UNIT - III

Hydrographs: Hydrograph –Distribution of Runoff – Hydrograph Analysis Flood Hydrograph – Effective Rainfall – Base Flow- Base Flow Separation - Unit Hydrograph, definition, limitations and applications and Unit hydrograph, S-hydrograph, Synthetic Unit Hydrograph.

HYDROGRAPHS

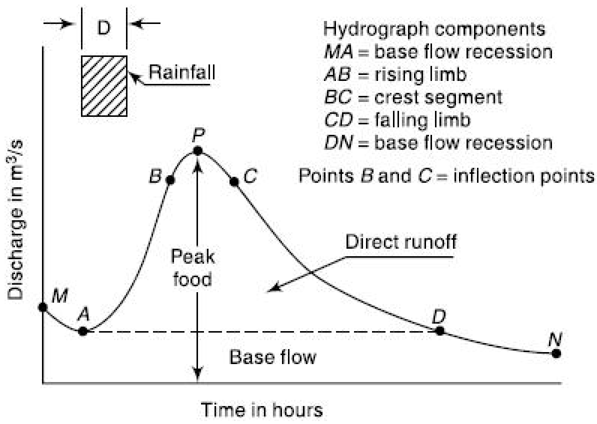
- A hydrograph is a graphical representation of the discharge flowing in the river at the given location with the passage of time
- It gives us peak flow, which is important for design of hydraulic structure at that site
- It is also known as storm hydrograph or flood hydrograph

Consider a concentrated storm that produces a fairly uniform rainfall of duration DDD over a catchment. After the initial losses and infiltration losses are satisfied, the rainfall excess reaches the stream through overland and channel flows. During this transfer, some storage develops in the overland and channel flow phases, which gradually depletes after the rainfall stops. Because of this, there is a time lag between when the rainfall occurs in the basin and when the water is observed at the gauging station at the outlet.

The runoff recorded at the stream-gauging station gives a typical hydrograph (as shown in Fig). The rainfall duration is also indicated in the figure, showing the time lag between rainfall and runoff. The hydrograph resulting from such an isolated storm is usually a single-peaked, skewed distribution of discharge. It is known as a **storm hydrograph, flood hydrograph,** or simply a **hydrograph.**

A hydrograph has three characteristic regions:

1. **Rising limb (AB):** From point A (start of the rising curve) to point B (first point of inflection).
2. **Crest segment (BC):** Between two points of inflection, with a peak PPP in between.
3. **Falling limb or depletion curve (CD):** From point C (second point of inflection) onward.



DISTRIBUTION OF RUNOFF

The distribution of runoff refers to the different types of water flow from a catchment, which include surface runoff (immediate overland flow), sub-surface runoff (quick interflow), and baseflow (delayed groundwater flow).

1. **Surface Runoff:**

   This is the portion of rainfall that flows over the land surface, reaching water bodies without infiltrating the soil. It includes overland flow and rapid interflow.

2. **Sub-Surface Runoff (Interflow):**

   Water that infiltrates the soil and flows parallel to the topsoil, reappearing on the surface or entering a stream system quickly, is known as interflow.

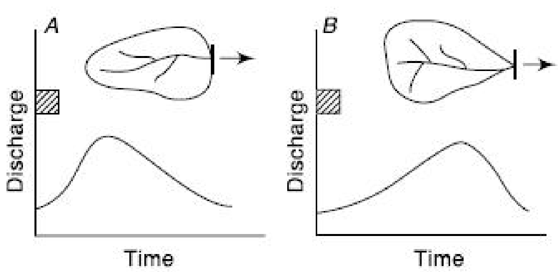
3. **Baseflow:**

   This is the delayed flow of water that reaches a stream from the saturated zone of the ground, eventually reaching water tables and flowing into streams.

FACTORS AFFECTING FLOOD HYDROGRAPH

1. Shape of the catchment

It influences the time taken for water from the remote parts of the catchment to arrive at the outlet of the catchment



2. Size of the catchment

- In small catchment over land flow is predominant over the channel flow

- Land use and intensity of the rainfall have important rate on the peak flood.
- On large catchment these effect are suppressed as the channel phase is more predominant. Its base time is also larger as compare to small catchment.

3. Slope of the Catchment

It will affect the recession limb of hydrograph. Steeper slope will give rise to quicker depletion of storage and hence result in steeper recession limb of hydrograph and also the smaller time base.

4. Land use

- For two catchment of equal area and keeping other factors being identical, the peak discharge is higher for a catchment that has a lower density of forest cover
- Forest cover increase infiltration.

5. Climate Factors

1. Rainfall Intensity: for a specified duration, the peak and volume of surface runoff are proportional to the intensity of rainfall.
2. Rainfall Duration: for the same volume of rainfall. If the rainfall duration increases then the peak of hydrograph reduces.
3. Direction of rainfall: if the rainfall direction is in the direction of the outlet then it will give left skewed hydrograph (early peak discharge) or if the rainfall direction is in the opposite direction of the outlet then it gives right skewed hydrograph (late peak discharge)

HYETOGRAPH

A hyetograph is a bar graph or plot that shows the intensity of rainfall over a specific period of time.

Distinguish between Hyetograph and Hydrograph

Hyetograph

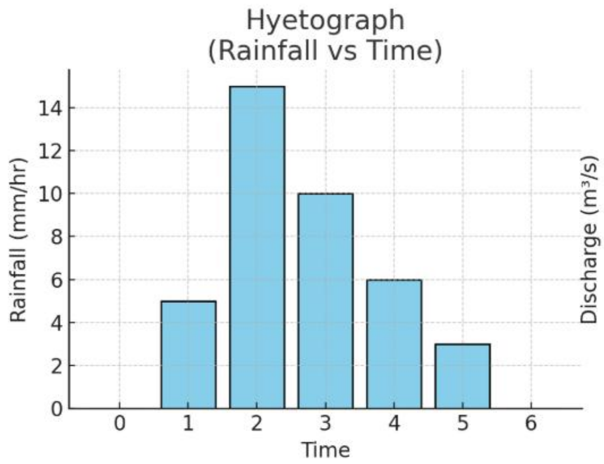
- A **graph of rainfall intensity (or depth) vs. time**.
- Represents the **rainfall pattern** over a catchment during a storm.
- **X-axis:** Time
- **Y-axis:** Rainfall intensity (mm/hr) or rainfall depth (mm).
- Used to understand **how rainfall is distributed** over the storm duration.
- Input for hydrologic analysis.

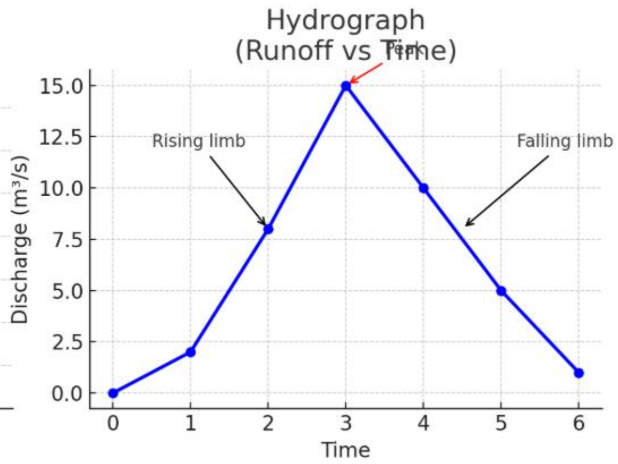
Hydrograph

- A **graph of stream discharge (runoff) vs. time** at a catchment outlet.
- Represents the **runoff response** of the catchment to rainfall.

- **X-axis:** Time
- **Y-axis:** Stream discharge (m³/s or cumecs).
- Used to study **flood peaks, lag time, and runoff characteristics**.
- Output of hydrologic response.

Aspect	Hyetograph	Hydrograph
Definition	Graph of rainfall intensity/depth vs. time	Graph of stream discharge/runoff vs. time
Represents	Rainfall pattern	Runoff response of the catchment
Axis (X vs. Y)	X: Time, Y: Rainfall (mm/hr or mm)	X: Time, Y: Discharge (m³/s)
Purpose	Shows distribution of rainfall	Shows effect of rainfall on streamflow
Role in Hydrology	Input data for runoff studies	Output response of catchment





The **Hydrograph sketch** is now labeled with:

- **Rising limb** → steep upward slope (runoff increasing).
- **Peak** → maximum discharge.
- **Falling limb** → gradual decline in discharge.

BASE FLOW

Base flow is the sustained flow in a stream or river that comes from groundwater discharge, rather than direct surface runoff from rainfall

BASE FLOW SEPARATION

The surface flow hydrograph is obtained from the total storm hydrograph by separating the quick-response flow from the slow response runoff.

Interflow is considered as quick response hence only base flow is deducted from the total storm hydrograph to obtain the surface flow hydrograph.

There are three methods of base-flow separation that are in common use.

Methods of Base-Flow Separation

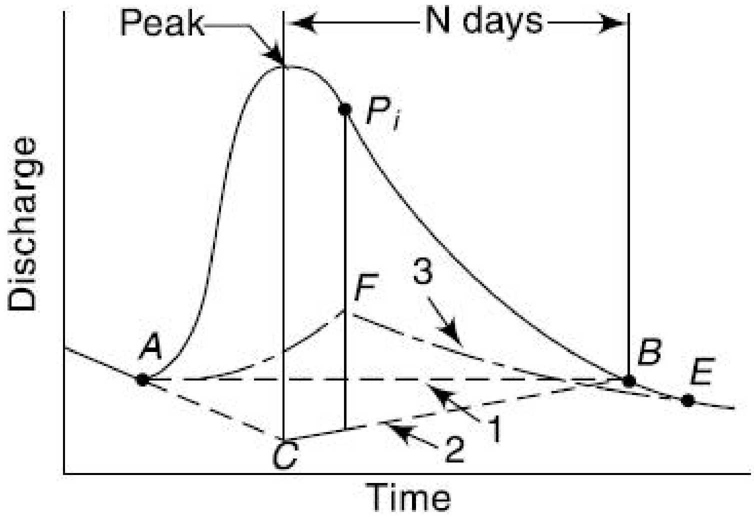
Method – 1: Straight – Line Method

In this method the separation of the base low is determined by drawing a straight line from the beginning of surface runoff to a point on the recession limb that represents the end of direct runoff. In Fig, point A marks the start of direct runoff, which can usually be identified easily because of the sharp change in the runoff rate at that point.

Point B, making the end of the direct runoff is rather difficult to locate exactly. An empirical equation for the time interval N (days) from the peak to the point B is

$$N = 0.83A^{0.2}$$

Where, A – drainage area in km2 and N is in days.



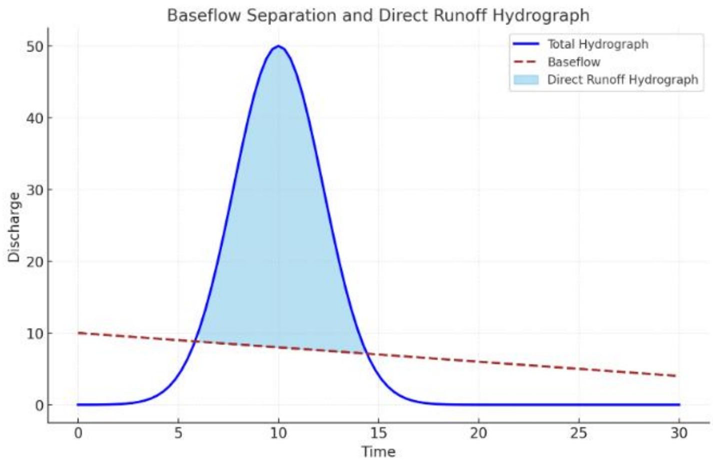
Method – 2

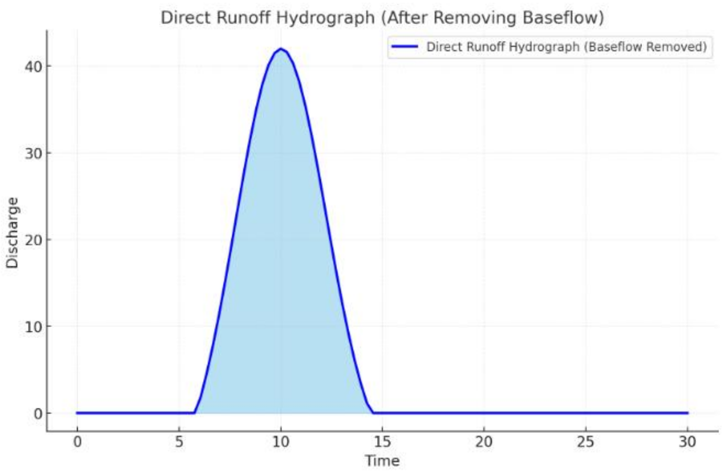
In this method, the base flow curve existing before the start of surface runoff is extended until it intersects the ordinate drawn at the peak (point C in Fig). From this point, a straight line is drawn joining point C to point B. The segments AC and CB represent the base flow and surface runoff, respectively. This method is the most widely used procedure for base-flow separation.

Method – 3

In this method, the base flow recession curve after the floodwater has depleted is extended backwards until it meets the ordinate at the point of inflection (line EF in Fig). Points A and F are then joined by a smooth curve. This approach is more realistic in situations where groundwater contributions are significant and quickly reach the stream.

DIRECT RUNOFF HYDROGRAPH [DRH]





Ordinates of DRH = Ordinates of Flood Hydrograph – Base Flow

Area of DRH = Multiple x and y axis

= m^3/sec x hours

= m^3 , So it is determined as the Volume of the Runoff

Area of DRH = Sum of ordinates x Δt

= (O1 + O2 + O3 + O4 +O5) x Δt

Volume of Runoff = Catchment area x Runoff Depth

Runoff Depth = Volume of Runoff/Catchment area

Runoff Depth = Area of DRH/Catchment area

Sometimes nothing will be given in the question,

Φindex = (P – R)/Te

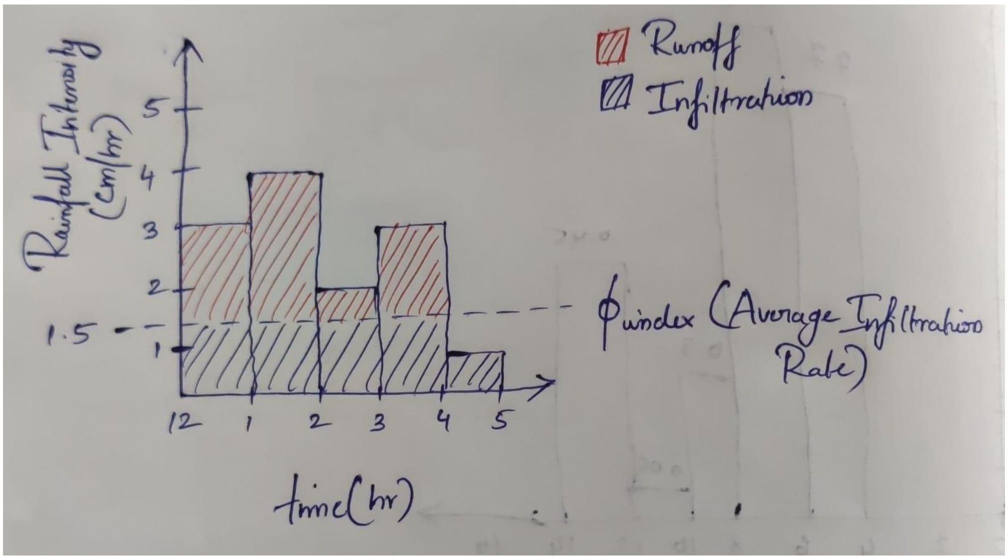
Runoff Depth = P – (Φindex x Te) [When volume of Runoff and catchment area is not given]

EFFECTIVE RAINFALL HYETOGRAPH [ERH]

Effective Rainfall (ER), also called Excess Rainfall, is the portion of rainfall that becomes direct runoff at the watershed outlet. It is the total rainfall over a certain period after subtracting abstractions such as infiltration and initial losses. In simple terms, ER is the rainfall that is neither stored on the land surface nor infiltrated into the soil.

To link the Direct Runoff Hydrograph (DRH) with the rainfall that produced it, the rainfall hyetograph is adjusted by deducting losses. The resulting hyetograph is called the Effective Rainfall Hyetograph (ERH) or Excess Rainfall Hyetograph.

Both DRH and ERH represent the same quantity but in different forms. The ERH is generally shown in units of rainfall intensity (cm/hr) plotted against time. The area under the ERH, when multiplied by the catchment area, gives the total volume of direct runoff, which is equal to the area under the DRH.



Area of ERH = Total Runoff Depth

Area of DRH = Volume of Runoff

Volume of Runoff = Catchment Area x Runoff Depth

Area of DRH = Catchment Area x Area of ERH

1. **Rainfall of magnitude 3.8 cm and 2.8 cm occurring two consecutive 4 hours duration on a catchment area of 27 km2 produced the following hydrograph of flow at the outlet of the catchment if the base flow is 5m3/s estimate the rainfall excess and Φindex.**

Time (in hrs)	0	6	12	18	24	30	36	42	48
Discharge (in m3/s)	5	13	26	21	16	12	9	7	5

A)

time (hr)	Flood hydrograph discharge (m^3/s)	Base flow (m^3/s)	DRH ordinates
0	5	5-5=0 5	0
6	13	13-5=8 5	8
12	26	26-5=21 5	21
18	21	5	16
24	16	5	11
30	12	5	7
36	9	5	4
42	7	5	2
48	5	5	0
			69

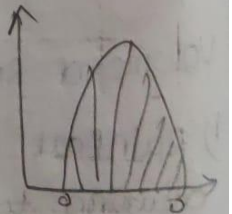
Area of DRH = Σ of ordinates $\times \Delta t_e$

$= (0+8+21+16+11+7+4+2+0) \times$

$= 69 \times \underbrace{6}_{\text{hours}} \times 60 \times 60$

$= 1490400$

$= 1.4904 \times 10^6 \, m^3$



Runoff depth $= \dfrac{\text{Volume of Runoff}}{\text{catchment Area}}$

$= \dfrac{1.4904 \times 10^6}{27 \times 10^6} = \dfrac{m^{\cancel{3}}}{m^{\cancel{2}}}$

$= 0.0552 \, m = 5.52 \, cm$

$\phi_{index} = \dfrac{P-R}{T_e} = \dfrac{(3.8+2.8)-5.52}{8} = 0.135 \, cm/hr$

$= 1.35 \, mm/hr$

2. **The flood data and base flow in a storm are estimate for a storm in a catchment area of 600 km2. Estimate the rainfall excess.**

Time (in days)	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Discharge (in m3/s)	**20**	**63**	**151**	**133**	**90**	**63**	**44**	**29**	**20**	**20**
Base Flow (in m3/s)	**20**	**22**	**25**	**28**	**28**	**26**	**23**	**21**	**20**	**20**

A) Find Rainfall excess:-

~~Rainfall depth~~

$$\text{Rainfall depth} = \frac{\text{sum of ordinates} \times \Delta t}{\text{catchment area}}$$

time	Flood hydro-graph (m^3/s)	Base flow m^3/s	DRH ordinates
0	20	20	0
1	63	22	41
2	151	25	126
3	133	28	105
4	90	28	62
5	63	26	37
6	44	23	21
7	29	21	8
8	20	20	0
9	20	20	0
			400

Area of DRH $= \Sigma$ of ordinates $\times \Delta t$

$= (0+41+126+105+62+37+21+8+0+0) \times$ days

$= 400 \times 1 \times 24 \times 60 \times 60$

$\boxed{34560000 = 34.56 \times 10^6\, m^3}$

$$\text{Rainfall depth} = \frac{\text{volume of Rainfall}}{\text{catchment area}}$$

$$= \frac{34.56 \times 10^6}{600 \times 10^6}$$

$\boxed{= 0.0576\, m = 5.76\, cm}$

3. **A storm over a catchment of area 5km2 has a duration of 14 hours. The mass curve of rainfall of the storm is as follows**

Time (in hrs)	**0**	**2**	**4**	**6**	**8**	**10**	**12**	**14**
Accumulated Rainfall (in cm)	**0**	**0.6**	**2.8**	**5.2**	**6.6**	**7.5**	**9.2**	**9.6**

If the Φindex for the catchment is 0.4 cm/hr. determine the effective rainfall hyetograph and the volume of direct runoff from the catchment due to storm.

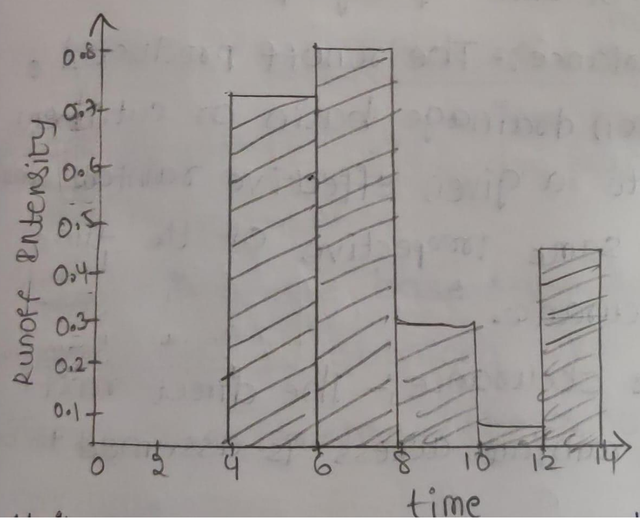
A) from the catchment due to the storm:

Time (in hr)	Time Interval Δt	Accumulated Rainfall (cm) in Δt	depth of rainfall on Δt (cm)	(0.4×2) $\phi \times \Delta t$	Effective Rainfall (cm)	Intensity of ER (cm/hr)
0	—	0	0	0.8	0	0
2	2	0.6	0.6	$0.4 \times 2 =$ 0.8	0	0
4	2	2.8	2.8 − 0.6 = 2.2	0.8	2.2 − 0.8 = 1.4	1.4/2 = 0.7
6	2	5.2	5.2 − 2.8 = 2.4	0.8	2.4 − 0.8 = 1.6	1.6/2 = 0.8
8	2	6.6	6.6 − 5.2 = 1.4	0.8	1.4 − 0.8 = 0.6	0.6/2 = 0.3
10	2	7.5	7.5 − 6.6 = 0.9	0.8	0.9 − 0.8 = 0.1	0.1/2 = 0.05
12	2	9.2	9.2 − 7.5 = 1.7	0.8	1.7 − 0.8 = 0.9	0.9/2 = 0.45
14	2	9.6	9.6 − 9.2 = 0.4	0.8	0.4 − 0.8 = 0	0
					4.6	

Volume of Direct Runoff = Runoff Depth × Catchment area

$$= \frac{4.6}{100} \times (5 \times 10^6)\ m^2$$

$$\boxed{V = 230000\ m^3}$$



28/8/

UNIT HYDROGRAPH

The problem of predicting the flood hydrograph that results from a known storm in a catchment has received much attention. Many methods are available to solve this problem, but one of the most popular and widely used is the **unit hydrograph method**. This method was first proposed by Sherman in 1932 and has since been refined many times.

A **unit hydrograph** is defined as the hydrograph of direct runoff caused by **one unit depth of rainfall excess (1 cm)** occurring uniformly over the entire catchment area at a uniform rate for a specified duration (D hours). Here, “unit” refers to the unit depth of rainfall excess, usually taken as 1 cm. The **duration** is an important characteristic and is used as a prefix to identify a specific unit hydrograph.

For example:

- A **6-hour unit hydrograph** corresponds to 1 cm of rainfall excess lasting for 6 hours.
- Similarly, we may have **12-hour unit hydrographs**, and in general, a **D-hour unit hydrograph** is applicable to a catchment.

Thus, the definition of a unit hydrograph implies certain assumptions and conditions.

- The unit hydrograph shows the combined response of a catchment to a unit rainfall excess of **D-hour duration**, producing a direct-runoff hydrograph. It connects only the direct runoff to the rainfall excess. Therefore, the **volume of water** under the unit hydrograph must equal the rainfall excess. For example, if 1 cm of rainfall excess is considered, then the area under the unit hydrograph equals the volume produced by 1 cm of rainfall spread over the entire catchment.
- The rainfall is assumed to have an **average intensity of excess rainfall (ER)** equal to **1/D cm per hour** during the storm of duration D hours.
- The storm is assumed to be **uniformly distributed** across the catchment.

A typical example is a **6-hour unit hydrograph**, which represents a rainfall excess of 6 hours duration.

For instance, the **area under the unit hydrograph** is given as **12.92×10^6 m³**.

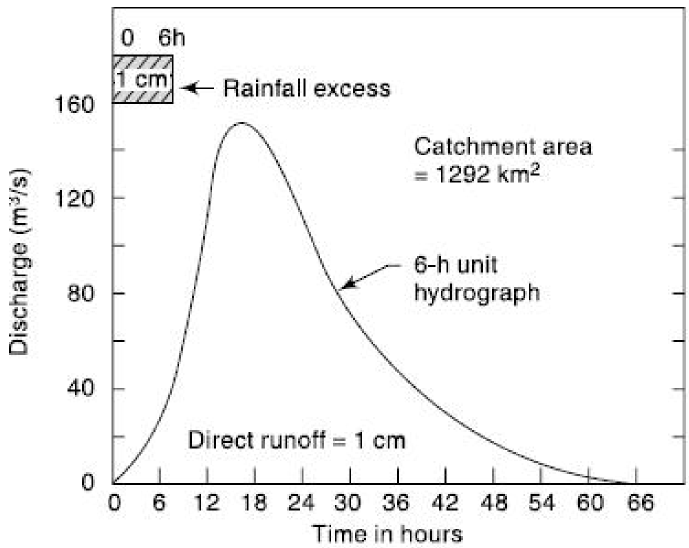


Fig. 6.9 Typical 6-h Unit Hydrograph

Hence,

Catchment area of the basin = 1292 km2

Two basic assumptions constitute the foundations for the unit-hydrograph theory. These are: (i) The Time Invariance and (ii) The Linear Response.

TIME INVARIANCE

The runoff produced from a given drainage basin due to a given effective rainfall shall always be the same, irrespective of the time of its occurrence.

LINEAR RESPONSE

The direct runoff response to the rainfall excess is assumed to be linear.

Other Assumptions:
(a) Effective rainfall is uniformly distributed over the catchment area.
(b) Rainfall intensity is constant during the storm period.
(c) Unit hydrograph cannot give reliable results for basins exceeding about **5000 km²** and is not used for small basins having area less than **2 km²**.

FLOOD HYDROGRAPH → **UNIT HYDROGRAPH**

(1) ordinate of DRH = ordinate of FH − Base flow

(2) Calculate Runoff Volume = area of DRH

area of DRH = Σ of all ordinate $\times \Delta t$

(3) Runoff depth $R = \dfrac{\text{Runoff volume}}{CA}$

(4) ordinate of UH = $\dfrac{\text{ordinate of DRH} \times 1\text{ cm}}{R\text{ cm}}$

(5) Peak of UH = $\dfrac{\text{Peak of DRH}}{R} \times 1$

STEPS TO DRIVE UNIT HYDROGRAPH FROM A FLOOD HYDROGRAPH

STEP 1: Separate base flow from a flood hydrograph to obtain a DRH.

STEP 2: To determine the runoff volume calculate are of DRH

$$\frac{\text{Runoff volume}}{\text{Catchment Area}}$$

STEP 3: Calculate Runoff Depth [R] =

STEP 4: Ordinate of Unit Hydrograph = $\dfrac{\text{ordinate of DRH}}{R\ \text{cm}} \times 1\text{cm}$

STEPS TO DERIVE FLOOD HYDROGRAPH FROM A UNIT HYDROGRAPH

DATA GIVEN

Runoff Depth [R], Base Flow and Ordinates of Unit Hydrograph

STEP 1: Calculate ordinates of DRH = $\dfrac{\text{Ordinate of UH}}{1\text{cm}} \times R\text{cm}$

STEP 2: Calculate ordinates of flood hydrograph = Ordinates of DRH + Base Flow

1. **Following are the ordinates of a storm hydrograph of a river draining a catchment area of 423 km2 due to 6 hours isolated storm**

Time (in hrs)	**0**	**12**	**24**	**36**	**48**	**60**	**72**	**84**	**96**
Discharge (in m3/s)	**10**	**87.5**	**102.5**	**71**	**47.5**	**31**	**21**	**15**	**12**
Base Flow (in m3/s)	**10**	**10**	**10**	**11**	**11.5**	**11.5**	**12**	**12**	**12**

(a) Drive the peak ordinates of a 6 hr unit hydrograph for the catchment
(b) if a storm of 6 hr duration at the rate of 1.5cm/hr occurs, calculate peak of resulting DRH, take Φindex = 0.4 cm/hr.

resulting DRH, Take ø index = ...

Time	Discharge	Baseflow	Ordinates of DRH	Ordinates of UH
0	10	10	10-10 = 0	0
12	87.5	10	87.5-10 = 77.5	$\frac{77.5}{3}\times 1$ 25.83
24	102.5	10	92.5	$\frac{92.5}{3}\times 1$ 30.83 → Peak of UH max
36	71	11	60	20
48	47.5	11.5	36	12
60	31	11.5	19.5	6.5
72	21	12	9	3
84	15	12	3	1
96	12	12	0	0
			297.5	

$$\text{Runoff depth} = \frac{\text{Runoff volume}}{\text{catchment area}}$$

$$= \frac{\Sigma \text{ of ordinates of DRH} \times \Delta t_e}{\text{Catchment area}}$$

$$= \frac{297.5 \times 12 \times 60 \times 60}{423 \times 10^6}$$

$$\boxed{= 0.03\text{ m} = 3\text{ cm}}$$

$\phi_6 = 0.4 \times 6 = 2.4$

P - 1hr - 1.5

P = 6hr - 1.5 × 6 = 9 cm/hr

$R = P - \phi t$

$R = 9 - 2.4$

$\boxed{R = 6.6}$

ii) $\text{Peak of DRH} = \frac{\text{Peak of UH} \times R}{1}$

$$= \frac{30.83 \times 6.6}{1}$$

$$\boxed{= 203.47\text{ m}^3/\text{s}}$$

29/8/25

2. Given below are the ordinates of a 6-hr UH for a catchment. Calculate the ordinates of DRH due to a rainfall excess of 3.5 cm occurring in 6hr.

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

$$\text{Ordinates of DRH} = \frac{\text{Ordinates of UH} \times R}{1}$$

$R = 3.5$ cm.

$\because$ DRH Ordinates $=$ UH $\times$ R [in table]

Time (hr)	UH Ordinates	DRH Ordinates
0	0	0
3	25	87.5
6	50	17.5
9	85	297.5
12	125	437.5
15	160	560
18	185	647.5
24	160	560
30	110	385
36	60	210
42	36	126
48	25	87.5
54	16	56
60	8	28
69	0	0

3. (a) The peak of food hydrograph due to 3 hr duration isolated storm in a catchment is 270 m^3/sec. The total depth of rainfall is 5.9 cm. Assuming an average infiltration loss is 0.3 cm/hr and a constant base flow of 20 m^3/sec. Estimate the peak of the 3 hr unit hydrograph of this catchment.

(b) If the area of catchment is 567 km^2. Determine base width of a 3 hr UH by assuming it to be triangular in shape.

a. Given data

Peak of 3hr Flood Hydrograph $= 270 m^3/s$

Rainfall depth (P) $= 5.9cm$

$\phi_{index} = 0.3cm/hr$

Base flow $= 20m^3/s$

Peak of DRH $= 270 - 20 = 250m^3/s$

" " UH $= \frac{\text{Peak of DRH}}{R} \times 1$

$R = P - \phi t$

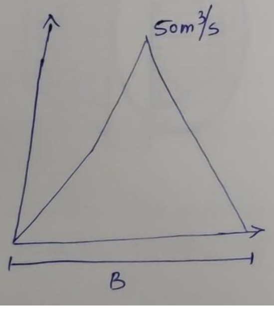
$= 5.9 - 0.3 \times 3$

$\boxed{R = 5cm}$

Peak of UH $= \frac{250}{5} \times 1$

$= 50m^3/s$

b.



Area of UH = Catchment Area $\times 0.01$

$\frac{1}{2} \times B \times H = 567 \times 10^6 \times 0.01$

$\frac{1}{2} \times B \times 60 \times 60 \times 50 = 567 \times 10^6 \times 0.01$

$\boxed{B = 63 \text{ hours}}$

UNIT HYDROGRAPH OF DIFFERENT DURATIONS

Ideally, unit hydrographs are derived from simple isolated storms, and if the duration of the various storms does not differ very much (say, within a band of ±20% D), they would all be grouped under one average duration of D-h. In practical applications, if unit hydrographs of different durations are needed, they are best derived from field data. However, due to lack of adequate data, it often becomes necessary to develop unit hydrographs covering a wide range of durations for a given catchment.

Under such conditions, a D-hour unit hydrograph is used to develop unit hydrographs of differing durations nD. Two methods are generally available for this purpose:

- Method of superposition
- The S-curve

2hr UH $\longrightarrow$ 8hr UH

Dhr UH $\longrightarrow$ n×Dhr UH

$= 4 \times 2$

$= 8$ — Integer

$n = 4$

Method of Superposition

2hr UH $\longrightarrow$ 3hr UH

$n = 1.5$ – not Integer

$n \times D$

$= 1.5 \times 2$

$= 3$

12hr UH $\longrightarrow$ 6hr UH

$n = \frac{6}{12} = 0.5$ – not Integer

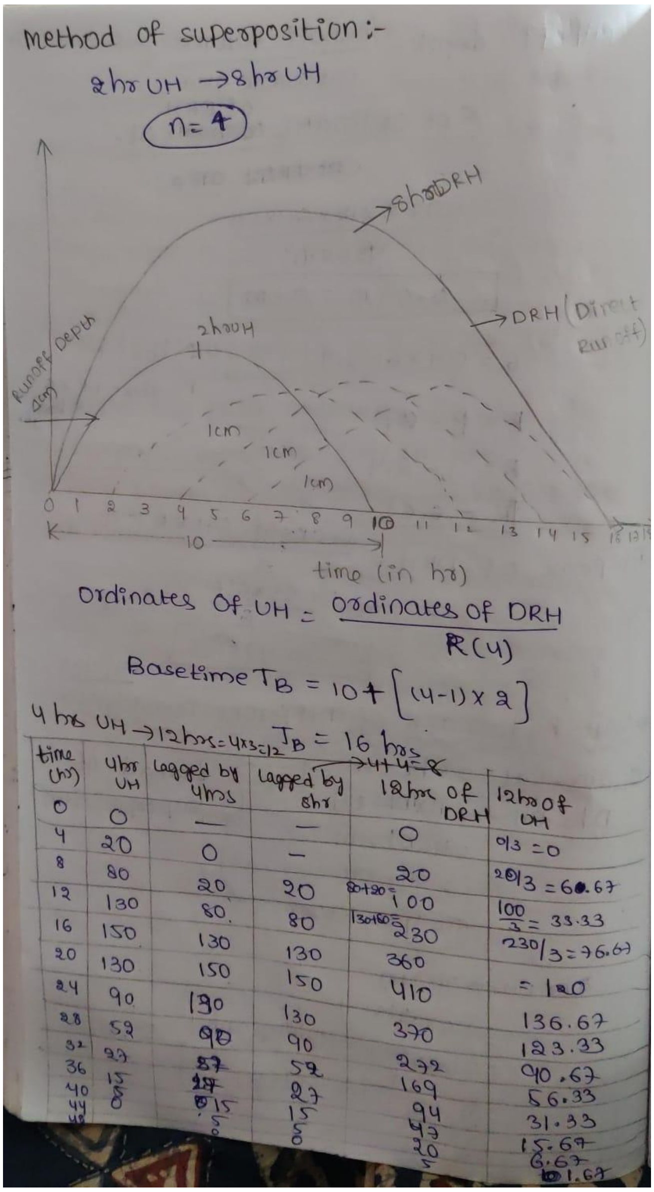
→ S-curve Method

These are discussed below.

METHOD OF SUPERPOSITION

If a D-h unit hydrograph is available, and it is required to develop a unit hydrograph of nD h, where n is an integer, it can be done easily by superimposing unit hydrographs with each graph separated from the previous one by D-h.

For example, consider Figure 6.15, which shows three 4-h unit hydrographs A, B, and C. Curve B begins 4 h after A, and curve C begins 4 h after B. The combination of these three curves is a direct runoff hydrograph (DRH) of 3 cm due to an effective rainfall (ER) of 12-h duration. If the ordinates of this DRH are now divided by 3, one obtains a 12-h unit hydrograph.



Method of superposition:-

2 hr UH → 8 hr UH

n = 4

$$\text{Ordinates of UH} = \frac{\text{Ordinates of DRH}}{R(4)}$$

$$\text{Basetime } T_B = 10 + [(4-1) \times 2]$$

4 hrs UH → 12 hrs = 4×3 = 12 $\quad T_B = 16$ hrs

time (hr)	4 hr UH	Lagged by 4 hrs	Lagged by 8 hr (4+4 = 8)	12 hr of DRH	12 hr of UH
0	0	—	—	0	0/3 = 0
4	20	0	—	20	20/3 = 6.67
8	80	20	20	80+20 = 100	100/3 = 33.33
12	130	80	80	130+100 = 230	230/3 = 76.67
16	150	130	130	360	= 120
20	130	150	150	410	136.67
24	90	130	130	370	123.33
28	52	90	90	272	90.67
32	27	57	52	169	56.33
36	15	27	27	94	31.33
40	5	15	15	47	15.67
44	0	5	5	20	6.67
48		0	0	5	1.67

1. **If two storms, each 1cm rainfall excess and 6 hr duration occur in succession. Calculate the resulting hydrograph of flow. Assume base flow 10m3/s. the ordinate of a 6-hour unit hydrograph are as given below**

Time (in hr)	0	6	12	18	24	30	36	42	48	54	60	66	72
6 hr Unit Hydrograph (UH)	0	20	60	150	120	90	66	50	32	20	10	0	

A)

Time	6hrs of UH	2nd Rainfall of 6th UH (Lagged)	Base Flow	Flood Hydrograph
0	0	—	10	10
6	20	0	10	20+10 = 30
12	60	20	10	60+20+10 = 80
18	150	60	10	220
24	120	150	10	280
30	90	120	10	220
36	66	90	10	166
42	50	66	10	126
48	32	50	10	92
54	20	32	10	62
60	10	20	10	40
66	0	10	10	20
72		0		10

2. **Using the 2 hr unit hydrograph given below, find the peak flow resulting from successive 2 hour periods of rainfall 0.40, 0.90 and 1.20 cm of runoff from a basin, no base flow.**

Time (in hr)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
2 hr (UH) ordinate	0	58	173	337	440	285	215	165	90	35	0					

Time	2hr UH	ordinates due to 0.40 Runoff	ordinates due to 0.90 Runoff	ordinates due to 1.20 runoff	Discharge
0	0	0×0.40 = 0	—		0
1	58	58×0.40 = 23.2	—	4hr	23.2
2	173	69.2	0×0.90 = 0		0
3	337	134.8	58×0.90 = 52.2		187
4	440	176	173×0.90 = 155.7	0×1.20 = 0	331.7
5	285	114	303.3	58×1.20 = 69.6	486.9
6	215	86	396	207.6	689.6
7	165	66	256.5	404.4	726.6
8	90	36	193.5	528	757.5 → Peak Flood
9	35	14	148.5	342	504.5
10	0	0	81	258	339
11			31.5	198	229.5
12			0	108	108
13				42	42
14				0	
15					0

3. **Find the peak of DRH due to 3 successive 2 hr rainfall if the runoff intensity is 0.8 cm/hr, 1cm/hr and 1.2 cm/hr respectively**

Time (in hr)	0	1	2	3	4	5	6	7	8	9	10	11	12
2 hr (UH) ordinate	0	6	10	12	18	10	6	4	0				

		1.6	2.4	24	
Time	2hrs of UH	Ordinates due to 0.8 runoff	Ordinates due to 1.2 run off	Ordinates of 12 runoff	Discharge
0	0	0×1.6 = 0			0
1	6	6×1.6 = 9.6			9.6
2	10	16	0×2.4 = 2.4		18.4
3	12	19.2	6×2.4 = 14.4		33.6
4	18	28.8	10×2.4 = 24	0×24 = 0	52.8
5	10	16	28.8	24×6 = 144	188.8
6	6	9.6	43.2	240	292.8
7	4	6.4	24	288	318.4
8	0	0	14.4	432	446.4
9			9.6	240	249.6
10			0	144	144
11				96	96
12				0	

4. **A storm had 3 succesive 6 hour intervals of rainfall magnitude of 3, 5 and 4 cm respectively. Assuming a Φindex of 0.20 cm/hr and a base flow of 30 m3/s. determine the resulting flood hydrograph.**

Time (in hr)	0	3	6	9	12	18	24	30	36	42	48	54	60	66	72
2 hr (UH) ordinate	0	150	300	450	600	800	600	450	320	100	0				

Time	6hrs of UH	Ordinates due to 1.8 Runoff	Ordinates due to 3.8	Ordinates due to 2.8c	Base Flow	Flood hydrograph
0	0	0			30	30
3	150	150×1.8 = 270			30	30
6	300	~~[illegible]~~ 540	3.8×0 = 0		30	570
9	450	~~[illegible]~~ = 810	150×3.8 = 570		30	1410
12	600	1080	1140	0×2.8 = 0	30	2250
18	800	1440	1710	~~0~~×150×2.8 = 420	30	3600
24	600	1080	2280	840	30	Peak 4220
30	450	810	3040	1260	30	5140
36	320	576	2280	1680	30	4566
42	100	180	1710	2240	30	4160
48	0	0	1216	1680	30	2926
54			380	1260	30	1670
60			0	896	30	~~926~~

280
280

280
0

Rainfall magnitude

$-\phi$ hr

1st Rainfall Runoff $= 3 - (0.2 \times 6)$

$= 1.8$ cm

2nd Rainfall Runoff $= 5 - (0.2 \times 6)$

$= 3.8$ cm

3rd Rainfall runoff $= 4 - (0.2 \times 6)$

$= 2.8$ cm

5. **The peak of a flood hydrograph due to a 6 hour is 470 m3/s. The mean depth of rainfall is 8 cm. Assume an average infiltration loss of 0.25 cm/h and a constant base flow of 15m3/s and estimate the peak of a 6 hr unit hydrograph for this catchment.**

A) Given data :-

$P = 8$ cm

ϕ index $= 0.25$ cm/hr

Peak of Flood hydrograph $= 470 m^3/s$

total infilitration $= 0.25$ cm/hr

$= 0.25 \times 6$

$= 1.5$ cm

Base flow $= 15 m^3/s$

$$\text{Peak of UH} = \frac{\text{Peak of DRH}}{R}$$

→ Flood hydrogra

$$= \frac{\text{Peak of FH} - \text{BF}}{\text{P} - \text{Infilitration}}$$

→ Base flow

$$= \frac{470 - 15}{8 - 1.5}$$

$$= \frac{455}{6.5} = 70 m^3/s$$

6. **The ordinates of a one hour unit hydrograph at sixty minute interval are 0, 3, 12, 8, 6, 3 & 0 m3/s. A two hour storm of 4 cm excess rainfall occurred in a basin from 10 Am. Considering constant base flow of 20 m3/s the flow of the river (in m3/s) at 1 Pm is ____________.**

	Time	1hr UH	lagged by 1hr	2hr DRH	2hr UH
10 AM	0	0	—	0	0
11 AM	1	3	0	3	15
12 PM	2	12	3	15	7.5
1 PM	3	8	12	20	10
2 PM	4	6	8	14	7
3 PM	5	3	6	9	4.5
4 PM	6	0	3	3	1.5
	7		0	0	0

$\therefore$ DRH = Ordinates of UH x Runoff

= 10x4

= 40 m³/s → $= 40\,m^3/s$

$\therefore$ Ordinates of flood Hydrograph =

$40 + 20 = 60\,m^3/s$

7. **Ordinates of a 1 hour UH at 1-hour interval staring from time t = 0 are 0, 2, 6, 4, 2, 1 and 0 m3/sec. Find the catchment area represented by this unit graph and also determine the ordinates of a 3-hour Unit hydrograph for the catchment at t = 3 hr.**

Time	1 hr UH
0	0
1	2
2	6
3	4
4	2
5	1
6	0

Area of unit Hydrograph = Volume of runoff = $CA \times 0.01$

$\sum \text{Ordinate} \times \Delta t = CA \times 0.01$

$15 \times 60 \times 60 = CA \times 0.01$

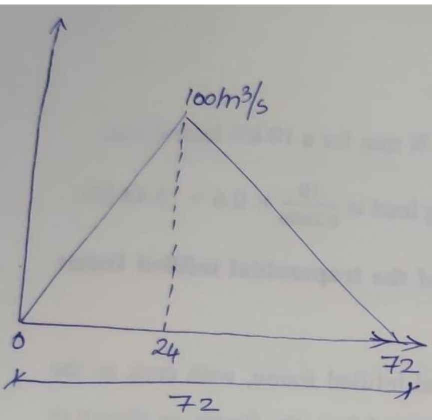
$CA = \dfrac{15 \times 60 \times 60}{0.01} = 5.4 \times 10^6\,m^2$

$= 5.4\,km^2$

K=3

Time	1hr UH	lagged by 1hour	lagged 2 hours	3hr DRH	3hr UH
0	0	–	–	0	0
1	2	0	–	2	066
2	6	2	0	8	8/3
3	4	6	2	12	4
4	2	4	6	12	4
5	1	2	4	7	7/3
6	0	1	2	3	1
7	–	0	1	1	0.33
8	–		0	0	0

8. **The 6-hr UH of a catchment is in the form of a triangle with the peak of 100 m3/s occurring at 24 hours from the start base time is 72 hours.**
   (i) Find catchment area
   (ii) calculate the flood hydrograph due to storm of rainfall excess of 2 cm during the first 6 hours and 4 cm during the second 6 hours interval. The base flow can be assumed to be 25 m3/sec constant discharge.



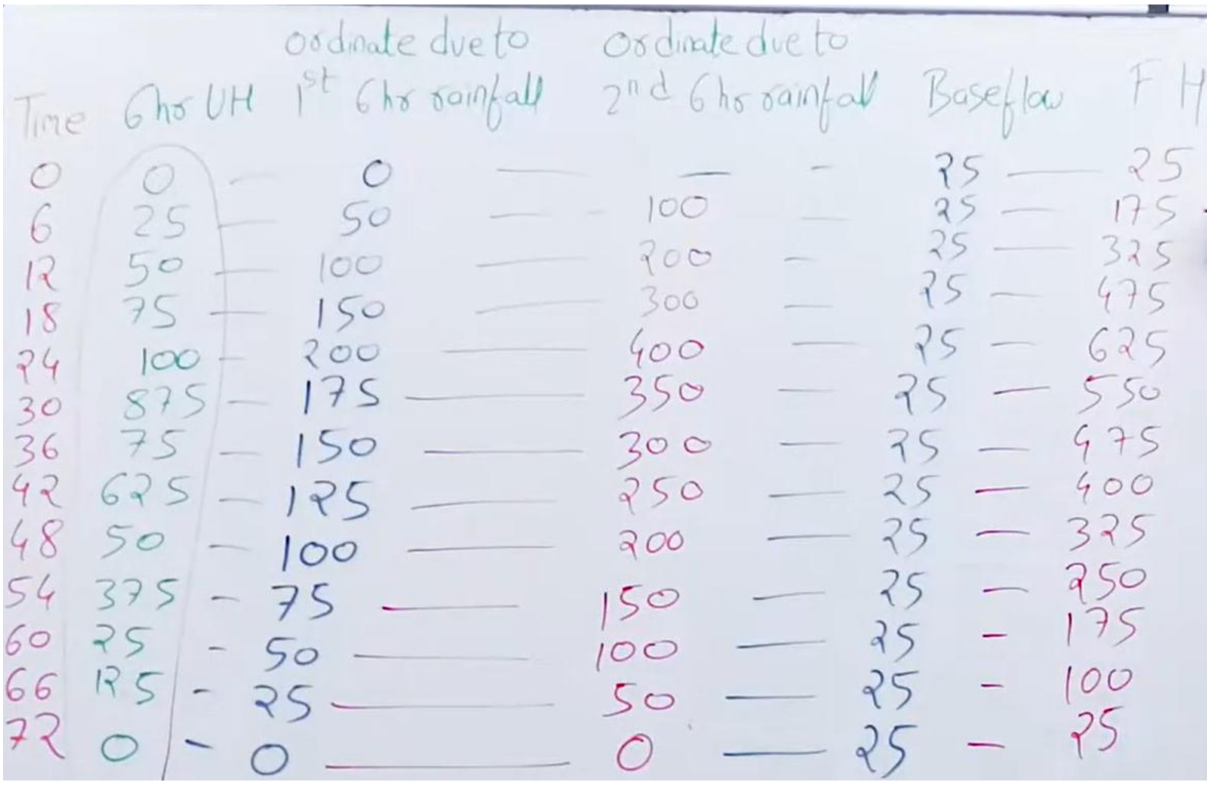
(i) $\frac{1}{2} \times B \times H = CA \times 0.01 = \frac{\frac{1}{2} \times 72 \times 60 \times 60 \times 100}{0.01}$

$CA = 1296 km^2$

(ii) 6^{th} hr Ordinate $= \frac{100}{24} \times 6 = 25$, 12^{th} hr Ordinate $= \frac{100}{\cancel{24}\,2} \times \cancel{12} = 50$

30^{th} hr " $= \frac{100}{72-24} \times (72-30) = 87.5$, 36^{th} hr Ordinate $= \frac{100}{72-24}(72-36)$

$= 75$



Time	6 hr UH	ordinate due to 1st 6 hr rainfall	ordinate due to 2nd 6 hr rainfall	Baseflow	F H
0	0	0	—	25	25
6	25	50	100	25	175
12	50	100	200	25	325
18	75	150	300	25	475
24	100	200	400	25	625
30	875	175	350	25	550
36	75	150	300	25	475
42	625	125	250	25	400
48	50	100	200	25	325
54	375	75	150	25	250
60	25	50	100	25	175
66	125	25	50	25	100
72	0	0	0	25	25

S-CURVE METHOD

If it is desired to develop a unit hydrograph of duration mD, where m is a fraction, the method of superposition cannot be used. A different technique known as the S-curve method is adopted in such cases, and this method is applicable for rational values of m. The S-curve, also known as S-hydrograph, is a hydrograph produced by a continuous effective rainfall at a constant rate for an infinite period. It is a curve obtained by summation of an infinite series of D-h unit hydrographs spaced D-h apart.

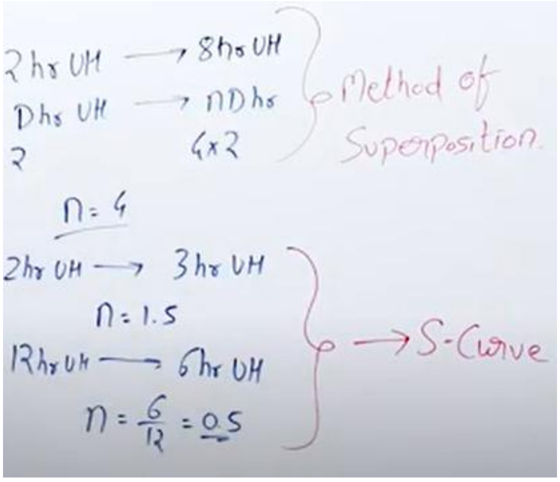
This S-curve is due to a D-h unit hydrograph. It has an initial steep portion and reaches a maximum equilibrium discharge at a time equal to the time base of the first unit hydrograph. The average intensity of ER producing the S-curve is 1/D cm/h and the equilibrium discharge,

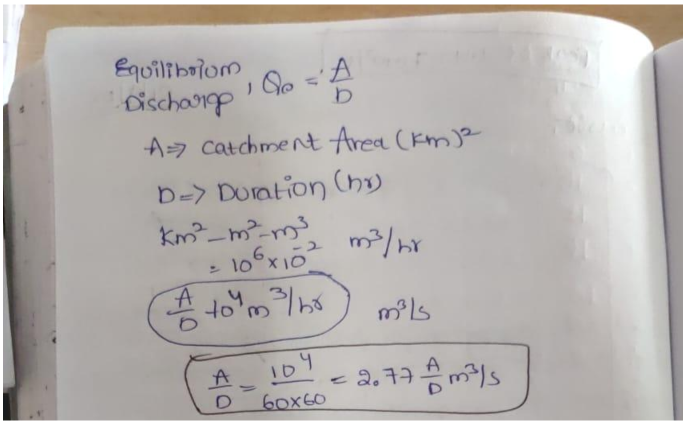
$$Q_s = \left(\frac{A}{D} \times 10^4\right) \text{m}^3/\text{h},$$

where A = area of the catchment in km2 and D = duration in hours of ER of the unit hydrograph used in deriving the S-curve. Alternatively,

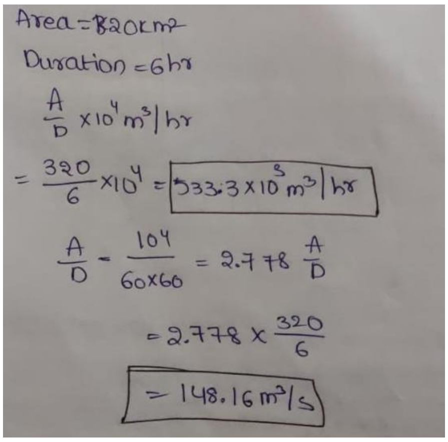
$$Q_s = 2.778\ \frac{A}{D}\ \text{m}^3/\text{s}$$

where A is in km2 and D is in h. The quantity Qs represents the maximum rate at which an ER intensity of 1/D cm/h can drain out of a catchment of area A.

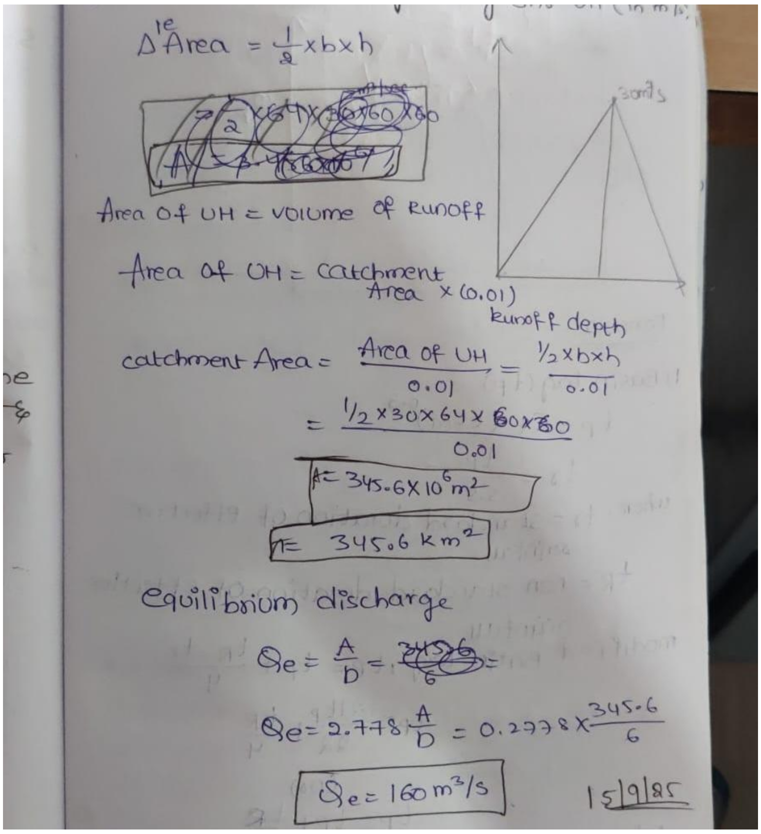

2 hr UH → 8 hr UH
D hr UH → nD hr
2 4×2
n = 4
Method of Superposition
2hr UH → 3 hr UH
n = 1.5
12 hr UH → 6 hr UH
$n = \frac{6}{12} = 0.5$
→ S-Curve


Equilibrium Discharge, $Q_e = \frac{A}{D}$
A ⇒ Catchment Area $(km)^2$
D ⇒ Duration (hr)
$km^2 - m^2 - m^3$ m^3/hr
$= 10^6 \times 10^{-2}$
$\frac{A}{D} 10^4 m^3/hr$ m^3/s
$\frac{A}{D} = \frac{10^4}{60 \times 60} = 2.77 \frac{A}{D} m^3/s$

1. **Determine the equilibrium discharge for the S-Curve of the catchment area is 320 km2 and the S-Curve is obtained from a 6-hr unit hydrograph.**


Area = 320 km²
Duration = 6 hr
$\frac{A}{D} \times 10^4 m^3/hr$
$= \frac{320}{6} \times 10^4 = \boxed{533.3 \times 10^3 m^3/hr}$
$\frac{A}{D} = \frac{10^4}{60 \times 60} = 2.778 \frac{A}{D}$
$= 2.778 \times \frac{320}{6}$
$\boxed{= 148.16 m^3/s}$

2. **An 6-hr unit hydrograph of a catchment is triangular in shape with base width of 64 hrs and peak ordinate of 30m3/sec. Calculate the equilibrium of an S-Curve obtained by using 6 hr UH (in m3/sec).**



Δ^{le} Area $= \frac{1}{2} \times b \times h$

Area of UH = volume of Runoff

Area of UH = catchment Area $\times$ (0.01) runoff depth

catchment Area = $\frac{\text{Area of UH}}{0.01} = \frac{\frac{1}{2} \times b \times h}{0.01}$

$= \frac{\frac{1}{2} \times 30 \times 64 \times 60 \times 60}{0.01}$

$\boxed{A = 345.6 \times 10^6 \, m^2}$

$\boxed{A = 345.6 \, km^2}$

equilibrium discharge

$Q_e = \frac{A}{D} = \cancel{\frac{345.6}{6}} =$

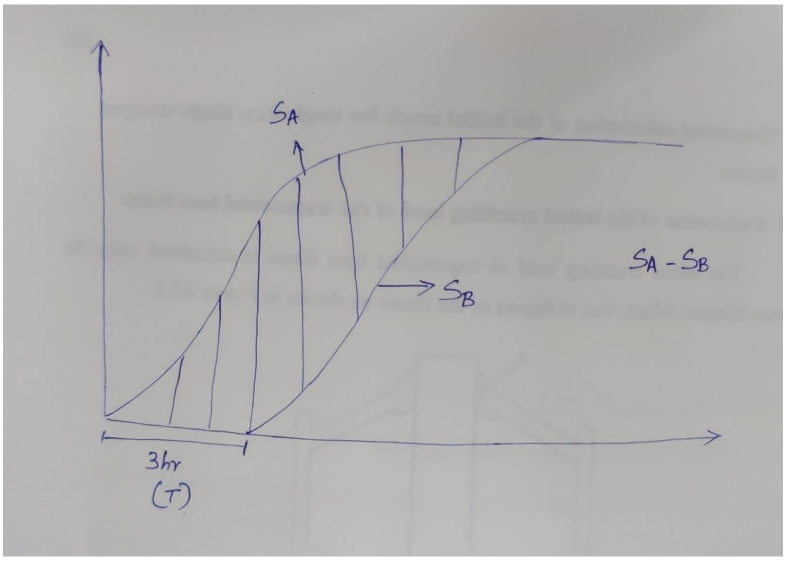
$Q_e = 2.778 \frac{A}{D} = 0.2778 \times \frac{345.6}{6}$

$\boxed{Q_e = 160 \, m^3/s}$

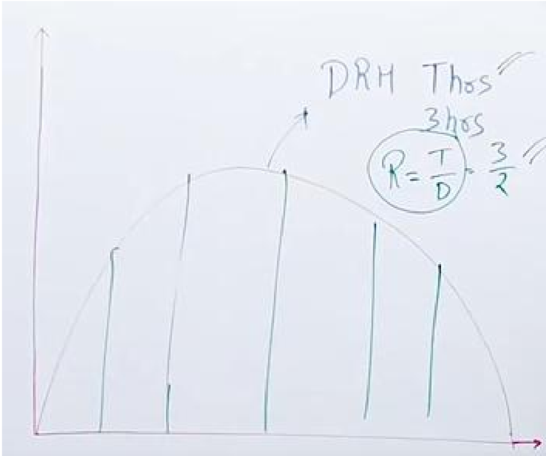
15/9/85

Steps to derive T hr Unit Hydrograph from D hr Unit Hydrograph (For example 3 hr Uh from 2 hr Uh)

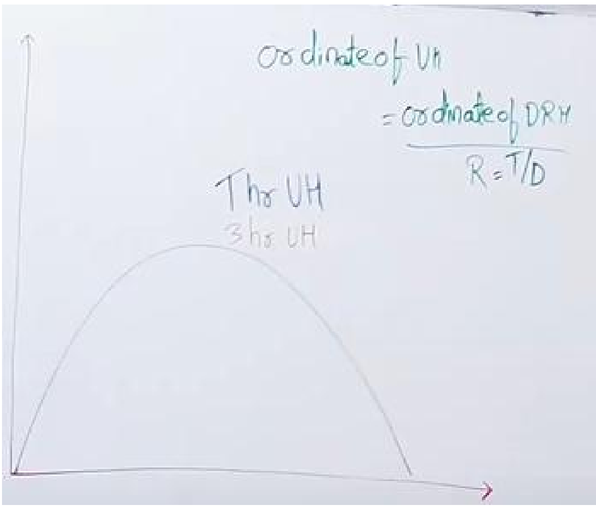
Step 1: Consider two D hr S-Curve S_A and S_B Curve S_B is lagged to S_A Curve by T hr.



Step 2: Ordinates of S_B are subtracted from S_A. This resulting curve is DRH produced by a rainfall of duration T hr but the magnitude is T/D cm.



Step 3: The ordinate of this resulting curve divided by T/D give the ordinate of unit hydrograph of T hour.



2hr UH → 4hr UH

Time	2hr UH	S_A	S_B	$S_A - S_B$	4hr UH $\frac{S_A - S_B}{4/2}$
0	0	0	-	0	0
2	25	25	-	25	12.5
4	100	125	0	125	62.5
6	160	285	25	260	130
8	190	475	125	350	175
10	170	645	285	360	180
12	110	755	475	280	140
14	70	825	645	180	90
16	30	855	755	100	50
18	20	875	825	50	25
20	6	881	855	26	13
22	0	881	875	6	3
24	-	881	881	0	0
26	-	881	881	0	0

1. **Ordinates of an 1 hour UH at 1 hour intervals are 0, 5, 8, 5, 3 and m3/sec. Calculate ordinates of 2 hour UH.**

Time	1hr UH	S_A	S_B	$S_A - S_B$	2hr UH $= \frac{S_A - S_B}{2}$
0	0	0	–	0	0
1	5	5	–	5	2.5
2	8	13	0	13	6.5
3	5	18	5	13	6.5
4	3	21	13	8	4
5	1	22	18	4	2
6	0	22	21	1	0.5
7	0	22	22	0	0

Use and Limitations of Unit Hydrograph

Use of Unit hydrograph

1. In development of flood hydrograph for extreme rainfall magnitude.

2. In extension of flood – flow record based on rainfall occurred.

3. In development of flood forecasting and warning based on rainfall.

Limitation of Unit hydrograph

1. Catchment area should not be more than 5000 km^2 and should not be less than 2 km^2.

2. Precipitation must be from rainfall only. Snow-melt runoff cannot be satisfactorily represented by unit hydrograph.

3. The catchment should not have unusually large storages in terms of tanks, ponds, large flood-bank storages, etc. which affect the linear relationship between storage and discharge.

4. If the precipitation is decidedly non-uniform, unit hydrographs cannot be expected to give good results.

1. A catchment of 200 hectares area has rainfalls of 7.5 cm, 2.0 cm and 5.0 cm on three consecutive days. The average ϕ index can be assumed to be 2.5 cm/day. Distribution-graph percentages of the surface runoff which extended over 6 days for every rainfall of 1-day duration are 5, 15, 40, 25, 10 and 5. Determine the ordinates of the discharge hydrograph by neglecting the base flow.

Time Interval (days)	Rainfall (cm)	Infiltration Loss (cm)	Effective Rainfall (cm)	Average Distribution Ration (percent)	Distributed Runoff for Rainfall Excess of			Runoff	
					5 cm	0	2.5 cm	cm	$m^3/s \times 10^{-2}$
0-1	7.5	2.5	5.0	5	0.250	0		0.250	5.79
1-2	2.0	2.5	0	15	0.750	0	0	0.750	17.36
2-3	5.0	2.5	5.0	40	2.000	0	0.125	2.750	49.19
3-4				25	1.250	0	0.375	2.125	37.62
4-5				10	0.500	0	1.000	1625	34.72
5-6				5	0.250	0	0.625	1.500	20.25
6-7				0	0	0	0.250	0.875	5.79
7-8						0	0.125	0.250	2.89
8-9							0	0.125	0

$$\left[\text{Runoff of 1 cm in 1 day} = \frac{200 \times 100 \times 100}{86400 \times 100}\ \text{m}^3\text{/s for 1 day} = 0.23148\ \text{m}^3\text{/s for 1 day.}\right]$$

(The runoff ordinates are plotted at the mid-points of the respective time intervals to obtain the *DRH*.)

SYNTHETIC UNIT HYDROGRAPH

To develop unit hydrographs to a catchment, detailed information about the rainfall and the resulting flood hydrograph is needed. However, such information would be available only at a few locations and in a majority of catchments, especially those which are at remote locations, the data would normally be very scanty. In order to construct unit hydrographs for such areas, empirical equations of regional validity which relate the salient hydrograph characteristics to the basin characteristics are available. Unit hydrographs derived from such relationships are known as synthetic-unit hydrographs.

Snyder's Method

Snyder (1938), based on a study of a large number of catchments in the Appalachian Highlands of the eastern United States, developed a set of empirical equations for synthetic-unit hydrographs in those areas. These equations are in use in the USA, and with some modifications in many other countries, and constitute what is known as Snyder's synthetic-unit hydrograph.

The most important characteristic of a basin affecting a hydrograph due to a storm is basin lag. While actually basin lag (also known as lag time) is the time difference between the centroid of the input (rainfall excess) and the output (direct runoff hydrograph), because of the difficulty in determining the centroid of the direct runoff hydrograph (DRH) it is defined for practical purposes as the elapsed time between the centroid of rainfall excess and peak of DRH. Physically, lag time represents the mean time of travel of water from all parts of the watershed to the outlet during a given storm. Its value is determined essentially on the topographical features, such as the size, shape, stream density, length of main stream, slope, land use and land cover. The modified definition of basin time is very commonly adopted in the derivation of synthetic unit hydrographs for a given watershed. The first of Snyder's equation relates the basin lag t_p, defined as the time interval from the mid-point of rainfall excess to the peak of the unit hydrograph, to the basin characteristics as

1. Basin Lag (t_p)

$$t_p = C_t(LL_{ca})^{0.3}$$

where

t_p = basin lag in hours

L = basin length measured along the water course from the basin divide to the gauging station in km

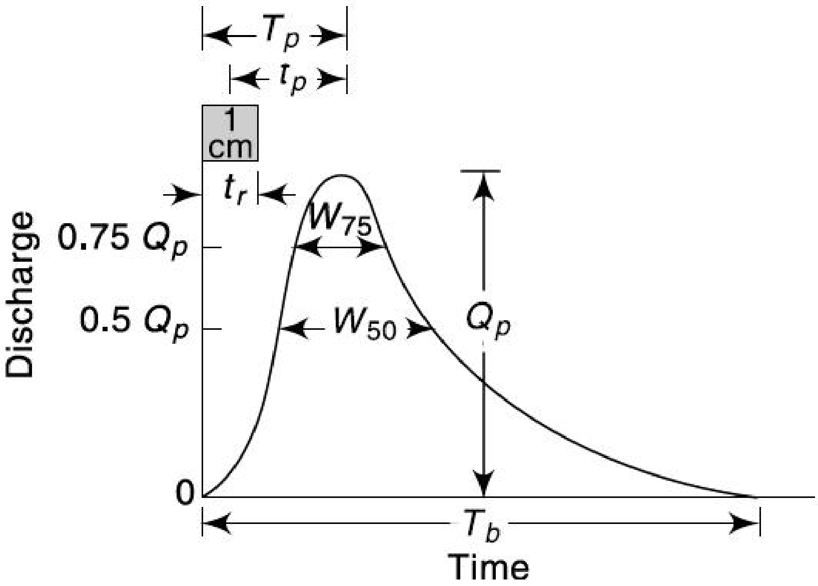
L_{ca} = distance along the main water course from the gauging station to a point opposite to the watershed centroid in km

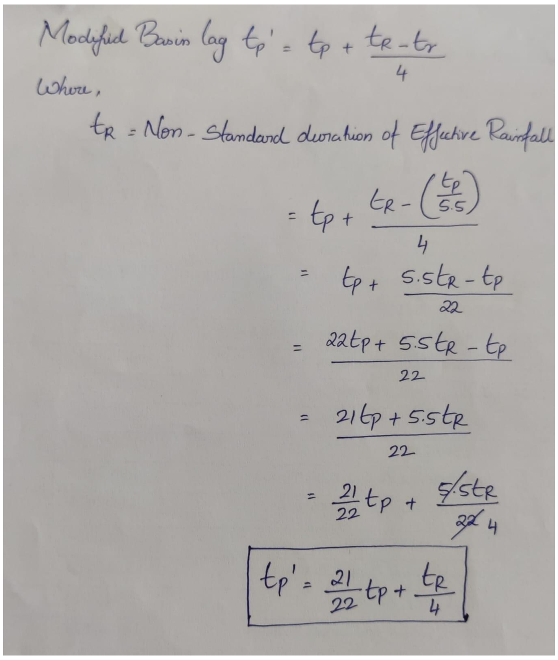
C_t = a regional constant representing watershed slope and storage effects

$$t_r = \frac{t_p}{5.5}$$

where

t_r = Standard duration of effective rainfall




Modified Basin lag $t_p' = t_p + \frac{t_R - t_r}{4}$

Where,

t_R = Non-Standard duration of Effective Rainfall

$$= t_p + \frac{t_R - \left(\frac{t_p}{5.5}\right)}{4}$$

$$= t_p + \frac{5.5t_R - t_p}{22}$$

$$= \frac{22t_p + 5.5t_R - t_p}{22}$$

$$= \frac{21t_p + 5.5t_R}{22}$$

$$= \frac{21}{22}t_p + \frac{\cancel{5.5}t_R}{\cancel{22}\,4}$$

$$\boxed{t_p' = \frac{21}{22}t_p + \frac{t_R}{4}}$$

2. Peak Discharge (Q_p)

$$Q_p = 2.78 C_p A / t'_p$$

where

C_p and C_t = Regional Constant

$$W_{50} = \frac{5.87}{q^{1.08}}$$

$$W_{75} = W_{50}/1.75$$

where

W50 = width of unit hydrograph in h at 50% peak discharge

W75 = width of unit hydrograph in h at 75% peak discharge

q = Q_p/A = peak discharge per unit catchment area in $m^3/s/km^2$

3. Base Time (T_b)

$$T_b = 3 + \frac{t'_p}{8} \text{ days} = (72 + 3\,t'_p) \text{ hours}$$ **[For larger Catchment]**

$$T_b = 5\left(t'_p + \frac{t_R}{2}\right) \text{ hours}$$ **[For Smaller Catchment]**

1. **Two catchments A and B are considered meteorologically similar. Their catchment characteristics are given below.**

Catchment *A*	Catchment *B*
$L = 30$ km $L_{ca} = 15$ km $A = 250$ km^2	$L = 45$ km $L_{ca} = 25$ km $A = 400$ km^2

For catchment A, a 2-h unit hydrograph was developed and was found to have a peak discharge of 50 m3/s. The time to peak from the beginning of the rainfall excess in this unit hydrograph was 9.0h. Using Synder's method, develop a unit hydrograph for catchment B.

Solution

for Catchment - A

$\boxed{t_R = 2.0 \text{ hours}}$ Given

Time to peak from begining of ER

$T_p = \frac{t_R}{2} + t'_p \Rightarrow \boxed{9.0 \text{ hours} = T_p}$ Given

$t'_p = T_p - \frac{t_R}{2}$

$= 9 - \frac{2}{2}$ ∵ $t_R = 2$ hours ⇒ Given.

$= \frac{18-2}{2}$

$= \frac{16}{2}$

$\boxed{t'_p = 8 \text{ hours}}$

$t'_p = \frac{21}{22} t_p + \frac{t_R}{4}$

$8 = \frac{21}{22} t_p + \frac{t_R}{4}$

$\frac{21}{22} t_p = t'_p - \frac{t_R}{4}$

$= 8 - \frac{2}{2}$

$= \frac{16-2}{2}$

$= \frac{14}{2}$

$= 7$

$t_p = 7 \times \frac{22}{21}$

$\boxed{t_p = 7.33 \text{ or } 7.857 \text{ hours}}$

1. $t_p = C_t(LL_{ca})^{0.3}$

$C_t = \dfrac{7.857}{(30 \times 15)^{0.3}}$

$\boxed{C_t = 1.257}$

Given

for Catchment A

$L = 30km$

$L_{ca} = 15km$

2. $Q_p = \dfrac{2.78 C_p A}{t_p'}$

$50 = \dfrac{2.78 C_p \times 250}{8.0}$

$C_p = \dfrac{50 \times 8.0}{2.78 \times 250}$

$\boxed{C_p = 0.576}$

$\because Q_p = 50 m^3/s$

$A = 250 km^2$ (for Catchment A)

for Catchment-B

Using the Values of $C_t = 1.257$ and $C_p = 0.576$ in Catchment A, the Parameters of the Synthetic unit Hydrograph for Catchment B are determined.

1. $t_p = C_t(LL_{ca})^{0.3}$

$= 1.257(45 \times 25)^{0.3}$

$\boxed{t_p = 10.34 \text{ hours}}$

$\because$ for Catchment B

$L = 45 km$

$L_{ca} = 25km$

$t_r = \dfrac{t_p}{5.5}$

$= \dfrac{10.34}{5.5}$

$\boxed{t_r = 1.88 \text{ hours}}$

$t_p' = \dfrac{21}{22} t_p + \dfrac{t_R}{4}$

$= \dfrac{21}{22}(10.34) + \dfrac{2}{4}$

$\boxed{t_p' = 10.37 \text{ hours}}$

2. $Q_p = \dfrac{2.78 C_p A}{t_p'}$

$= \dfrac{2.78 \times 0.576 \times 400}{10.37}$

$\boxed{Q_p = 61.77 m^3/s}$

$\because$ for Catchment B

$A = 400 km^2$

$W_{50} = \dfrac{5.87}{q^{1.08}} = \dfrac{5.87}{\left(\frac{Q}{A}\right)^{1.08}}$

$= \dfrac{5.87}{\left(\frac{61.77}{400}\right)^{1.08}}$

$\boxed{W_{50} = 44 \text{ hours}}$

$W_{75} = \dfrac{W_{50}}{1.75} = \dfrac{44}{1.75}$

$\boxed{W_{75} = 25 \text{ hours}}$

3. $T_B = 72 + 3t_p'$ [large Catchment Area]

$= 72 + (3 \times 10.37)$

$\boxed{T_B = 103 \text{ hours}}$

$T_b = 5 \times \left(t_p' + \dfrac{t_R}{2}\right)$ [Small Catchment Area]

$= 5 \times \left(10.37 + \dfrac{2}{2}\right)$

$\boxed{T_b = 56.85 \text{ hours}}$