

Module 3

Lecture 3: Hydrograph analysis

Hydrograph analysis

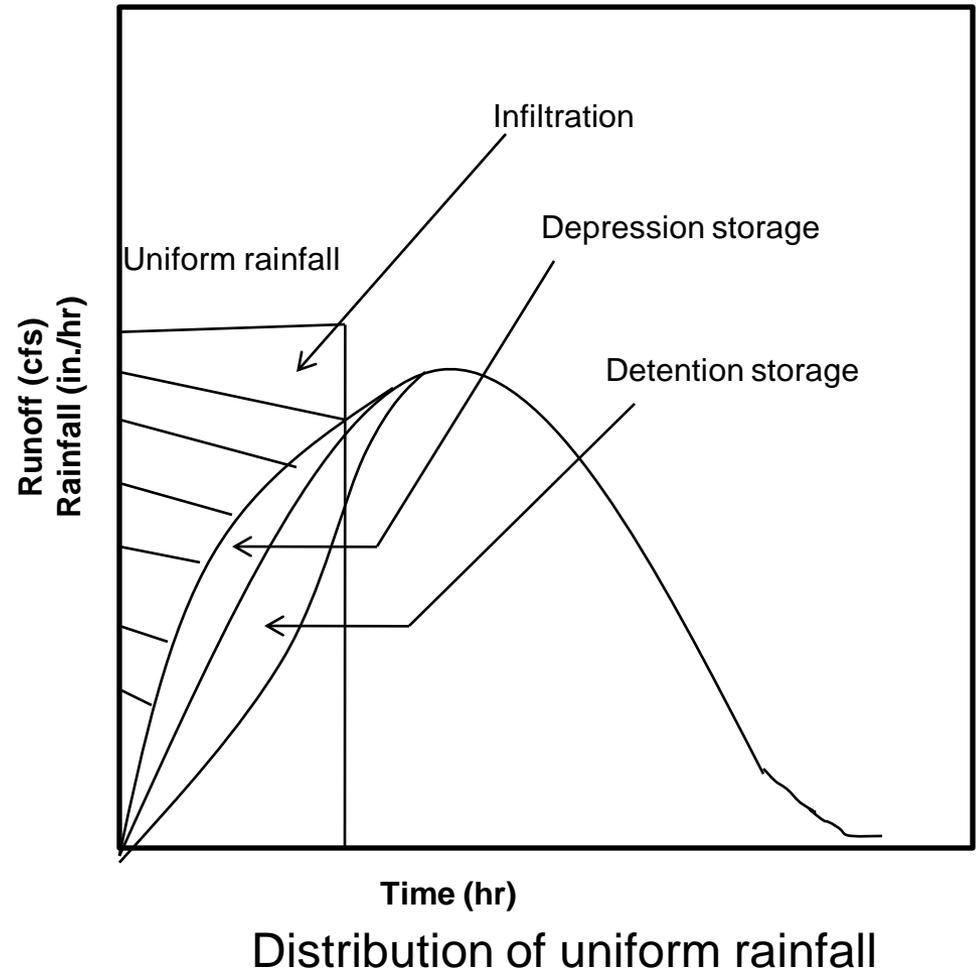
- ❖ A hydrograph is a continuous plot of instantaneous discharge v/s time. It results from a combination of physiographic and meteorological conditions in a watershed and represents the integrated effects of climate, hydrologic losses, surface runoff, interflow, and ground water flow
- ❖ Detailed analysis of hydrographs is usually important in flood damage mitigation, flood forecasting, or establishing design flows for structures that convey floodwaters
- ❖ **Factors that influence the hydrograph shape and volume**
 - Meteorological factors
 - Physiographic or watershed factors and
 - Human factors

- **Meteorological factors include**
 - Rainfall intensity and pattern
 - Areal distribution or rainfall over the basin and
 - Size and duration of the storm event
- **Physiographic or watershed factors include**
 - Size and shape of the drainage area
 - Slope of the land surface and main channel
 - Channel morphology and drainage type
 - Soil types and distribution
 - Storage detention in the watershed
- **Human factors include the effects of land use and land cover**

Hydrograph analysis

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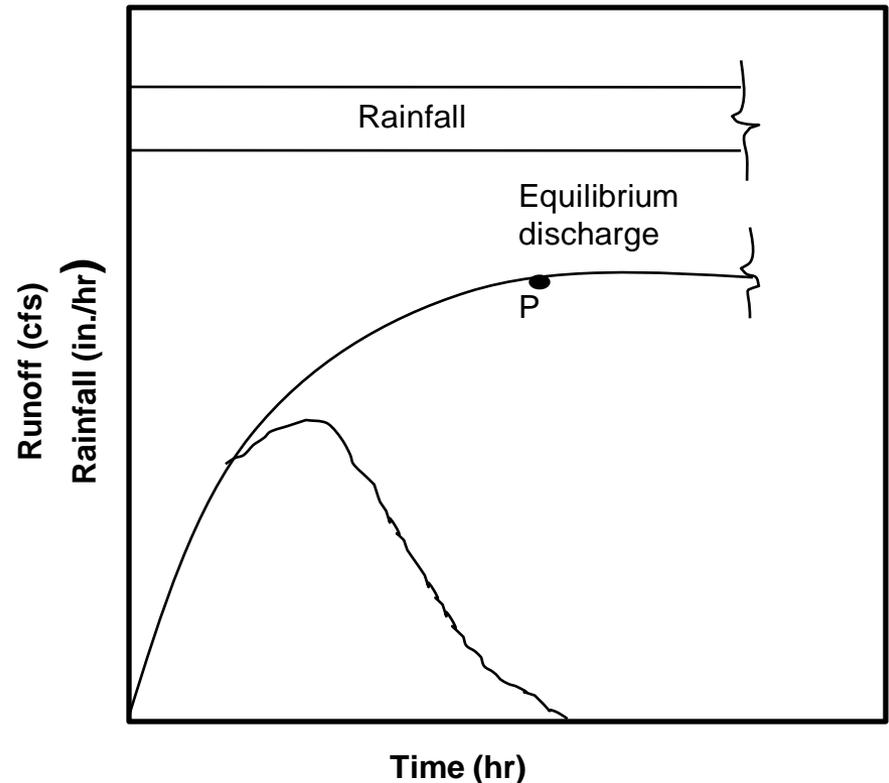
- During the rainfall, hydrologic losses such as infiltration, depression storage and detention storage must be satisfied prior to the onset of surface runoff
- As the depth of surface detention increases, overland flow may occur in portion of a basin
- Water eventually moves into small rivulets, small channels and finally the main stream of a watershed
- Some of the water that infiltrates the soil may move laterally through upper soil zones (subsurface stormflow) until it enters a stream channel



Hydrograph analysis

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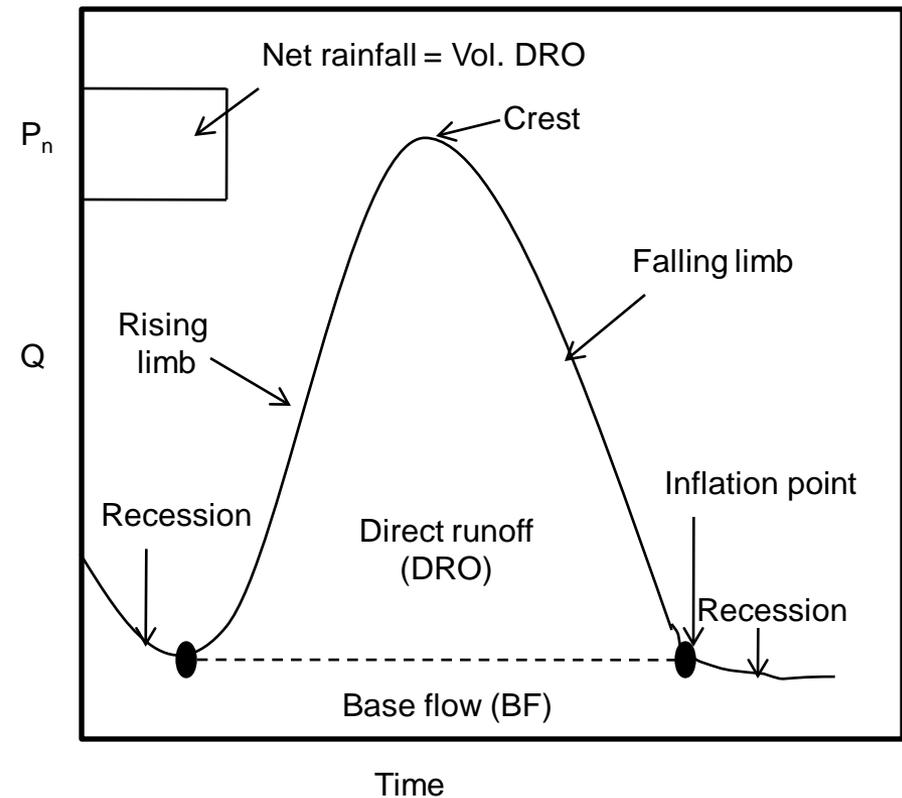
- If the rainfall continues at a constant intensity for a very long period, storage is filled at some point and then an **equilibrium discharge** can be reached
- In equilibrium discharge the inflow and outflow are equal
- The point **P** indicates the time at which the entire discharge area contributes to the flow
- The condition of equilibrium discharge is seldom observed in nature, except for very small basins, because of natural variations in rainfall intensity and duration



Equilibrium hydrograph

Hydrograph relations

- The typical hydrograph is characterized by a
 1. Rising limb
 2. Crest
 3. Recession curve
- The inflation point on the falling limb is often assumed to be the point where direct runoff ends



Hydrograph relations

Recession and Base flow separation

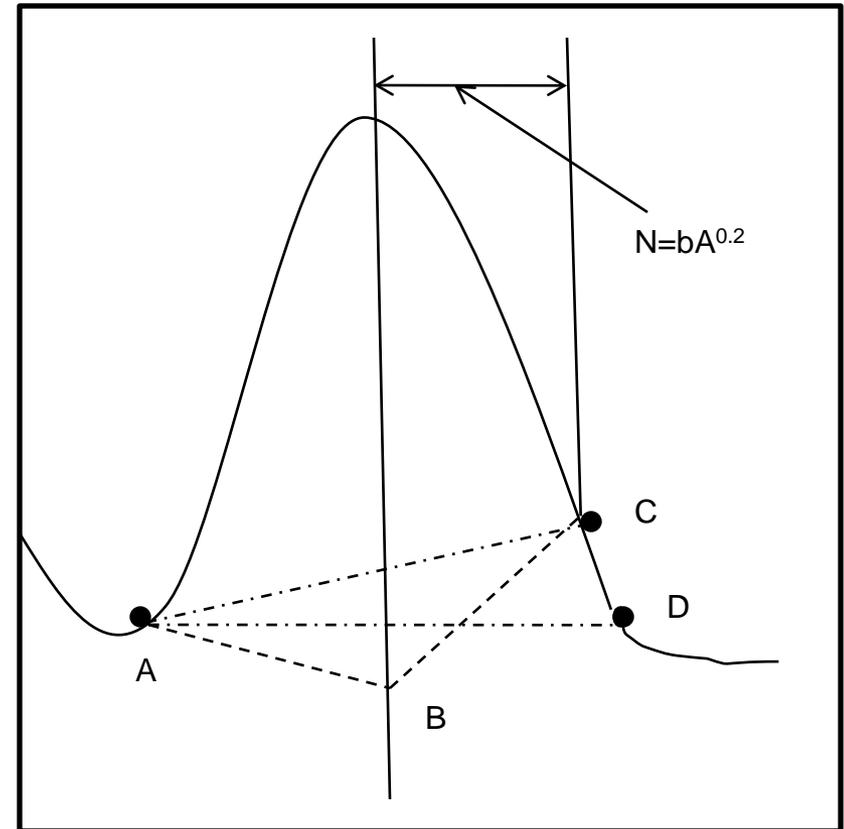
- In this the hydrograph is divided into two parts
 1. Direct runoff (DRO) and
 2. Base flow (BF)
- DRO include some interflow whereas BF is considered to be mostly from contributing ground water
- Recession curve method is used to separate DRO from BF and can be by an exponential depletion equation

$$q_t = q_0 \cdot e^{-kt} \quad \text{where}$$

q_t = discharge at a later time t

q_0 = specified initial discharge

k = recession constant



Base flow separation

Baseflow Separation Methods

- There are three types of baseflow separation techniques
 1. Straight line method
 2. Fixed base method
 3. Constant slope method

1. Straight line method

- Assume baseflow constant regardless of stream height (discharge)
- Draw a horizontal line segment (A-D) from beginning of runoff to intersection with recession curve

2. Constant slope method

- connect inflection point on receding limb of storm hydrograph to beginning of storm hydrograph
- Assumes flow from aquifers began prior to start of current storm, arbitrarily sets it to inflection point
- Draw a line connecting the point (A-C) connecting a point N time periods after the peak.

3. Fixed Base Method

- Assume baseflow decreases while stream flow increases (i.e. to peak of storm hydrograph)
- Draw line segment (A –B) from baseflow recession to a point directly below the hydrograph peak
- Draw line segment (B-C) connecting a point N time periods after the peak

where

N = time in days where DRO is terminated, A = Discharge area in km^2 ,

b = coefficient, taken as 0.827

Rainfall excess

- The distribution of gross rainfall can be given by the continuity equation as

Gross rainfall = depression storage+ evaporation+ infiltration+ surface runoff

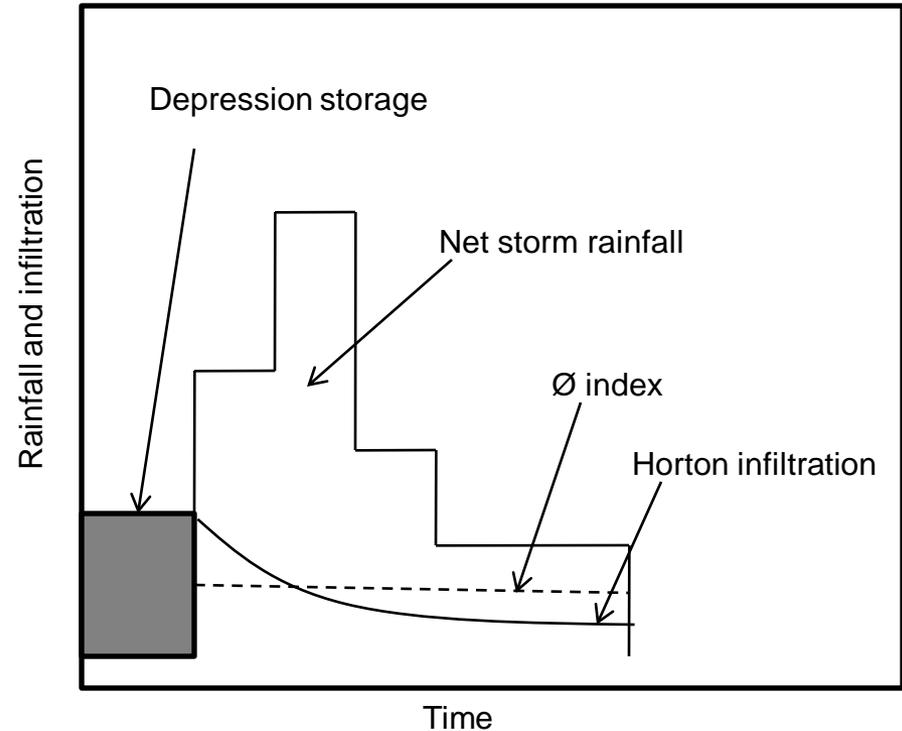
- In case, where depression storage is small and evaporation can be neglected, we can compute rainfall excess which equals to direct runoff, DRO, by

Rainfall excess (P_n) = DRO = gross rainfall – (infiltration+ depression storage)

Rainfall excess

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- The simpler method to determine rainfall excess include
 1. Horton infiltration method
 2. ϕ index method
- **Note:-** In this, the initial loss is included for depression storage



Infiltration loss curves

- **Horton infiltration method**

Horton method estimates infiltration with an exponential-type equation that slowly declines in time as rainfall continues and is given by

$$f = f_c + (f_o - f_c) e^{-kt} \quad (\text{when rainfall intensity } i > f)$$

where

f = infiltration capacity (in./hr)

f_o = initial infiltration capacity (in./hr)

f_c = final infiltration capacity (in./hr)

k = empirical constant (hr^{-1})

- **Ø index method**

It is the simplest method and is calculated by finding the loss difference between gross precipitation and observed surface runoff measured as a hydrograph

Example Problem-1

- Rainfall of magnitude 3.8 cm and 2.8 cm occurring on two consecutive 4-h durations on a catchment area 27km² produced the following hydrograph of flow at the outlet of the catchment. Estimate the rainfall excess and ϕ -index

Time from start of rainfall (h)	-6	0	6	12	18	24	30	36	42	48	54	60	66
Observed flow (m ³ /s)	6	5	13	26	21	16	12	9	7	5	5	4.5	4.5

Baseflow separation:

Using Simple straight line method,

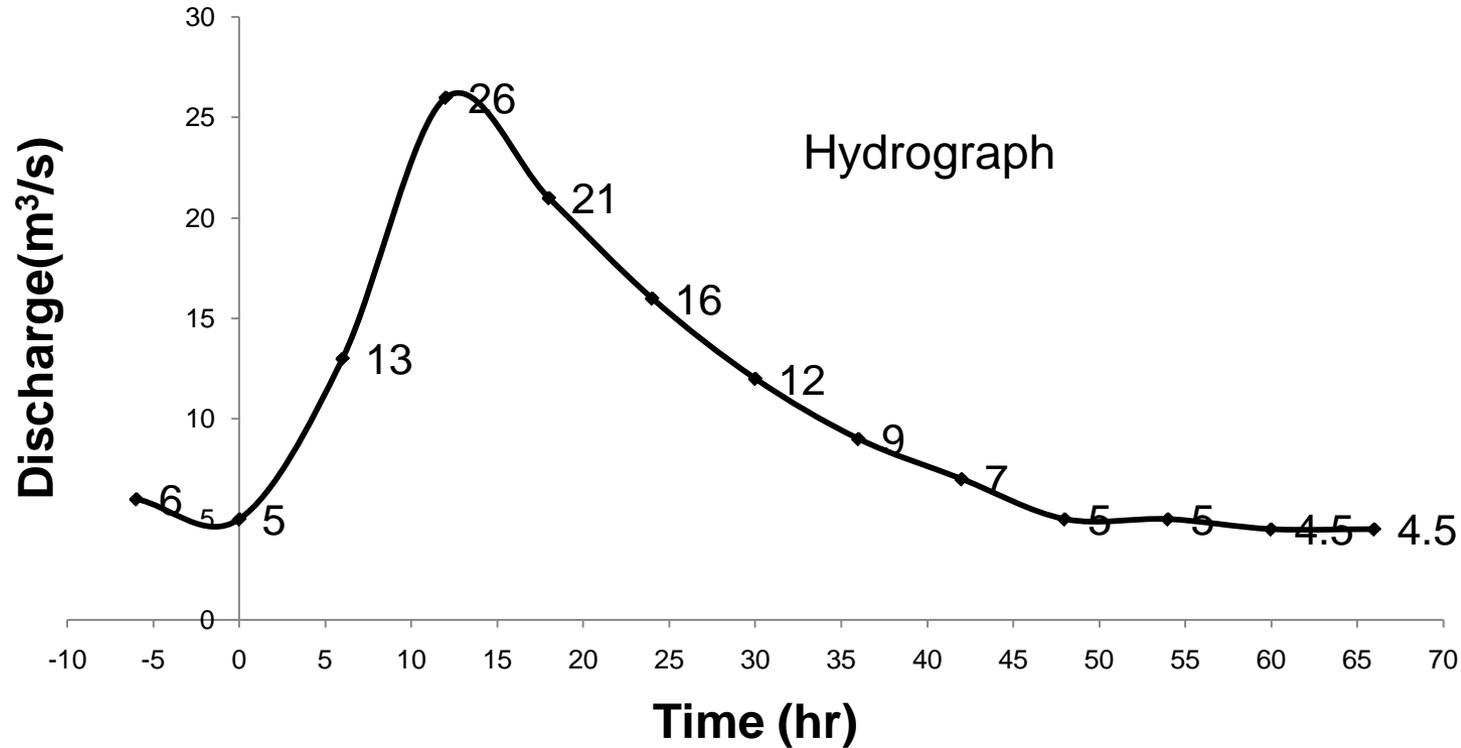
$$N = 0.83 A^{0.2} = 0.83 (27)^{0.2}$$

$$= 1.6 \text{ days} = 38.5 \text{ h}$$

So the baseflow starts at 0th h and ends at the point (12+38.5)h

Example Problem-1

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→ 50.5 h (say 48 h approx.)

Constant baseflow of 5m³/s

Example Problem-1

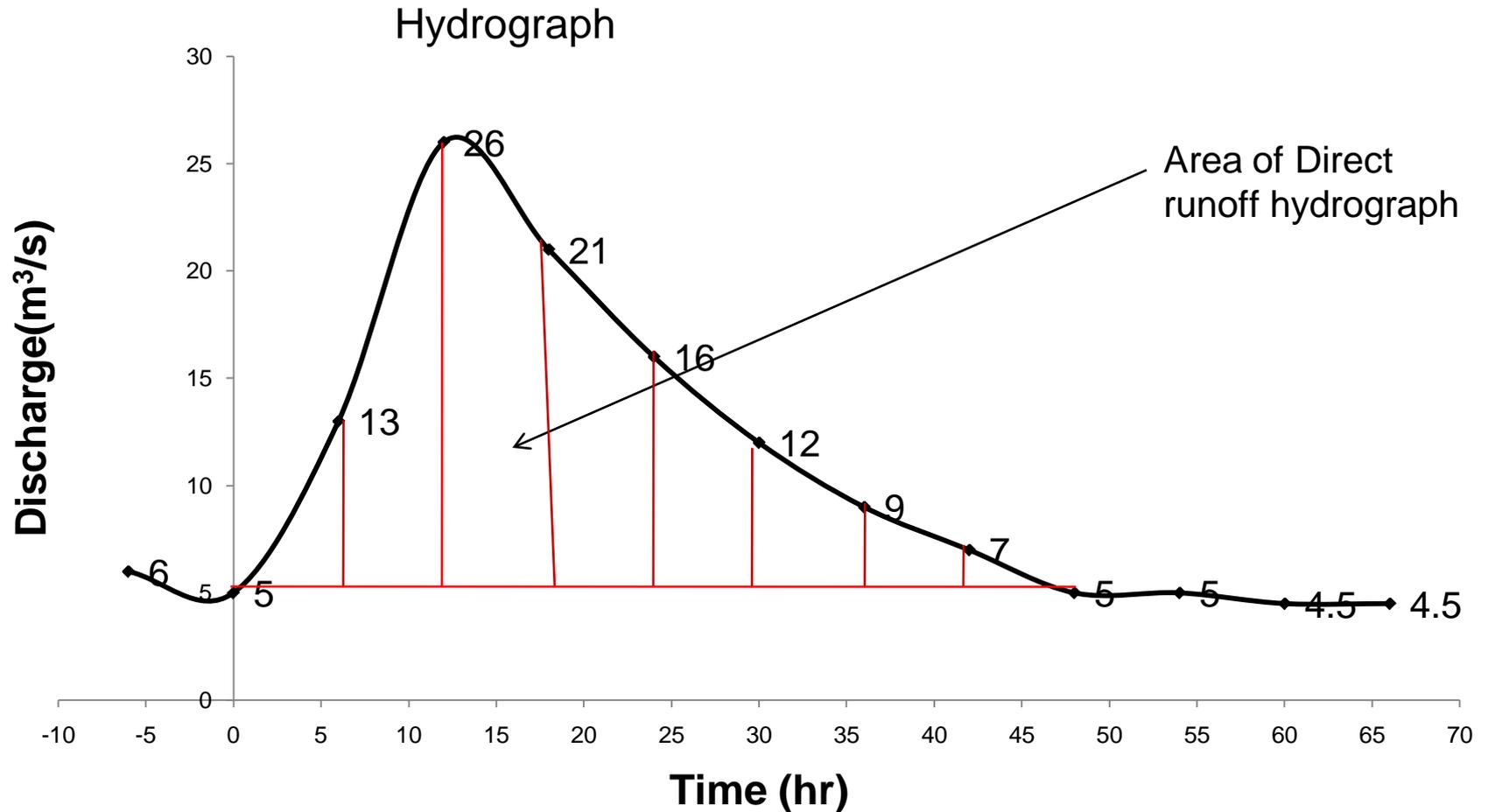
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Time (h)	FH Ordinates(m ³ /s)	DRH Ordinates (m ³ /s)
-6	6	1
0	5	0
6	13	8
12	26	21
18	21	16
24	16	11
30	12	7
36	9	4
42	7	2
48	5	0
54	5	0
60	4.5	0
66	4.5	0

DRH ordinates are obtained from subtracting the corresponding FH with the base flow i.e. 5 m³/s

Example Problem-1

Contd...



Example Problem-1

Contd...

$$\begin{aligned} \text{Area of DRH} &= (6 \times 60 \times 60) \left[\frac{1}{2} (8) + \frac{1}{2} (8+21) + \right. \\ &\quad \left. \frac{1}{2} (21+16) + \frac{1}{2} (16+11) + \right. \\ &\quad \left. \frac{1}{2} (11+7) + \frac{1}{2} (7+4) + \frac{1}{2} (4+2) + \frac{1}{2} (2) \right] \\ &= 1.4904 \times 10^6 \text{m}^3 \text{ (total direct runoff due to storm)} \end{aligned}$$

Run-off depth = Runoff volume/catchment area

$$\begin{aligned} &= 1.4904 \times 10^6 / 27 \times 10^6 \\ &= 0.0552 \text{m} = 5.52 \text{ cm} = \text{rainfall excess} \end{aligned}$$

$$\text{Total rainfall} = 3.8 + 2.8 = 6.6 \text{cm}$$

$$\text{Duration} = 8 \text{h}$$

$$\text{\(\phi\)-index} = (P-R)/t = (6.6-5.52)/8 = \underline{\underline{0.135 \text{cm/h}}}$$

Example Problem-2

A storm over a catchment of area 5.0 km^2 had a duration of 14 hours. The mass curve of rainfall of the storm is as follows:

Time from start of storm (h)	0	2	4	6	8	10	12	14
Accumulated rainfall (cm)	0	0.6	2.8	5.2	6.6	7.5	9.2	9.6

If the ϕ -index of the catchment is 0.4 cm/h , determine the effective rainfall hyetograph and the volume of direct runoff from the catchment due to the storm.

Example Problem-2

Contd...

Time from start of storm(h)	Time interval Δt	Accumulated rainfall in Δt (cm)	Depth of rainfall in Δt (cm)	$\phi \Delta t$ (cm)	ER (cm)	Intensity of ER (cm/h)
0	—	0	—	—	—	—
2	2	0.6	0.6	0.8	0	0
4	2	2.8	2.2	0.8	1.4	0.7
6	2	5.2	2.4	0.8	1.6	0.8
8	2	6.7	1.5	0.8	0.7	0.35
10	2	7.5	0.8	0.8	0	0
12	2	9.2	1.7	0.8	0.9	0.45
14	2	9.6	0.4	0.8	0	0

- Total effective rainfall = Direct runoff due to storm = area of ER hyetograph
= $(0.7+0.8+0.35+0.45)*2 = 4.6$ cm
- Volume of direct runoff = $(4.6/100) * 5.0*(1000)^2$
= 230000m^3

Run-off Measurement

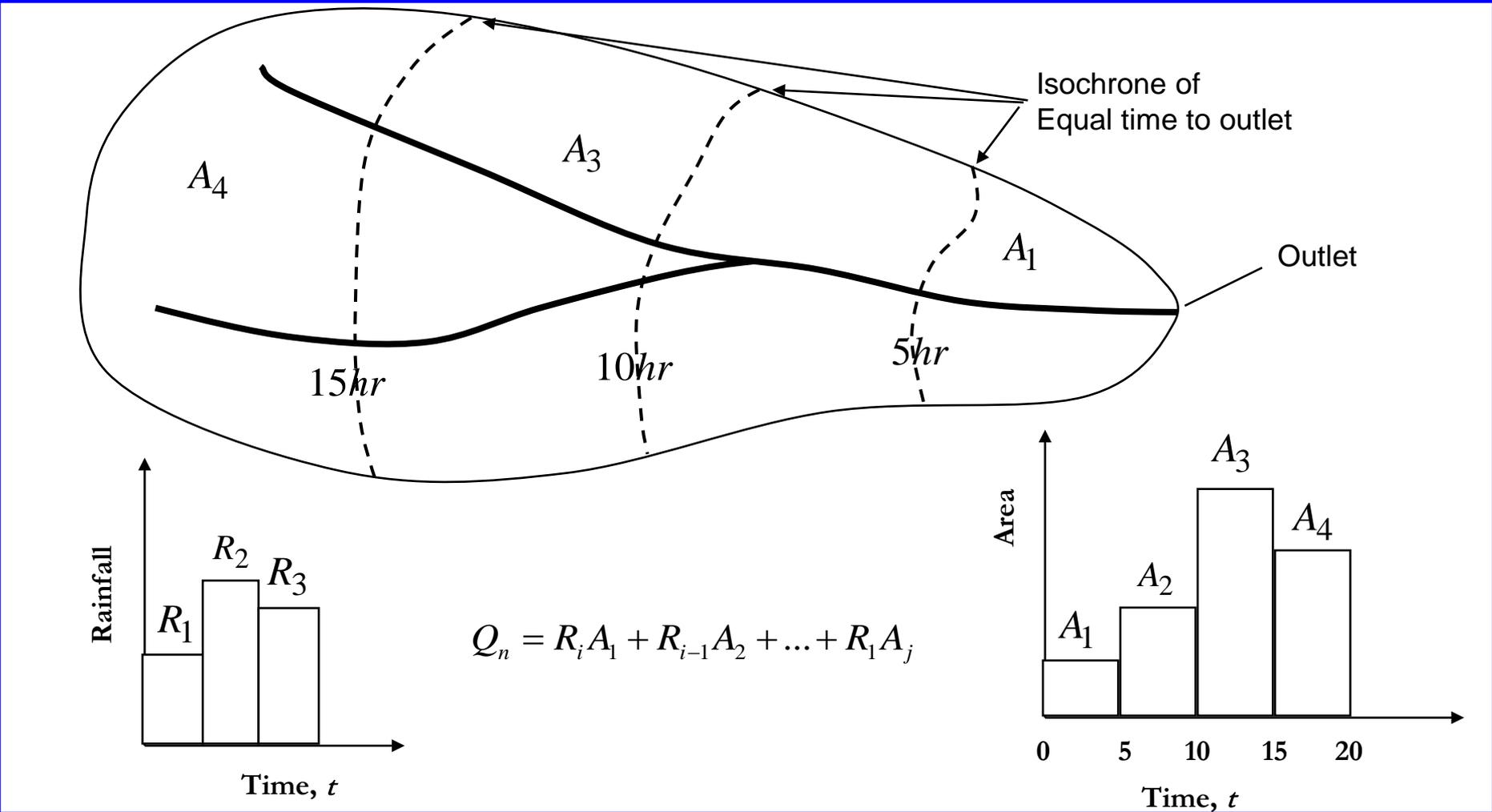
Time- Area method

- This method assumes that the outflow hydrograph results from pure translation of direct runoff to the outlet, at a uniform velocity, ignoring any storage effect in the watershed
- The relationship is defined by dividing a watershed into subareas with distinct runoff translation times to the outlet
- The subareas are delineated with isochrones of equal translation time numbered upstream from the outlet
- In a uniform rainfall intensity distribution over the watershed, water first flows from areas immediately adjacent to the outlet, and the percentage of total area contributing increases progressively in time
- The surface runoff from area A_1 reaches the outlet first followed by contributions from A_2 , A_3 and A_4 ,

Run-off Measurement

Contd...

Time- Area method



Time- Area method

where

Q_n = hydrograph ordinate at time n (cfs)

R_i = excess rainfall ordinate at time i (cfs)

A_j = time –area histogram ordinate at time j (ft^2)

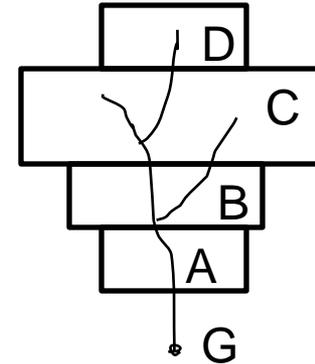
Limitation of time area method

- This method is limited because of the difficulty of constructing isochronal lines and the hydrograph must be further adjusted to represent storage effects in the watershed

Example Problem

- Find the storm hydrograph for the following data using time area method. Given rainfall excess ordinate at time is 0.5 in./hr

	A	B	C	D
Area (ac)	100	200	300	100
Time to gage G (hr)	1	2	3	4



Time area histogram method uses

$$Q_n = R_i A_1 + R_{i-2} A_2 + \dots + R_i A_j$$

For $n = 5$, $i = 5$, and $j = 5$

$$Q_5 = R_5 A_1 + R_4 A_2 + R_3 A_3 + R_2 A_4$$

$$(0.5 \text{ in./hr}) (100 \text{ ac}) + (0.5 \text{ in./hr}) (200 \text{ ac}) + (0.5 \text{ in./hr}) (300 \text{ ac}) + (0.5 \text{ in./hr}) (100)$$

$$Q_5 = 350 \text{ ac-in./hr}$$

Note that 1 ac-in./hr \approx 1 cfs, hence

$$Q_5 = 350 \text{ cfs}$$

Example Problem

Contd...

Excel spreadsheet calculation

Time (hr)	Hydrograph Ordinate (R1:Rn)	Basin No.	Time to gage	Basin area A1:An (ac)	R1:An	R2:An	R2:An	R2:An	R2:An	Storm hydrograph
0										0
1	0.5	A	1	100	* 50					50
2	0.5	B	2	200	100	50				+150
3	0.5	C	3	300	150	100	50			300
4	0.5	D	4	400	50	150	100	50		350
5						50	150	100	50	350
6							50	150	100	300
7								50	150	200
8									50	50
9										0

* $= (R1 * A1) = (0.5 * 100)$ and + = (adding the columns from 6 to 10)

Example Problem

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