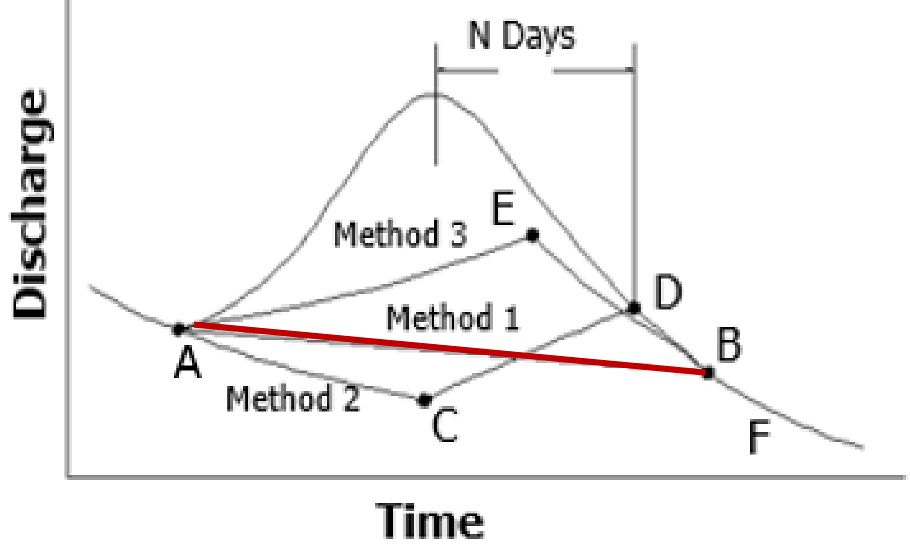
- Several Methods
- There is no clear basis for making a precise distinction between the direct and base flow after they have intermixed in a stream, thus all methods available are approximate

- Selection of a method for a particular basin
  - local practice
  - past experience

Hydrograph Analysis or Baseflow Separation

Method 1:

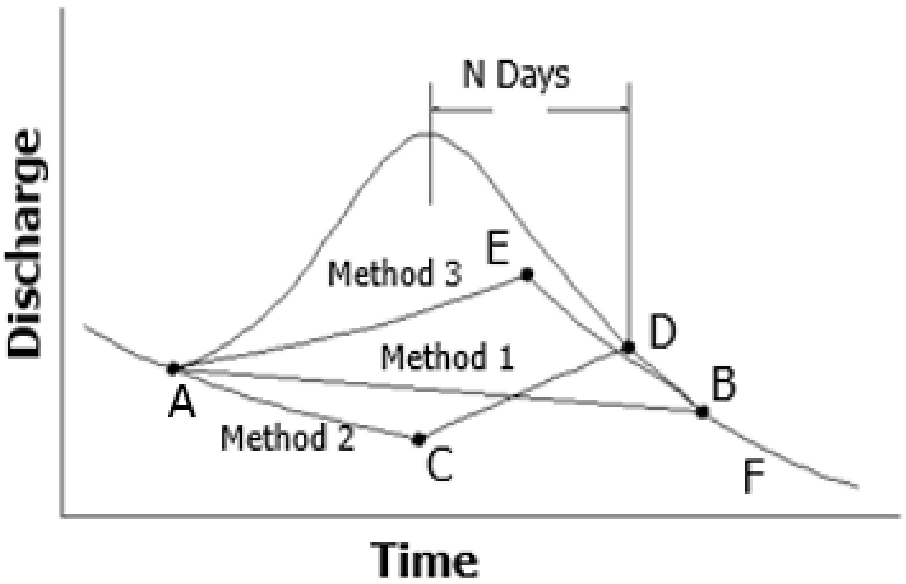
- Join the beginning of the direct runoff (point A) to the end of direct runoff (point B) by straight line.
- If point B is not well defined draw a horizontal line from point A.



Hydrograph Analysis or Baseflow Separation

Method 2:

- Extend the recession curve before the storm to point C beneath the peak.
- Connect point C to point D by straight line.
- Point D on the hydrograph represents N days after the peak



$$N = 0.8A^{0.2}$$

where N = time measured from peak, days

A = drainage area of the basin, sq. km

- It is the most widely used method for base flow separation.

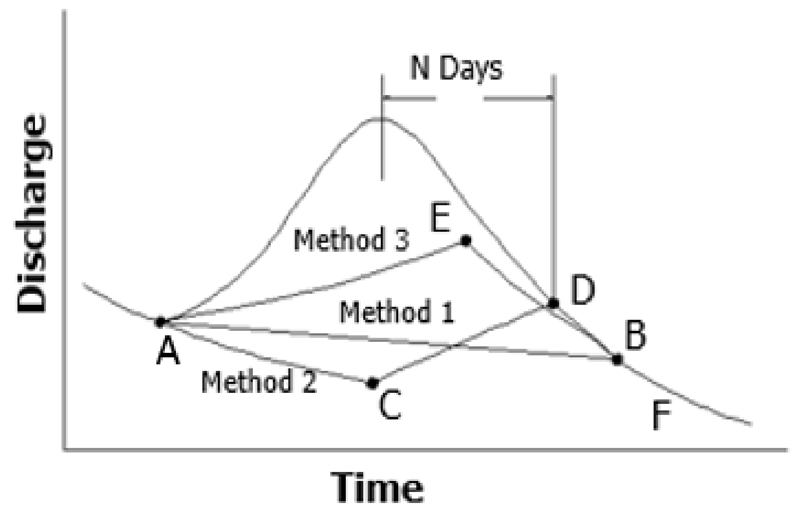
Hydrograph Analysis or Baseflow Separation

Method 3:

- Extend the recession curve backward to point E below the inflection point.

- Connect A and E by a straight line or an arbitrary shape.

- This method is suitable in situations where the groundwater contribution is significant and reaches the stream quickly.



Time

- The inaccuracies involved in the separation of base flow are usually not important.

Problem

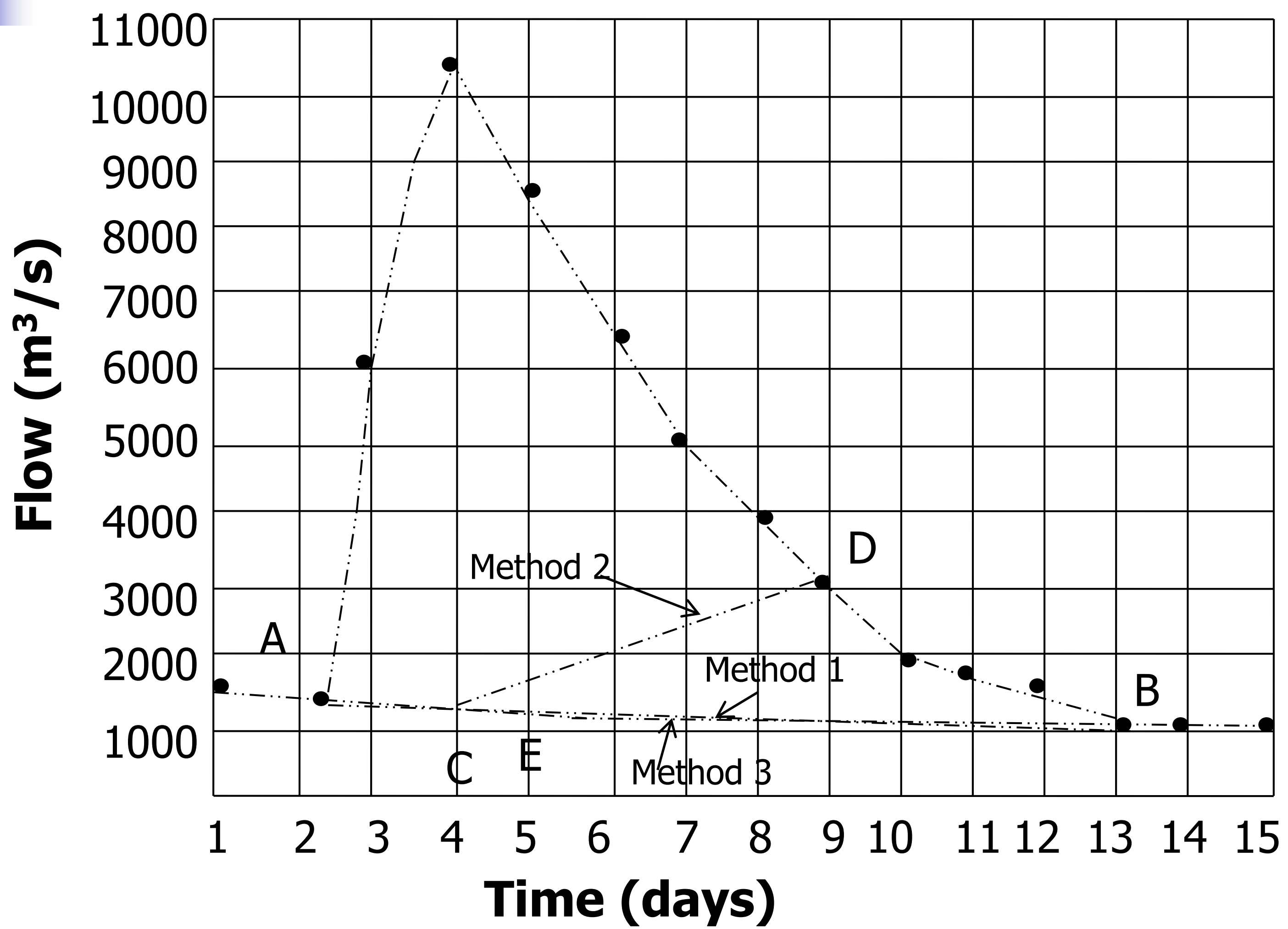
The daily stream flow data at a site having a drainage area of 6500km^2 are given in the following table. Separate the base flow using the above three methods.

Time (days)	Discharge (m^3/s)	Time (days)	Discharge (m^3/s)
1	1600	9	2800
2	1550	10	2200
3	5000	11	1850
4	11300	12	1600
5	8600	13	1330
6	6500	14	1300
7	5000	15	1280
8	3800		

Solution

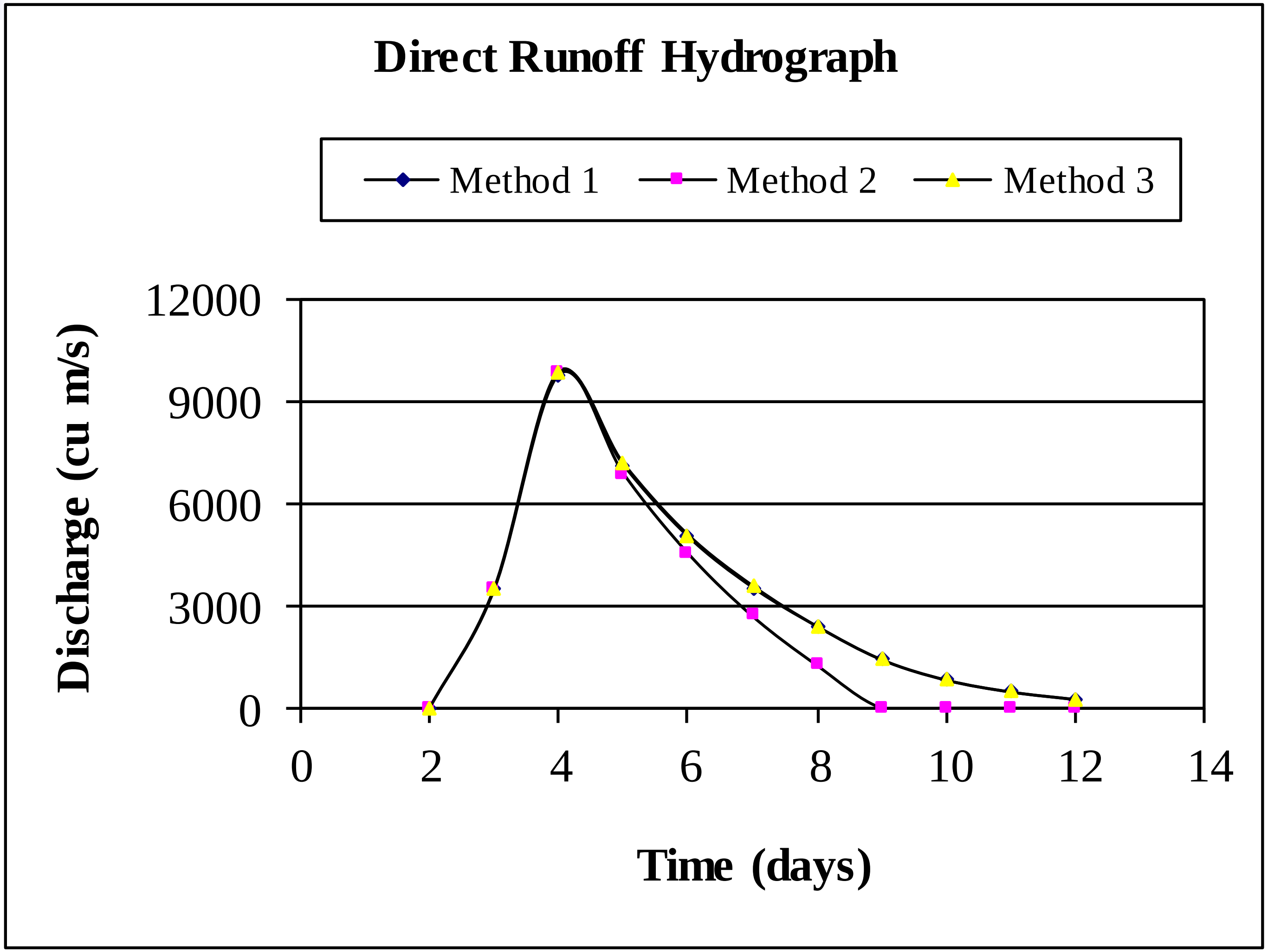
1. Plot the runoff hydrograph
2. Method 1- Join point A, the beginning of direct runoff, to point B, the end of direct runoff. Both points are selected by judgement.
3. Method 2- Extend the recession curve before the storm up to point C below the peak. Joint point C to Point D, computed as follows

   $N = 0.8A^{0.2} = 0.8(6500)^{0.2} = 4.6$ days (approx. 5 days)
4. Method 3- Extend the recession curve backward to point E. Join point E to A.
5. The ordinates of DRH by three methods are given in Table


11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
Flow (m³/s)
A
B
C
D
E
Method 1
Method 2
Method 3
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Time (days)

Ordinates of DRH by different methods

Time (days)	Total Runoff (m^3/s)	Base flow (m^3/s)			Direct runoff (m^3/s)		
		Method 1	Method 2	Method 3	Method 1	Method 2	Method 3
1	1600	1600	1600	1600	0	0	0
2	1550	1550	1550	1550	0	0	0
3	5000	1520	1480	1500	3480	3520	3500
4	11300	1500	1400	1450	9800	9900	9850
5	8600	1450	1700	1400	7150	6900	7200
6	6500	1450	1950	1400	5050	4550	5100
7	5000	1450	2300	1400	3550	2700	3600
8	3800	1400	2550	1400	2400	1250	2400
9	2800	1380	2800	1380	1420	0	1420
10	2200	1380	2200	1380	820	0	820
11	1850	1380	1850	1380	470	0	470
12	1600	1350	1600	1350	250	0	250
13	1330	1330	1330	1330	0	0	0
14	1300	1300	1300	1300	0	0	0
15	1280	1280	1280	1280	0	0	0

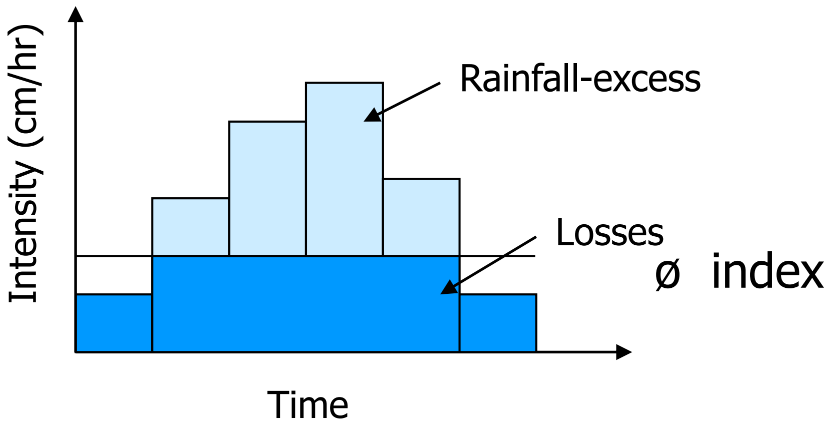


Direct Runoff Hydrograph
Method 1
Method 2
Method 3
12000
9000
6000
3000
0
0
2
4
6
8
10
12
14
Discharge (cu m/s)
Time (days)

Effective Rainfall Hyetograph

- From a hyetograph of a storm, the initial and infiltration losses are deducted

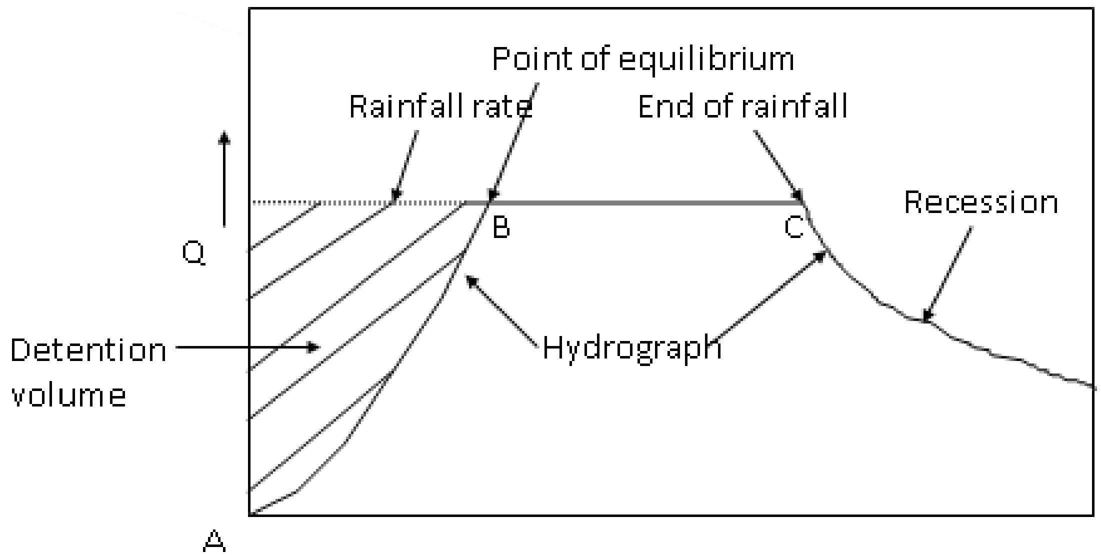
- The resulting hyetograph is known as ERH



- Both DRH and ERH represent the same total volume

- Since ERH is usually in cm/h plotted against time, the area of ERH multiplied by area of catchment gives the total volume of direct runoff, which is same as area under DRH

Elemental Hydrograph



❖If a small, impervious area is subjected to a constant rate rainfall, the resulting runoff hydrograph will appear much as above, and is known as ***elemental hydrograph***.

- Problem

A storm in a certain catchment had three successive 6-h intervals of rainfall magnitude of 3.0 cm, 5.0 cm and 4.0 cm, respectively. The flood hydrograph at the outlet of the catchment resulting from this storm is as follows:

Time (h)	**0**	**6**	**12**	**18**	**24**	**30**	**36**	**42**
Flood Hydrograph Ordinates (m^3/s)	30	480	2060	4450	6010	6010	5080	3996

Time (h)	**48**	**54**	**60**	**66**	**72**	**78**
Flood Hydrograph Ordinates (m^3/s)	2866	1866	1060	500	170	30

If the area of the catchment is 8791.2 km^2, estimate the Φ–index of the storm. Assume the base flow as 30 m^3/s.

Solution

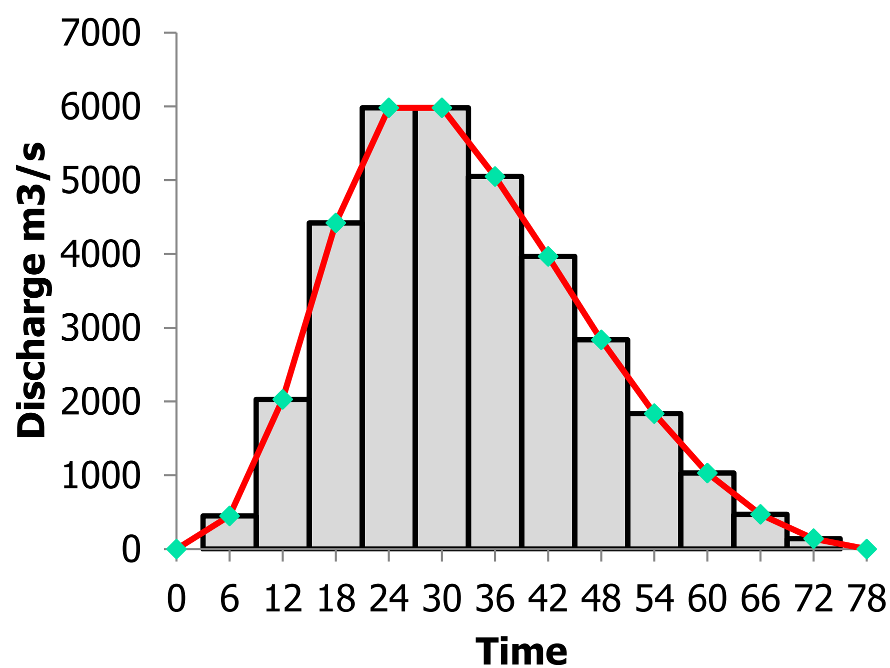
Direct Runoff (cm) $= 0.36 * \frac{(\sum_{i=1}^{N} DRO_i)\Delta t}{A}$

DRO_i =Direct runoff ordinates, m^3/s

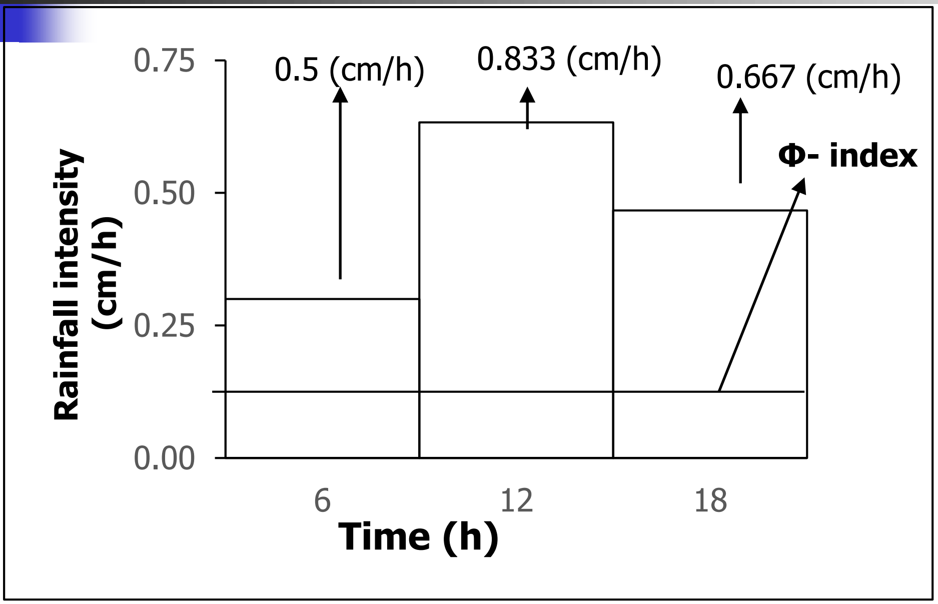
Δt = time interval between successive ordinates, hour

A = catchment area, km^2

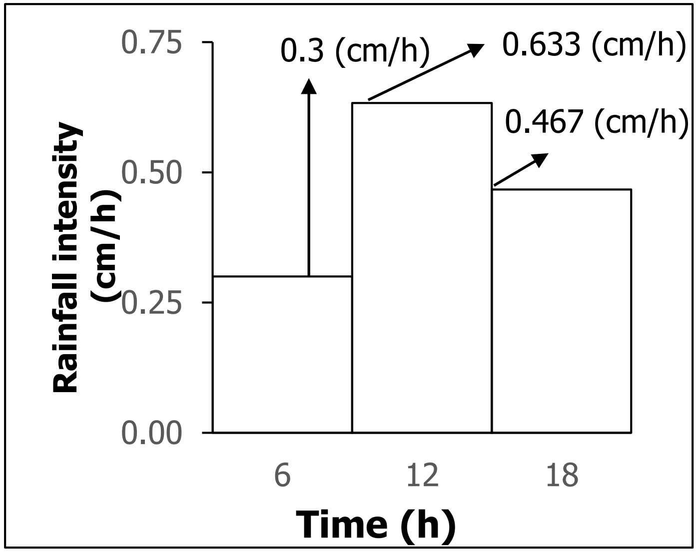
Direct Runoff (cm) = 8.4 cm



Time (h)	Flood Hydr. Ordinates (m^3/s)	Base flow (m^3/s)	Direct Runoff Hyd. Ordinates (m^3/s)
0	30	30	0
6	480	30	450
12	2080	30	2030
18	4450	30	4420
24	6010	30	5980
30	6010	30	5980
36	5080	30	5050
42	3996	30	3966
48	2866	30	2836
54	1866	30	1836
60	1060	30	1030
66	500	30	470
72	170	30	140
78	30	30	0
			34188
		DR	8.4 cm



Hyetograph



Effective rainfall hyetograph

$$(3 - 6\emptyset) + (5 - 6\emptyset) + (4 - 6\emptyset) = 8.4$$
$$18\emptyset = 12 - 8.4 = 3.6$$
$$\emptyset = 0.2\ cm/h$$

Unit Hydrograph (UH)

- UH Concept – developed by Sherman (1932)
- UH is the hydrograph of direct runoff resulting from one unit depth (1 cm or mm or inch) of rainfall excess occurring uniformly over the basin and at a uniform rate for a specified duration (D - h)
- The duration, being a very important characteristic, is used as a prefix to represent a specific unit hydrograph
  - e.g., 2-h unit hydrograph, or 6-h unit hydrograph

Assumptions of UH Theory

1. The effective rainfall is uniformly distributed within its duration or specified period of time

2. The effective rainfall is uniformly distributed over the whole area of drainage basin

3. The unit hydrograph reflects the basic effects of various physical characteristics of the basin, which do not change in time. This implies that the **principle of time invariance** is valid

Assumptions of UH Theory

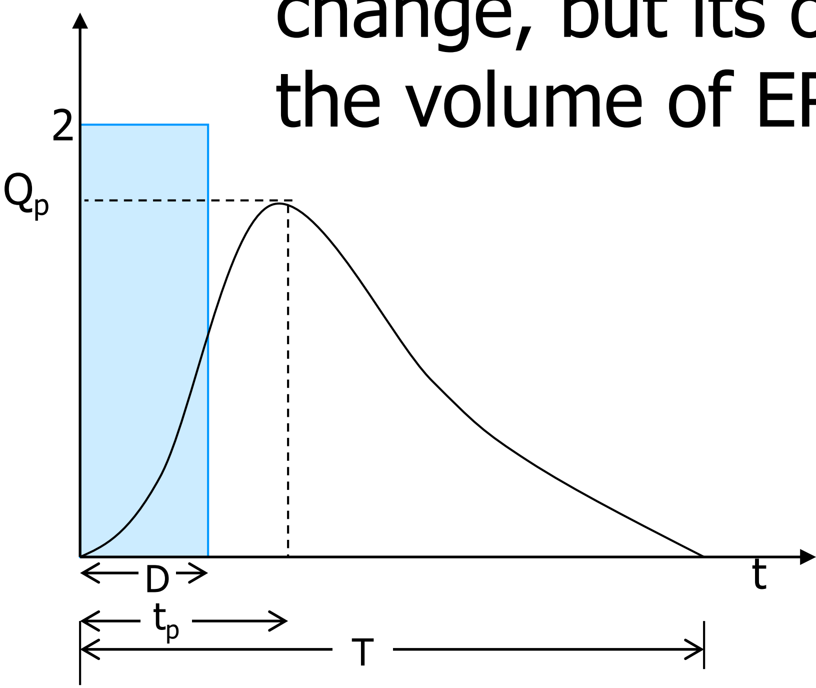
4. The response of the drainage basin is linear. This implies that the **principles of proportionality** and **superposition** are applicable.

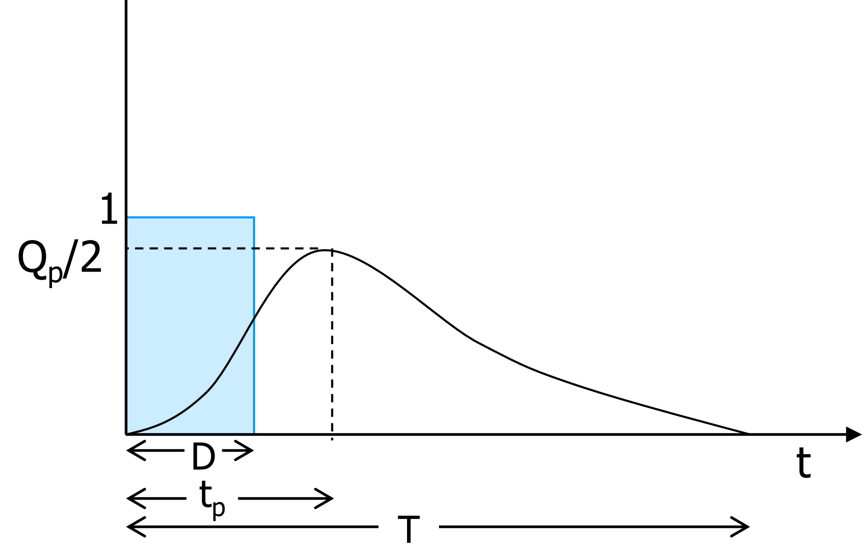
   As per **proportionality principle**, the DRH ordinates are proportional to the effective rainfall intensity.

   As per **superposition principle,** DRH ordinates due to a complex storm, having varying effective rainfall intensities, can be obtained by superimposing the DRH due to each element of effective rainfall in succession

Principle of proportionality

- According to the principle of proportionality, if the duration of ER is fixed but its volume changes, then the duration of DR does not change, but its ordinates do in proportion to the volume of ER



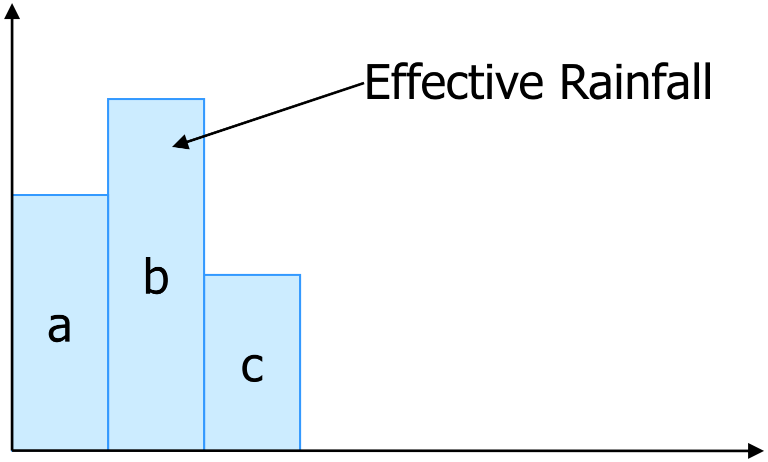


Principle of superposition

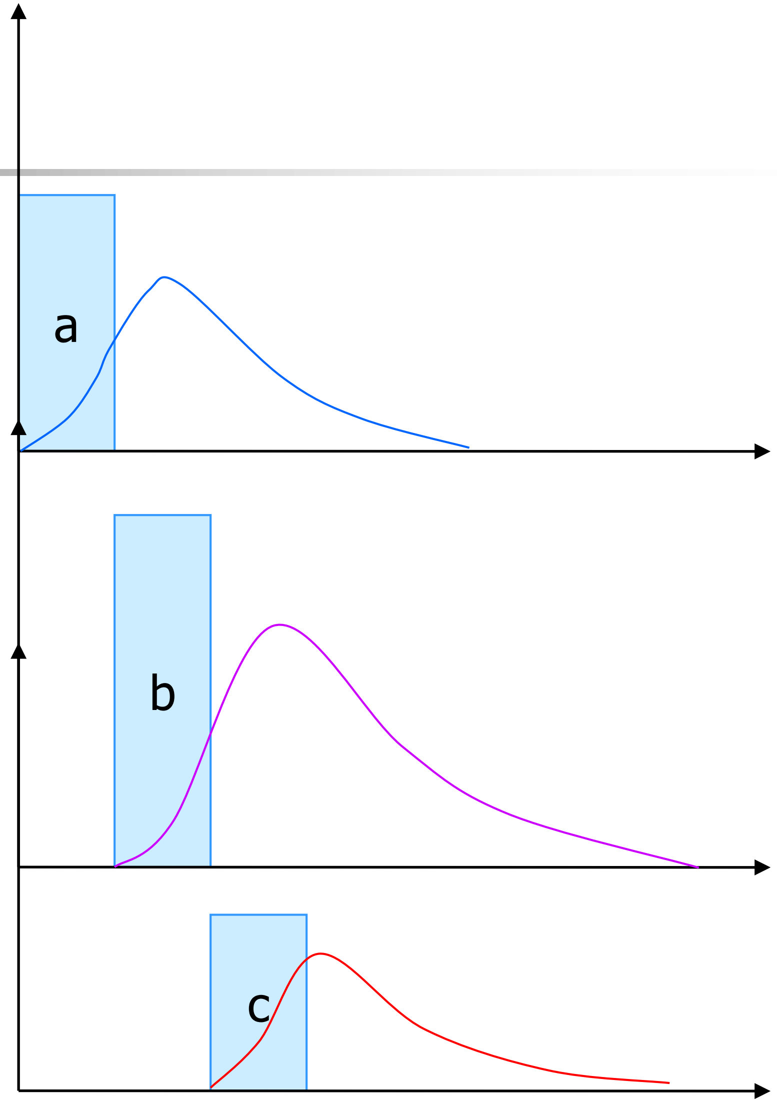
- The principle of superposition

  allows the decomposition of a complex ERH into rectangular blocks or pulses and then superimposing on one another the hydrograph of these rectangular pulses, each of steady intensity, to obtain the total DRH

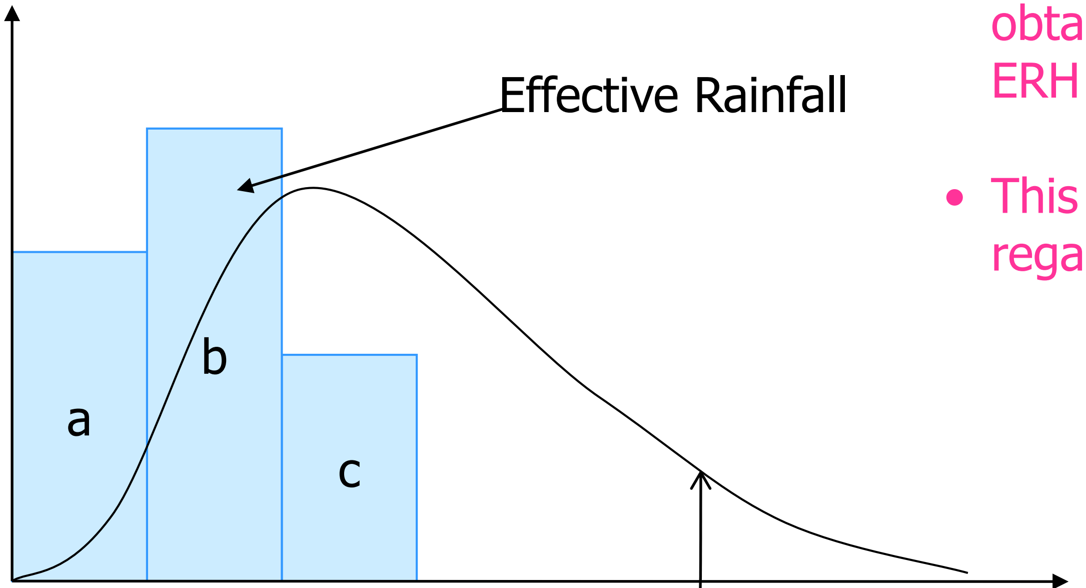
Application of Principle of Superposition



- ERH can be broken down into three rectangular pulses
- DRH due to each pulse is determined



Application of Principle of Superposition



- DRH due to these pulses are added to obtain the DRH due to the complex ERH
- This can be generalized to any ERH regardless of its complexity

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

Assumptions of UH Theory

- Since in practice, assumption (1) and (2) are never satisfied, these form the limitations of unit hydrograph theory

- Unit hydrograph theory can be applied only for a basin having drainage area between 200 ha to 5,00,000 ha

Uses of UH

- Development of flood hydrograph for extreme rainfall magnitudes for use in the design of hydraulic structures
- Extension of flood-flow records based on rainfall records, and
- Development of flood forecasting and warning systems based on rainfall

Construction of Unit Hydrograph

1. From the past records, select some unit period of intense rainfall duration, corresponding to an isolated storm uniformly distributed over the area.
2. Plot the storm hydrograph for some days before and after the period of rainfall of that duration.
3. Separate the base flow from the direct runoff.
4. Estimate the ordinates of direct runoff by subtracting the ordinates of base flow from the total ordinates:

$$DRO_i = TRO_i - BRO_i$$

Where, DRO, TRO, and BRO are the ordinates of direct runoff hydrograph, total runoff hydrograph and base flow at time i, respectively.

Construction of Unit Hydrograph

5. Calculate the volume of direct runoff (in cm) as follows:

$$D.R. \quad = 0.36\,\frac{\left(\sum_{i=1}^{n} DRO_i\right)\Delta t}{A}$$

where
DRO= direct runoff ordinates, cumec
Δt= time interval between successive ordinates, hour
A= drainage basin area, km^2

6. Calculate the ordinates of unit hydrograph as follows:

$$UHO_i \quad = \frac{DRO_i}{D.R.}$$

where UHO = unit hydrograph ordinates, and other terms are defined earlier.

Example

- Given below are observed flows from a storm of 6-hr duration on a stream with catchment area of 500 km^2. Assuming the base flow to be 10, derive the ordinate of 6 hour unit hydrograph.

Time, (hr)	**Discharge, (m^3/s)**	**Time, (hr)**	**Discharge, (m^3/s)**
0	10	42	50
6	100	48	35
12	250	54	25
18	200	60	20
24	150	66	15
30	100	72	10
36	70		

Solution Computation of UH

Time (h)	**Total Runoff (m^3/s)**	**Base flow (m^3/s)**	**Direct Runoff (m^3/s)**	**Unit hydrograph (m^3/s)**
0	10	10	0	0
6	100	10	90	23
12	250	10	240	61
18	200	10	190	49
24	150	10	140	36
30	100	10	90	23
36	70	10	60	15
42	50	10	40	10
48	35	10	25	6
54	25	10	15	4
60	20	10	10	3
66	15	10	5	1
72	10	10	0	0
Sum		Sum	905	231
		DR	3.9096	1

Application of UH for construction of flood hydrograph (FH)

- UH can be used to construct a flood hydrograph resulting from *rainfall of same unit duration* for which the UH is available
- UH selected for computing FH should be corresponding to storm of like duration and pattern (Theoretically)
- However, tolerance of as much as 25% of the UH duration can be ordinarily be accepted without any serious error.

Calculation for storm hydrograph corresponding to n cm of rainfall excess

Calculation procedure for construction of flood hydrograph from UH

Date	Time (hr)	UH ordinates (m^3/s)	Base flow (m^3/s)	DRH ordinates (m^3/s)	TRH ordinates (m^3/s)
(1)	(2)	(3)	(4)	(5) = n(3)	(6) = (4) +(5)

Example

- The ordinates of a 6-h unit hydrograph are given below. Calculate the flood hydrograph due to storm of rainfall-excess of 4 cm. The base flow can be assumed to 25 m^3/s constant throughout.

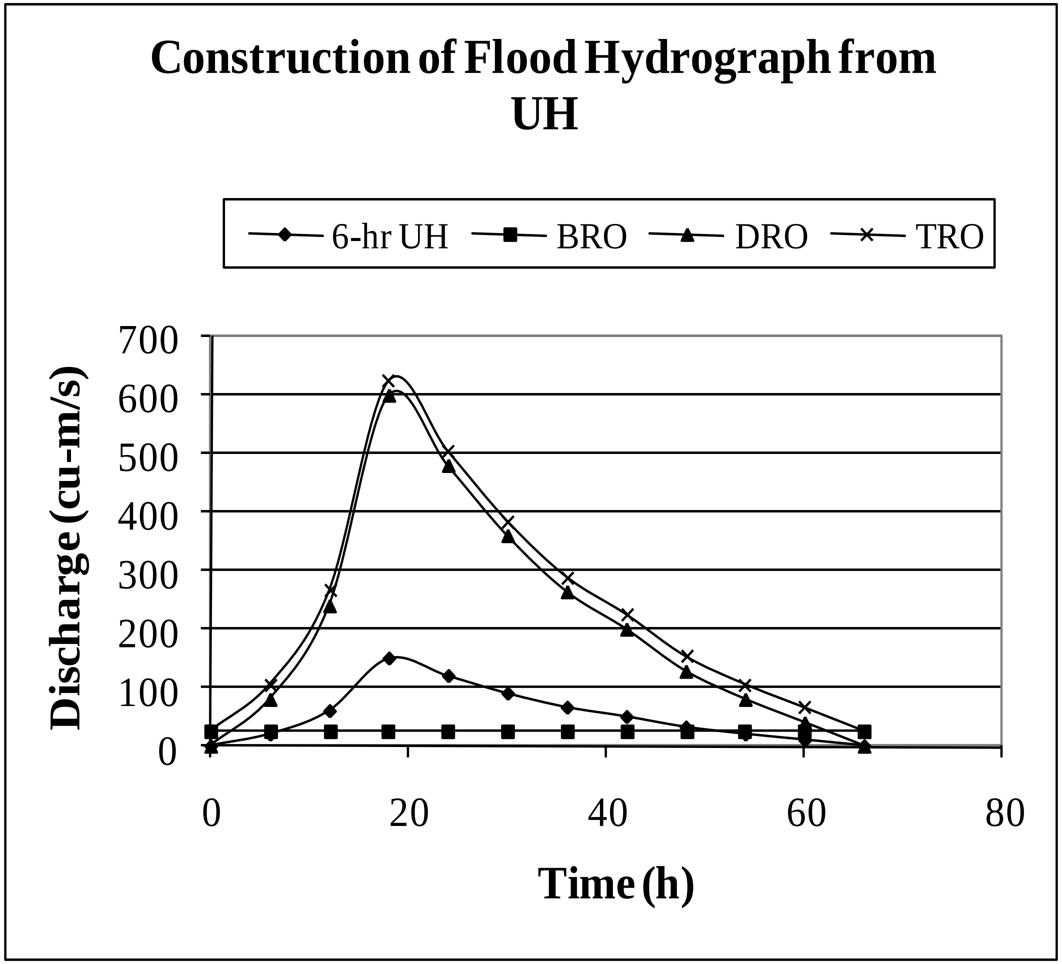
Time, (hr)	**6-h UH ordinates, (m^3/s)**	**Time, (hr)**	**6-h UH ordinates, (m^3/s)**
0	0	36	66
6	20	42	50
12	60	48	32
18	150	54	20
24	120	60	10
30	90	66	0

Solution

Time	6-h UH ordinates	Base flow	DRH ordinates	TRH ordinates	Time	6-h UH ordinates	Base flow	DRH ordinates	TRH ordinates
(hr)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(hr)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)
0	0	25	0	25	36	66	25	264	289
6	20	25	80	105	42	50	25	200	225
12	60	25	240	265	48	32	25	128	153
18	150	25	600	625	54	20	25	80	105
24	120	25	480	505	60	10	25	40	65
30	90	25	360	385	66	0	25	0	25

- We assume that the DR response to ER is linear (Principle of Proportionality).

- Thus, if ER in a duration D is n times the unit depth, then resulting DRH ordinates will be n times corresponding *D-h unit hydrograph ordinates*



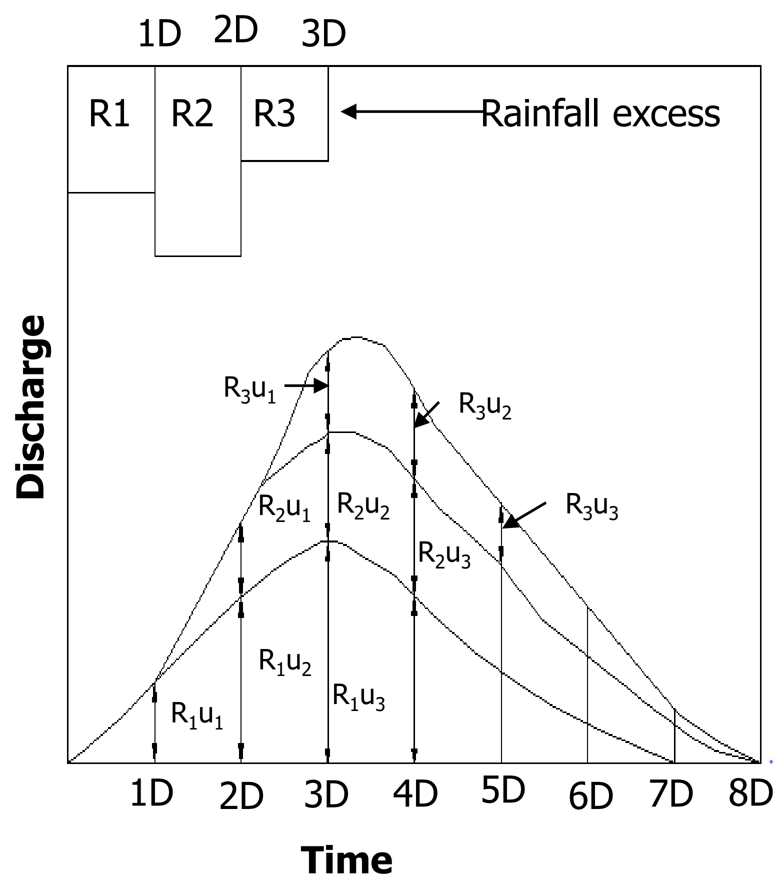
Unit hydrograph from complex storm

- Due to non-availability of isolated storm data, sometimes UH is derived from complex storms data of longer duration.

- Assuming that the complex storms has three storms, each of effective duration equal to D-h.

- The effective rainfall values are R_1, R_2 & R_3, respectively

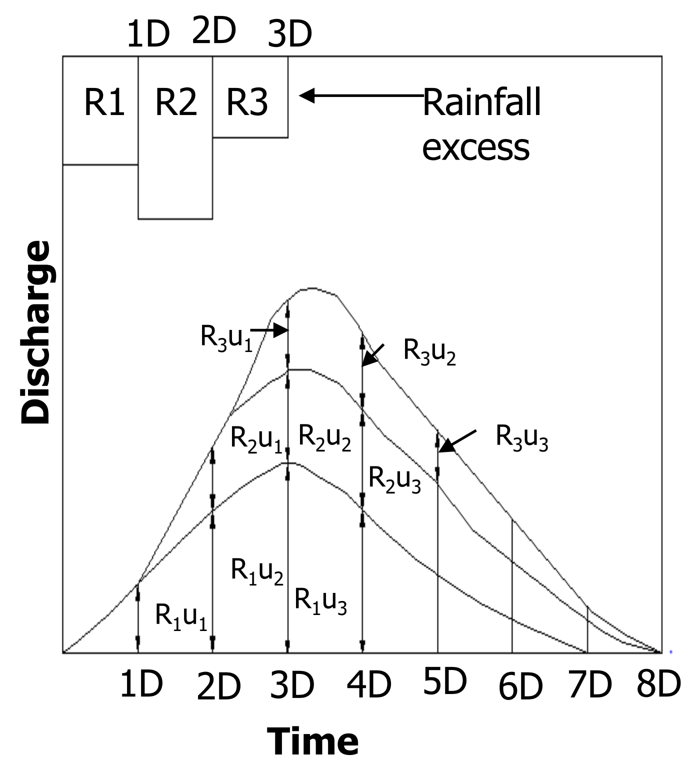
- Let the ordinates of the composite DRH be drawn at a time interval of D-h.



At various time interval 1D, 2D, 3D…….. from the start of the ERH, let the ordinates of the UH be u_1, u_2, u_3……

The ordinates of composite DRH be a_1, a_2, ………..

Thus



$$a_1 = R_1u_1$$
$$a_2 = R_1u_2 + R_2u_1$$
$$a_3 = R_1u_3 + R_2u_2 + R_3u_1$$
$$a_4 = R_1u_4 + R_2u_3 + R_3u_2$$

……………………………… so on

Since a_1, a_2 …….. and R_1, R_2, R_3 are known, value of u_1, u_2, ………… can be estimated.

Similarly if we have a unit hydrograph, we can operate in this fashion to obtain flood hydrograph. i.e.

U(t) is the ordinates of D-h UH at t-h from the beginning,

thus DR due to R_1 at time t

$$Q_1=R_1u(t)$$

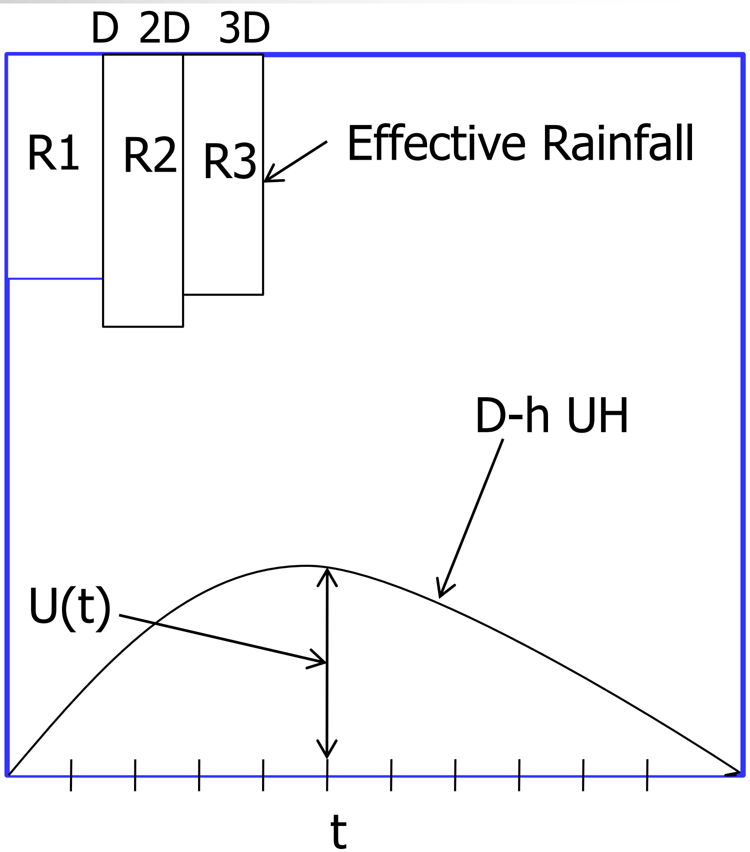
Similarly DR due to R_2 at (t-D) h is

$$Q_2=R_2.u(t-D)$$

Hence, $Q_i=R_i.u[t-(i-1)D]$

Thus , any time total DR $Q_t = \sum_{i=1}^{m} Q_i$

m = no of rainfall excess



Problem

- The excess rainfall and direct runoff recorded for a storm are as follow:

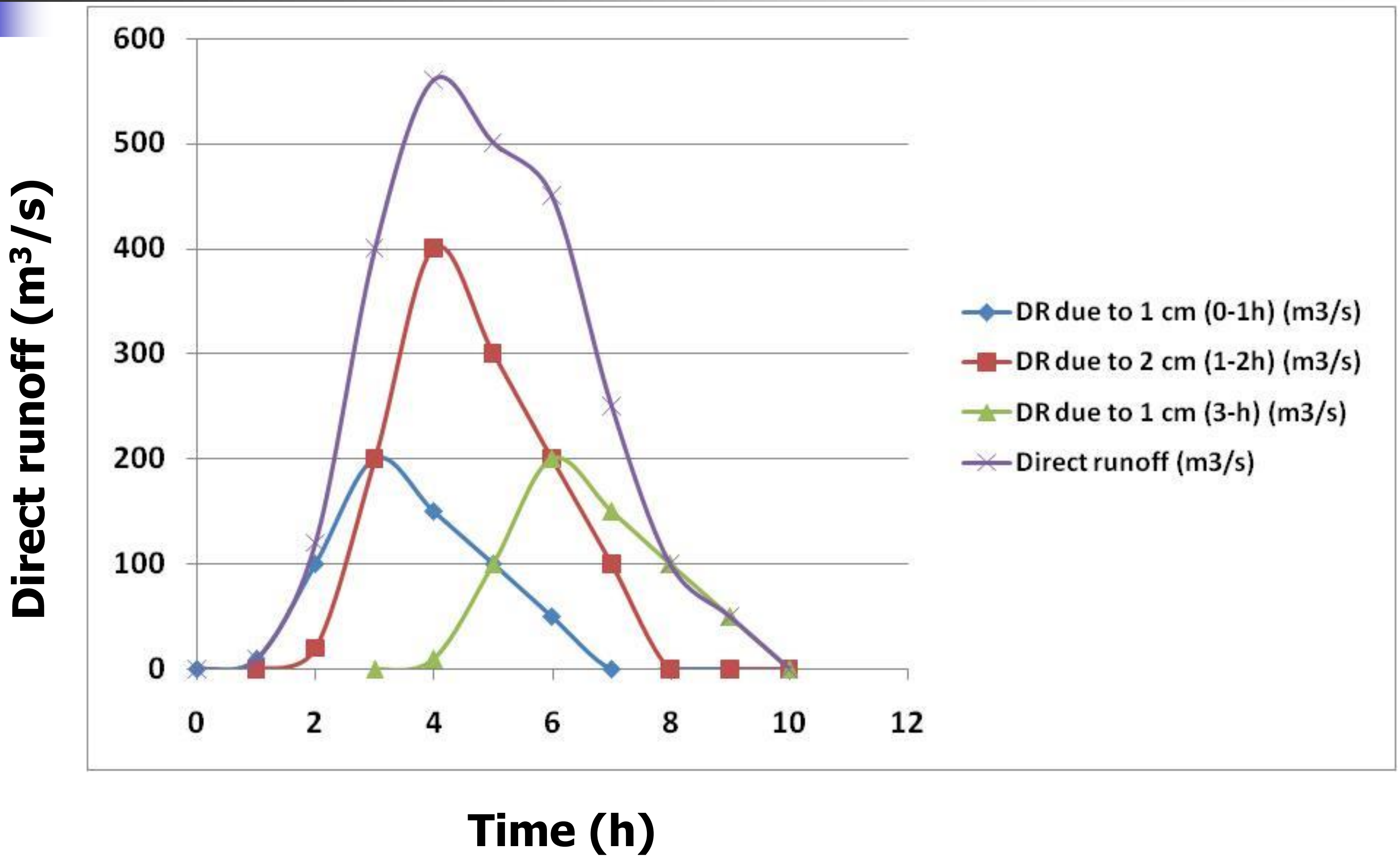
Time (h)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Excess rainfall (cm)	1.0	2.0		1.0					
Direct runoff (m^3/s)	10	120	400	560	500	450	250	100	50

Calculate 1h unit hydrograph.

Excess rainfall= 1 cm in 0 to 1h, 2 cm in 1 to 2h, and 1 cm in 3 to 4h

Let 1h UH ordinates be $u_0, u_1, u_2, u_3, u_4, u_5, u_6, u_7, u_8$ m^3/s

Time (h)	**Direct runoff (m^3/s)**	**DR due to 1 cm (0-1h) (m^3/s)**	**DR due to 2 cm (1-2h) (m^3/s)**	**DR due to 1 cm (3-h) (m^3/s)**	**1 h UH Ordinates (m^3/s)**
0	0	1*u0			u0=0
1	10	1*u1	2*u0		u1=10
2	120	1*u2	2*u1		u2=100
3	400	1*u3	2*u2	1*u0	u3=200
4	560	1*u4	2*u3	1*u1	u4=150
5	500	1*u5	2*u4	1*u2	u5=100
6	450	1*u6	2*u5	1*u3	u6=50
7	250	1*u7	2*u6	1*u4	u7=0
8	100	1*u8	2*u7	1*u5	u8=0
9	50	1*u9	2*u8	1*u6	u9=0
10	0	1*u10	2*u9	1*u7	u10=0



600
500
400
300
200
100
0
0
2
4
6
8
10
12
DR due to 1 cm (0-1h) (m3/s)
DR due to 2 cm (1-2h) (m3/s)
DR due to 1 cm (3-h) (m3/s)
Direct runoff (m3/s)
Direct runoff (m³/s)
Time (h)

Problem

Ordinates of a 6-h UH are given below

Time (h)	0	6	12	18	24	30	36	42	48	54	60	66
Ordinates (cumec)	0	50	125	185	160	110	60	36	25	16	8	0

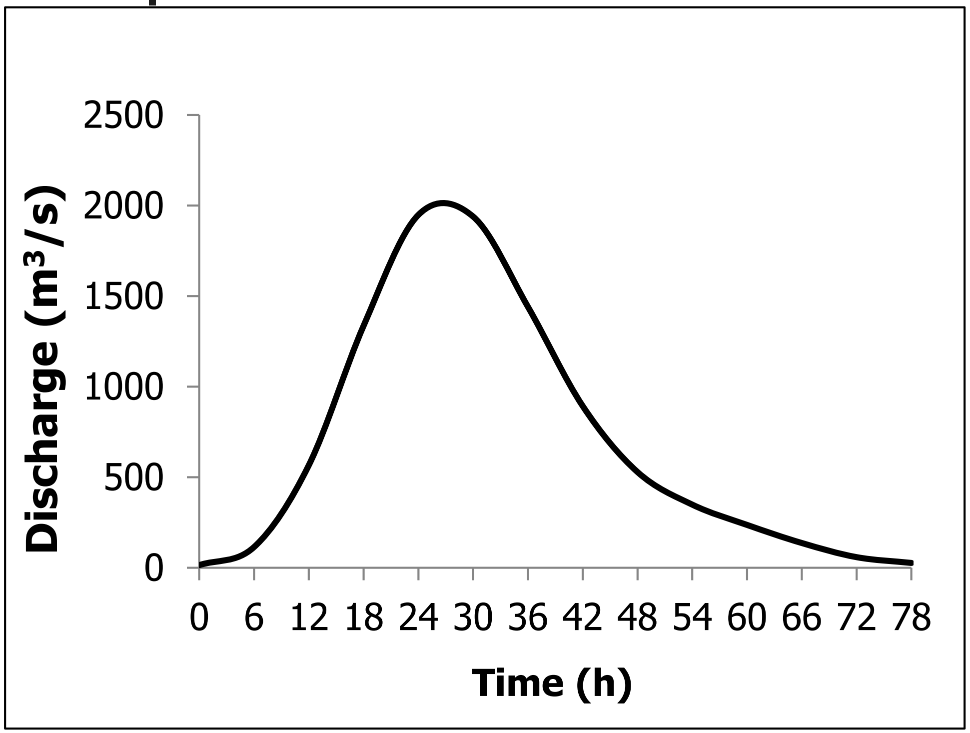
Derive the flood hydrograph for the following storm

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

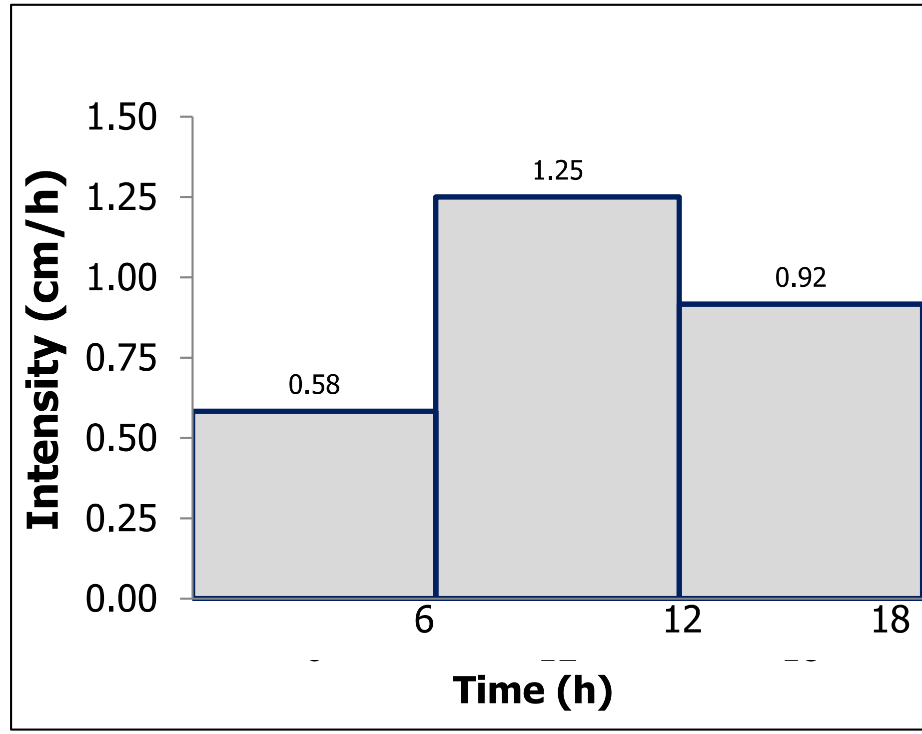
Assume Φ-index as 0.25 cm/hr and base flow as 15 cumec in the beginning and increased by $2 m^3/s$ for every 12 h till the end of DRH.

Solution

		DRH					
Time	**UH ordinate**	**Due to 2 cm rainfall col. 2*2 cm**	**Due to 6 cm rainfall col. 2*6 cm**	**Due to 4 cm col. 2*4 cm**	**DRH ordinates 6=col. (3+4+5)**	**Base flow**	**Flood hydrograph ordinates**
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
0	0	0	0	0	0	15	15
6	50	100	0	0	100	15	115
12	125	250	300	0	550	17	567
18	185	370	750	200	1320	17	1337
24	160	320	1110	500	1930	19	1949
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	0	0	48	64	112	25	137
72			0	32	32	27	59
78				0	0	27	27



Flood hydrograph



Hyetograph

Changing the Duration of UH

- UH of different durations, if required, should be derived from field data.
- Lack of data necessitates the development of UHs of different durations say nD h from a D-h UH.
- For this purpose, two methods are normally used:
  - Method of superposition- when n is an integer
  - S-curve technique-when n is a fraction.

Method of Superposition:

- To develop a nD-h UH, n number of D-h UHs are superimposed with each graph lagged by D-h.
  - To construct a 12-h UH from a 4 h UH, three 4-h UH have to be superimposed.
  - Three 4-h UHs are plotted separated by 4-h from one another (fig.).
  - Combination of these three curves gives a *DRH of 3 cm due to ER of 12-h duration*.
  - Ordinates of 12-h unit hydrograph can be obtained by dividing the ordinates of DRH by 3.

Calculation are done in tabular form

Time	Ordinates of D-h UH			DRH ordinates	Ordinates of nD-h UH
	A	B lagged by D-h	C lagged by 2D-h	Col.(2+3+4)	Col.5/n
1	2	3	4	5	6

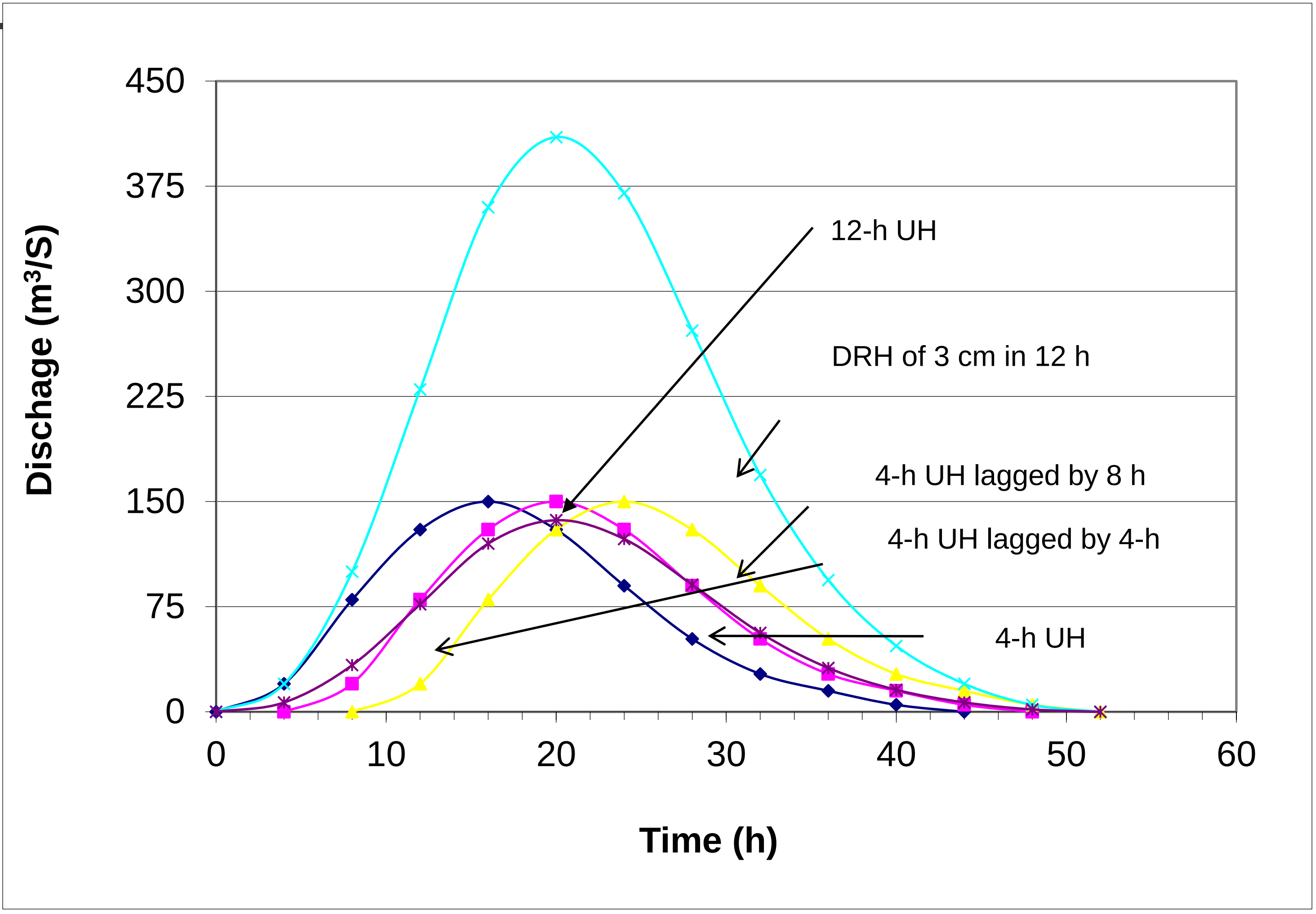
Problem:

The ordinates of a 4-h unit hydrograph are given below. Derive a 12-h unit hydrograph for the catchment.

Time (hr)	**0**	**4**	**8**	**12**	**16**	**20**	**24**	**28**	**32**	**36**	**40**	**44**
U H Ordinates (cumec)	**0**	**20**	**80**	**130**	**150**	**130**	**90**	**52**	**27**	**15**	**5**	**0**

Solution

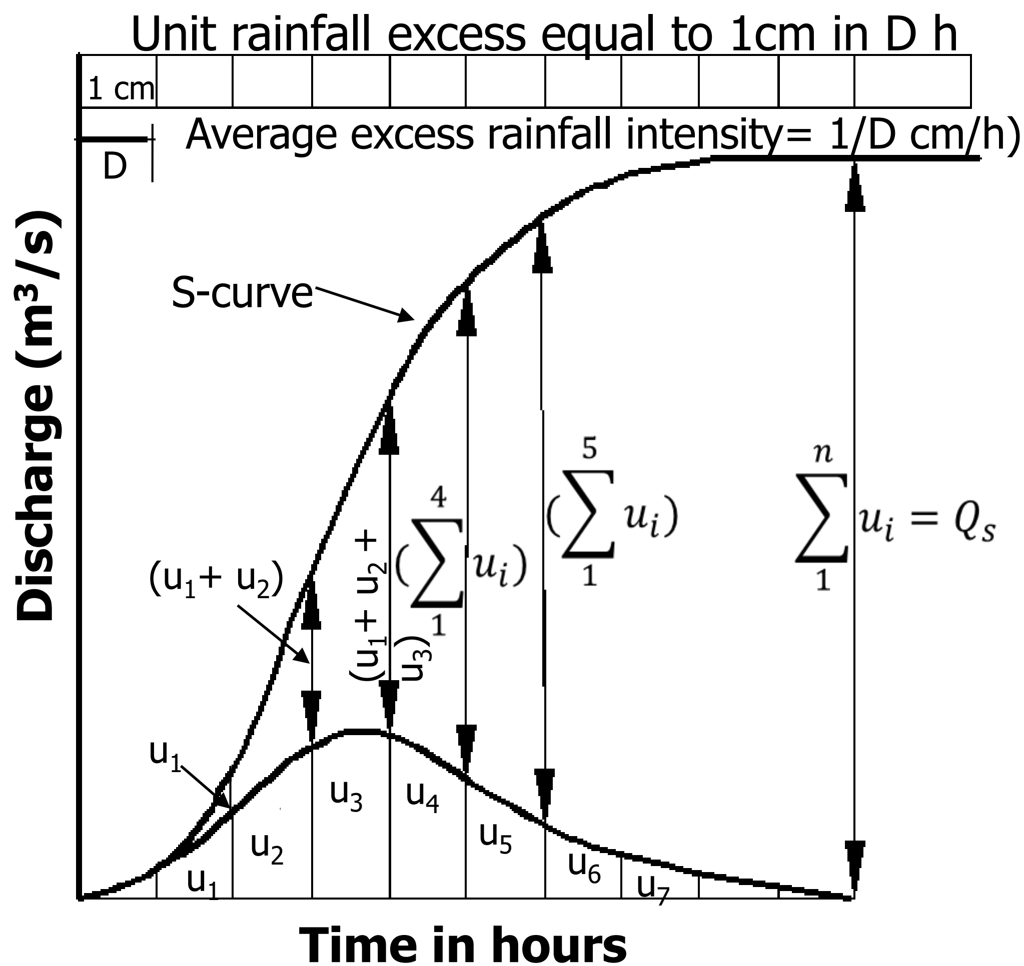
Time	Ordinates of 4-h UH			DRH of 3cm in 12 h (m^3/s)	Ordinates of 12 UH (m^3/s)
	A	B lagged by 4-h	C lagged by 8-h	Col.(2+3+4)	Col.5/3
(1)	(2)	(3)	(4)	(5)	(6)
0	0	-	-	0	0
4	20	0	-	20	6.7
8	80	20	0	100	33.3
12	130	80	20	230	76.7
16	150	130	80	360	120.0
20	130	150	130	410	136.7
24	90	130	150	370	123.3
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



450
375
300
225
150
75
0
Dischage (m^3/S)
0
10
20
30
40
50
60
Time (h)
12-h UH
DRH of 3 cm in 12 h
4-h UH lagged by 8 h
4-h UH lagged by 4-h
4-h UH

S-curve or S-hydrograph

- S-curve is a hydrograph produced by a continuous effective rainfall at constant rate for an infinite duration.
- In other words, it is a curve obtained by summation of an infinite series of D-h unit hydrograph spaced D-h apart.



- If the time base of the UH is T-h, then a continuous rainfall producing one unit of runoff every period would develop a constant outflow at the end of T-h.

- Thus, T/D unit hydrographs need to be combined to produce a S-curve which would reach the equilibrium at flow q_e (equilibrium discharge)

$$q_e = \frac{2.78A}{D} cumec$$

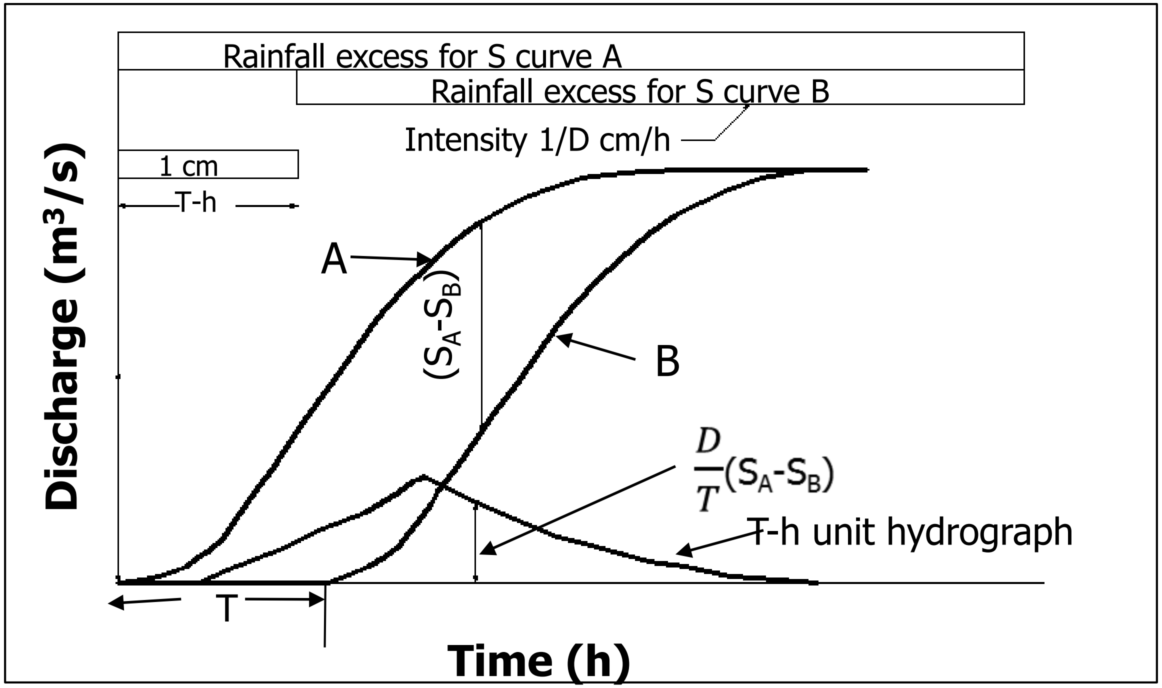
Where , A is in sq. km and D is in h

• qe represents the maximum rate at which an ER intensity of 1/D cm/h can drain out of a catchment of area A.

Derivation of t-h UH by S-curve method

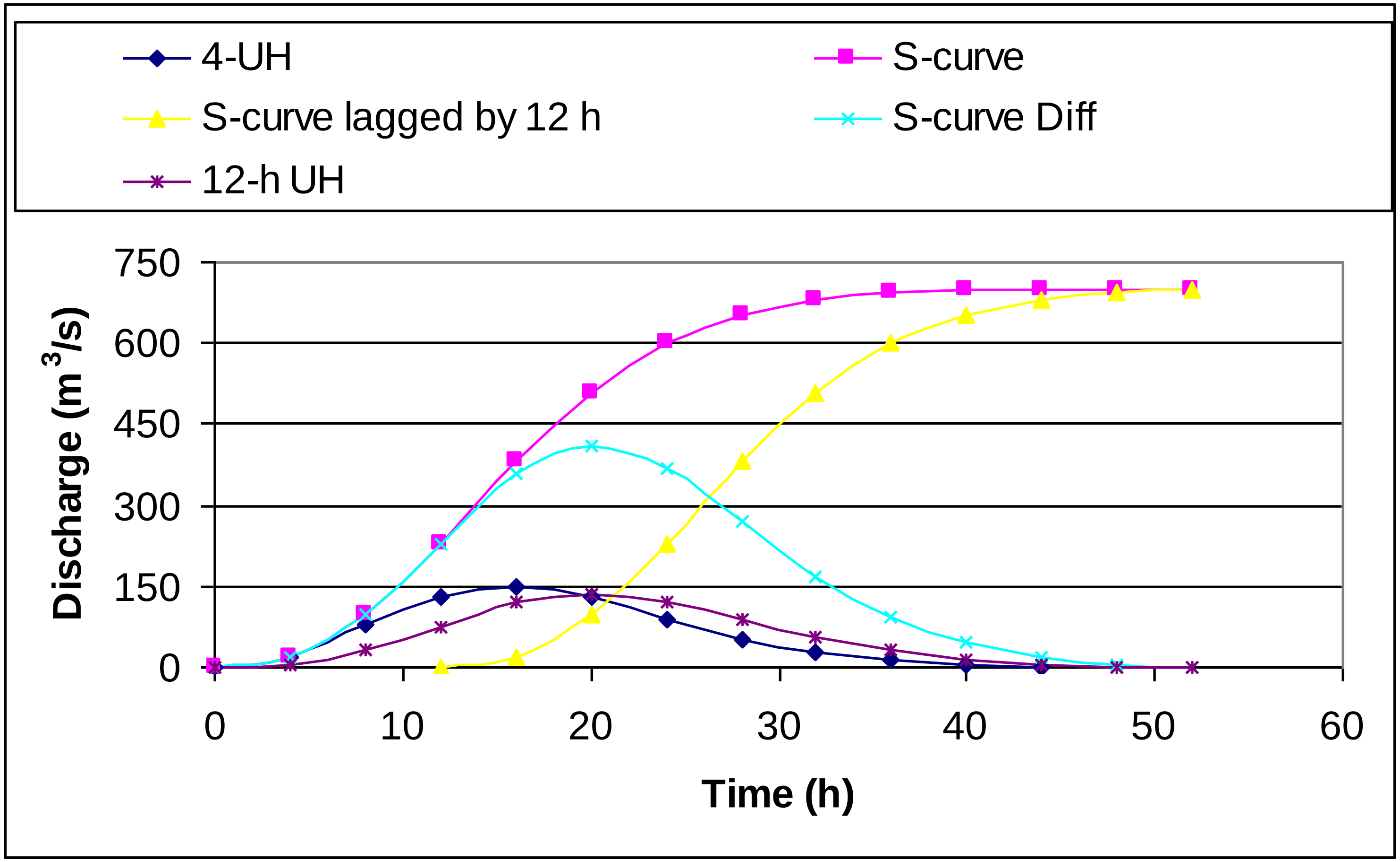
- Ordinates (S_A-S_B) represent a DRH by T-h effective rainfall and magnitude (T/D).

$$\frac{(S_A - S_B) * D}{T} = T - h \quad UH$$



Determination of 12 UH by S- curve method (Earlier Problem)

Time (h)	Ordinate of 4-h UH (m3/s)	S-curve addition (m3/s)	S-Curve ordinates (m3/s)	S-Curve lagged by 12 h (m3/s)	Col. 4-Col. 5	12-UH Ordinates (m3/s)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
0	0	-	0	-	0	0
4	20	0	20	-	20	6.7
8	80	20	100	-	100	33.3
12	130	100	230	0	230	76.7
16	150	230	380	20	360	120.0
20	130	380	510	100	410	136.7
24	90	510	600	230	370	123.3
28	52	600	652	380	272	90.7
32	27	652	679	510	169	56.3
36	15	679	694	600	94	31.3
40	5	694	699	652	47	15.7
44	0	699	699	679	20	6.7
48		699	699	694	5	1.7
52		699	699	699	0	0


4-UH
S-curve
S-curve lagged by 12 h
S-curve Diff
12-h UH
Discharge (m^3/s)
750
600
450
300
150
0
0
10
20
30
40
50
60
Time (h)