Civinnovate

Discover, Learn, and Innovate in Civil Engineering

1st Dec,
MONDAY

HYDROLOGY

(5 marks - 6 marks)

- Hydrology is a study of science of water.

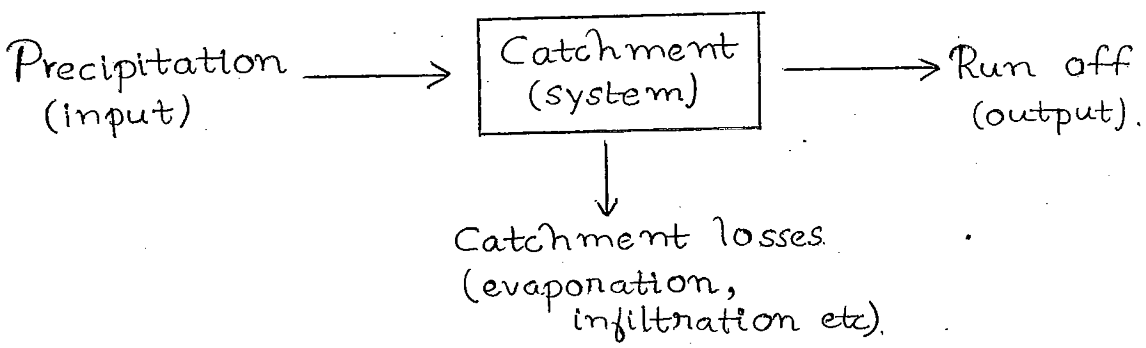
- Hydrology deals with occurence, movement, distribution and circulation of water above the ground, below the ground or even in the atmosphere.

- Hydrology deals with depletion and replenishment of water resource of earth.

- Objective:

  To estimate yield (water) from drainage basin.

Drainage basin means watershed (or) catchment.



- Applications:

  (i) Design of hydraulic structures.

  (ii) Flood forecasting & management.

(iii) Irrigation.

(iv) Municipal and industrial water supply.

(v) Hydropower generation.

(vi) Pollution control.

(vii) Navigation.

(viii) Drought management.

→ World's Water Resource:

Total water available – 1380 million km^3

Saline water – 97.2 % available water

Fresh water – 2.8 % available water.

Glaciers (locked in polar ice caps) – 2.15% available water.

Deep below the ground (depth of 800 m below ground) – 0.32% available water.

∴ 0.33% of total water available for human use and consumption.

$$= \frac{0.33}{100} \times 1380 \simeq 4.5 \text{ million } km^3$$

– Average annual precipitation of world = 100 cm

→ Water Resource of India:

Average annual precipitation = 119.4 cm

Geographic area = 3.28×10^6 km^2

Total volume of water = $3.28 \times 10^6 \times 119.4 \times 10^{-5}$

= 3916 km^3

Including snowfall, total water available = 4000 km^3

Evaporation loss = 700 km^3

Water soak into ground = 2150 km^3

Net water available = 4000 − 700 − 2150

= 1150 km^3

% world's water available with India = $\frac{1150}{4.5 \times 10^6} * 100$

= <u>0.025 %</u>

→ Hydrologic Cycle:

– Water circulatory cycle. which shows how water circulate from one place to other place and from one form to other form with time.

– Components of Hydrologic Cycle:

(i) Precipitation.

(ii) Evaporation.

(iii) Transpiration

(iv) Evapo-transpiration.

(v) Infiltration.

(vi) Run-off.

01. PRECIPITATION

Precipitation denotes all forms of moisture that reach ground from atmosphere.

→ Forms of Precipitation:

1. Rain :-

Precipitation in the form of water droplets. of size > 0.5 mm and intensity (rate of rain) > 1 mm/hr.

$$\text{Intensity of rain } (I) = \frac{dP}{dt} = \frac{P}{t}$$

* Based on intensity, rains are classified into :

(i) Light rain :- 1 mm/hr ≤ i ≤ 2.5 mm/hr.

(ii) Moderate rain :- 2.5 mm/hr ≤ i ≤ 7.5 mm/hr.

(iii) Heavy rain :- i > 7.5 mm/hr.

2. Drizzle :-

Precipitation in the form of water droplets of size < 0.5 mm and intensity < 1 mm/hr.

3. Snow :-

Precipitation in the form of fine ice crystals of size < 1 mm.

4. Sleet :- (Frozen rain).

Ice crystals of size 1 mm to 5 mm.

5. Hail :-

Ice crystals of size > 8 mm

6. Dew :- vapour accumulated during day condenses during night and deposited on the ground as dew.

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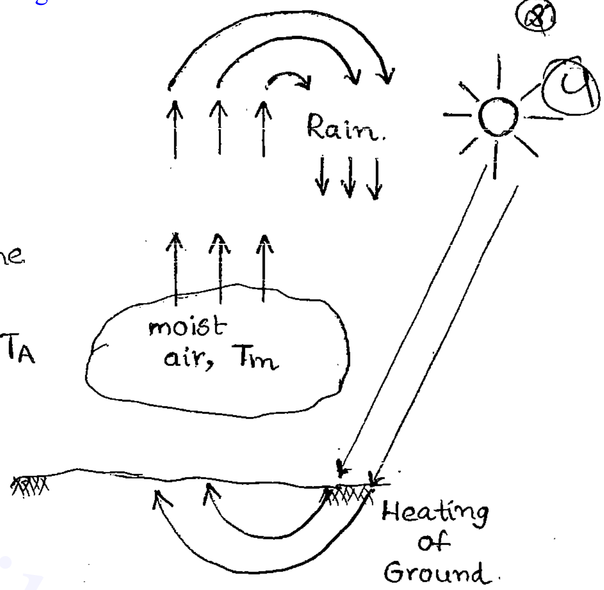
→ Types of Precipitation:

1. Convective Precipitation –

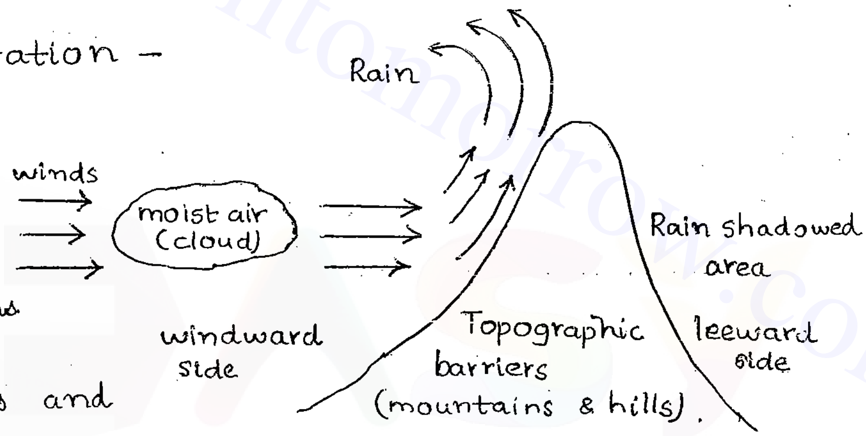
This occurs due to heating of the ground and temperature difference b/w moist air and its surroundings.



Eg:- Summer rains: high intensity rains occuring for short periods.

2. Orographic Precipitation –

It is caused by topographic barriers such as hills & mountains.



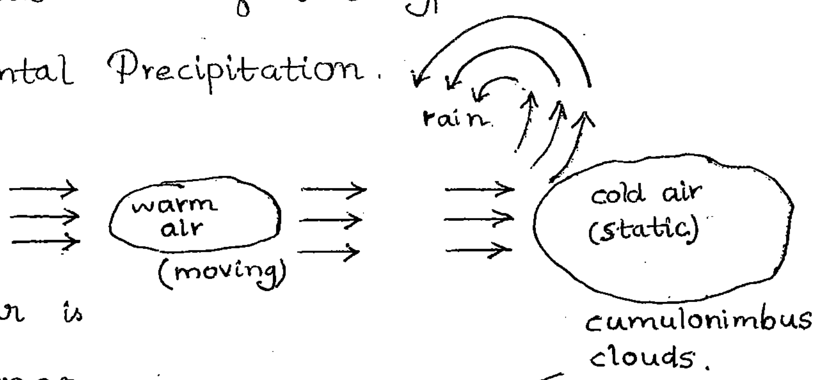
Eg: Rains at himalayas and Western ghats: moderate intensity rains for longer periods.

3. Frontal Precipitation –

Front air: It is an interface between two distinct air masses.

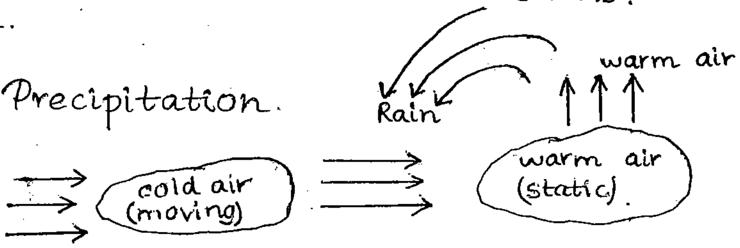
– Frontal precipitation are of two types:-

(i) Warm air frontal Precipitation.



Warm air is lighter, thinner and weaker whereas cold air is denser, thicker and stronger.

(ii) Cold air frontal Precipitation.



Cold air approaches warm air mass.

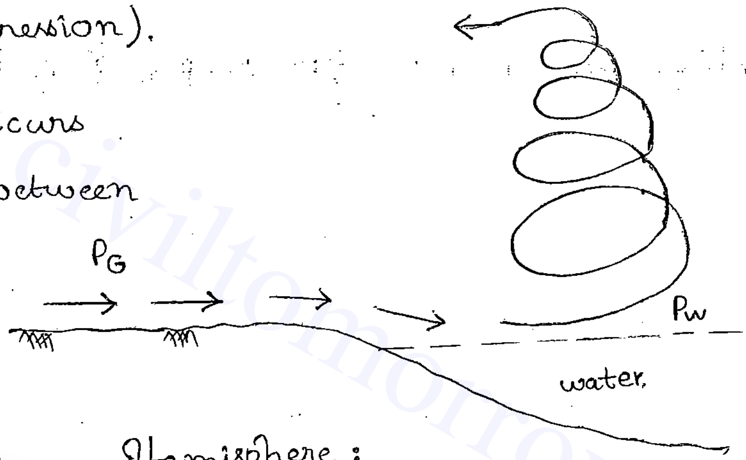
Eg : rains during rainy season.

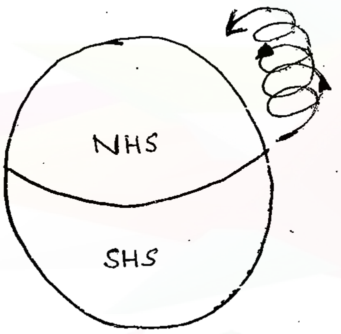
4. Cyclonic Precipitation

- precipitation caused by cyclones.

cyclone :- large area of low pressure region with circular wind motion. (depression).

- cyclonic precipitation occurs due to pressure difference between ground and water bodies. $(P_w <<< P_G)$





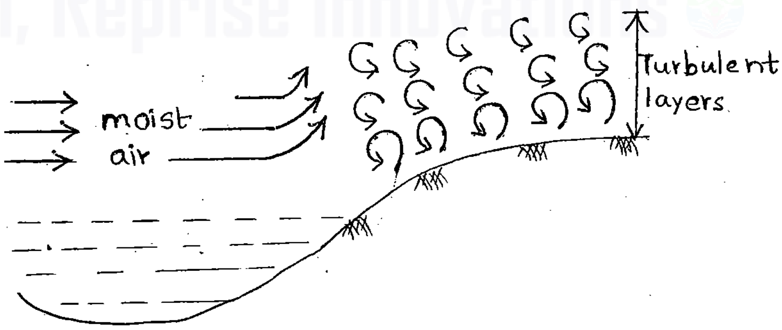
Northern Hemisphere :
Inward and anti-clockwise wind motion at northern hemisphere.

Southern Hemisphere :
Clockwise and outward.

- high intensity rains for longer period.

5. Precipitation due to Turbulent Ascent.

Eg:- winter rains along the coastal areas.



→ Rainfall Season

1. Monsoon period
   - Principal rainy season.
   - starts from May last week and lasts upto Oct 1^{st} week.
   - ~~North~~ South west winds cause rains during this period.

– Except Tamil Nadu & Jammu Kashmir, rest of the country receives rain during this period.

2. Post monsoon period.

– Nov 1st week to December 1st week.

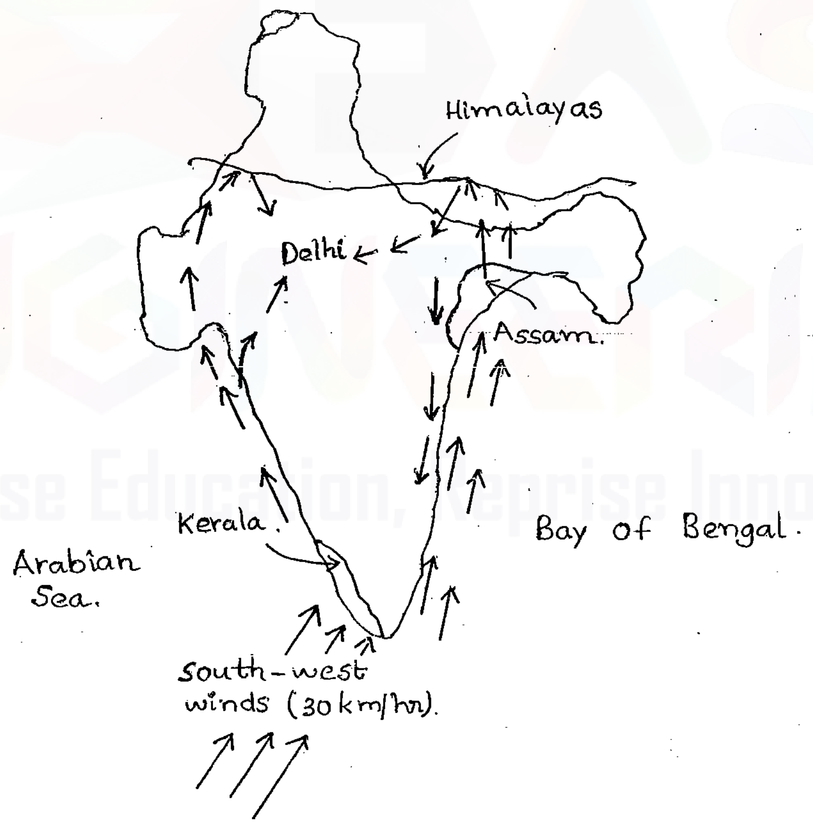
– TN and its surroundings receives rains (Southern Peninsular region)

– North East winds cause rains during this period.

3. Winter Rains

– Dec last week to Feb last week

– J & K receive rainfall and snowfall.



– Kerala & Assam receive first rainfall from South-west winds.

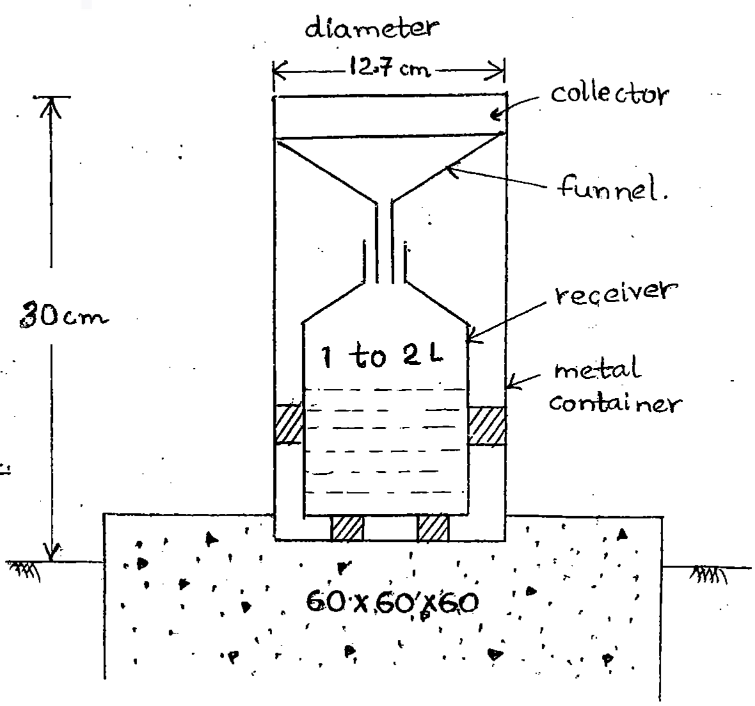
– Assam records the highest rainfall in the country

– Arabian branch reaches upto Punjab in the North and sent back to Delhi by Himalayan Ranges.

→ Measurement of Rainfall.

- Precipitation is measured as a vertical depth of water that would accumulate over a level ground if precipitation is retained where it fell.
- It is expressed in mm or cm.
- Precipitation is measured by using devices known as 'rain gauges' (also known as Ombrometers, Pluviometers or Hyetometers)
- There are two types of rain gauges:
  (i) Non Recording type Rain gauges
    a) Symon's Raingauge.
    b) IS (IMD) raingauge.
  (ii) Recording type Raingauge.
    a) Weighing Bucket type raingauge.
    b) Tipping Bucket type raingauge.
    c) Syphon raingauge (float type raingauge)
    d) Radar measurement.

* Symon's Raingauge :
  - universal gauge.
  - Diameter of collector = 12.7 cm.



- Depth of rain (cm or mm) = $\frac{\text{volume of water collected by gauge}}{\text{c/s area of collector}}$

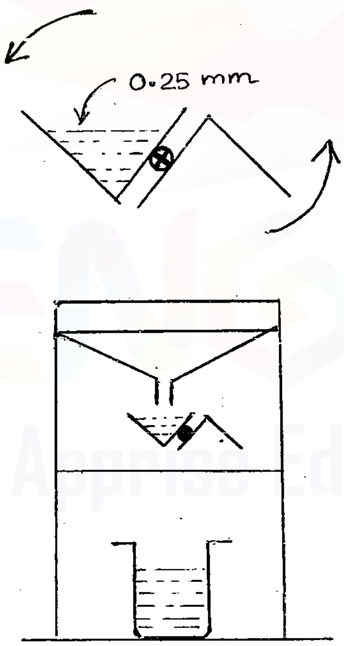
- measures 100 mm to 175 mm rain at a time.

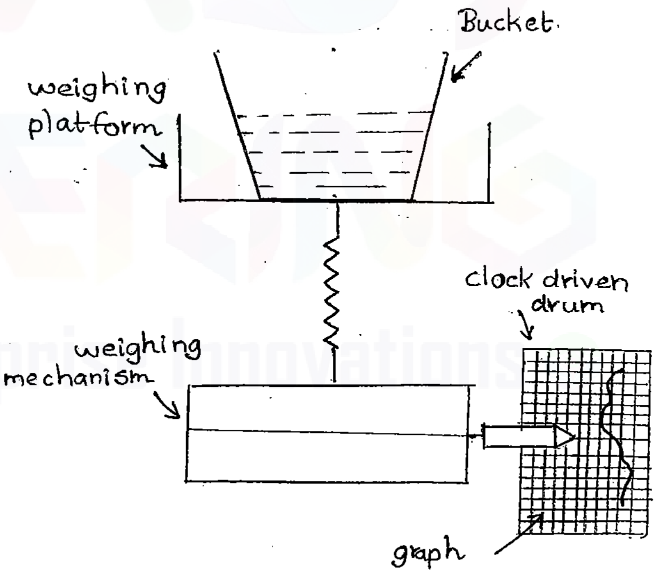
* IS raingauge

- Indian Standard raingauge to match Indian conditions.
- Similar to Symon's gauge with following modifications.
  - (i) c/s area of collector : 100 cm² to 200 cm²
  - (ii) Receiver capacity : 2 to 10 L
  - (iii) Metal container replaced with Fibre Reinforced Plastic, FRP, container.
- Measures 100 mm to 1000 mm rain at a time.
- Measurement is recorded at IST 8:30 manually.

* Weighing Bucket type Raingauge

- used to measure both rainfall and snowfall.



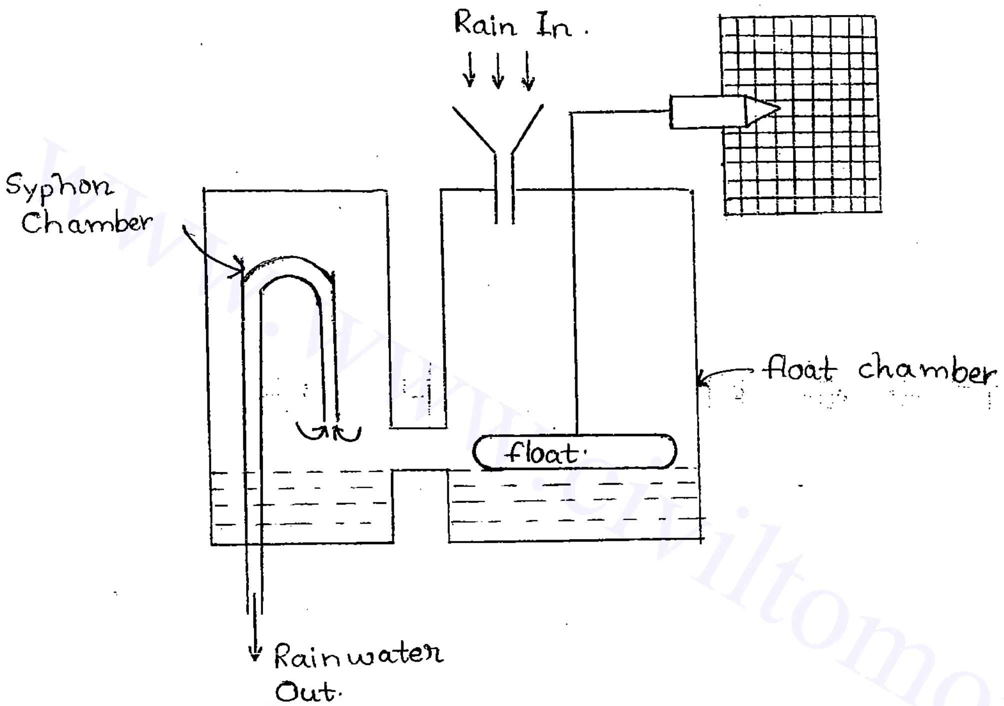


* Tipping Bucket Type Raingauge :

- to measure rainfall at remote and Inaccessible location
- tips for every 0.25 mm rainwater collection.

* Syphon's Rain gauge.

- under normal conditions
- Syphon raingauges are preferred to other gauges as per IS code.



* Radar Measurement (Radio Detection And Ranging).

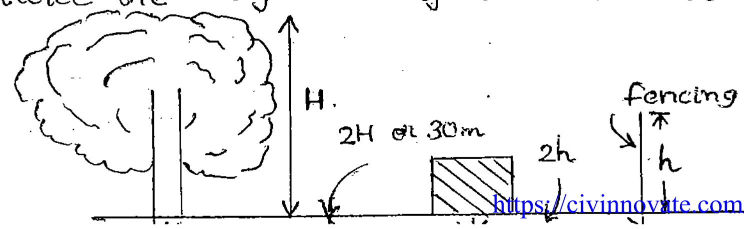
– measures rainfall over an area, whereas other gauges measure rainfall at a point.

– Range = 200 km^2

:nd Dec, UESDAY → **Rain Gauge Station**

The place where rain gauge is installed and rainfall measurement is carried out is called Rain gauge Station.

- To install raingauge, min. plot of size 5.5m x 5.5 m required.
- Level ground open to sky is required.
- Minimum distance b/w the gauge and the nearest tall object is 30m (or) twice the height of object whichever is more



→ Density of Raingauge Network :

Number of rain gauges per given area is called Raingauge Density (or) density of raingauge network.

- For plain and flat catchment : 1 raingauge for 520 km^2
- Areas elevated above 1000 m : 1 raingauge for 260-390 km^2
- Mountains and hilly regions : 1 raingauge for 130 km^2

→ Optimum number of Raingauges, 'n'

Let $P_1, P_2 \ldots P_m$ be the rainfall values recorded at the existing raingauge stations, 1, 2 ... m respectively.

By subjecting the rainfall data recorded at 'm' no. of existing raingauge stations to statistical analysis, optimum no. of raingauges 'n' can be determined for a given percentage of allowable or admissible error 'E'

Step 1: Find mean of rainfall data.

$$\bar{P} = \frac{P_1 + P_2 + \ldots P_m}{m} = \frac{\Sigma P_i}{m}$$

Step 2: Find standard deviation of rainfall data.

$$\sigma = \sqrt{\frac{\Sigma (P_i - \bar{P})^2}{m-1}}$$

Step 3: Find coeffecient of variation.

$$C_v = \frac{100\,\sigma}{\bar{P}}$$

Step 4: For a given allowable (or) admissible % error, E

$$\left.\begin{array}{l}\text{Optimum no: of}\\ \text{raingauges}\end{array}\right\} n = \left(\frac{C_v}{E}\right)^2$$

$$\left.\begin{aligned} n &\propto \frac{1}{E} \\ E &\propto \frac{1}{\%\ \text{accuracy}} \end{aligned}\right\} \Rightarrow n \propto \%\ \text{accuracy}$$

$$\left.\begin{aligned} C_v &\propto \sigma \\ n &\propto C_v \\ \sigma &\propto \frac{1}{m} \end{aligned}\right\} \Rightarrow n \propto \frac{1}{m}$$

- If $n < m$, gauges installed are sufficient in number.
- If $n > m$, gauges installed are deficient in number

∴ additional number of raingauges $= n - m$

% accuracy $= 100 - E$

P-6

1. $\bar{P} = 92.8$ cm

$\sigma = 30.7$ cm

$E = 10\%$

$$C_v = \frac{100\,\sigma}{\bar{P}} = 33.08\%$$

$$n = \left(\frac{C_v}{E}\right)^2 = \left(\frac{33.08}{10}\right)^2 = 10.94 \sim 11$$

2. $C_v = 33\%$, $n = 5$

$$n = \left(\frac{C_v}{E}\right)^2$$

$$\therefore E = \frac{33}{\sqrt{5}} = 14.76\%$$

% accuracy $= 85.24\%$

3. $C_v = 29.54\%$, $E = 10\%$

$$\therefore n = \left(\frac{C_v}{E}\right)^2 = \left(\frac{29.54}{10}\right)^2 = 8.73 \sim 9$$

Q. There are 4 rain gauges in a catchment recorded 3 cm, 5 cm, 6 cm & 8 cm rainfall values resptly. Find optimum number for 90% accuracy. Also recommend no. of additional raingauges required.

$\sigma = 1.443^2$, $C_v = \frac{100 \times 2.08}{5.5} = 37.82\%$

$\bar{x} = 5.5$,

$$n = \left(\frac{37.82}{100-90}\right)^2 = 14.3 \sim 15\%$$

Additional rain gauges required $= 15 - 4 = 11$

→ **Preparation of Rainfall Data**

Before using the rainfall data in hydrological analysis, data is verified with following two conditions :

(i) Continuity – data should be continuous without any broken information.

(ii) Consistency – data should be truly representative of the region.

* **Missing Rainfall Data :**

Let $P_1, P_2, \ldots P_m$ be the rainfall values recorded by the adjacent raingauge stations during the period, station 'X' was missed in recording rainfall. & $N_1, N_2 \ldots N_x \ldots N_m$ be the normal annual rainfall values (min 30 years latest average rainfall data) of raingauge stations $1, 2, \ldots x \ldots m$, then missing rainfall data at station X is worked out by :

(i) Simple Mean Method.

– used when $N_1 = N_2 = \cdots N_m = N_x \pm 10\%$

$$P_x = \frac{P_1 + P_2 + \cdots + P_m}{m}$$

; $P_x \rightarrow$ missing rainfall data at station X

(ii) Normal Ratio Method.

– used when $N_1 = N_2 = \cdots N_m \neq N_x \pm 10\% N_x$.

$$P_x = \frac{N_x}{m}\left[\frac{P_1}{N_1} + \frac{P_2}{N_2} + \dots \frac{P_m}{N_m}\right]$$

While working missing rainfall data at any station, rainfall data of all adjacent stations lying in same climatic zone is considered.

04. A — $N_A = 170.6$ cm, $P_A = 153$ cm

B — $N_B = 180.3$ cm, $P_B = ?$

C — $N_c = 165.3$, $P_c = 145.1$.

$N_B \pm 10\%\ N_B$ — 198.33 / 162.27.

$N_A = N_c = N_B \pm 10\%\ N_B$.

∴ Simple mean method is used.

$$P_B = \frac{P_A + P_c}{2} = \frac{153 + 145.1}{2} = \underline{149.1 \text{ cm}}$$

05. I — $N_I = 60$ cm, $P_I = 90$ cm

II — $N_{II} = 75$ cm, $P_{II} = 60$ cm.

III — $N_{III} = 80$ cm, $P_{III} = ?$

IV — $N_{IV} = 100$ cm, $P_{IV} = 70$ cm.

$80 \pm 10\%(80)$ — 88 / 72

$N_I = N_{IV} \neq N_{III} \pm 10\%\ N_{III}$

∴ Normal ratio method used

$$P_{III} = \frac{N_{III}}{m}\left(\frac{P_1}{N_I} + \frac{P_2}{N_{II}} + \frac{P_{IV}}{N_{IV}}\right) = \frac{80}{3}\left(\frac{90}{60} + \frac{60}{75} + \frac{70}{100}\right) = \underline{80 \text{ cm}}$$

06. A — $N_A = 75$ cm, $P_A = 8.5$ cm.

B — $N_B = 84$ cm, $P_B = 6.7$ cm

C — $N_c = 70$ cm, $P_c = 9$ cm

D — $N_D = 90$ cm. $P_D = ?$

$90 \pm 10\%\ (90)$ → 99 / → 81

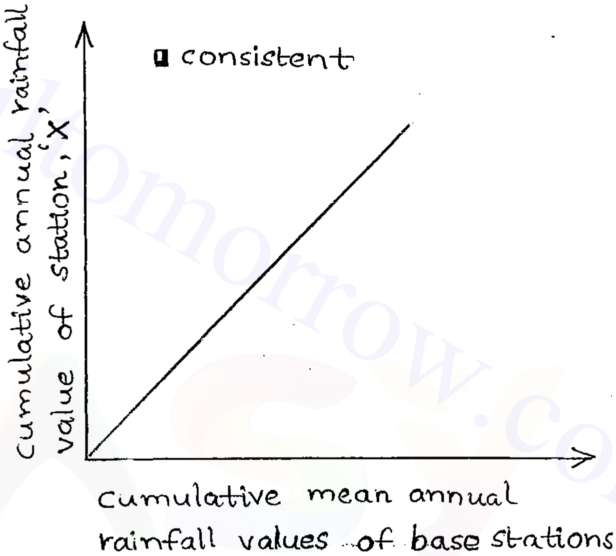
Normal ratio method is used.

$$P_D = \frac{N_D}{m}\left(\frac{P_A}{N_A} + \frac{P_B}{N_B} + \frac{P_C}{N_C}\right)$$

$$= \frac{90}{3}\left(\frac{8.5}{75} + \frac{6.7}{84} + \frac{9}{70}\right) = \underline{9.65 \text{ cm}}$$

* Consistency of Rainfall Data : (true representation)

Consistency of rainfall data is verified by plotting "Double Mass Curve."

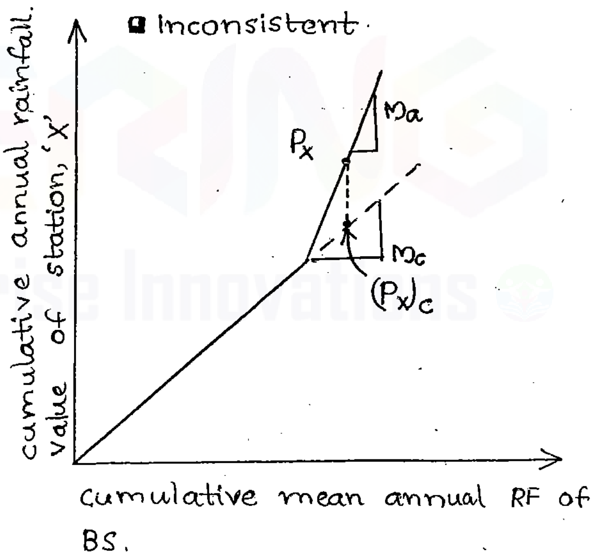


Base Stations :-

Adjacent rain gauge station's whose data is consistent.

Corrected consistent rainfall at station 'X',

$$(P_x)_c = P_x * \frac{M_c}{M_a}$$



→ Presentation of Rainfall Data :

(i) Rainfall Mass curve.

(ii) Rainfall Hyetograph

(iii) Depth – area – duration curves.

(iv) Intensity – duration – Frequency curves.

(v) Depth – duration – Frequency curves.

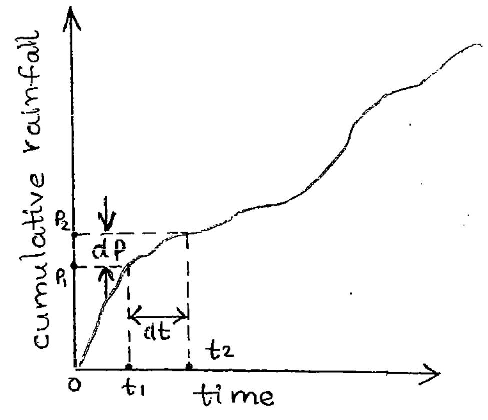
* Rainfall mass curve :

Recording type raingauges record rainfall data in the form of mass curve. Mass curve is a plot b/w accumulated rainfall and time.

* Rainfall Hyetograph:

It is a plot between rainfall intensity and time.

$$i = \frac{dP}{dt} = \frac{P}{t}$$

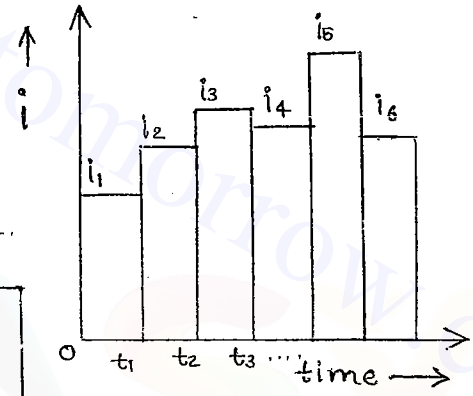


Rainfall Mass Curve

– It is a histogram (or) bar diagram, easy to read rainfall information from this.

$$i = \frac{dP}{dt}$$

$$\Rightarrow \int dP = \int_0^t i_i \, dt = \text{area of hyetograph}$$



∴ Total rainfall in time 't'

$$= \text{total area of hyetograph} = \sum_0^t i_i t_i$$

Eg: Total rainfall b/w time intervals t_i & t_{i+n} = area of hyetograph b/w t_i & t_{i+n}

$$= \sum_{t_i}^{t_{i+n}} i_i t_i$$

09 Total rainfall = total area of hyetograph

$$= (66+75+54)\frac{20}{60} + (48+69+51)\frac{40}{60} + (38+47+25)\frac{60}{60}$$

$$= \underline{\underline{287 \text{ mm}}}$$

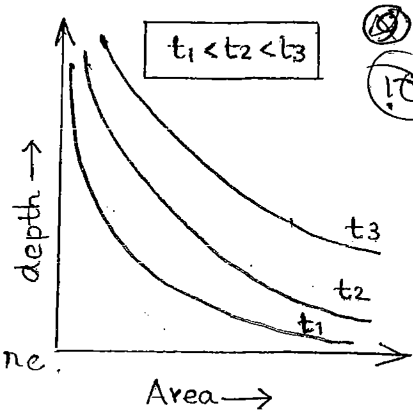
07.

time (min)	i	i (20 min duration)
0 – 10	0.7	$\frac{0.7\times10 + 1.1\times10}{20} = 0.9$
10 – 20	1.1	~~1.65~~
20 – 30	2.2	$\frac{2.2\times10+1.5\times10}{20} = 1.85$
30 – 40	1.5	
40 – 60	1.2	$\frac{1.2\times10 + 1.3\times10}{20} = 1.25$
50 – 60	1.3	
60 – 70	0.9	$\frac{0.9\times10+0.4\times10}{20} = 0.65$
–	0.4	

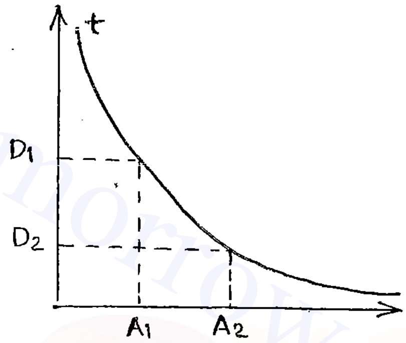
⇒ Max intensity of rainfall for 20 min duration of storm = $\underline{\underline{1.85}}$ mm/min

* Depth – Area – Duration curve

$$P = P_0 \, e^{-K A^n}$$

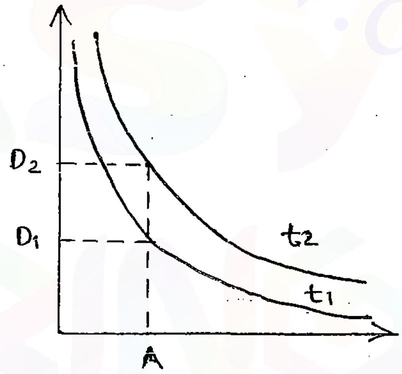


where,
- P_0 → depth of rainfall at storm centre.
- P → depth of rainfall.
- A → areal distribution of storm.
- K & n are constants.

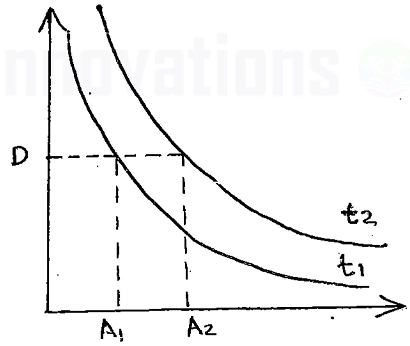


⊙ For a given t hour storm,
if $A_2 > A_1$, then $D_2 < D_1$

⊙ For a given catchment basin of area A,
if $t_2 > t_1$, then $D_2 > D_1$



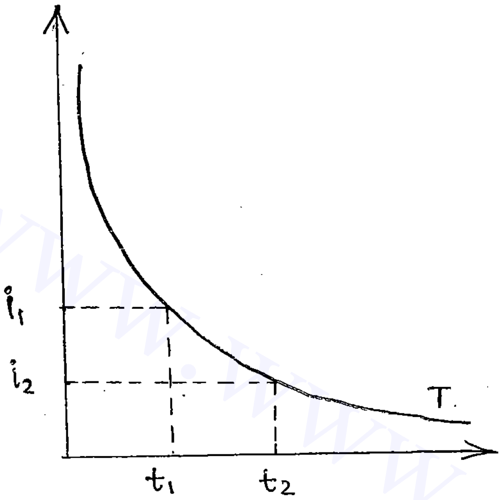
⊙ For given depth 'D', if $t_2 > t_1$
then $A_2 > A_1$

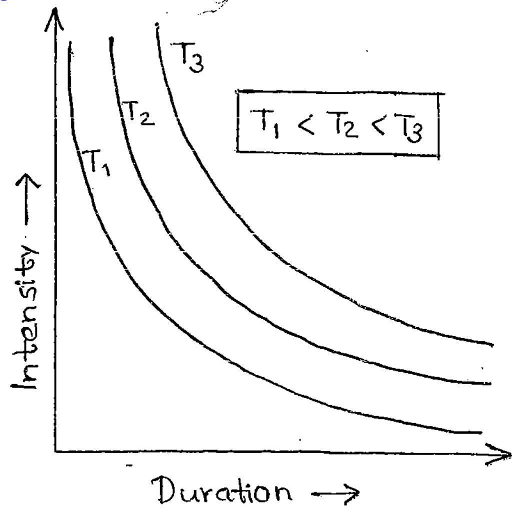


* Intensity – Duration – Frequency Curves

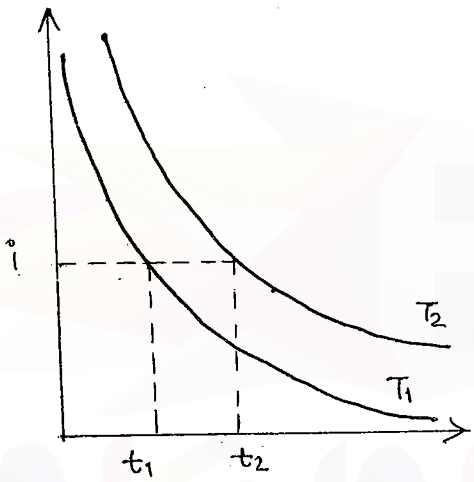
$$i = \frac{K T^x}{(D+a)^n}$$

where
- i → intensity of rainfall.
- T → frequency (year) of rainfall.
- D → duration of rainfall.
- K, x, a, n are constants.

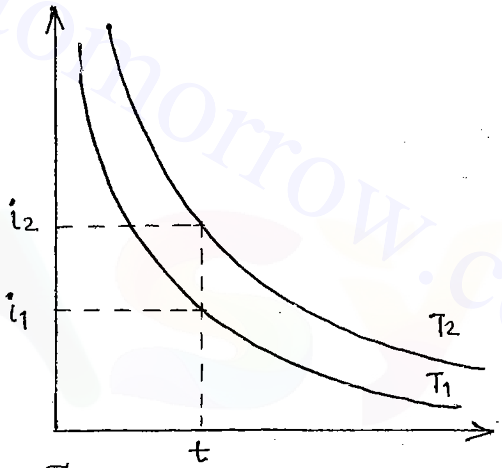




⊙ For given T, if $t_2 > t_1$, then $i_2 < i_1$

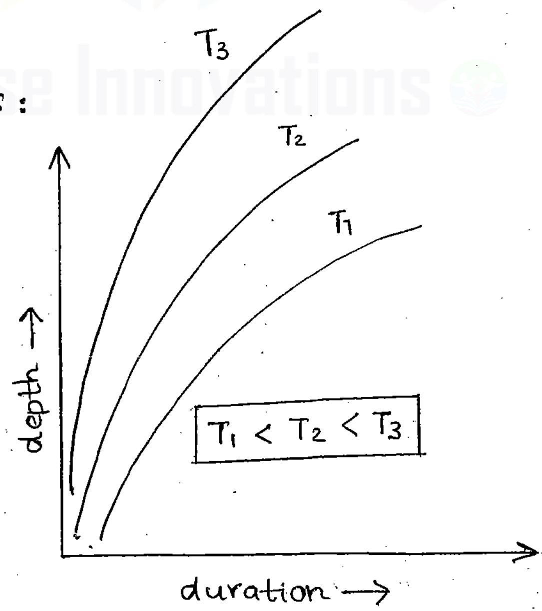


⊙ For given i, if $T_2 > T_1$, then $t_2 > t_1$



⊙ For given duration 't', if $T_2 > T_1$, then $i_2 > i_1$

* Depth - duration - frequency curves :



3rd nov,
WEDNESDAY

02. MEAN PRECIPITATION CALCULATION

Rainfall values recorded at various raingauge stations in a catchment represent point rainfall data, ie, point sampling of areal distribution of a storm.

To convert many point rainfall data recorded at various raingauge stations into single rainfall data representing entire catchment known as 'mean precipitation', the following mathematical methods are used.

→ Arithmetic Mean method

– also known as 'Constant Weightage method'.

– applicable for catchments satisfying following conditions:

(i) catchment should be flat and plain.

(ii) when rain gauges are uniformly distributed over a catchment.

(iii) rainfall values recorded at various rain gauge stations show little variation.

– let $P_1, P_2 \ldots P_n$ be the rainfall values recorded at rain gauge stations 1, 2, ... n respectively.

$$\therefore \text{mean precipitation}, \bar{P} = \frac{P_1 + P_2 + P_3 + \cdots P_n}{n}$$

→ Thiessen Polygon Method: (Weighted average method)

– This method is applicable to flat and plain catchments, ie, catchment with no topographic variations.

– In this method, Thiessen weightages are assigned for each rain gauge station based on area represented by them.

Let $\frac{A_1}{A}, \frac{A_2}{A} \dots \frac{A_n}{A}$ are the Thiessen weightages assigned for rain gauge stations 1, 2, ... n and $P_1, P_2 \dots P_n$ be the rainfall values recorded at respective raingauge station.

Then
$$\text{mean precipitation}, \bar{P} = P_1 * \frac{A_1}{A} + P_2 * \frac{A_2}{A} + \dots P_n * \frac{A_n}{A}$$

$$\Rightarrow \quad \bar{P} = \frac{P_1 A_1 + P_2 A_2 + \dots + P_n A_n}{A}$$

-10

1. $\bar{P} = \frac{75 \times 3 + 125 \times 5 + 150(4+6)}{500} = \underline{\underline{4.7 \text{ cm}}}$

2. $\bar{P} = 10 \times 0.1 + 15 \times 0.2 + 20 \times 0.3 + 25(1 - (0.1 + 0.2 + 0.3))$

$= \underline{\underline{20 \text{ cm}}}$

* Procedure to assign Thiessen weightages:

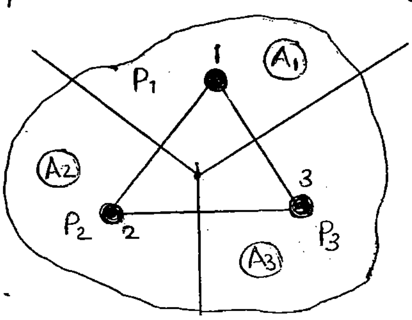
Step 1: Plot catchment to some suitable scale.

Step 2: Identify rain gauge stations within a catchment.

Step 3: Join all adjacent triangle stations by straight lines.

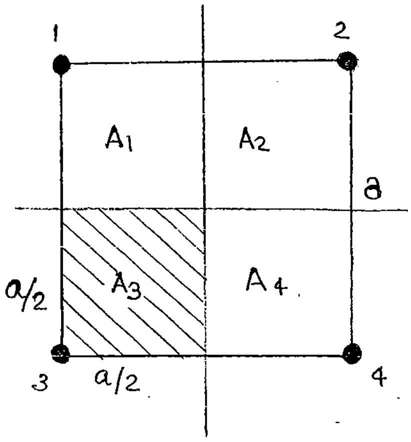
Step 4: Draw perpendicular bisectors. The area enclosed b/w the bisectors and boundary of a catchment; ie, polygonal area represent a rain gauge station enclosed within that polygon.

Step 5: Measure area of each polygon and total area of polygon using a planimeter and assign Thiessen weightages.



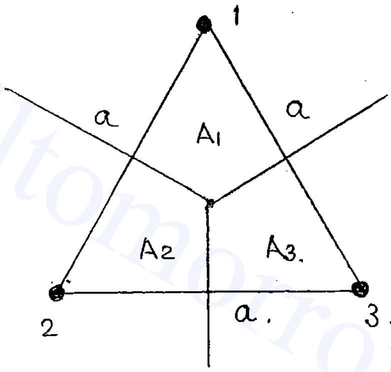
(12)

$$A_1 = A_2 = A_3 = A_4 = \frac{a}{2} * \frac{a}{2}$$



$$A = \frac{\sqrt{3}}{4} a^2$$

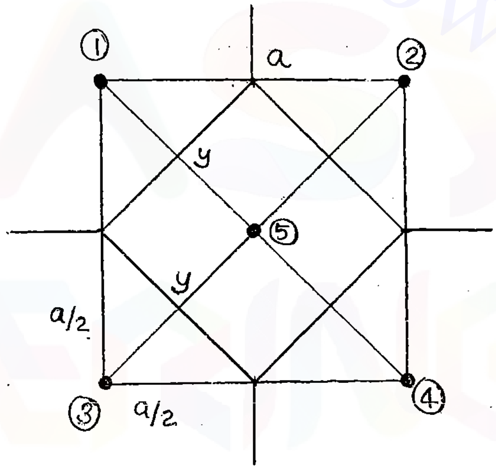
$$A_1 = A_2 = A_3 = \frac{1}{3} * \frac{\sqrt{3}}{4} a^2$$



$$A_1 = A_2 = A_3 = A_4 = \frac{1}{2} * \frac{a}{2} * \frac{a}{2}$$

$$A_5 = y * y$$

$$y = \sqrt{\left(\frac{a}{2}\right)^2 + \left(\frac{a}{2}\right)^2}$$

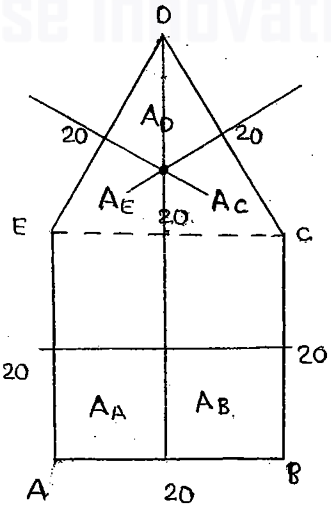


3. $A_A = A_B = \frac{20}{2} * \frac{20}{2} = 100 \text{ km}^2$

$$A_D = \frac{1}{3} \times \frac{\sqrt{3}}{4} * 20^2 = 57.735 \text{ km}^2$$

$$A_E = 100 + 57.735 = 157.735 \text{ km}^2$$

$$A_C = 157.735 \text{ km}^2$$



Average depth of rainfall $= \frac{\Sigma P_i A_i}{A}$

$$= \frac{100 \times 60 + 100 \times 81 + 157.735 \times 73 + 57.735 \times 59 + 157.735 \times 45}{20 \times 20 + \frac{\sqrt{3}}{4} \times 20^2}$$

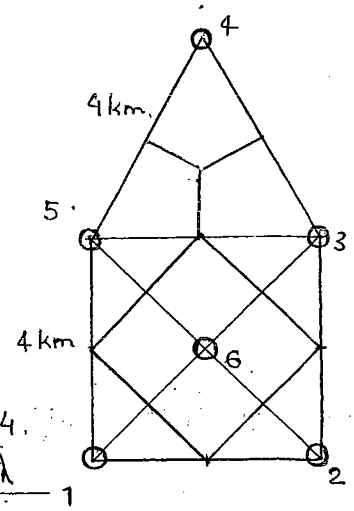
$= 63.01$ mm

4. $A_1 = A_2 = \frac{1}{2} \times \frac{4}{2} \times \frac{4}{2} = 2\ km^2$.

$A_4 = \frac{1}{3} \times \frac{\sqrt{3}}{4} \times 4^2 = 2.31\ km^2$.

$A_5 = A_3 = 4.31\ km^2$

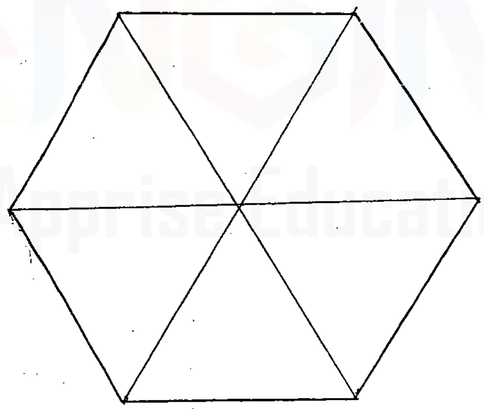
$A_6 = 4^2 - 4 \times 2 = 8\ km^2$.

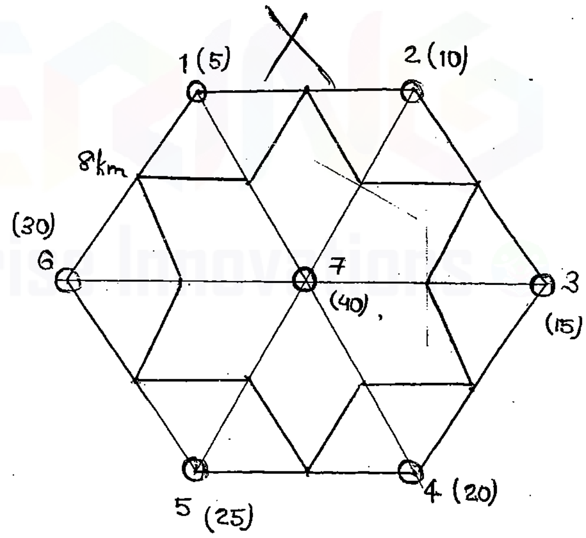


$$\text{Mean precipitation} = \frac{2(8+13) + 4.31(5.4+4.8) + 2.31 \times 3.2 + 8 \times 9.4}{4^2 + \frac{\sqrt{3}}{4} \times 4^2}$$

$= \underline{\underline{7.35\ cm}}$

Q A catchment is in the form of a regular hexagon of side 8 km. 6 Rain-gauges installed, one at each corner and one more at centre recorded 5, 10, 15, 20, 25, 30 & 40 cm at central station. Find mean precipitation by Thiessen polygon method.





(13)

Q. A catchment is in the form of a circle of radius 10 km centre at (0,0). Location of raingauge stations and their respective rainfall values are given below. Find mean precipitation by Thiessen polygon.

Raingauge Stations	1	2	3	4	5
Location (x, y)	(−5, 5)	(5,5)	(−5, −5)	(5, −5)	(0, 0)
Rainfall (cm)	4	6	3	5	2

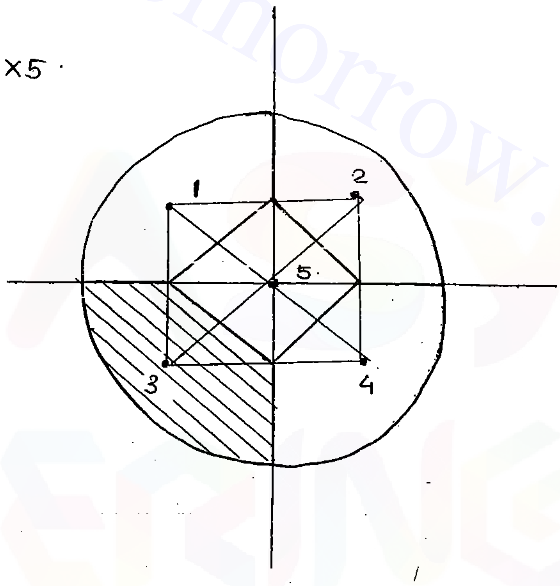
$$A_1 = A_2 = A_3 = A_4 = \frac{\pi}{4} \times 10^2 - \frac{1}{2} \times 5 \times 5$$

$$= 66.04 \text{ km}^2$$

$$A_5 = 10^2 - 4 \times 12.5 = 50 \text{ km}^2.$$

$$\bar{P} = \frac{66.04(4+6+3+5) + 50 \times 2}{\pi \times 10^2}$$

$$= 4.10 \text{ cm}$$



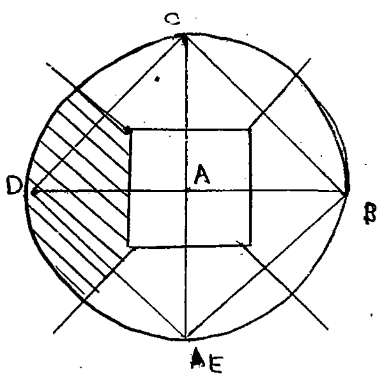
Q. 5 raingauge stations A, B, C, D, E are located on a circular shaped basin of diameter 20 km as shown in fig. Compute mean aerial rainfall over the basin using TP method. If the rainfall at stations A, B, C, D, & E are 100 cm, 90 cm, 110 cm, 120 cm and 80 cm resptly.

$$A_A = 10 \times 10 = 100 \text{ km}^2$$

$$A_B = A_C = A_D = A_E = \frac{\frac{\pi}{4} \times 20^2 - 10 \times 10}{4}$$

$$= 53.54 \text{ km}^2$$

$$\bar{P} = \frac{53.54(90+110+120+80) + 100 \times 100}{\frac{\pi}{4} \times 20^2} = 100 \text{ cm}$$



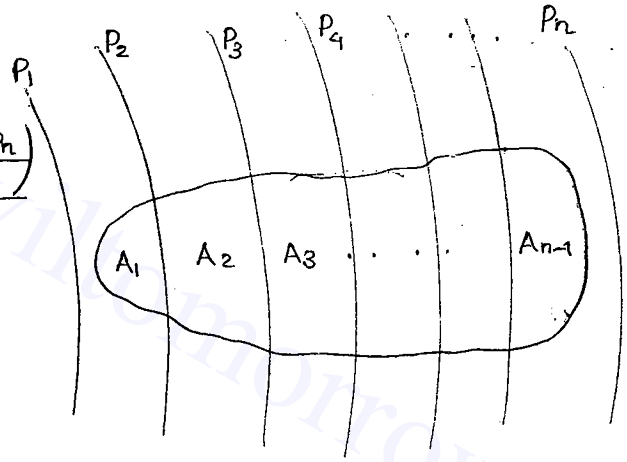
→ Isohyetal Method.

– The best and more accurate method to find mean precipitation.

Isohyet : line joining points of equal rainfall.

Isonif : line joining points of equal snowfall.

$$\bar{P} = \frac{A_1\left(\frac{P_1+P_2}{2}\right) + A_2\left(\frac{P_2+P_3}{2}\right) + \dots A_{n-1}\left(\frac{P_{n-1}+P_n}{2}\right)}{A}$$



– At first extreme ends, if there is no isohyetal line,

$$\text{mean precipitation, } \bar{P} = \frac{A_1 P_2 + A_2\left(\frac{P_2+P_3}{2}\right) + \dots A_{n-1}\left(\frac{P_{n-1}+P_n}{2}\right)}{2}.$$

-10.

Q.5 $$\bar{P} = \frac{100\left(\frac{55+45}{2}\right) + 150\left(\frac{55+65}{2}\right)}{150+100} = \underline{\underline{56\text{ cm}}}$$

6. $$\bar{P} = \frac{92\left(\frac{15+12}{2}\right) + 128\left(\frac{12+9}{2}\right) + 120\left(\frac{9+6}{2}\right) + 175\left(\frac{6+3}{2}\right) + 85\left(\frac{3+1}{2}\right)}{92+128+120+175+85} = \underline{\underline{7.4\text{ cm}}}$$

7. $$\bar{P} = \frac{30\times12 + 140\times11 + 80\times9 + 180\times7 + 20\times5}{30+140+80+180+20} = \underline{\underline{8.84\text{ cm}}}$$

03. FREQUENCY ANALYSIS

- Frequency Analysis is performed for random & rare events.
- Rainfall and floods are the two hydrological events which occur rarely and randomly. The probability of occurence of these events is worked out by performing frequency analysis. Knowing the frequency, risk associated with that event if used in the design is worked out. Knowing the risk, safety can be evaluated.
- In many hydraulic engineering applications such as those concerned with floods and rains, the probability of occuring max. flood or max. rainfall is the basis. Their probabilties of occurences are worked out by performing frequency (probability) analysis using the past data.
- Data used in frequency analysis is usually annual series (time series)

→ Frequency (or) Return Period (or) Recurence Interval, 'T'

It is defined as time interval between the occuring of an event of certain magnitude which is likely to be equalled or exceeded. The following emperical formulas are used to find frequency (or) return period (T):

1. Weibulls Formula.

$$T = \frac{n+1}{m}$$

n → no. of annual series (time series) of data used in analysis

m → rank assigned for a given data in that series for which T is ...ined

2. Hazen's formula

$$T = \frac{n}{m-0.5}$$

3. California formula

$$T = \frac{n}{m}$$

* Procedure to find frequency:

Step 1: Arrange given data in descending order of their magnitude.

Step 2: Assign rank for each data in that order.

Step 3: Using any of the above formula, obtain return period for given data.

?-14

Q.1.

14.2	1
13.0	2
12.0	3
12.0	3
7.9	5
6.0	6
6.0	6
4.8	8
3.7	9
2.9	10

(i) Hazen formula

$$T = \frac{n}{m-0.5} = \frac{10}{6-0.5}$$

$$= 20/11$$

(ii) Weibull formula

$$T = \frac{n+1}{m} = \frac{11}{6}$$

11.

1	2	3	4	5	6	7	8	9
130	120	100	80	75	70	60	50	40

(i) Return period $80\ m^3/s$ flood $= \frac{n+1}{m} = \frac{10}{4} = 2.5$

(ii) ,, $75\ m^3/s$ flood $= \frac{10}{5} = 2$

(iii) ,, $50\ m^3/s$ flood $= \frac{10}{8} = 1.25$

- Let p be the probability of occuring an event & q be the probability of not occuring an event.

$$\text{Probability of occurence} = p = \frac{1}{T}$$

$$q = 1 - \frac{1}{T}$$

- Probability of occuring an event r times in n successive years,

$$P_{(r,n)} = {}^{n}C_{r}\, p^{r} q^{n-r}$$

$$P_{(r,n)} = \frac{n!}{(n-r)!\, r!}\, p^{r} q^{n-r}$$

- Probability of not occuring in n successive years $= q^n$
- Probability of occuring an event atleast once in 'n' successive years. $= 1 - q^n$
- Probability of occuring an hydrologic event atleast once in 'n' successive years = hydrologic risk, 'R' $= 1 - q^n$

$\Rightarrow$

Hydrologic risk, 'R' $= 1 - q^n$
% safety = 100 − % risk.

NOTE:

1. Probability of occurence if its expressed in fractions, then it is known as 'exceedence probability'. If its expressed in percentage, then its known as 'chance percentage'

02. T = 20 years.

$$p = \frac{1}{T} = \frac{1}{20} \; ; \; q = 1 - \frac{1}{20} = \frac{19}{20}$$

Probability that it may occur in next 12 years

= occuring atleast once in next 12 years.

$= 1 - q^n = 1 - \left(\frac{19}{20}\right)^{12} = 45.96 \approx \underline{46\%}$

03. T = 8 years.

$P = \frac{1}{8} \qquad q = \frac{7}{8}.$

Probability that flood magnitude will be exceeded once in 5 years $= 1 - q^n = 1 - \left(\frac{7}{8}\right)^5 = \underline{0.487}$

04. T = 100 years. , n = 50 years

$P = \frac{1}{100} \quad \& \quad q = \frac{99}{100}$

Risk associated with hydraulic design $= 1 - q^n$

$= 1 - \left(\frac{99}{100}\right)^{50} = \underline{39.5\%}$

06. T = 100 years , n = 2 years

$P = \frac{1}{100}, \quad q = \frac{99}{100}$

Risk during 2 year service life of project $= 1 - \left(\frac{99}{100}\right)^2$

$= \underline{1.99\%}$

05. $0.2 = 1 - \left(1 - \frac{1}{T}\right)^{10.}$

$\left(\frac{T-1}{T}\right)^{10} = 0.8 \quad \Rightarrow T = \underline{45.32} \text{ years}$

log 1 - log $\frac{1}{T}$ = -0.02

07. $T = 40$ years.

a) Exceedence probability, $p = \frac{1}{T} = \underline{2.5\ \%}$

b) Probability of occuring atleast once during next 20 years

$= 1 - q^n = 1 - (0.975)^{20} = 39.73\ \%$

c). Probability of occuring a flood less than 4000 m³/s

= probability of not occuring a flood $\geq 4000\ m^3/s$.

$= \underline{0.975}\ (= q)$.

Level 1

08. $p = \frac{1}{50}$; $q = \frac{49}{50}$

(i) P(one time in 10 years) $= {}^{10}C_1 \left(\frac{1}{50}\right)^1 \left(\frac{49}{50}\right)^9$

$= \underline{0.167}$

(ii) P(2 time in 10 years) $= {}^{10}C_2 \left(\frac{1}{50}\right)^2 \left(\frac{49}{50}\right)^8 = \underline{0.0153}$

(iii) P(atleast once in 10 years) $= 1 - q^n$

$= 1 - \left(\frac{49}{50}\right)^{10} = \underline{0.183}$

→ Probable Maximum Precipitation, (PMP)

Extreme rainfall which is physically possible to occur.

$$\boxed{PMP = \bar{P} + K\sigma}$$

$\bar{P}$ → mean of rainfall data.

σ → standard deviation of rainfall data

K → frequency factor.

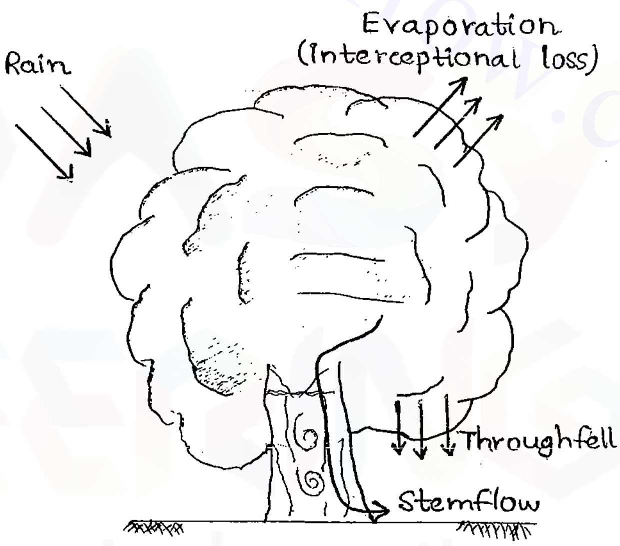
→ Station Year Method.

The method of generating long length of record at an imaginary station by combining the all the records from all of the stations lying in meteorologically and hydrologically homogeneous area (same climatic zone).

ABSTRACTIONS OF PRECIPITATION (Rainfall Losses)

1. Interceptional Loss
2. Evaporation
3. Transpiration.
4. Evapotranspiration.
5. Infiltration

→ Interceptional Loss

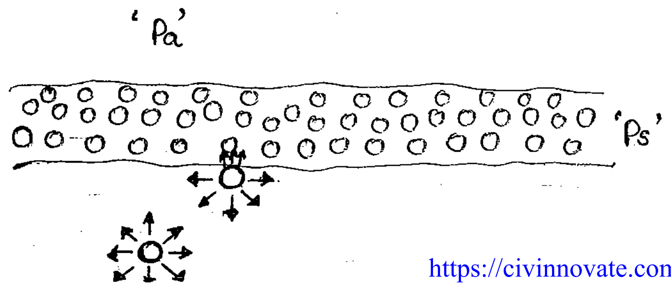


Rain which is intercepted by the tall objects lying above the ground. (ie trees and buildings) evaporate part of the intercepted rain back to space.

Rain without being collected on the ground evaporating back to space from such objects is known as 'Interceptional Loss'

→ Evaporation

Evaporation is the process by which water change its state from liquid to vapour and escape to atmosphere as a vapour.



* Dalton's Law of Evaporation :

Rate of evaporation, $E \propto (P_s - P_a)$

– Evaporation is essentially a cooling process, since average velocity of water molecules in water body decreases during evaporation (temp. of water body ∝ avg. velocity of water molecules)

* Factors affecting Evaporation:

1. Solar Radiation –

$$E \propto R$$

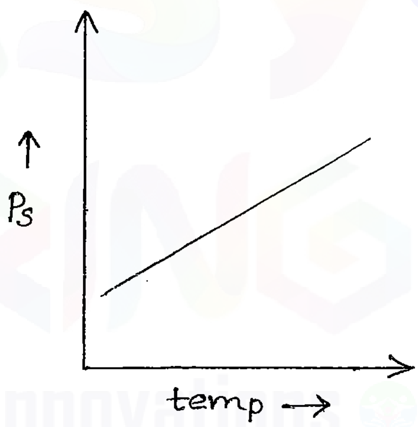
As radiation increases, evaporation also increases.

2. Temperature –

$$P_s \propto \text{temperature.}$$

$$E \propto (P_s - P_a)$$

$$\Rightarrow \quad E \propto \text{temperature.}$$



As temperature increases, saturation vapour pressure increases and thus rate of evaporation increases.

3. Winds –

$$E \propto V$$

where V is windspeed.

4. Pressure (P_a) –

$$E \propto \frac{1}{P_a}$$

Night time evaporation is due to drop in atmospheric pressure, P_a.

5. Humidity -

$$E \propto \frac{1}{Humidity}$$

6. Surface area of water body -

$$E \propto \text{surface area}$$

7. Depth of water body -

$$E \propto \frac{1}{depth}$$

Summer evaporation is more for shallow water bodies and less for deep water bodies whereas winter evaporation is less for shallow water bodies and more for deep water bodies.

8. Quality of water.-

$$\text{Evaporation} \propto \text{Quality}$$

More quality means fresh water body

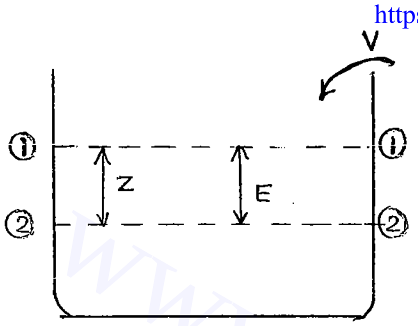
Less quality means saline water body.

In saline water bodies, evaporation is 2-3 % less than fresh water bodies.

* Measurement & Estimation of Evaporation :

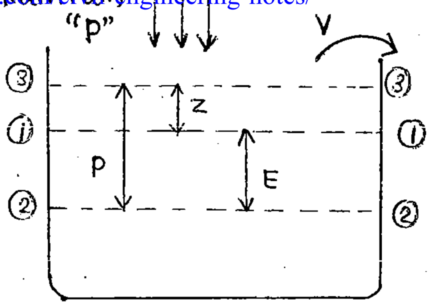
1. Pan Measurement -

Pan is a container of some standard dimensions filled with water to a stipulated level and installed close to the water body. Over a period of time by observing the changes in water level of a container, evaporation loss from the actual water body can be worked out.



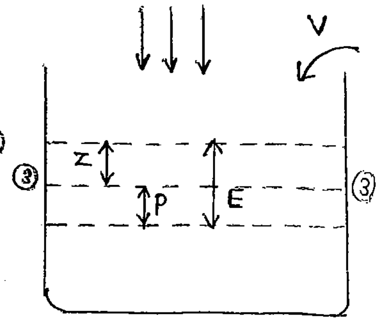
Case 1 : no rainfall. (P=0).

$$E = Z$$



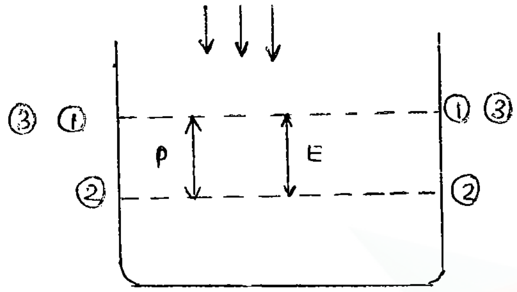
Case 2 : P > E

$$E = P - Z$$



Case 3 : P < E

$$E = P + Z$$



Case 4 : E = P. (V = 0, Z = 0).

In general,

Pan evaporation, $E = P \pm Z$

where Z → depth of water added or removed.

P → rainfall.

$$Z = \frac{\text{Volume of water added (or) removed.}}{\text{Surface area of pan.}}$$

Z = +ve , when water added to pan.

Z = −ve , when water removed from pan.

Z = 0 , no water added or removed.

P = 0 , if there is no rainfall.

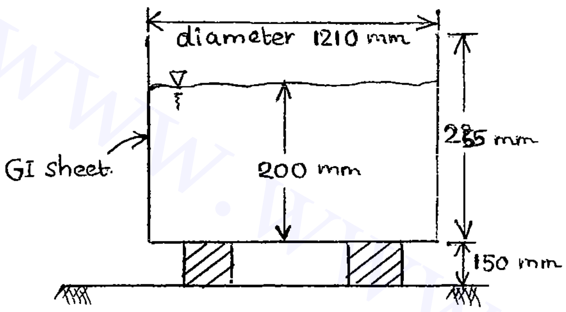
- **Actual evaporation from water body = C_p * pan evaporation.**

where C_p = coeffecient of pan = $\frac{\text{actual evaporation}}{\text{pan evaporation}}$

- Volume of water loss due to evaporation from water body = actual evaporation * SA of water body.

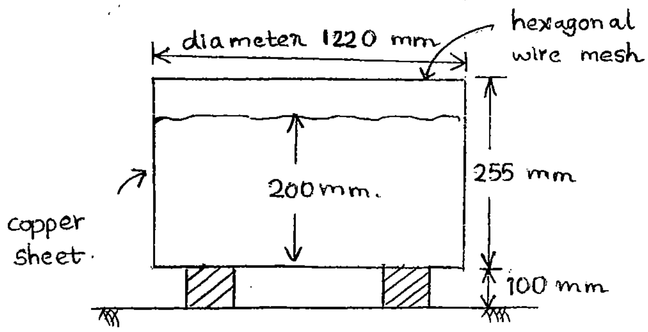
* Types of Pans.

(i) USWB Class A Pan



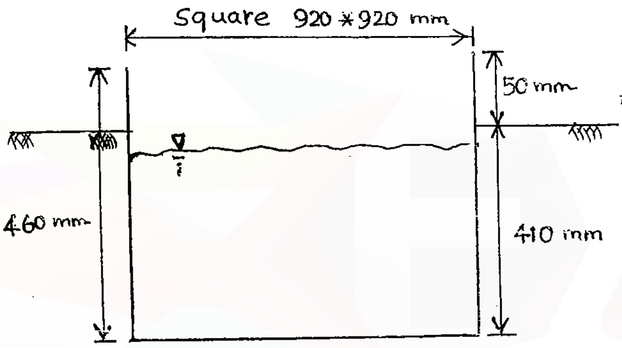
$C_p = 0.7$

(ii) IS Class A Pan.



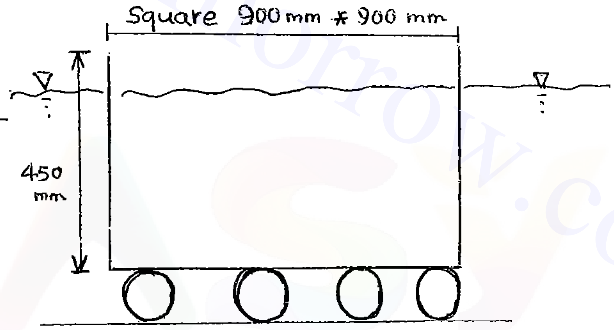
$C_p = 0.8$

(iii) Colarado Sunken Pan.



$C_p = 0.78$

(iv) USGS Floating Pan.



$C_p = 0.8$

2-19

Q.1 Volume of water removed = 4.2 L

Diameter of pan = 1.22 m.

Rainfall, P = 8.75 mm.

Depth of water removed, $z = \dfrac{4.2 \times 10^{-3}}{\frac{\pi}{4} \times 1.22^2} = 3.59$ mm

Pan evaporation, $E = P - Z = 8.75 - 3.59 = 5.16$ mm

Q.2. Depth of water added, $z = \dfrac{8.75 \times 10^{-3}}{\frac{\pi}{4} \times 1.2^2} = 7.74$ mm

Rainfall, P = 4.2 mm.

Pan evaporation, $E = 7.74 + 4.2 = 11.94$ mm

Actual evaporation ≈ 8.36 mm

03. IS Pan $\Rightarrow C_p = 0.8$

Surface area of reservoir = 100 ha

Pan evaporation, E = 4 cm

Anticipated evaporation loss = ?

Actual evaporation on that day = C_p * pan evaporation

$= 0.8 \times 4 = 3.2$ cm

∴ Anticipated evaporation = volume of water evaporated on that day

= actual evaporation * surface area of reservoir

$= \frac{3.2}{100} \times 100 \times 10^4 \ m^3 = 3.2 \times 10^4 \ m^3/day$

04.

Day	1	2	3	4	5	6	7
Rainfall.	14	6	12	8	0	5	6
water added (or) removed.	−5	3	0	0	7	4	3.
Daily Pan evaporation.	9	9	12	8	7	9	9.

Total pan evaporation in that week = 63 mm.

$C_p = 0.75$

Actual evaporation from lake in that week = C_p * pan evaporation.

$= 0.75 \times 63 = 47.25$ mm

Volume of water evaporated from lake = actual evaporation * S.A.

$= \frac{47.25}{1000} \times 640 \times 10^4 = 302400 \ m^3$

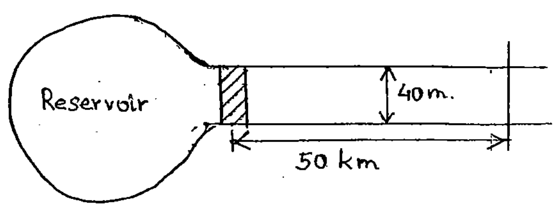
P-61

08. Pan evaporation = 0.5 m

Actual evaporation = C_p * 0.5

$= 0.7 \times 0.5$

$= 0.35$ m/day



Evaporation loss to be considered in releasing water

= actual evaporation * SA of channel.

$$= \frac{0.35 \times 50 \times 10^3 \times 40}{10^4} = \underline{70 \text{ ha-m}}$$

2. Empirical Formulae:

(i) Fitzrald Equation

$$\text{Rate of evaporation, 'E' (mm/day)} = (0.4 + 0.124\,V)(P_s - P_a)$$

where $V \rightarrow$ wind speed (in km/hr).

P_s & $P_a \rightarrow$ saturation & actual vapour pressures (in mm of Hg)

(ii) Meyer's Equation

$$\text{Rate of evaporation (mm/month)} = (1 + 0.06215\,V)\,C\,(P_s - P_a).$$

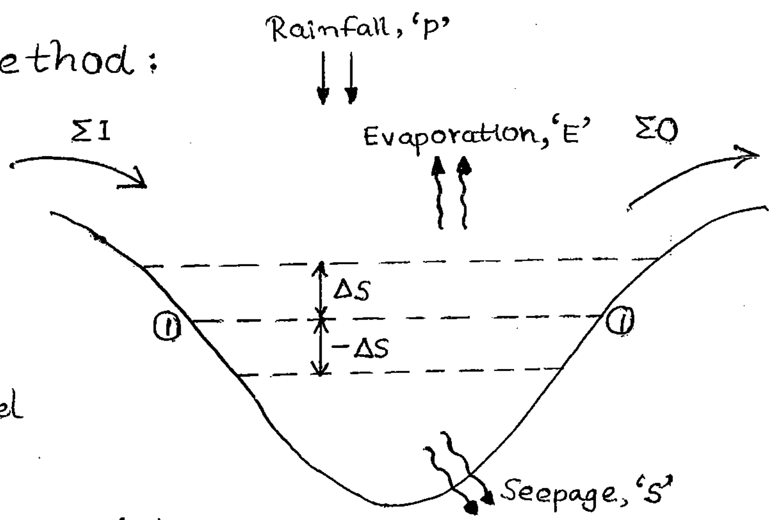
where $C \rightarrow$ Meyer's constant.

(iii) Rohwer's formula.

$$\text{Rate of evaporation (mm/day)} = 0.771(1.465 - 0.000732\,P_a)(0.44 + 0.07334\,V)(P_s - P_a).$$

3. Water Budget Method:

$$\boxed{\Sigma I - \Sigma O = \pm \Delta S}$$



$\Delta S \rightarrow$ '+ve' when water level increases.

$\Delta S \rightarrow$ '−ve' when water level decreases.

Inflows: Rainfall (P), Run off (I).

Outflows: Evaporation (E), Seepage (S), water used (O).

$$\Sigma I - \Sigma O = \pm S$$

$$\boxed{(I+P) - (O+E+S) = \pm \Delta S.}$$

05. $\Delta S = 103.258 - 103.2 = 0.058$

$$\left(\frac{6 \times 86400 \times 30}{5000 \times 10^4} + 0.145\right) - \left(\frac{6.5 \times 86400 \times 30}{5000 \times 10^4} + E\right) = 0.058$$

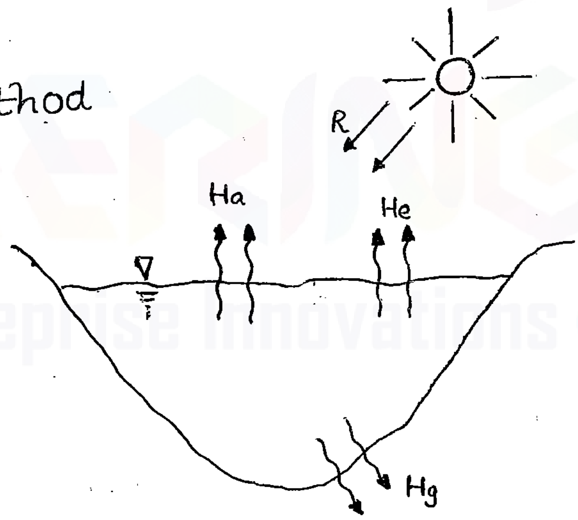
$$E = 0.06108 \text{ m} = \underline{\underline{61.08}} \text{ mm}$$

06. $$\left(\frac{10 \times 10^4}{(10^3)^2} + 0.03\right) - \left(\frac{20 \times 10^4}{(10^3)^2} + 0.12 \times 0.7 + S\right) = -0.2$$

$$S = 0.046 \text{ m}$$

$$\text{Seepage loss in ha-m} = \frac{0.046 \times 10^6}{10^4} = \underline{\underline{4.6}} \text{ ha-m}$$

4. Energy Balance Method



$$\boxed{H_e = R - H_a + H_g}$$

R → incoming solar radiation (insolation) , watts/m²

Ha → sensible heat loss to atmosphere

Hg → ground heat flux.

He → heat energy used in evaporation.

$$H_e = \rho_w L E$$

where ρ_w → mass density of water (kg/m³)

L → latent heat of vapourization (J/kg)

E → rate of evaporation. (m/s)

$$\rho_w L E = R - (H_a + H_g).$$

$$E = \frac{R - (H_a + H_g)}{\rho_w L}$$

∵ H_a & H_g being so small, they are neglected.

$$\boxed{E = \frac{R}{\rho_w L}}$$

07. $R = 200$ watt/m²

$L = 2441$ kJ/kg $= 2441 \times 10^3$ J/kg.

$\rho_w = 997$ kg/m³

$$E = \frac{200}{2441 \times 10^3 \times 997} = 8.22 \times 10^{-8} \text{ m/s}$$

$$= \underline{\underline{7.1 \text{ mm/day}}}$$

✱ Methods to Control Evaporation:

(i) Mechanical cover. – used for small water bodies.

(ii) Surface Floats – exposed surface area decreases

(iii) Surface Films – surface active chemical substances

(imp) a) Cetyl Alcohol (Hexa deconol).
b) Steryl Alcohol. (Octa decanol).
} evaporation suppressors (or) evaporation inhibitors.

(iv). Better Reservoir Planning

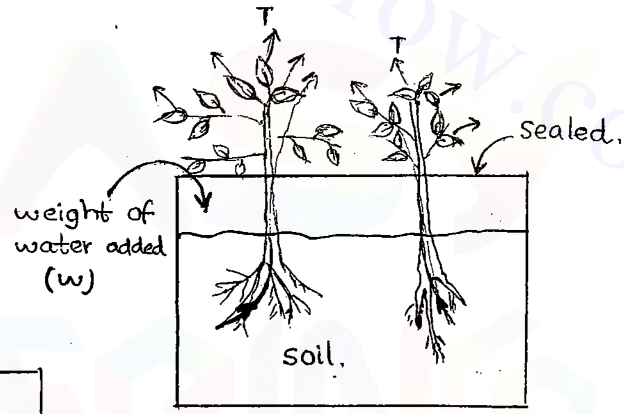
(v) Better reservoir operation

(vi) Planting Trees

→ Transpiration :

Transpiration is the process by which water leaves the living plant through the stomatal openings of the leaves and diffuse into atmosphere as vapour.

- Transpiration is plant evaporation.
- Transpiration is confined only to daylight hours.
- Plants transpire more than 80 times water than what they consume during photosynthesis.
- Transpiration is measured by a device known as 'Phytometer.'



* Weight of container along with plant & soil $= W_1$

Weight of water added $= w$

Final wt. of container $= W_2$.

$$\text{Transpiration} = (W_1 + w) - W_2.$$

* Transpiration Ratio, 'Tr'

$$Tr = \frac{\text{Mass of water consumed by plant during its full growth}}{\text{Mass of dry matter produced by plant after wilting}}$$

* Factors affecting Transpiration.

(i) Plant Factors -

a) Type plant

b) Stage of plant growth.

c) type of leaf structure.

(ii) Soil Factors -

a) Type of soil b) moisture content of soil c) Porosity

d) Permeability.

(iii) Weather Factors -

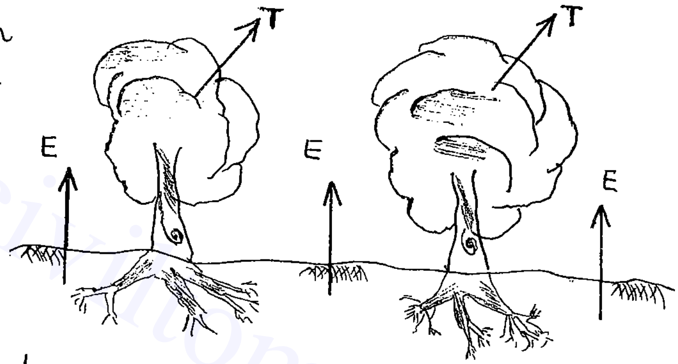
a) Temperature b) Radiation c) Winds d) Pressure e) Humidity

→ Evapotranspiration :

Evapotranspiration is the sum of plant evaporation and land evaporation surrounding the plant.

1. Potential Evapotranspiration (PET)

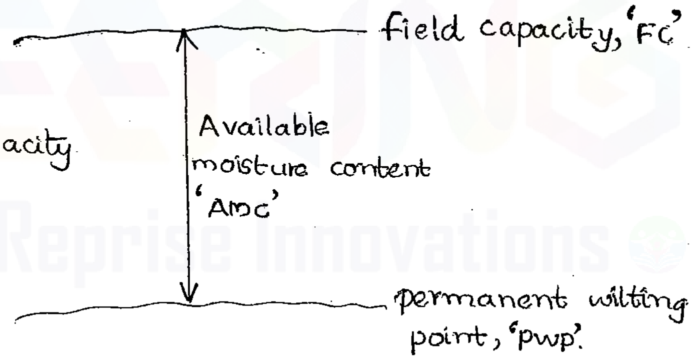
Evapotranspiration which would occur if soil contain adequate moisture to meet the vegetative needs of the ground covered by full vegetation.



2. Actual Evapo-Transpiration. (AET).

Evapotranspiration at a given time at a given place under specific conditions.

* Relation b/w PET & AET :



⊙ If moisture content = field capacity

Then. AET = PET

$$\frac{AET}{PET} = 1$$

⊙ If moisture content < field capacity, then AET < PET

$$\frac{AET}{PET} < 1.$$

⊙ If moisture content = permanent wilting capacity.

then AET = 0

$$\frac{AET}{PET} = 0$$

NOTE :

⊙ Above relation is true for all soils except clayey soils. For clayey soils, moisture content is greater than 50% FC, then

$MC \geq 0.5\ FC \Rightarrow \frac{AET}{PET} = 1.$ (due to low coeffecient of permeability)

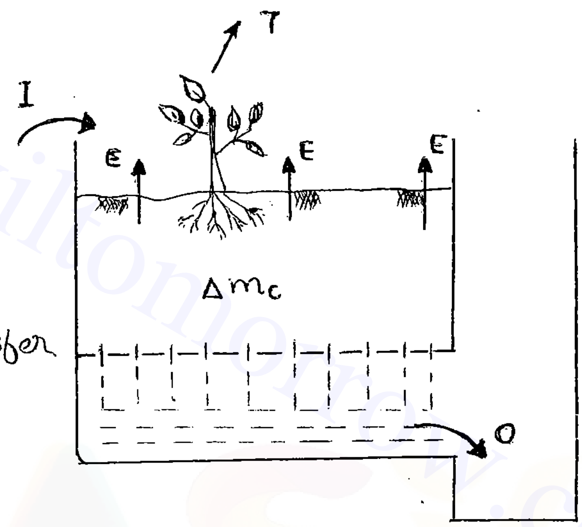
If $MC < 0.5\ Fc$, soil behaves normally.

5th friday november

* Measurement & Estimation of Evapotranspiration

1. Lysi meter

$$ET = I - O - \Delta mc$$



2. Penman's Equation.

- Energy balance & mass transfer

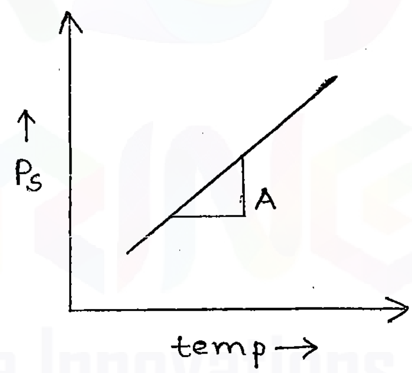
$$PET = \frac{A H_n + E\gamma}{A + \gamma}$$

where $A \rightarrow$ slope of P_s-temp curve

$H_n \rightarrow$ net radiation.

$E \rightarrow$ constant which account wind speed 'V' & $P_s - P_a$.

$\gamma \rightarrow$ Psychrometric constants.



3. Blanney - Criddle Formula.

$$PET = \frac{KPT_m}{100}$$; $P \rightarrow$ % daylight hours in a month.

PET in 'inch per month'

where $K \rightarrow$ crop factor (or) consumptive use factor.

$T_m \rightarrow$ mean monthly temperature, in '°F'

$$K = \frac{\text{consumptive use, } C_u}{\text{evapotranspiration}}$$

$$°F = 1.8°C + 32$$

NOTE

- $C_u \simeq PET \rightarrow$ when water used by the plants is neglected.

$$C_u = PET = \frac{KPT_m}{100}$$

- $C_u > PET \rightarrow$ when water used by plants is considered.

In general, $\boxed{C_u \geq PET}$

P-19.

08 $P = 7.2$ hours

$T_m = 18^\circ C = 1.8 \times 18 + 32 = 64.4^\circ F$

$K = 0.7$.

$$C_u = \frac{KPT_m}{100} = \frac{0.7 \times 7.2 \times 64.4}{100} = 3.246 \text{ inch/month}$$

$$= \frac{3.246 \times 25.4}{30} = 2.748 \text{ mm/day}$$

09. Pan evaporation in January $= 9.5$ cm.

$K = 0.52$

$$K = \frac{C_u}{\text{Pan evaporation}}$$

$C_u = 0.52 * 9.5 = 4.94$ cm/month.

$$= \frac{4.94 \times 10}{31} = 1.6 \text{ mm/day}$$

10.

Month	Mean monthly temp, (°c)	Mean monthly temp (°F).	% day time hours.	K	PET.
April	25	~~80.6~~ 77	8.6	0.6	4.16
May	27	~~82.4~~ 80.6	9.29	0.65	4.976
June	28	~~84.2~~ 82.4	9.18	0.7	5.41
July	29	84.2	9.39	0.75	5.93
August	29	84.2	9.04	0.75	5.71.

PET for the season = 65.4 cm

* Isoplith – line joining points of equal evapotranspiration.

* Aridity Index (AI) = $\frac{PET - AET}{PET} \times 100$

$AI \propto \frac{1}{AET}$ & $AET \propto$ moisture content (mc)

$mc \propto$ Rainfall.

$\Rightarrow AI \propto \frac{1}{\text{rainfall}}$.

With areas of less rainfall, AET will be less and aridity index will be maximum. (arid or drought prone areas).

$AI > 50\%$ → severe drought

$25\% < AI < 50\%$ → moderate drought

$AI < 25\%$ → mild drought.

→ Infiltration

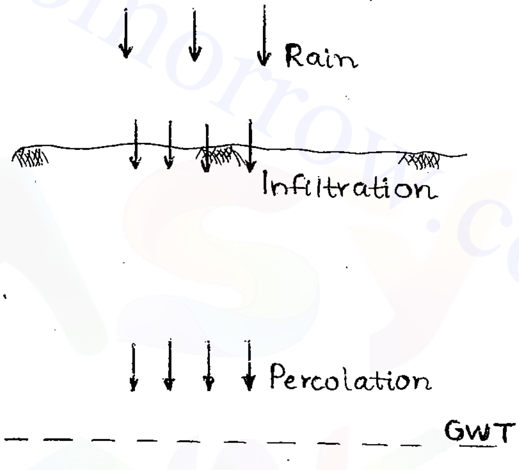
Infiltration is the method (or) process by which water get into surface strata of Earth to meet soil moisture deficiencies.

5th nov,
FRIDAY

05. INFILTRATION

Infiltration is the method by which water get into surface strata of the Earth to meet soil moisture deficiency.

- After meeting the soil moisture deficiency if any excess water remain in the ground, flow vertically deep into the ground and join ground water table.
- Deep vertical movement of water in the ground is known as ~~'Precipitation'~~. 'Percolation'



* Infiltration Capacity : (f_c)

It is the maximum rate at which soil is capable of absorbing water.

* Infiltration Rate : (f_a)

It is the actual rate of infiltration at a given time at a given place under specific conditions.

* Relation among f_a, f_c, i :

$f_a = f_c$ when $i \geq f_c$

$f_a = i$ when $i < f_c$

-23.

1. When $i < f_c$, $f_a < f_c$ or $f_a = i$

2. $f_c = 0.2$ cm/hr.

   $i = 0.5$ cm/hr.

   $i > f_c \Rightarrow f_a = f_c = 0.2$ cm/hr

→ Factors affecting Infiltration:

1. Porosity of Soil, (n)

$$f \propto n$$

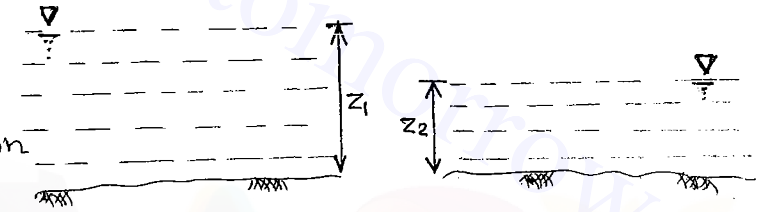
2. Moisture content of Soil, (mc)

$$f \propto \frac{1}{mc}$$

3. Depth of Surface retention, (z)

$$f \propto z$$

more depth ⇒ more infiltration



4. Vegetation

$$f \propto \text{vegetative cover}$$

5. Compaction (due to men, animal, rain etc).

$$f \propto \frac{1}{\text{compaction}}$$

6. Washing of fines

$$f \propto \frac{1}{\text{washing of fines}}$$

7. Entrapment of air.

$$f \propto \frac{1}{\text{entrapment of air}}$$

8. Temperature

As temperature increases, viscosity decreases and resistance to flow decreases and infiltration increases.

$$f \propto \text{temperature.}$$

→ Measurement & Estimation of Infiltration :

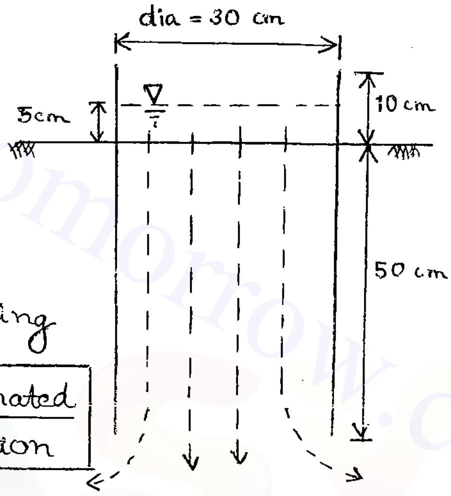
1. Infiltrometer

- For field measurement of infiltration.

(i) Single Ring Infiltrometer.

- Depth of water infiltrated (infiltration)

$$= \frac{\text{vol. of water infiltrated}}{\text{c/s area of infiltrometer.}}$$



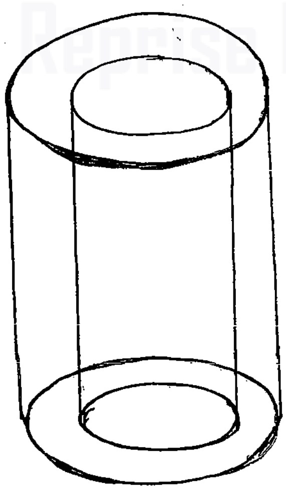
Volume of water infiltrated

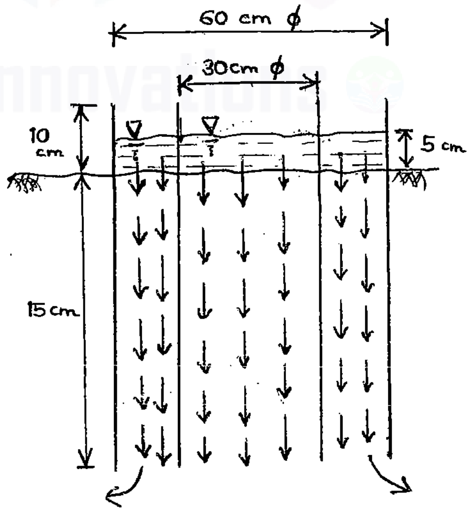
= volume of water added to ring

$$\boxed{\text{Infiltration rate} = \frac{\text{depth of water infiltrated}}{\text{duration of infiltration}}}$$

- Test is conducted till constant infiltration rate is achieved.
- Single ring infiltrometer always overestimate because of lateral movement of water. To overcome this problem, double ring infiltrometers are used

(ii) Double Ring Infiltrometer





Infiltration

$$= \frac{\text{vol of water added to internal ring}}{\text{c/s area of internal ring}}$$

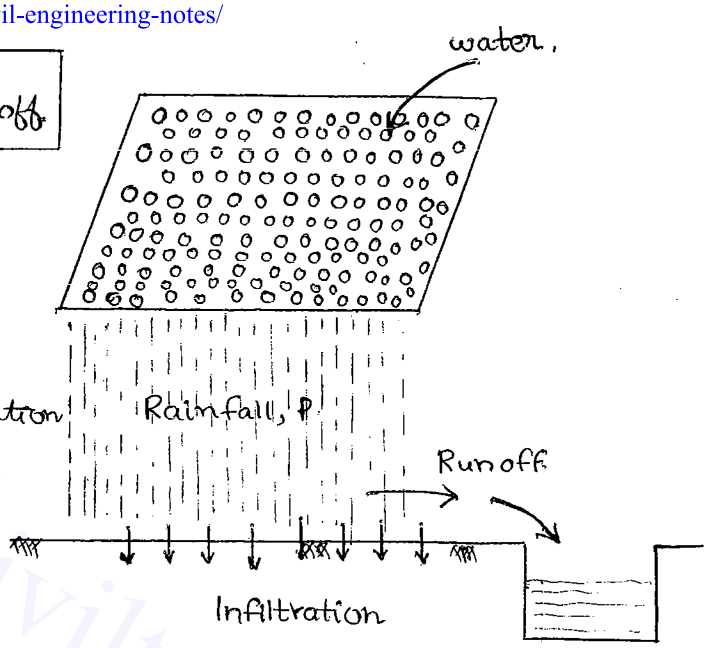
Infiltration rate

$$= \frac{\text{infiltration}}{\text{duration of infiltration}}$$

2. Rainfall Simulator

- laboratory measurement
- test plot of size 2m * 4 m

$$\text{Infiltration} = \text{Rainfall} - \text{Runoff}$$



⊙ $f_{(\text{infiltrometer})} > f_{(\text{rainfall simulator})}$

As depth of retention increases in infiltrometer, rate of infiltration is more in infiltrometer compared to rainfall simulation.

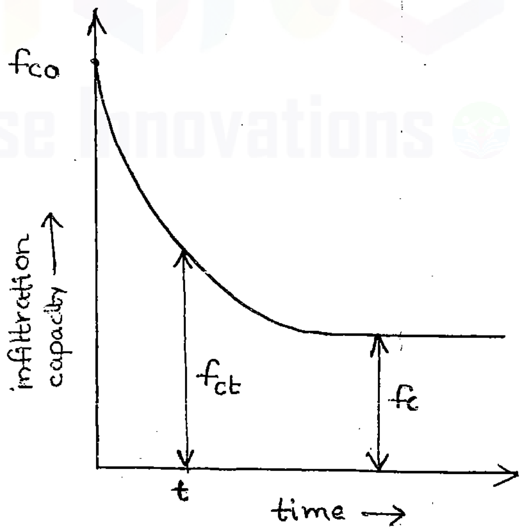
3. Horton's Infiltration Capacity Curve.

– Horton has conducted infiltration studies in his laboratory by simulating $i \geq f_c$ on different soils and concluded the following:

(i) Infiltration capacity is max at the beginning of the storm and it exponentially decreases as storm duration increases

(ii) It attain steady state at some point of time and remain in that state indefinitely.

(iii) I



– The above diagram is obtained by plotting the observations of the test known as 'Horton's Infiltration Capacity Curve'.

$$f_{ct} = f_c + (f_{co} - f_c)\, e^{-kt}$$

Above equation represents the curve, where.

f_{co} → infiltration capacity at time $t=0$

f_c → steady state infiltration capacity.

f_{ct} → infiltration capacity at any time 't'

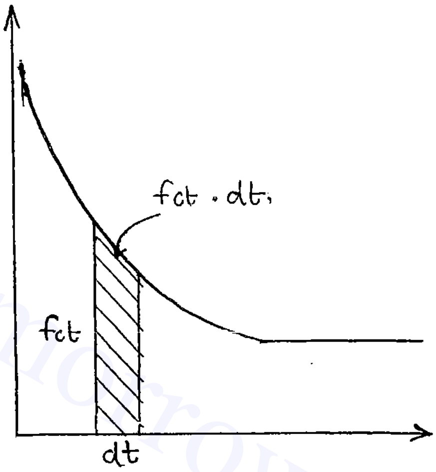
k → infiltration rate constant'

– using the Horton Infiltration Curve, total infiltration in given time 't' as well as infiltration b/w any two periods can be worked out; along with actual rate of infiltration.

⊙ Infiltration in time 'dt'

= Area under Horton's Infiltration Capacity Curve in time, 'dt'

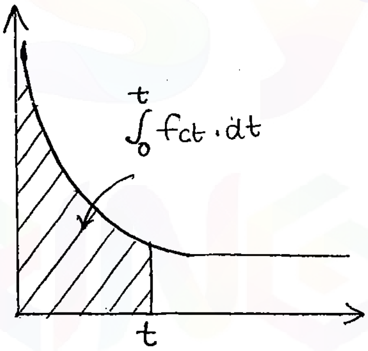
= $f_{ct} * dt$



⇒ Total infiltration in time t

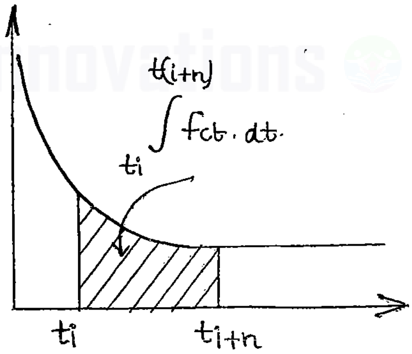
= Area under Hortons IC Curve upto time t.

$$= \int_0^t f_{ct} * dt.$$



⊙ Infiltration b/w time intervals t_i & t_{i+n} $= \int_{t_i}^{t_{i+n}} f_{ct} \cdot dt.$

= Area under Horton's IC Curve b/w time intervals t_i & t_{i+n}.



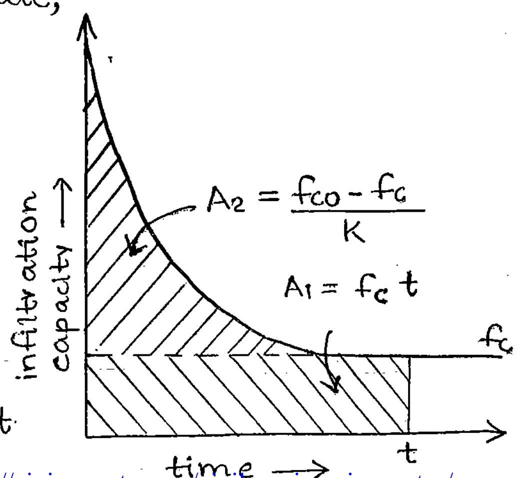
⊙ When Soil has attained steady state,

At any time, 't', $f_{ct} = f_c$

Total infiltration = area under IC Curve

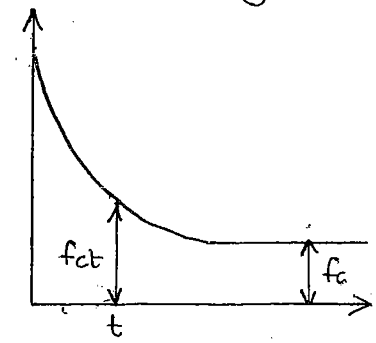
$= A_1 + A_2$

$$\left.\begin{array}{l}\text{Total infiltration} \\ \text{in time 't'}\end{array}\right\} = f_c t + \frac{f_{co} - f_c}{K} = \int_0^t f_{ct}\, dt$$



⊙ At any time t, $f_{ct} > f_c$, soil yet to attain steady state

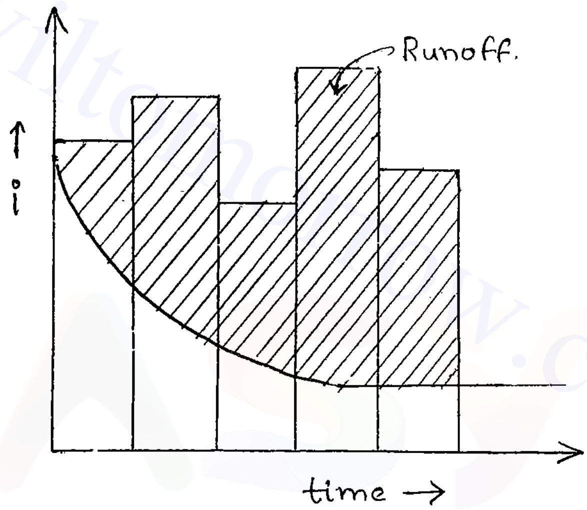
$$\text{Infiltration} = \int_0^t f_{ct} \cdot dt.$$



– By superimposing, Horton's IC curve over Rainfall Hyetograph, along with infiltration, runoff can also be estimated.

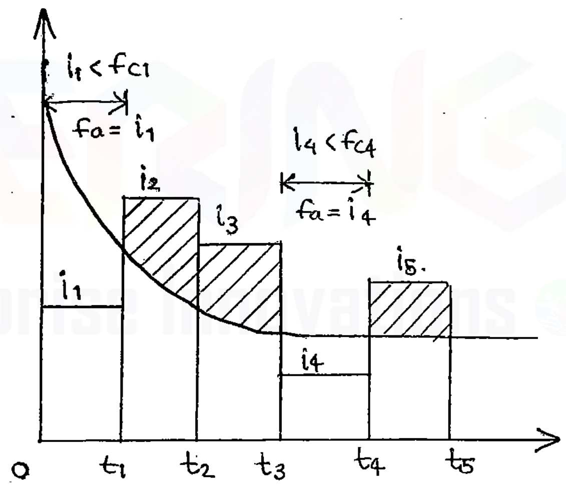
Run off = Area of hyetograph above Horton IC Curve

$$\text{Runoff} = \sum_0^t i_i t_i - \int_0^t f_{ct} \cdot dt$$



Total rainfall = $i_1(t_1-0) + i_2(t_2-t_1) + i_3(t_3-t_2) + i_4(t_4-t_3) + i_5(t_5-t_4)$.

Total infiltration = $i_1(t_1-0) + \int_{t_1}^{t_2} f_{ct}\, dt + i_4(t_4-t_3) + \int_{t_4}^{t_5} f_{ct}\, dt.$



2.23

03. $f_c = 1.34$, $f_0 = 7.62$, $k = 4.182$, $t = 2$ hours.

Infiltration at the end of 2 hours $= f_c \times t + \dfrac{f_0 - f_c}{K} \times$

$= 1.34 \times 2 + \dfrac{7.62 - 1.34}{4.182}$

$= \underline{\underline{4.182}}$ cm

26 27

04. $f_c = 0.5$ cm/hour ; $t = 8$ hours.

$f_o = 2$ cm/hour. ; $K = 4$ (hour)$^{-1}$

Total infiltration during 8 hours $= f_c t + \dfrac{f_o - f_c}{K}$

$= 0.5 \times 8 + \dfrac{2 - 0.5}{4}$

$= \underline{\underline{4.375 \text{ cm}}}$

05. Rainfall in 24 hours = 10 cm.

Pan evaporation in 24 hours = 0.6 cm.

Actual evaporation in 24 hours $= 0.6 \times 0.7 = 0.42$ cm.

Steady state has attained @ 15th hour:

$f_{co} = 1$ cm/hr , $f_c = 0.3$ cm/hr

$K = 5$ (hr)$^{-1}$

Total infiltration in 24 hours $= 0.3 \times 24 + \dfrac{1 - 0.3}{5}$

$= 7.34$ cm.

Run off = Rainfall − (infiltration + evaporation).

$= 10 - (7.34 + 0.42) = 2.24$ cm.

Volume of run off $= 2.24 \times 10^{-2} \times 1.8 \times 10^{06}$

$= \underline{\underline{40320}}$ m^3

th Dec,
TURDAY

$f_{ct} = 6 + 16\, e^{-2t}$ $\quad (f_{ct} = f_c + (f_{co} - f_c)\, e^{-kt})$.

$f_c = 6$ mm/hr

$f_{co} - f_c = 16$

$\therefore f_{co} = 16 + 6 = 22$ mm/hr

$K = 2$ hr^{-1}

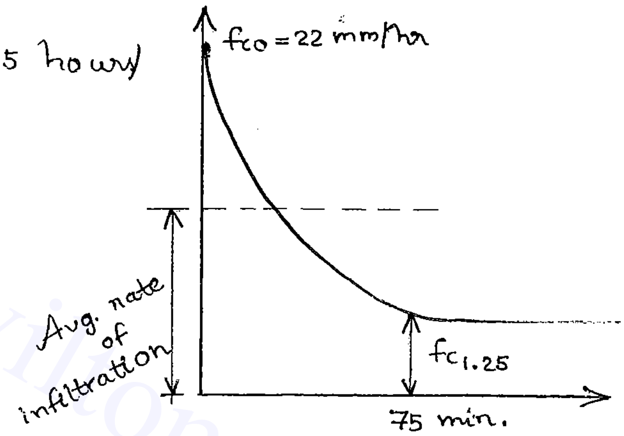
Total infiltration in first 45 min $= \int_0^{0.45} (6 + 16e^{-2t})\, dt.$

$= \underline{\underline{10.715 \text{ mm}}}$

Total Infiltration at 75 min (1.25 hours)

$= 6 + 16e^{-2 * 1.25}$

$= 7.31$ mm/hr.



Total infiltration in 1.25 hours.

$= \int_0^{1.25} f_{ct}\, dt = \int_0^{1.25} (6 + 16e^{-2t})\, dt$

$= 14.84$ mm.

$\therefore$ Average infiltration rate for first 75 min $= \dfrac{\text{total infiltration}}{\text{time}}$

$= \dfrac{14.844}{1.25} = \underline{\underline{11.875 \text{ mm/hr}}}$

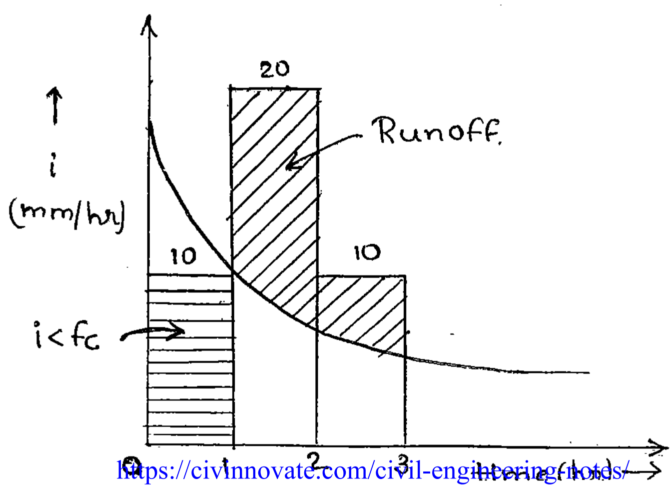
07.

Time	i (mm/hr)	$f_{ct} = 6.8 + 8.7e^{-t}$ (mm/hr)
0	10	15.5
1	20	10
2	10.	7.97
3		7.23

15.5, 10 } Horton's approach failed: $i < f_c \Rightarrow f_a = i$

10, 7.97, 7.23 } Horton's approach is true. $i > f_c \Rightarrow f_a = f_{ci}$

Run off = Effective rain
= Rainfall excess
= Excess rainfall.
= Net rain.



Runoff = area of hyetograph above IC curve $= \sum_{i=1}^{3} i_1 t_1 - \int_1^3 f_{ct}\, dt$

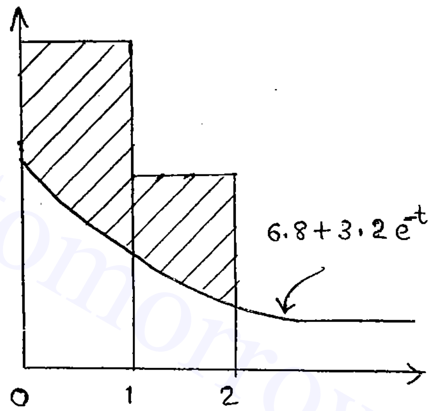
$= 20\times1 + 10\times1 - \int_1^3 (6.8 + 8.7e^{-t})\, dt$

$= 30 - 16.367 = \underline{13.633 \text{ mm}}$

OR

$f_{ct} = 6.8 + (10 - 6.8)e^{-t}$

$= 6.8 + 3.2e^{-t}$



Runoff = rainfall − infiltration.

$= 20\times1 + 10\times1 - \int_0^2 (6.8 + 3.2e^{-t})\, dt$

$= \underline{13.63}$

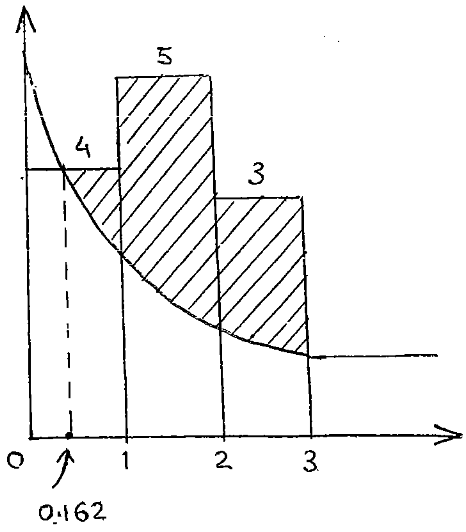
Q. Rainfall over a basin in 3 consecutive hours are 4 cm, 5 cm, 3 cm resptly. Estimate the surface runoff from basin assuming negligible surface retention and evaporation losses. Infiltration loss can be estimated using Horton's equation $f = 1.2 + 4.2e^{-2.5t}$, where f is infiltration in cm/hr, t is time in hour from start of rainfall.

Time t	Rainfall intensity i (cm/hr)	$f_{ct} = 1.2 + 4.2e^{-2.5t}$
0		$f_{c0} = 5.4$
0–1	4	
1		$f_{c1} = 1.54$
1–2	5	
2		$f_{c2} = 1.23$
2–3	3	
3		$f_{c3} = 1.20$

$f_{ct} = 4 = 1.2 + 4.2e^{-2.5t}$

$e^{-2.5t} = \frac{4-1.2}{4.2}$

$t = \frac{0.415}{2.5} = 0.162\ hr.$



Runoff = area of hyetograph above IC Curve.

$= \sum_{t=0.162}^{3} i_1 t_1 - \int_{0.162}^{3} f_{ct} \cdot dt$

$= (4 \times 0.838 + 5\times1 + 3\times1) - \int_{0.162}^{3} (1.2 + 4.2e^{-2.5t})\,dt$

$= 6.8627\ cm$

08. $f_{co} = 10\ mm/hr,\ f_c = 1.2\ mm/hr,\ t = 10\ hr.$

Total infiltration $= f_c t + \frac{f_{co} - f_c}{K}$

$33 = 1.2\times10 + \frac{10-1.2}{K}$

$\Rightarrow K = 0.42\ hr^{-1}$

* Limitations of Horton's Approach:

1. True only for $i \geq f_c$

2. Applicable only for catchments with homogenous soil conditions.

→ Infiltration Indices :

Infiltration indices represents infiltration at an average rate.

- There are two infiltration indices :

1. ϕ index

ϕ index is the average rate of infiltration during the period of a storm at which there is runoff.

$$\phi \text{ index} = \frac{\text{infiltration during period of effective storm}}{\text{duration of effective storm.}}$$

Let Pe be the magnitude of effective storm.
te be the duration of effective storm.
R be the runoff.

$$\boxed{\phi_{index} = \frac{Pe - R}{te}}$$

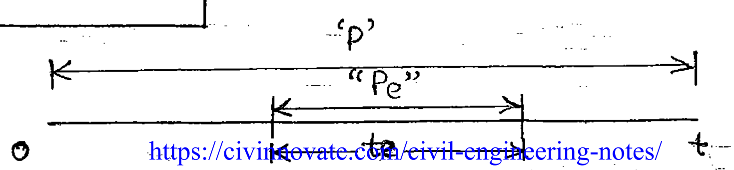
2. ω index.

ω index is the average rate of infiltration during the entire period of a storm.

Let P be the total rainfall
t be the duration of total storm.
R be the runoff

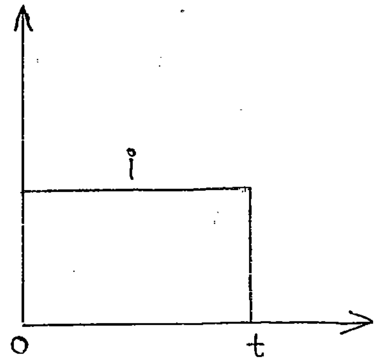
$$\omega \text{ index} = \frac{\text{total infiltration during storm}}{\text{duration of storm.}}$$

$$\boxed{\omega \text{ index} = \frac{P - R - \text{losses}}{t}}$$



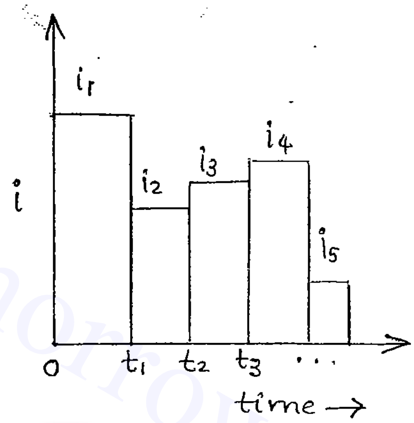
- For uniform rains, $P = P_e$
  $t = t_e$.

  $\Rightarrow \phi$ index $= \omega$ index.
  (neglecting losses).



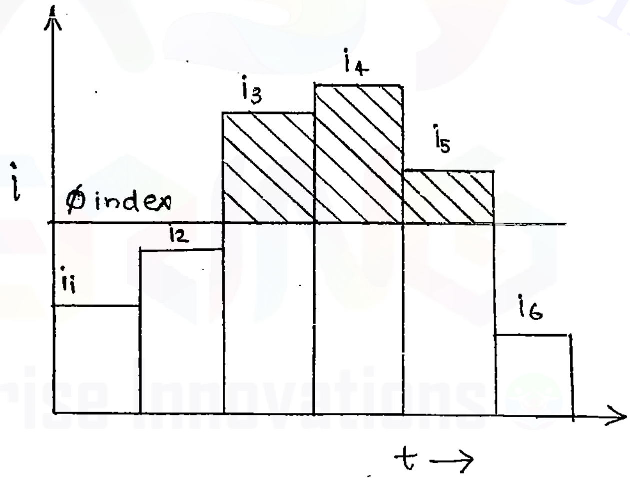
- For non-uniform rains, $P > P_e$
  $t > t_e$

  $\Rightarrow \phi$ index $>$ W index.



- When ϕ index line is superimposed over rainfall hyetograph, then, ϕ index is also defined as 'average rainfall intensity'; anything above which is runoff.

For the given example,



$$P = i_1 t_1 + i_2 t_2 + i_3 t_3 + i_4 t_4 + i_5 t_5 + i_6 t_6.$$

$$P_e = i_3 t_3 + i_4 t_4 + i_5 t_5$$

$$t = t_1 + t_2 + t_3 + t_4 + t_5 + t_6$$

$$t_e = t_3 + t_4 + t_5.$$

- Hyetograph lying above ϕ index is known as Effective Rainfall Hyetograph, 'ERH'

Run off = Area of effective rainfall hyetograph.

$$\boxed{\text{Run off} = \Sigma (i_i - \phi)\, t_i} \quad ; \quad i_i > \phi \text{ index}.$$

9. ϕ index = 0.5 cm/hr   Rainfall @ uniform storm, $P = P_e = 2$ cm.

$P = 2$ cm, $t = 6$ hour.

$$\phi = \frac{P_e - R}{t}$$

$$0.5 = \frac{2-R}{6} \; ; \; R = -1 \Rightarrow R = 0$$

whenever run off value is −ve, then equate it to zero.

10. Uniform intensity – uniform storm.

$P = P_e$ & $t = t_e = 4$ hour.

$P = P_e = i \times t = 2.8 \times 4 = 11.2$ cm.

Volume of runoff $= 25.2 \times 10^6$ m³.

Catchment area $= 280$ km² $= 280 \times 10^6$ m².

$$\text{Depth of runoff} = \frac{\text{volume of runoff}}{\text{catchment area}} = \frac{25.2 \times 10^6}{282 \times 10^6}$$

$$= 0.09 \text{ m} = 9 \text{ cm}$$

Average infiltration rate of ϕ index = w index.

$$= \frac{P_e - R}{t_e} = \frac{11.2 - 9}{4}$$

$$= 5.5 \text{ mm/hour}$$

11. 4 hour storm.

4 cm = rainfall.

$$\phi \text{ index} = \frac{P-R}{t_e} = \frac{4-2}{4} = 0.5 \text{ cm/hour.}$$

$$0.5 \text{ cm/hr} = \frac{10-R}{8} \Rightarrow R = 6.0 \text{ cm}$$

12. **Storm 1**

$t_e = 5$ hour.

$i = 2$ cm/hour

$R = 4$ cm

$$\phi \text{ index} = \frac{P-R}{t_e} = \frac{5\times2-4}{5} = 1.2 \text{ cm/hr}$$

Storm 2

$t_e = 8$ hour.

$R = 8.4$ cm

13. Storm II :

$$\phi \text{ index} = \frac{P-R}{t_e}$$

$P = 1.2\times8 + 8.4 = 18$ cm.

$$i = \frac{18}{8} = 2.25 \text{ cm/hour}$$

14. $P = 7\times1 + 18\times1 + 25\times1 + 17\times1 + 11\times1 + 3\times1$

$= 81$ mm.

$R = 39$ mm.

$$\phi \text{ index} = \frac{P-R}{t} = \frac{81-39}{6} = 7 \text{ mm/hr}$$

15. $P = 1.6\times0.5 + 3.6\times0.5 + 5\times0.5 + 2.8\times0.5 + 2.2\times0.5 + 1\times0.5$.

$= 8.1$ cm.

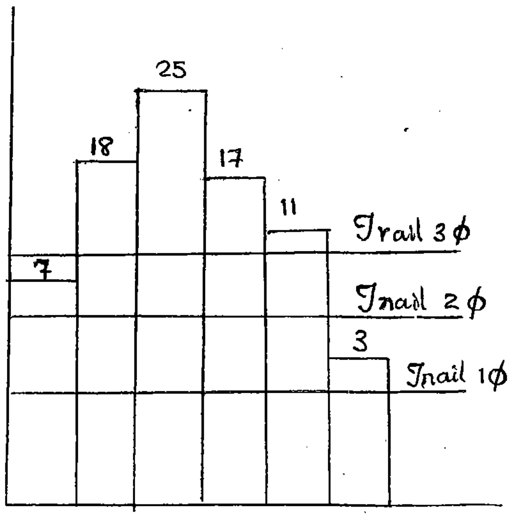
$$\phi \text{ index} = \frac{P-R}{t} = \frac{8.1-3.6}{3} = 1.5 \text{ cm/hr}$$

14. Trail 1 : Assuming ϕ index < 3 mm/hr.

Run off $= \Sigma(i_i-\phi)t_i \rightarrow i_i > \phi$

$39 = (7-\phi) + (18-\phi) + (25-\phi) + (17-\phi) +$
$(11-\phi) + (3-\phi)$

$$\phi = \frac{81-39}{6} = 7 \text{ mm/hr} \quad \text{(assumption failed)}$$



Trail 2 : Assuming $3 < \phi < 7$ mm/hr

Run off $= \Sigma (i_i - \phi) t_i \rightarrow i_i > \phi$

$39 = (7-\phi) + (18-\phi) + (25-\phi) + (17-\phi) + (11-\phi)$

$\phi = \frac{79-39}{5} = 7.8$ mm/hr $\Rightarrow$ assumption failed.

Trail 3 : Assuming $7 < \phi$ index < 11 mm/hr.

Run off $= \Sigma (i_i - \phi) t_i \rightarrow i_i > \phi$ index.

$39 = (18-\phi) + (25-\phi) + (17-\phi) + (11-\phi)$.

$\phi = 8$ mm/hr

OR

$P = \Sigma P_i t_i = 7\times1 + 18\times1 + 25\times1 + 11\times1 + 3\times1$

$= 81$ mm.

$t = 6$ hour.

W index $= \frac{P-R-\text{losses}}{t} = \frac{81-39}{6} = 7$ mm/hr

To find P_e & t_e, neglect $i_i \leq$ W index :

$\therefore P_e = 18\times1 + 25\times1 + 17\times1 + 11\times1 = 71$ mm

$t_e = 4$ hours

ϕ index $= \frac{71-39}{4} = 8$ mm/hr

15 $P = \Sigma P_i t_i = 1.6\times0.5 + 3.6\times0.5 + 5\times0.5 + 2.8\times0.5 + 2.2\times0.5 + 1\times0.5$

$= 8.1$ cm/hr.

$t = 3$ hour.

W index $= \frac{8.1-3.6}{3} = 1.5$ cm/hour.

ϕ index : to find P_e & t_e neglect $i \leq$ w index

$P_e = 1.6 \times 0.5 + 3.6 \times 0.5 + 5 \times 0.5 + 2.8 \times 0.5 + 2.2 \times 0.5$

$= 7.6$ cm/hour

$t_e = 3 - 0.5 = 2.5$ hour.

ϕ index $= \frac{7.6 - 3.6}{2.5} = 1.6$ cm/hr

16. $P = 1.6 + 5.4 + 4.1 = 11.1$

W index $= \frac{P - R - L}{t} = \frac{11.1 - 4.7 - 0.6}{24} = 0.242$ cm/hr

$i_1 = \frac{1.6}{8} = 0.2$ cm/hr $\quad$ $i_2 = \frac{5.4}{8} = 0.675$ cm/hr

$i_3 = \frac{4.1}{8} = 0.5125$ cm/hr

Neglect i_1 because $i_1 <$ W index.

$P = 0.675 \times 8 + 0.5125 \times 8 = 9.5$ cm

$t = 16$ hours.

ϕ index $= \frac{P - R}{t} = \frac{9.5 - 4.7}{16} = 0.3$ cm/hr

17. W index $= \frac{P - R}{t} = \frac{(0.5 + 2.8 + 1.6) - 3.2}{2 + 2 + 2} = 0.283$ cm/hr

$i_1 = \frac{0.5}{2} = 0.25$ cm/hr

$i_2 = \frac{2.8}{2} = 1.4$ cm/hr

$i_3 = \frac{1.6}{2} = 0.8$ cm/hr.

$P = 1.4 \times 2 + 0.8 \times 2 = 4.4$.

$t_e = 2 + 2 = 4$

ϕ index $= \frac{P - R}{t} = \frac{4.4 - 3.2}{4} = 0.3$ cm/hr

18. ϕ index $= 10$ mm/hour.

Time	Rainfall (mm)	i (mm/hr) = P/t
0–1	9	9
1–2	28	28
2–3	12	12
3–4	7	7

$$\phi \text{ index} = \frac{P-R}{t}$$

$$10 = \frac{28+12-R}{2}$$

$$\Rightarrow R = 20 \text{ mm}$$

19 Total $P = 3+8+12+6+2 = 31$ cm

$$w \text{ index} = \frac{P-R}{t} = \frac{31-15}{24 \times 5} = 0.1333 \text{ cm/hr}.$$

$i_1 = \frac{3}{24} = 0.125$ cm/hr. $\quad i_4 = \frac{6}{24} = 0.25$ cm/hr.

$i_2 = \frac{8}{24} = 0.33$ cm/hr. $\quad i_5 = \frac{2}{24} = 0.0833$ cm/hr.

$i_3 = \frac{12}{24} = 0.5$ cm/hr

Neglecting $i_i \leq w$ index,

$$P = 8+12+6 = 26 \text{ cm}$$

$$\phi \text{ index} = \frac{P-R}{t} = \frac{26-15}{24 \times 5} = 0.153 \text{ cm/hr}$$

$$= 1.53 \text{ mm/hr}.$$

th dec,
ATURDAY

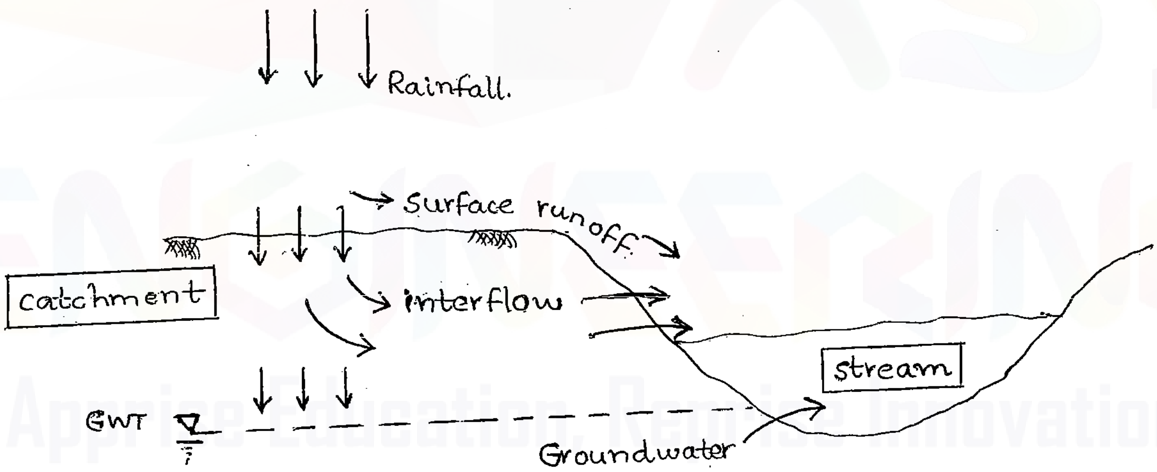
06. RUNOFF

Run off is that portion of a rain which ultimately joins streams and rivers.

- It is an output produced by the catchment for a given input rainfall.

→ Components of Runoff

1. Surface Runoff (Overland Flow)
2. Subsurface Runoff (Interflow)
3. Groundwater



* Based on time delay in joining the runoff into stream:

(i) Direct Runoff.

Runoff without much delay in joining the stream.

(ii) Base flow

Runoff which take its own time ; ie late joining run off

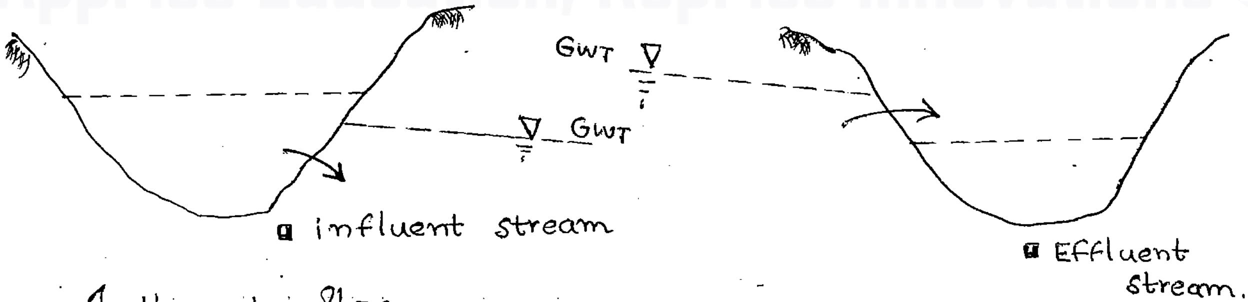
- Direct Runoff includes :
  a) Surface Runoff
  b) Prompt Interflow.
  c) Channel Precipitation.
- Base Flow includes :
  a). Delayed interflow.
  b) Groundwater flow.

→ Classification of Streams :

- Based on availability of flow in stream :-
  (i) Perennial Streams
  (ii) Non perennial Streams.
  (iii) Ephemeral Streams (short-lived (or) temporary streams)
- Based on contribution of ground to stream (or) stream to ground.

(i) Effluent Stream.

when ground contribute flow to stream.

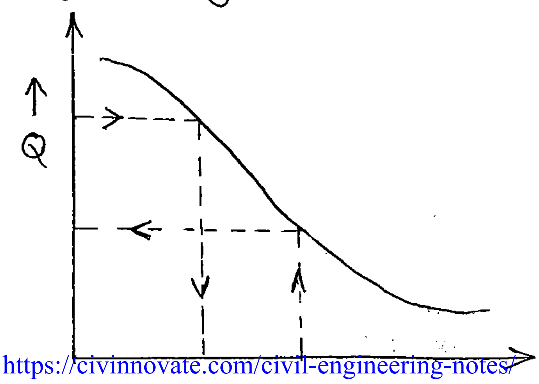


(ii) Influent Stream.

when stream contribute flow to groundwater.

* Flow Duration Curve.

x axis : % times flow equals (or) exceeds.



→ Methods to Estimate Run off

1. Rainfall & Runoff relation (regression analysis)
2. Emperical Procedures.

 Eg :- Binnies Percentages – used for catchments in Vidarbha & MP.

 Barlow's Tables – for catchments in UP.

 Strange Tables – for catchments in Karnataka & Maharashtra.

3. Watershed Simulation

$$R = P - E - T - ET - I$$

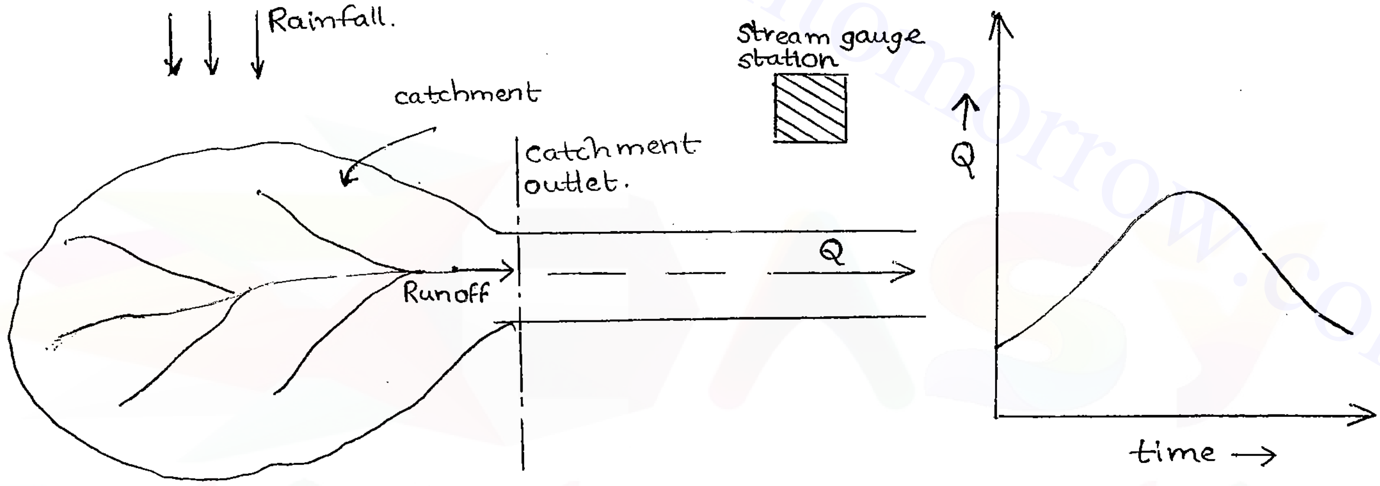
4. Horton's Infiltration Capacity Curves
5. Infiltration Indices.
6. Hydrographs.

7th dec,
SUNDAY

07. HYDROGRAPHS

Hydrograph is a plot between discharge versus time.

- Hydrograph shows time distribution of runoff.
- Hydrograph is the measure of response of catchment for a given storm.



1. Storm Hydrograph (or) Flood Hydrograph (or) Total Runoff Hydrograph (SHG (or) FHG (or) TRH)

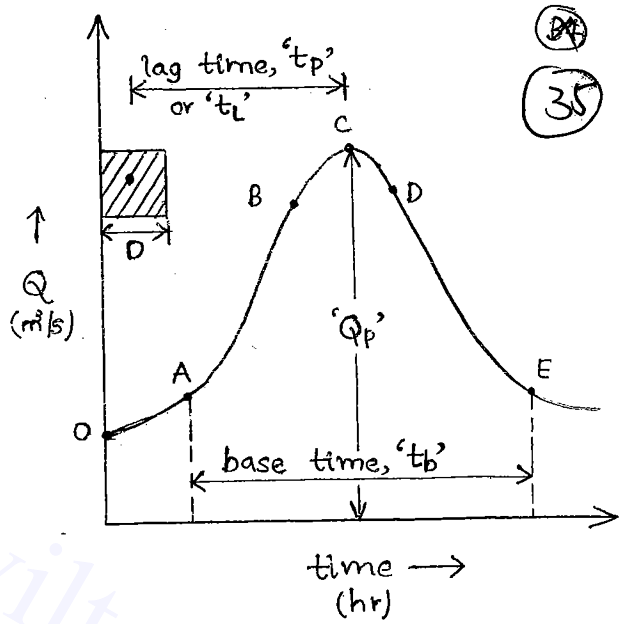
A storm of certain duration if it occur over a catchment after meeting the catchment losses, the rainfall excess (runoff) delivered into stream, then it result into stream flow variation. If stream flow variation is measured at a point in a stream, the resulting plot is known as 'Storm Hydrograph' (or) 'Flood Hydrograph' (or) 'Total Runoff Hydrograph'.

OA → approach segment

AB → rising limb.

BD → crest segment.

DE → recession limb (or) falling limb.



A : Point of rise.

B & D : Inflexion point.

C : Peak point.

D : End of overland flow.

E : End of direct runoff.

* Factors affecting hydrograph :

(i) Catchment factors –

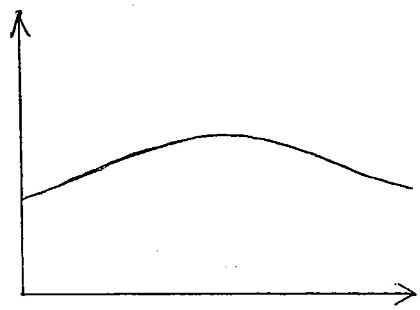
a) Size of Catchment
b) Shape of Catchment
c) Slope of catchment.
d) Drainage density.

(ii) Storm factors –

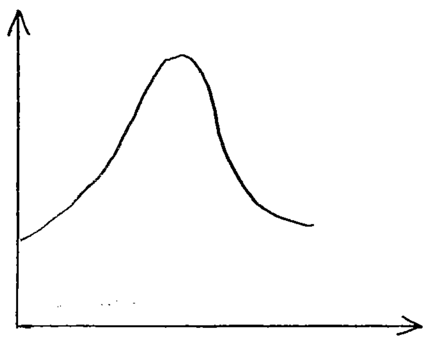
a) Duration of storm
b) Intensity of storm
c) Direction of storm.

– For small catchment, overland flow > channel flow.

– land use pattern influences shape of hydrograph.

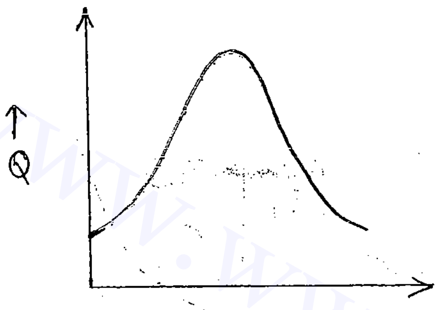


▪ catchment with vegetation



▪ catchment without vegetation

- For large catchments, channel flow > overland flow.

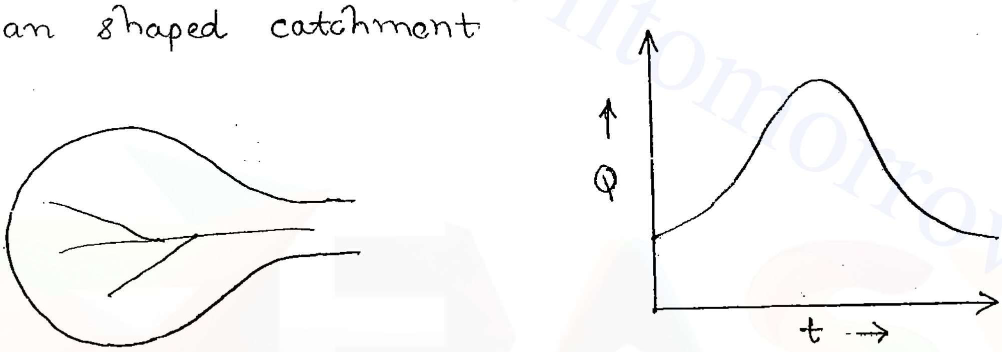


▪ steep channel

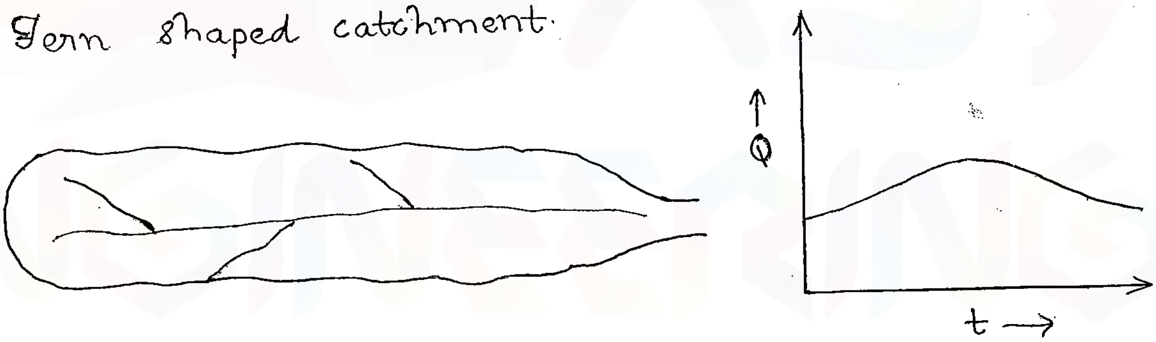
▪ flat channel.

- Based on shape, catchments are classified as:

a) Fan shaped catchment

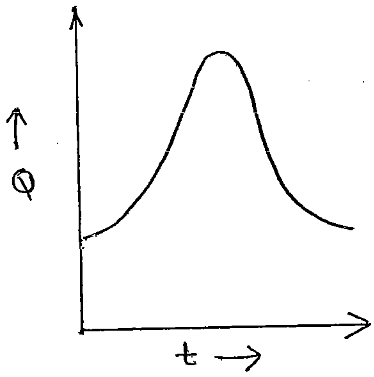


b. Fern shaped catchment.

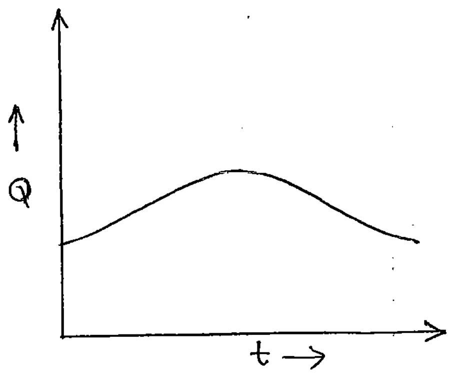


- Slope of catchment classifies catchments into:

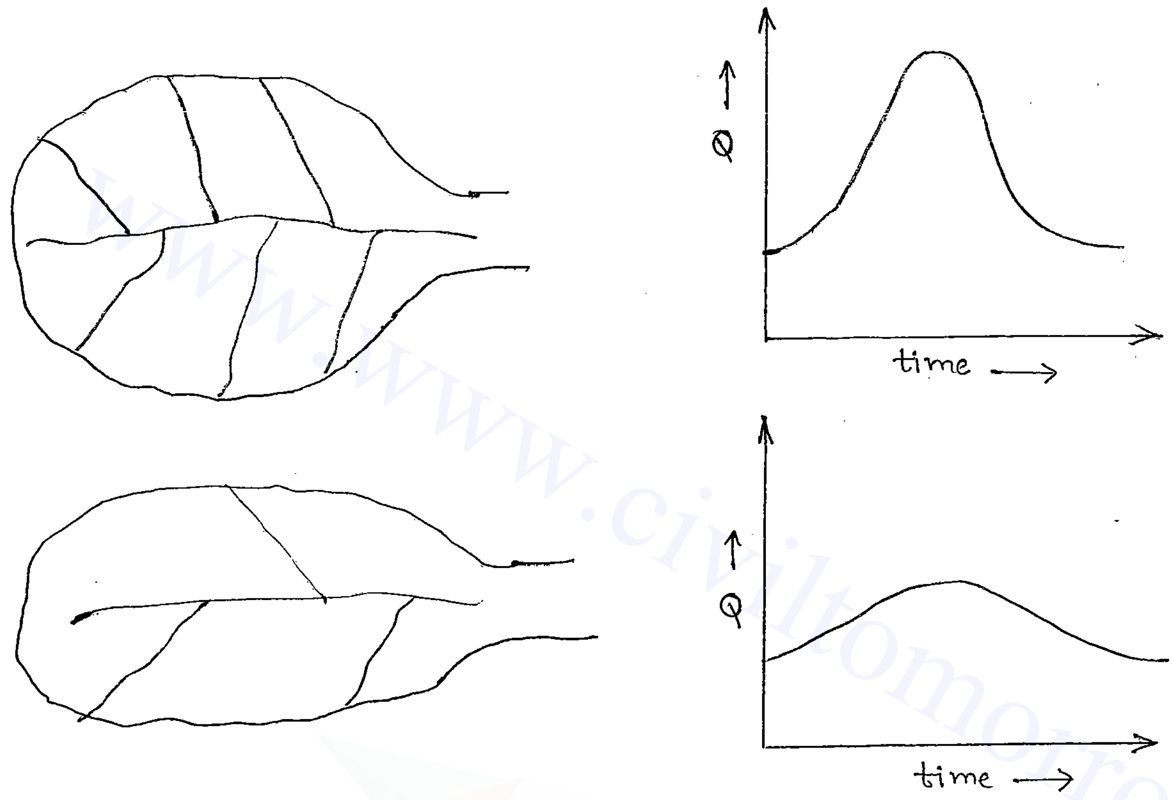
a) Steep Catchment



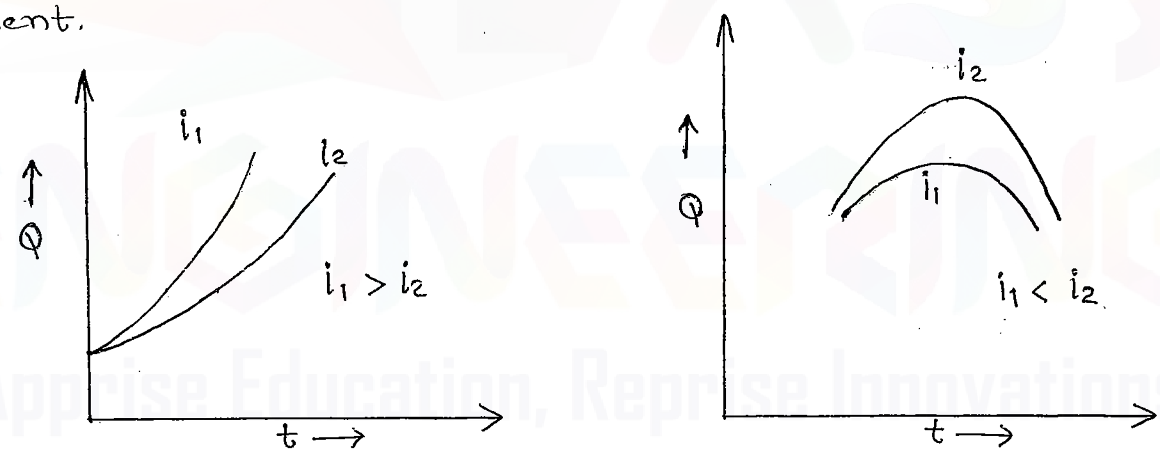
b) Flat catchment.



- Drainage density = $\frac{\text{total length of channels}}{\text{catchment area}}$

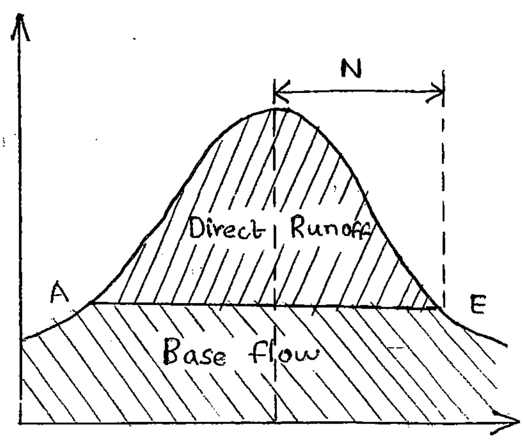


– Intensity of rain influences rising limb and crest segment.



⊙ Rising limb & crest segments are influenced by storm factors and catchment factors but recession limb is influenced by catchment factors only.

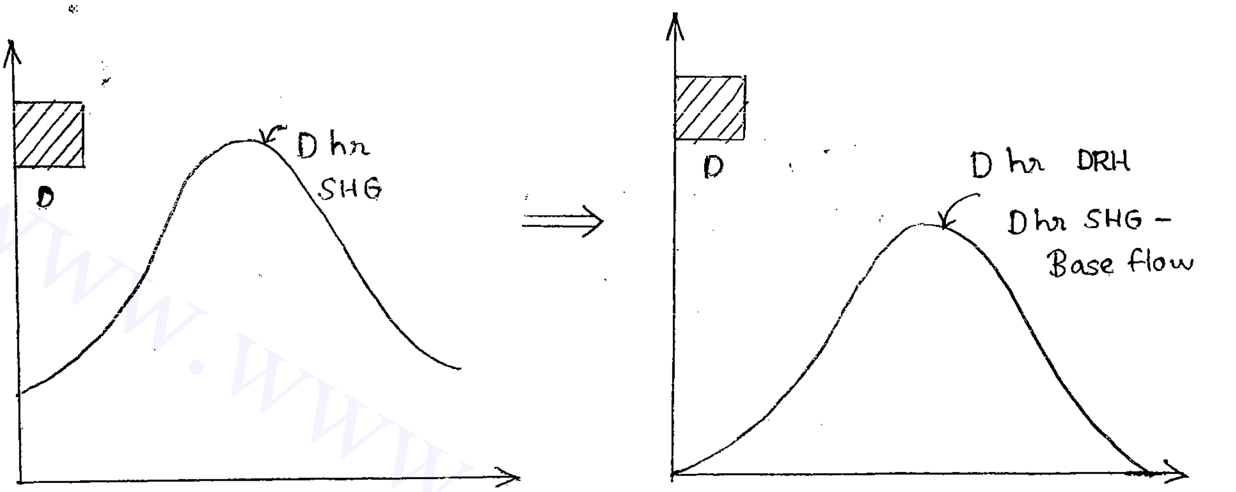
* Base flow Seperation :



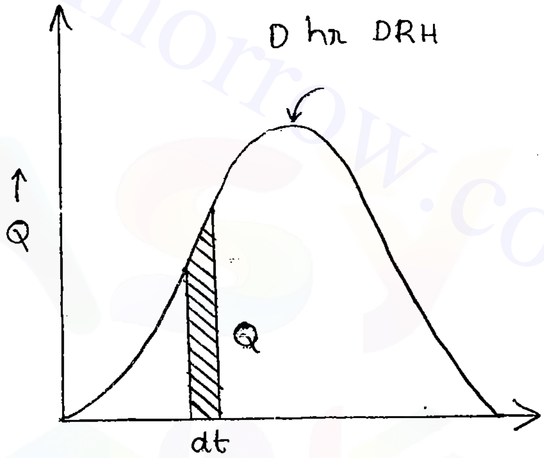
$$N = 0.83\,(A)^{0.2}$$

where,

A → catchment area (in km^2)



→ Runoff estimation using Direct Runoff Hydrograph (DRH)



D hr DRH obtained from the D hr SHG is used in finding the runoff resulting from a catchment of area 'A' km^2.

(A storm of D hr duration if it occur over a catchment area A km^2 yield D hr SHG. After subtracting base flow from D hr SHG, then D hr DRH is obtained)

– Volume of runoff drained into stream by the catchment in time interval 'dt' = Q.dt

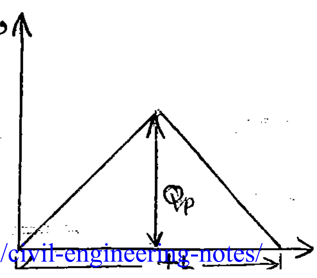
= area under D hr DRH in time period 'dt'

– **Total volume of runoff = area under D hr DRH**

$$\text{Depth of runoff} = \frac{\text{Volume of Runoff}}{\text{Catchment area.}}$$

NOTE :

1. If D hr DRH is in the form of a triangle,



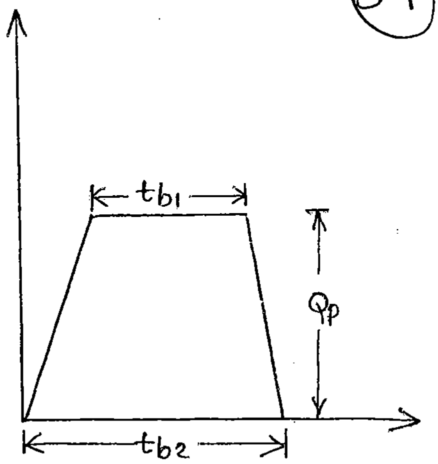
Volume of Runoff = area of DRH.

$= \frac{1}{2} * Q_P * t_b$

2. If D hr DRH is in trapezoidal form,

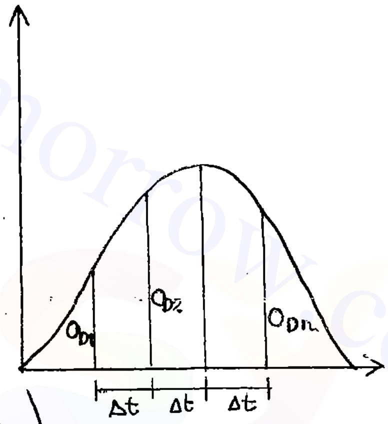
Volume of Runoff = area of D hr DRH.

$$= \left[\frac{t_{b1} + t_{b2}}{2}\right] * Q_p$$



3. If D hr DRH is non linear,

Area of non linearly shaped hydrograph can be worked out by finite integration method using Trapezoidal Rule.



Volume of Run off = area of D hr DRH

$$= \Delta t \left(\frac{1^{st}\text{ ord} + \text{last ord}}{2} + \Sigma \text{ remaining ordinates}\right)$$

$$= \Delta t \left(\frac{0+0}{2} + \Sigma \text{ Remaining ordinates}\right)$$

$$= \Delta t \left(O_{D1} + O_{D2} + O_{D3} + \dots O_{Dn}\right)$$

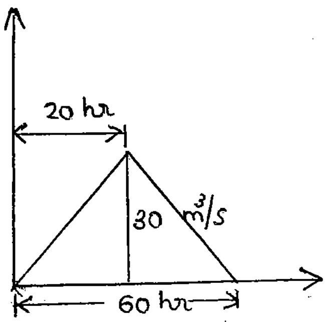
-34.

1. Catchment area = 1440 km^2.

Volume of run off $= \frac{1}{2} \times 200 \times 3600 \times 80$

Depth of run off $= \frac{0.5 \times 200 \times 3600 \times 80}{1440 \times 1000^2} = 0.02\ m = \underline{\underline{2\ cm}}$

2. Catchment area = 300 km^2.



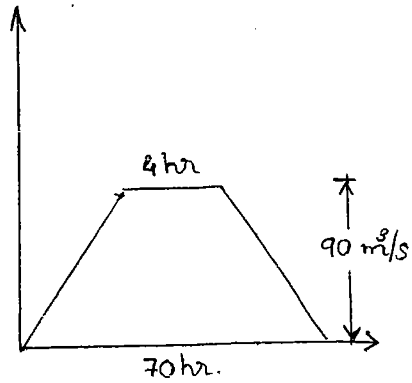
Volume of runoff $= \frac{1}{2} \times 30 \times 60 \times 60 \times 60\ m^3$

Depth of runoff $= \frac{\frac{1}{2} \times 30 \times 3600 \times 60}{300 \times 1000^2}$

$= 0.0108\ m = \underline{\underline{10.8\ mm}}$

3. Volume of runoff = area of DRH.

$$= \left(\frac{4+70}{2}\right) \times 90 \times 3600$$

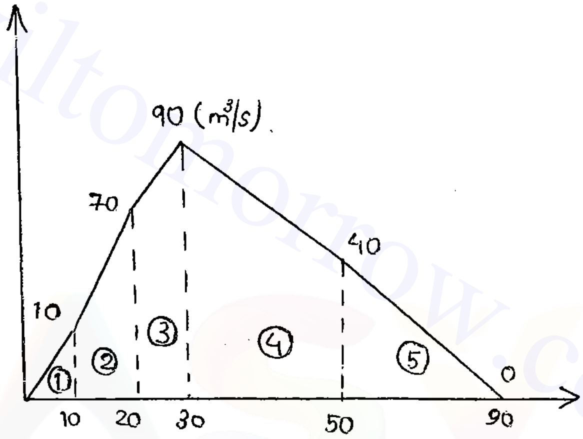


Effective rainfall = runoff

$$= 2 \text{ cm}.$$

Catchment area $= \dfrac{37 \times 90 \times 3600}{0.02 \times 10^6} = \underline{\underline{599.4 \text{ km}^2}}$

4. Area of DRH $= A_1 + A_2 + A_3 + A_4 + A_5$.



$A_1 = \frac{1}{2} \times 10 \times 10 \times 3600$

$A_2 = \left(\frac{10+70}{2}\right) 10 \times 3600$

$A_3 = \left(\frac{70+90}{2}\right) \times 10 \times 3600$

$A_4 = \left(\frac{90+40}{2}\right) \times 20 \times 3600$

$A_5 = \frac{1}{2} \times 40 \times 40 \times 3600$

Volume of runoff = area of DRH $= 12.06 \times 10^6 \text{ m}^3$.

Rainfall excess $= \dfrac{12.06 \times 10^6}{300 \times 10^6} = 0.0402 \text{ m} = \underline{\underline{4.02 \text{ cm}}}$

5. $Q_p = 10 \text{ m}^3/\text{s}$; $t_b = 20$ hr, area of catchment $= 10 \text{ km}^2$.

Volume of runoff $= \frac{1}{2} \times Q_p \times t_b$.

$$= \frac{1}{2} \times 10 \times 3600 \times 20$$

Rainfall excess $= \dfrac{\frac{1}{2} \times 10 \times 3600 \times 20}{10 \times 10^6} = 0.036 \text{ m} = \underline{\underline{3.6 \text{ cm}}}$

6.

time (hr)	0	6	12	18	24	30	36
4 hr FHG ordinates (m³/s)	6	18	30	24	12	8	6
Base flow (m³/s).	6	6	6	6	6	6	6
4 hr DRH ordinates = 4 hr FHG − base flow.	0	12	24	18	6	2	0.

Volume of runoff = area of 4 hr DRH.

$= 6 \times 60 \times 60 \,(12 + 24 + 18 + 6 + 2)$

$= 1.3392 \times 10^6 \; m^3$

Rainfall excess $= \dfrac{1.3392 \times 10^6 \times 10^2}{50 \times 10^6} = \underline{\underline{2.67 \text{ cm}}}$

2. Unit Hydrograph (UHG)

Unit Hydrograph is a direct run off hydrograph produced by a uniform storm of certain duration resulting into a runoff depth of unity (1 cm) uniformly over the entire catchment.

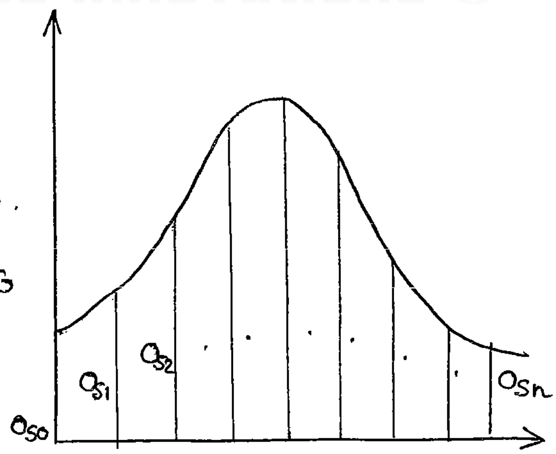
- Concept was proposed by 'Sherman' based on following two assumptions:

(i) Time invariance.

(ii) Linear Response.

→ Construction of D hr UHG from the given D hr SHG :

Let $O_{S0}, O_{S1} \ldots O_{Sn}$ be the ordinates of D hr SHG @ respective time interval. and 'B' be the base flow.



1). Construct D hr DRH from D hr SHG

D hr DRH ordinates = D hr SHG ordinates − base flow.

⇒ Ordinates of D hr DRH are :

$O_{D0} = O_{S0} - B \;,\; O_{D1} = O_{S1} - B \;, \ldots\; O_{Dn} = O_{Sn} - B.$

2) Find volume of runoff resulting from storm.

Volume of runoff = area of DRH.

$$= \Delta t \left(\frac{0+0}{2} + \Sigma \text{remain ordinates} \right).$$

3). Find depth of runoff, 'R' produced by the storm.

$$R = \frac{\text{Volume of Runoff}}{\text{Catchment area}}$$

4). Construct D hr UHG by dividing the ordinates of D hr DRH by 'R'.

$$\boxed{\text{D hr UHG ordinates} = \frac{\text{D hr DRH ordinates}}{R}}$$

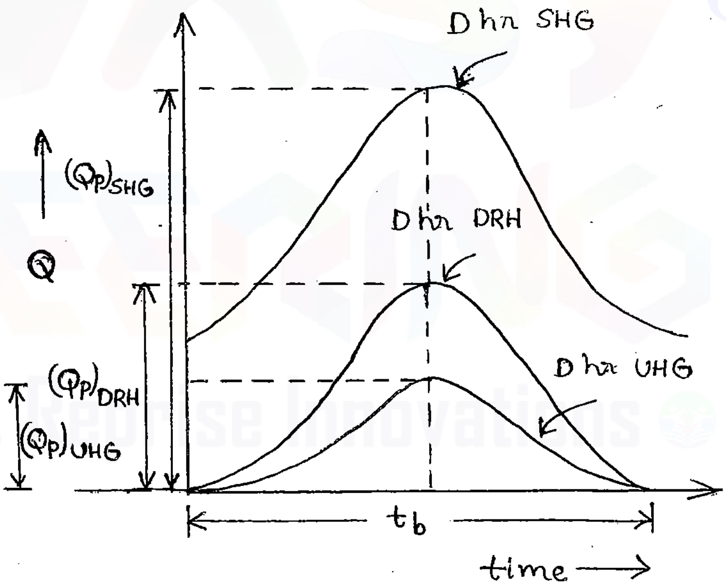
⇒ Ordinates of D hr UHG:

$$O_{U0} = \frac{O_{D0}}{R}$$

$$O_{U1} = \frac{O_{D1}}{R}$$

⋮

$$O_{Un} = \frac{O_{Dn}}{R}$$



7 Volume of runoff = area of UHG

$$= 0.5 \times 300 \times 48 \times 3600$$

$$\text{Catchment area} = \frac{0.5 \times 300 \times 48 \times 3600}{10^{-2} \times 10^{6}} = \underline{\underline{2592}} \ km^2$$

08. t_b = 20 hr., Area of watershed = $500 \times 10^4 \ m^2$.

$$\frac{1}{2} \times 20 \times Q_p = 500 \times 10^4 \times 10^{-2} \Rightarrow Q_p = \underline{\underline{5000}} \ m^3/h$$

9. $Q_p = 100\ m^3/s$, $t_b = 72\ h$

Area of catchment $= \dfrac{\frac{1}{2} \times 100 \times 3600 \times 72}{10^{-2} \times 10^6} = \underline{\underline{1296}}\ km^2$

10. For 2 hr UHG, $t_b = 40$ hr, $Q_p = 10\ m^3/s$

Area of catchment $= \dfrac{0.5 \times 40 \times 10 \times 3600}{10^{-2} \times 10^6} = 72\ km^2$

For 6 hr UHG, $t_b = 44$ hr, Area $= 72 \times 10^6\ m^2$.

$\frac{1}{2} \times Q_p \times 44 = 72 \times 10^6 \times 10^{-2}$

$\Rightarrow Q_p = \underline{\underline{9.09}}\ m^3/s$

11. For 1st catchment area,

$A = 235\ km^2$

$Q_p = 30\ m^3/s$

$\frac{1}{2} \times t_b \times 30 \times 3600 = 235 \times 10^6 \times 10^{-2}$

$t_b = \underline{\underline{43.52}}$ hour

For 2nd catchment area,

$Q_p = 90\ m^3/s$

$t_b = 43.52$ hour.

Area of catchment $= \dfrac{\frac{1}{2} \times 90 \times 3600 \times 43.52}{10^{-2} \times 10^6} = \underline{\underline{705}}\ km^2$

12.

Time (hr)	0	12	24	36	48	60	72	84	96
Ordinates of SHG (m^3/s)	10	87.5	102.5	71	47.5	31	21	15	12,
Base flow (m^3/s)	10	10	10	11	11.5	11.5	12	12	12,
Ordinates of DRH	0	77.5	92.5	60	36	19.5	9	3	0.
Ordinates of UHG $= O_{DR}/3.034$	0	25.51	30.44	19.7	11.85	6.42	2.96	0.99	0

(DRH) = 3.03 cm

$$\text{Runoff} = \frac{12 \times 3600\,(77.5 + 92.5 + 60 + 36 + 19.5 + 9 + 3 + 0)}{423 \times 10^6}$$

$$= 3.04 \text{ cm} = 0.0304 \text{ m}.$$

(i) Peak ordinate of 6 hr unit hydrograph $= \frac{92.5}{3.04} = \underline{\underline{30.5 \text{ m}^3/\text{s}}}$

$\frac{92}{?} \times 423000000 = \frac{1}{2} \times 96 \times Q_p$

(ii) Duration of storm = 6 hour.

Uniform storm $\Rightarrow t = t_e = 6$ hr.

$i = 1.5$ cm/hr.

ϕ index $= 0.4$ cm/hr.

$P = P_e = i \times t = 1.5 \times 6 = \underline{\underline{9 \text{ cm}}}$

$\phi \text{ index} = \frac{P_e - R}{t_e} \Rightarrow 0.4 = \frac{9 - R}{6}$

$\therefore R = 6.6.$

Peak ordinate 6 hr UHG $= 30.5 \text{ m}^3/\text{s}$

Peak ordinate of 6 hr DRH = Peak ordinate of 6 hr UHG $\times$ R.
(R = 6.6 cm)

$= 30.5 \times 6.6 = \underline{\underline{201.3}} \text{ m}^3/\text{s}$

13.

Time (hr)	0	1	2	3	4	5	6
UHG ordinates	0	5	15	12	10	6	0.

$P = P_e = 4.2$ cm; $t_e = 2$ hour, ϕ index $= 0.8$ cm/hr.

$$\phi \text{ index} = \frac{4.2 - R}{t_e}$$

$$0.8 = \frac{4.2 - R}{2} \Rightarrow R = \underline{\underline{2.6}} \text{ cm}$$

Peak discharge of 2 hr UHG = $15 \text{ m}^3/\text{s}$

Peak discharge of 2 hr DRH (R = 2.6 cm) $= 15 \times 2.6 = \underline{\underline{39}} \text{ m}^3/\text{s}$

Max flood discharge = Peak 2 hr DRH + base flow $= 39 + 7 = \underline{\underline{46}} \text{ m}^3/\text{s}$

14. 6 hr UHG ordinates 0 15 36 30 17.5 8.5 30.

$0.06 = \frac{P-4}{6}$

Peak 6 hr UHG ordinate $= 36\ m^3/s$

Peak 6 hr SHG ordinate $= 150\ m^3/s$

Peak 6 hr DRH ordinate $= 150 -$ Base flow

$= 150 - 6 = \underline{144\ m^3/s}$

$$\text{Run off, } R = \frac{\text{Peak 6 hr DRH}}{\text{Peak 6 hr UHG}} = \frac{144}{36} = \underline{4\ cm}$$

$$\phi \text{ index} = \frac{P-R}{te.}$$

$$0.6 = \frac{P-4}{6}$$

$\Rightarrow$ Depth of storm rainfall, $P = \underline{7.6}$ cm

Stream flow at 15^{th} hour $= (O_{SHG})_5 = (O_{UHG})_5 * \text{runoff} + \text{baseflow}.$

$= 8.5 \times 4 + 6 = \underline{40\ m^3/s}$

15. 3 hour duration storm:

$P = 2.7$ cm, ϕ index $= 0.3$ cm/hr.

$$\phi \text{ index} = \frac{P-R}{t.}$$

$$0.3 = \frac{2.7-R}{3.}$$

$R = \underline{1.8}$ cm

$$\text{Peak of 3 hr unit HG} = \frac{\text{Peak FHG} - \text{baseflow}}{\text{Run off}}$$

$$= \frac{210-20}{1.8} = \underline{105.55\ m^3/s}$$

16. Peak flood HG = 470 m^3/s

Base flow = 15 m^3/s.

$$\phi \text{ index} = \frac{P-R}{t}$$

$$0.25 = \frac{8-R}{6} \Rightarrow R = 6.5 \text{ cm}$$

$$\text{Peak UHG ordinate} = \frac{470-15}{6.5} = 70 \text{ m}^3/s$$

17. For 4 hr UHG,

$t_b = 80$ hours, Area of catchment = 720 km^2

$$\frac{1}{2} \times Q_p \times t_b = \text{Area of catchment} \times 10^{-2}.$$

$$\frac{1}{2} \times Q_p \times 3600 \times 80 = 720 \times 10^6 \times 10^{-2}$$

$$Q_p = 50 \text{ m}^3/s$$

18.

$$\phi \text{ index} = \frac{P-R}{t}$$

$$0.1 = \frac{4-R}{4} \Rightarrow R = 3.6 \text{ cm.}$$

∴ Peak flood discharge = Peak UHG discharge × runoff + baseflow.

$$= 50 \times 3.6 + 30 = 210 \text{ m}^3/s$$

19. For 1 hr UHG,

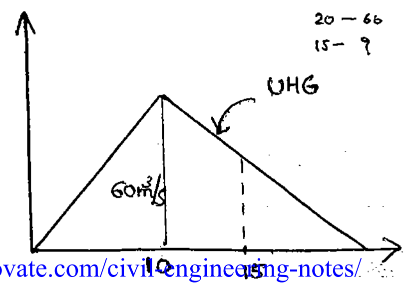
$Q_p = 60$ m^3/s, $t_b = 30$ hours.

$$\text{Area of catchment} = \frac{\frac{1}{2} \times 60 \times 3600 \times 30}{10^{-2} \times 10^6} = 324 \text{ km}^2$$

20. 15th hour UHG ordinate :

$$\frac{30-10}{30-15} = \frac{60}{x}$$

$$x = 45 \text{ m}^3/s$$



$$\phi \text{ index} = \frac{P-R}{t}$$

$$0.4 = \frac{5.4-R}{1} \Rightarrow R = 5 \text{ cm}$$

Ordinate of FHG at 15^{th} hour = Ordinate of UHG at 15^{th} hour * runoff + baseflow.

$$= 45 \times 5 + 15 = 240 \text{ m}^3/s$$

21. Area of watershed = 50 km^2 ; ϕ-index = 0.5 cm/hr

Baseflow = 10 m^3/s ; t_b = 15 hours, Depth of rainfall = 5.5 cm

$$\frac{1}{2} \times Q_p \times t_b = \text{Area of catchment} * 10^{-2}$$

$$\frac{1}{2} \times Q_p \times 3600 \times 15 = 50 \times 10^6 \times 10^{-2}$$

$$Q_p = 18.52 \text{ m}^3/s$$

22. $$\phi \text{ index} = \frac{P-R}{t}$$

$$0.5 = \frac{5.5-R}{1} \Rightarrow R = 5 \text{ cm.}$$

Peak ordinate of FHG = Q_p * run off + baseflow.

$$= 18.52 * 5 + 10 = 102.6 \text{ m}^3/s$$

23. Area = 252 km^2 ; t_b = 35 h.

$$\frac{1}{2} Q_p t_b = \text{area} * 10^{-2}$$

$$\frac{1}{2} \times Q_p \times 3600 \times 35 = 252 \times 10^6 \times 10^{-2}$$

$$\Rightarrow Q_p = 40 \text{ m}^3/s.$$

Effective rainfall = run off = 5 cm.

Peak discharge of DRH (run off = 5 cm) = 40 × 5 = 200 cumecs.

th dec,
MONDAY

→ Hydrograph Analysis of Complex T-hr Storms:

To find complex T hr storm information from the given D hr UHG of a simple storm, the following methods are used:-

- For uniform storms;
  - (i) Method of Superposition.
  - (ii) S-Curve method (Summation Curve method)
- For non-uniform storms;
  - (i) Convolution.
  - (ii) Deconvolution

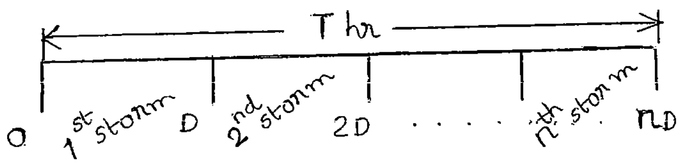
* Method of Superposition

This method is applicable for uniform storms if it satisfies the following conditions:-

- T > D (to find T hr UHG from D hr UHG)
- T = nD (where n = 2, 3, 4...)

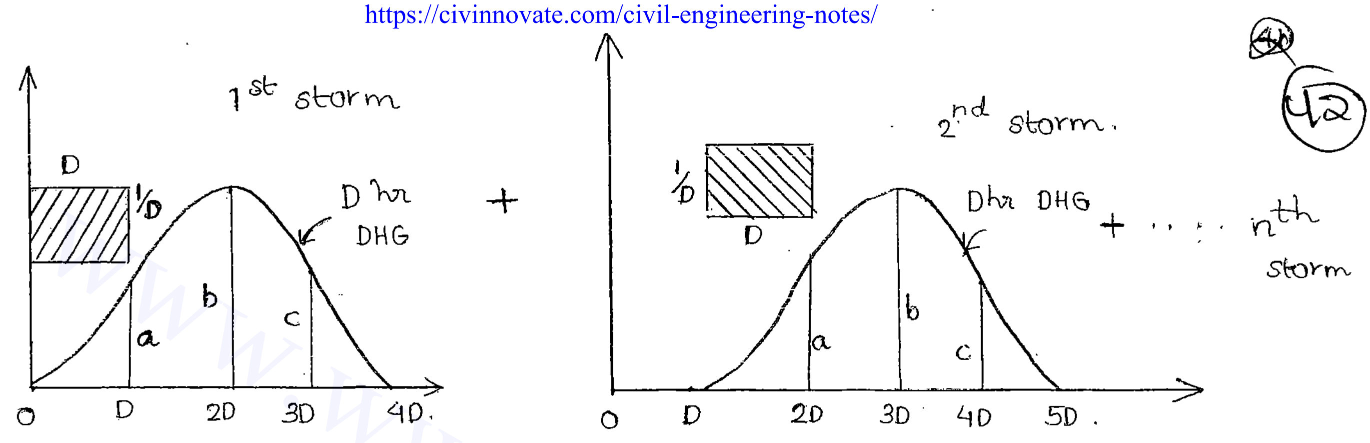
Procedure:-

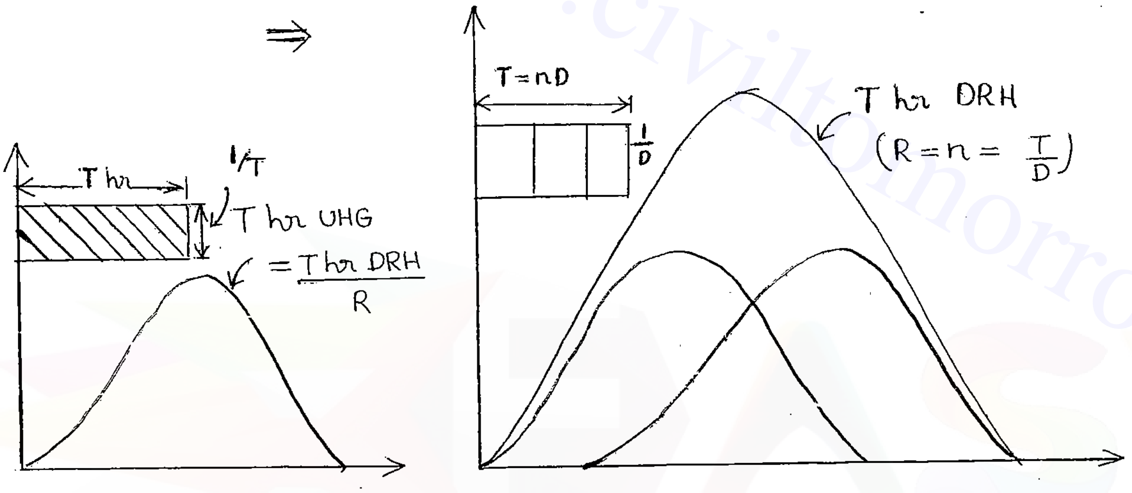
Step 1: Split the T hr storm into n number of D hr storms.



assuming that each D hr storm occur in succession (one after the other)

Step 2: Superimpose D hr unit hydrographs one above the other each with a time delay of D hr duration.





Step 3: The combined resulting hydrograph represents T hr Direct runoff hydrograph resulting into a run off depth of n cm, where $\boxed{R = n = \frac{T}{D}}$

Step 4: Find the T hr unit hydrographs by dividing the T hr DHG ordinates by R.

time	1st storm D hr DHG ordin	2nd storm (D hr lagged) D hr DHG ord.	3rd storm (2D hr lagged) D hr DHG ord.	T hr DRH ord. (= 1st + 2nd + 3rd)	T hr UHG ord = T hr DRH ord / R
0	0	–	–	0	
D	a	0	–	a	
2D	b	a	0	a+b	
3D	c	b	a	a+b+c	
4D	0	c	b	b+c	
5D	–	0	c	c	
6D	–	–	0	0	

-36.

24.

Time	1st storm 2hr UHG ord (m³/s)	2nd storm. 2hr delayed 2hr UHG ord (m³/s)	4 hr DRH ord. (1st + 2nd)	4hr UHG ord = 4hr DRH / R, R'=n = 2 cm.
0	0	—	0	0
1	20	—	20	10.
2	60	0	60	30
3	80	20	100	50
4	50	60	110	55
5	20	80	100	50
6	0	50	50	25
7	—	20	20	10
8	—	0	0	0

Uniform Storm : 2hr UHG ⟶ 4 hr UHG.

D = 2hr & T = 4 hr.

$n = \frac{T}{D} = \frac{4}{2} = 2$ cm.

T > D, T = nD } conditions satisfied.

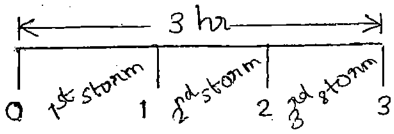
Max discharge of 4 hr UHG = Peak ordinate of 4 hr UHG
= 55 m³/s

27 1 hr UHG (D = 1 hr)

1 hr UHG → 3 hr UHG (uniform storm)

D = 1 , T = 3

n = 3



Time	1st storm. 1 hr UHG	2nd storm. 1hr delayed	3rd storm 2 hr delayed.	3 hr DRH. ordinates (R=n=3 cm)
0	0	—	—	0
1	2	0	—	2
2	6	2	0	8
3	4	6	2	12
4	2	4	6	12
5	1	2	4	7
6	0	1	2	3
7	—	0	1	1
8	—	—	0	0

$$\text{Catchment area} = \frac{1 \times 60 \times 60\,(2+6+4+2+1)}{1/100 \times 1000^2}$$

$$= \underline{\underline{5.4\ km^2}}$$

3^{rd} hour ordinate of 3 hour UHG $= \frac{12}{3} = \underline{\underline{04}}\ m^3/s$

31.

Time	1st storm 2hr UHG.	2nd storm (2hr delayed).	4 hr DRH (R = 2 cm).	4hr UHG. (4 hr DRH/2).
0	0	—	0	0
2	12	0	12	6
4	54	12	66	33
6	126	54	180	90
8	112	126	238	119
10	94	112	206	103
12	64	94	158	79
14	36	64	100	50
16	14	36	50	25
18	0	14	14	07
20	—	0	0	0

Peak ordinate of 4 hr UHG = $\underline{\underline{119\ m^3/s}}$

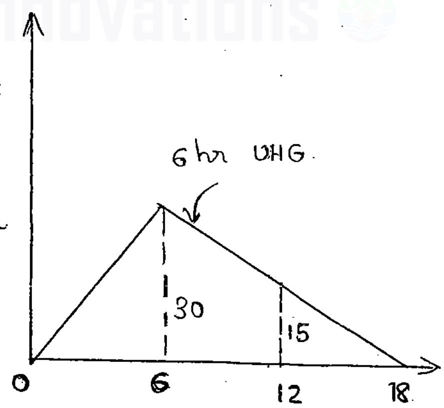
25. Uniform storm:

$P = P_e = 16$ cm.

$t = t_e = 12$ hour

ϕ index $= 0.5$ cm/hr.

$D = 6$ hour
$T = 12$ hour
$n = \frac{T}{D} = 2$
} conditions satisfied for superposition



$$\phi \text{ index} = \frac{P_e - R}{t_e}$$

$$0.5 = \frac{16 - R}{12}$$

$\therefore\ R = 10$ cm.

12 hr DRH ordinates = 12 hr UHG $\times 10$.

Time	1st storm 6hr UHG	2nd storm 6hr delayed	12 hr DRH (R = n = 2 cm)	12 hr UHG = (12 hr DRH / 2)	12 hr DRH (R = 10 cm)
0	0	–	0	0	0
6	30	0	30	15	150
12	15	30	45	22.5	225
18	0	15	15	7.5	75
24	–	0	0	0	0.

Peak discharge of resulting DRH = Peak ordinate of 12 hr DRH.
= 225 m^3/s.

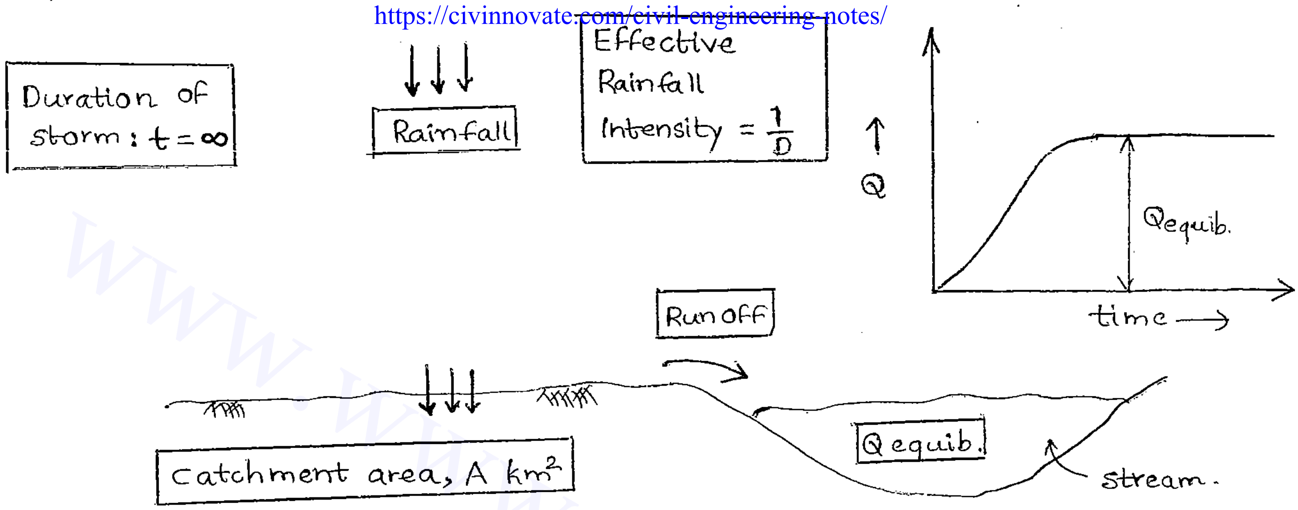
26. Area of catchment $= \frac{0.5 \times 30 \times 3600 \times 18}{10^{-2} \times 10^4} = 9720$ ha

$= \frac{0.5 \times 22.5 \times 3600 \times 24}{10^{-2} \times 10^4} = 9720$ ha

* Summation Curve Method (S-Curve method)

This method is applied for uniform storms. There is no precondition to apply this method. ie, this method is applicable for conditions $T < D$ or $T > D$ and $T = nD$ or $T \neq nD$.

A storm of effective rainfall intensity $\frac{1}{D}$ cm/hr if it occur over a catchment of area A km^2 for ~~a per~~ infinite duration, after meeting the initial losses catchment drain constant amount of runoff into stream. Then stream attain equilibrium discharge (const. discharge). For such storm if stream flow variation is measured at a point on a stream, the hydrograph resulting is known as S-curve hydrograph or simply S-curve.



in every D hour

- Volume of runoff delivered by catchment into stream

= catchment area * depth of runoff.

= A * 1.

- Discharge delivered into stream = $\frac{A \times 1}{D}$

$$Q_{equil} = \frac{A \times 1}{D} \quad \left(\frac{km^2 . cm}{hr}\right)$$

$$= A * (1000)^2 * \frac{1}{100} * \frac{1}{D*60*60}$$

$$\Rightarrow \boxed{\underset{(m^3/s)}{Q_{equi}} = \frac{2.778\,A}{D}}$$

where A → area of catchment (in km²).

D → duration of UHG (in hour)

29. $A = 270\ km^2$, $D = 3\ hr$

$$Q_{equi} = \frac{2.778 \times 270}{3} = \underline{\underline{250}}\ m^3/s$$

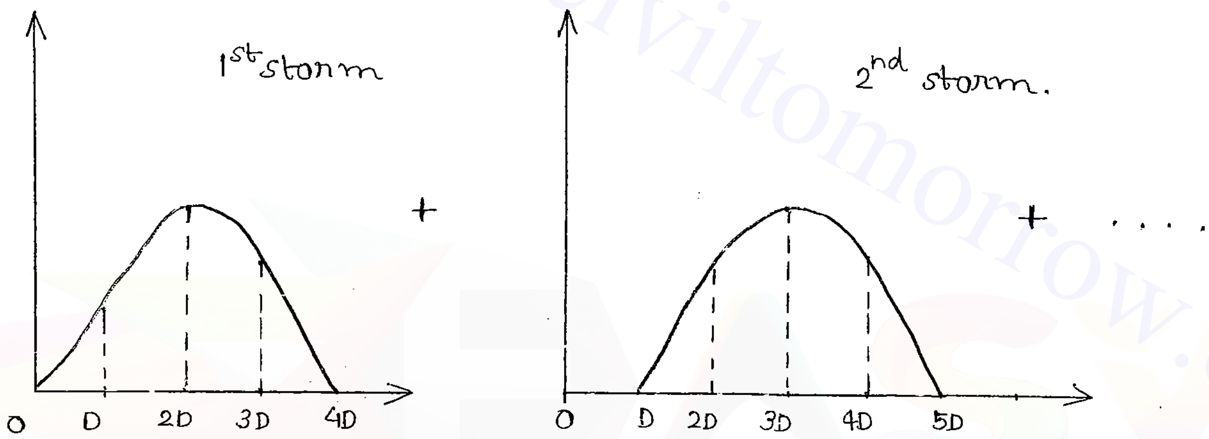
30. Area of catchment, $A = \frac{0.5 \times 30 \times 3600 \times 64}{10^{-2} \times 10^6} = 345.6\ km^2$.

$$Q_{equil} = \frac{2.778 \times 345.6}{6} = \underline{\underline{160}}\ m^3/s$$

– Procedure for construction of S curve :

Step 1 : Split infinite duration storm into infinite no. of D hr storms assuming that they occur in succession each with a time delay of D hours.

Step 2 : Superimpose D hr UHG one above the other till eqbm. discharge is obtained and find the ordinates of S curve.



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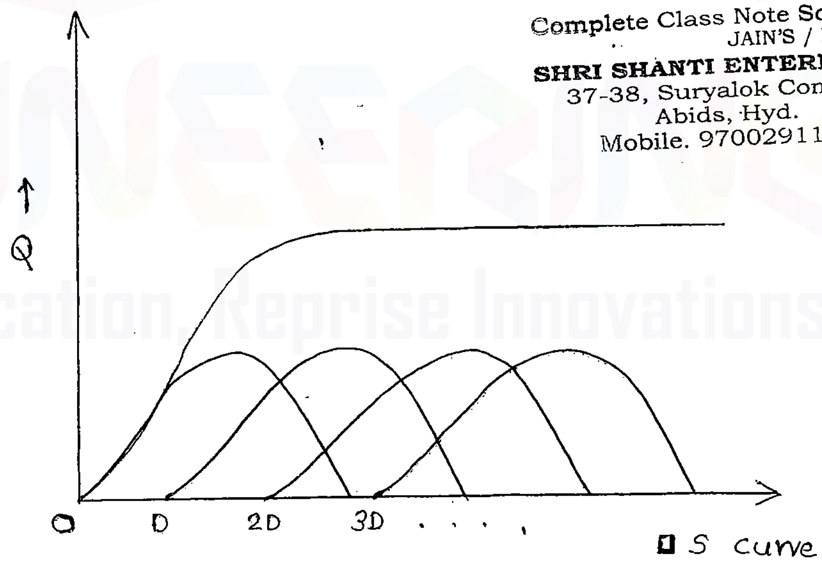

time	1st storm D hr UHG	Delayed D hr UHG Ord. 1D	2D	3D	4D.	S curve ordinate
0	0	–	–	–	–	0
D	a	a	–	–	–	a
2D	b	a	0	–	–	a+b
3D	c	b	a	0	–	a+b+c
4D	0	c	b	a	0	a+b+c
5D	–	0	c	b	a	a+b+c
6D	–		0	c	b	

time	Dhr UHG (m^3/s)	S-curve additions (m^3/s)	S-curve ordinates (m^3/s)
0	0		0
D	a	0	a
2D	b	a	a+b
3D	c	a+b	a+b+c
4D	0	a+b+c	a+b+c

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32.

time	4 hr UHG ordinates (m^3/s)	S curve additions	S curve ordinates
0	0		0
2	6		6
4	33	0	33
6	90	6	96
8	119	33	152
10	103	96	199
12	79	152	231
14	50	199	249
16	25	231	256
18	7	249	256
20	0	256	256
	0	256	256

$$\text{Area} = \frac{2 \times 60 \times 60\,(6+33+90+119+103+79+50+25+7)}{1/100 \times (1000)^2} = \underline{\underline{368.64\ km^2}}$$

$$Q_{equi} = 2.778\frac{A}{D} = \frac{2.778 \times 368.64}{4} = \underline{\underline{256\ m^3/s}}$$

45

Q. Construct S curve from 3 hr UHG having ordinates at one hour time intervals starting t=0 are 0, 2/3, 8/3, 4, 4, 7/3, 1, 1/3, 0.

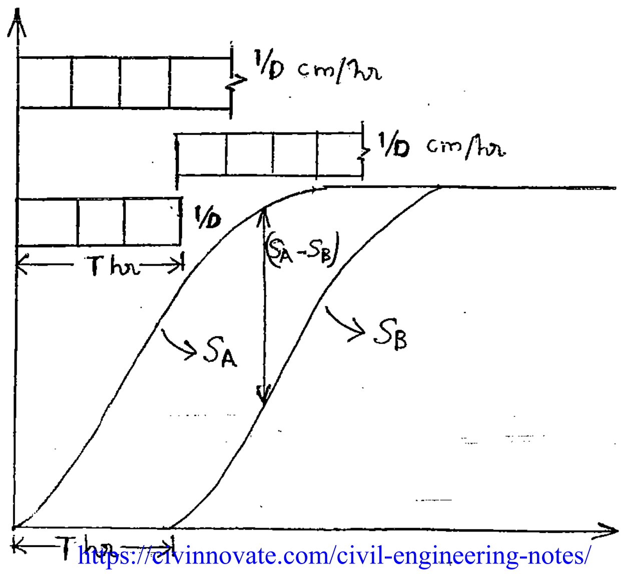
time	3 hr UHG ordinates.	S curve addition	S curve ordinates.
0	0		0
1	2/3		2/3
2	8/3		8/3.
3	4	0	4
4	4	2/3	14/3
5	7/3	8/3.	5
6	1	4	5
7	1/3	14/3	5
8.	0.	5.	5.

– Construction of T hr UHG using S curve :-

Step 1 : Construct S curve from the given D-hr UHG. Let it be 'S_A'

Step 2: Construct one more S curve with time delay of T hours. Let it be 'S_B'.

Step 3 : Find difference in ordinates of two S curve, ie, $S_A - S_B$.



T hr DRH ord $= S_A - S_B$.

$(R = \frac{T}{D}$ cm)

T hr UHG ord $= \frac{S_A - S_B}{R}$

$= \frac{S_A - S_B}{T/D} = \frac{(S_A - S_B)D}{T}$

7th Dec,
TUESDAY

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time	1hr UHG	S-curve ordinates. (S_A)	S-curve delayed by 3hr (S_B)	3hr DRH ($S_A - S_B$)	3hr UHG $\{(S_A - S_B)\,1/3\}$
0	0	0	—	0	0
1	5	5	—	5	5/3
2	8	13	—	13	13/3
3	5	18	0	18	18/3
4	3	21	5	16	16/3
5	1	22	13	9	3
6.	0	22	18	4	4/3
7	0	22	21	1	1/3
8	0	22	22	0	0

Watershed area $= \dfrac{\frac{1}{2}\times 60\times 60\times(8+5+5+3+1)}{10^{-2}\times 10^{6}} = \underline{7.92}$ km

34. Catchment area $= \dfrac{1\times 3600\times(3+8+6+3+2)}{10^{-2}\times 10^{4}} = 7.92\ km^2$.

35.

time	2hr UHG.	S curve additions	S curve ordinates (S_A).	S curve delayed by 3 hours	3 Hr DRH. ($S_A - S_B$).	3hr UHG $(S_A - S_B)\frac{2}{3}$
0	0		0	—	0	0
1	3		3	—	3	2
2	8	0	8	—	8	5.33
3	6	3	9	0	9	6
4	3	8	11	3	8	5.33
5	2	9	11	8	3	2
6	0	11	11	9	2	1.33.
7.	0	11	11	11.	0.	0.

ϕ-index $= \dfrac{P-R}{t}$; Baseflow $= 5\ m^3/s$

$0.2 = \dfrac{6.6-R}{3} \Rightarrow R = 6$ cm.

Peak flow due to storm = 3 hr UHG peak ordinate * runoff + baseflow.

$= 6\times 6 + 5$

$= \underline{41}\ m^3/s$

36. S curve ordinates due to rainfall of intensity 1 cm/hr is : (45) (46)

$$Q = 1 - (1+t)\, e^{-t}$$

time	S-curve ordinates (S_A)	S-curve delayed by 2 hr (S_B)	2 hr DRH $(S_A - S_B)$	2 hr UHG $(S_A - S_B) \times \frac{1}{2}$
0	0	—	0	0
1	0.264	—	0.264	0.132
2	0.594	0	0.594	0.297
3	0.8008	0.264	0.537	0.2685
4	0.908	0.594	0.314	0.157
5	0.959	0.8008	0.1582	0.079
6	0.983	0.908	0.075	0.037
7	0.993	0.959	0.034	0.017
8	0.997	0.983	0.014	0.007

From given S-curve ordinates,

$ERI = \frac{1}{D}$ cm/hr = 1 cm/hr

$\Rightarrow D = 1$ hr

$$Q_{equib} = 0.999 \sim 1 \ m^3/s.$$

$$Q_{equib} = 2.778 \frac{A}{D}$$

$\therefore$ Area of catchment $= \frac{1 \times 1}{2.778} = \underline{\underline{0.36 \ km^2}}$

37. Ordinate of 2 hr UHG at 3rd hour = 0.2685 m³/s ≈ $\underline{\underline{0.27 \ m^3/s}}$

(OR)

At time $t = \infty$, $Q = Q_{equi}$.

$$Q = Q_{equi} = 1 - (1+t)\, e^{-t}$$

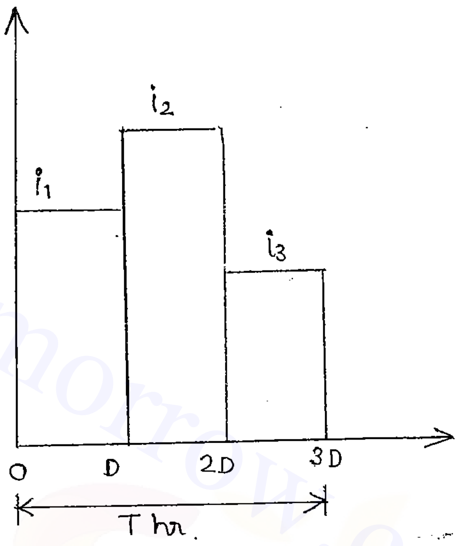
$$= 1 - (1+\infty)\, e^{-\infty} = \underline{\underline{1 \ m^3/s}}$$

* Convolution

This method is used to find T hr complex storm information using D hr UHG (D-hr storm) for non-uniform storm. This method is used if it satisfies the following:

(i) T > D

(ii) T = nD ; n = 2, 3, 4, ...



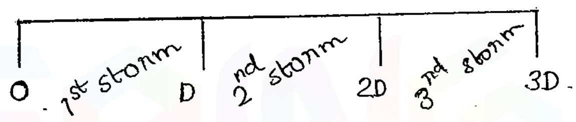
Procedure :-

(i) Split the T hr storm into n number of D hr storms.

(ii) Find run off resulting from each of the T hr storm by using ϕ index.

(iii) Find DRH for each D hr storm seperately

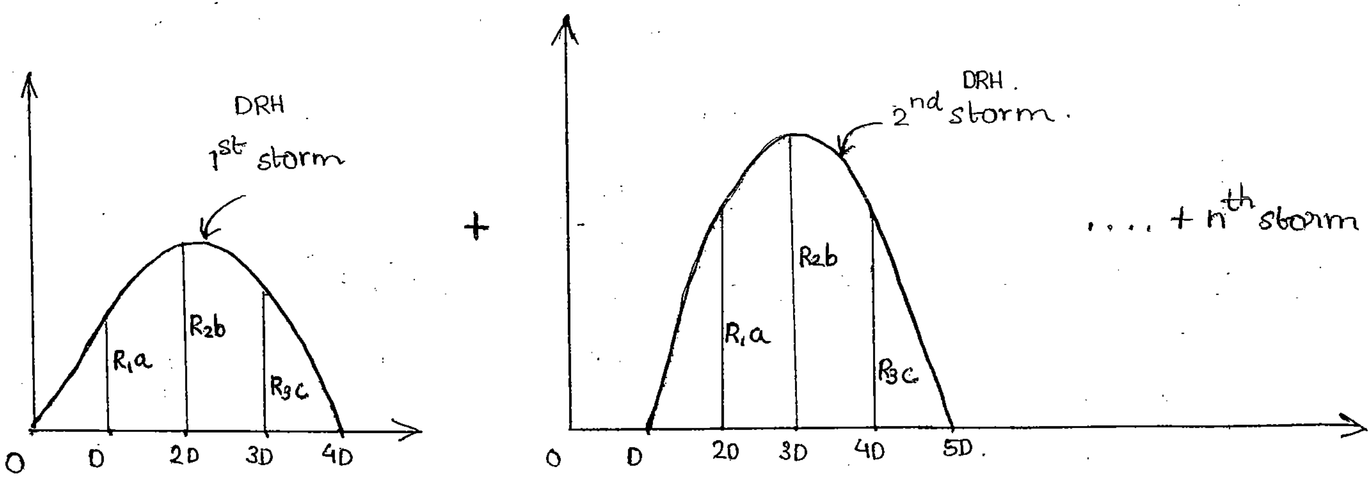
(DRH ordinates = UHG ordinates * R)



$P_1 = P_{e1}$	$P_2 = P_{e2}$	$P_3 = P_{e3}$
$t_1 = t_{e1}$	$t_2 = t_{e2}$	$t_3 = t_{e3}$
R_1	R_2	R_3

(using ϕ index)

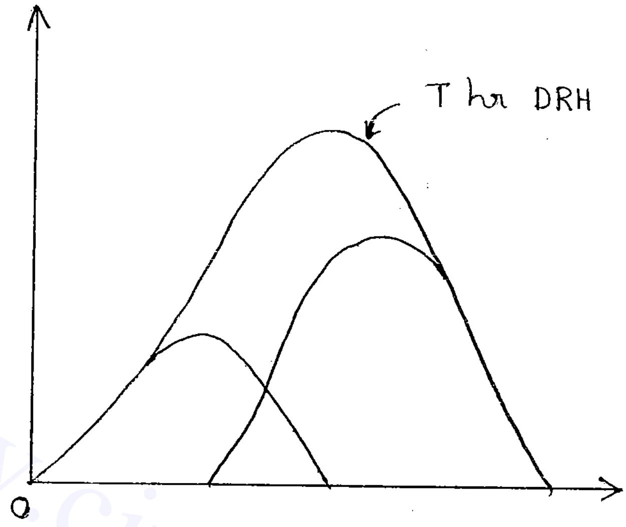
(iv) Superimpose D hr DRH one above the other, each with a time delay of D hours.



(v) The combined resulting direct run off hydrographs for multiple storms represent T hr DRH.

(vi) Find T hr SHG by adding baseflow to T hr DRH.

⇒



time	D hr UHG ord.	1^{st} storm D hr DRH ord = D hr UHG * R_1	2^{nd} storm D hr delayed D hr DRH ord = D hr UHG * R_2	T hr DRH ord. = 1^{st} + 2^{nd}	Baseflow	T hr SHG = T hr DRH + baseflow
0	0	0	—	0		
D	a	$R_1 a$	0	$R_1 a$.		
2D	b	$R_1 b$	$R_2 a$	$R_1 b + R_2 a$.		
3D	c	$R_1 c$	$R_2 b$	$R_2 b + R_1 c$		
4D	0	0.	$R_2 c$.	$R_2 c$		
5D	—	—	0	0.		

38 $P_{e1} = 3.8$ cm.

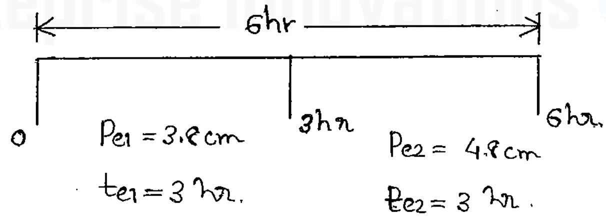
$\phi = \frac{3.8 - R_1}{3}$

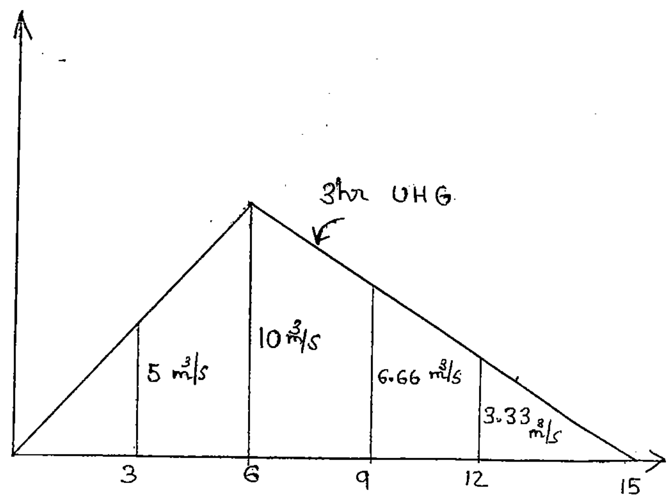
$\Rightarrow R_1 = 2$ cm.

$P_{e2} = 4.8$ cm.

$\phi = \frac{4.8 - R_2}{3}$.

$\Rightarrow R_2 = 3$ cm.





time	3hr UHG	1st storm (3hr UHG×2)	2nd storm 3 hr delayed (3hr UHG×3)	6hr DRH
			—	0
0	0	0	0	10
3	5	10	15	35
6	10	20	30	43.33
9	6.66	13.33	20.	26.667
12	3.33	6.667	10	10.
15	0.	0.	0.	0
18	0	0		

∴ Peak discharge of 6hr DRH = $43.33\ m^3/s$

39.

Time	6h UHG	1st storm (6h UHG * 1.5)	2nd storm 6hr delayed (6h UHG * 3.5)	12 hr DRH	12hr SHG (12 hr DRH + 10)
			—		10
0	0	0	0	0	40
6	20	30	70	30	170.
12	60	90	210	160	445
18	150	225	525.	435	715
24.	120.	180		705.	

Given baseflow = $10\ m^3/s$

12 hr SHG = 12hr DRH + baseflow.

Resulting discharge at 24th hour = $715\ m^3/s$

$\phi = \frac{3 - R_1}{6}$

$\Rightarrow R_1 = 3 - 6 \times 0.25$

$= 1.5$ cm

$\phi = \frac{5 - R_2}{6}$

$\Rightarrow R_2 = 5 - 6 \times 0.25$

$= 3.5$ cm

40. $t_b = \overset{72}{\cancel{24}}$ hours, $Q_p = 100\ m^3/s$

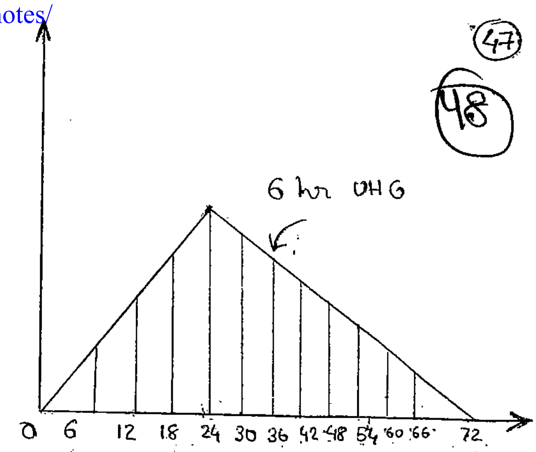
Area of catchment $= \frac{\frac{1}{2} \times 72 \times 100 \times 3600}{10^{-2} \times 10^6} = 1296\ km^2$

$R_1 = 2\text{ cm}$ & $R_2 = 4\text{ cm}$.

Base flow = $25\ m^3/s$

Ordinates of 6 hr UHG from t=0 to t=72 with 6 hr interval are:

0, 25, 50, 75, 100, 87.5, 75, 62.5, 50, 37.5, 25, 12.5, 0.



Time	6 hr UHG	1st storm. (6 hr UHG * 2)	2nd storm. (6 hr UHG * 4)	12 hr DRH	12 hr SHG
0	0	0	—	0	25
6	25	50	0	50	75
12	50	100	100	200	225
18	75	150	200	350	375
24	100	200	300	500	525
30	87.5	175	400	575	600
36	75	150	350	500	525
42	62.5	125	300	425	450
48	50	100	250	350	375
54	37.5	75	200	275	300
60	25	50	150	200	225
66	12.5	25	100	125	150
72	0	0	50	50	75

* Deconvolution

This method is used to find D hr unit hydrograph from the given T-hr DRH of a non-uniform storm.

Procedure :-

(i) Assume D hr UHG ordinates as 0, a, b, . . . 0.

(ii) Apply method convolution in terms of assumed ordinates and obtain T hr DRH ordinates

(iii) Equate T hr DRH ordinates in terms of assumed ordinates to real T hr DRH ordinates (given in problem).

(iv) Solve for a, b, c ... and obtain D hr UHG ordinates.

41. 12 hr complex storm DRH ordinates are given and we are asked to find 4 hr UHG. (non uniform storm)

∴ deconvolution technique is used.

$R_1 = 2 \times 4 = 8\,cm$ {Run off = Effective rainfall intensity * time}

$R_2 = 0.75 \times 4 = 3\,cm$.

$R_3 = 4 \times 4 = 16\,cm$.

time	4 hr UHG ord (assumed)	1st storm 4 hr DRH ord (4hr UHG * 8)	2nd storm 4 hr delayed (4hr UHG * 3)	3rd storm 8 hr delayed (4hr UHG * 16)	12 hr DRH	12 hr DRH (given)
0	0	0	—	—	0	0
4	a	8a	0	—	8a	160
8	b	8b	3a	0	8b+3a	300
12	c	8c	3b	16a	8c+3b+16a	570
16	d	8d	3c	16b	8d+3c+16b	636
20	e	8e	3d	16c	8e+3d+16c	404
24	f	8f	3e	16d	8f+3e+16d	234
28	0	0	3f	16e	3f+16e	105
32	—	—	0	16f	16f	48
36	—	—	—	0	0	0

Solving,

$a = 20,\ b = 300,\ c = 20,\ d = 12,\ e = 6,\ f = 3,$

$8a = 160 \Rightarrow a = 20$

$8b + 3a = 300 \Rightarrow b = \frac{300 - 3*20}{8} = 30$

∴ 4 hr UHG ordinates are (in m^3/s):

0, 20, 300, 20, 12, 6, 3, 0.

10th dec,
WEDNESDAY

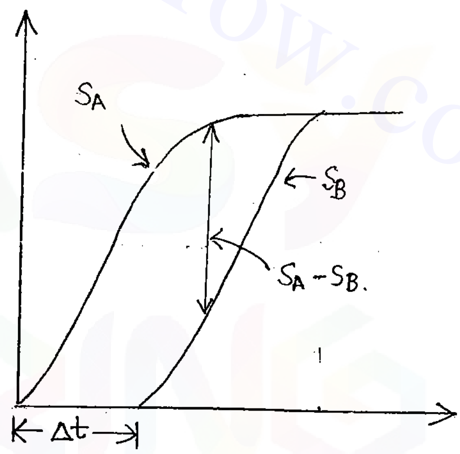
→ Instantaneous Unit Hydrograph (IUH):

- Also known as 'Clark's IUH'.
- IUH is a UHG produced by a storm of shortest possible duration. ie zero duration. (like UHG, S-curve etc, this is also another hypothetical concept)

Let 'Δt' be the shortest possible duration rain. To find Δt hr UHG from the given D hr UHG (1 hr UHG)

$\{ T = \Delta t,\ D = 1\text{ hr},\ \Delta t < D\ \&\ \Delta t \neq nD \}$

⇒ S-curve method used.



Δt hr DRH ordinates $= S_A - S_B$

$\left(R = \frac{\Delta t}{D}\ \text{cm} \right)$

Δt hr UHG ordinates $= \frac{S_A - S_B}{\Delta t / D}$

$= \frac{(S_A - S_B)\, D}{\Delta t}$

∴ Δt hr UHG ordinates $= \frac{\Delta S}{\Delta t} D$; $\Delta S = S_A - S_B$, $D = 1\text{ hr}$

$= \frac{\Delta S}{\Delta t}(1)$

$$\lim_{\Delta t \to 0} \frac{\Delta S}{\Delta t} = IUH = \frac{ds}{dt}$$

∴ IUH ordinate $= \frac{ds}{dt}$ = Slope of S curve constructed by a storm of effective rainfall intensity 1 cm/hr.

→ Synthetic Unit Hydrograph (SUH):

– Also known as 'Snyder's SUH'.

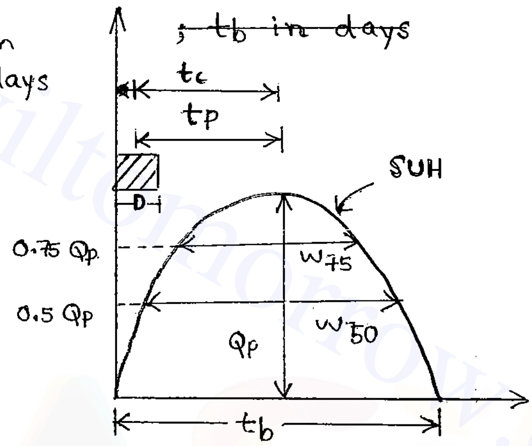
1. Basin lag (or) Lag time, 't_p' (hr) $= C_t (L * L_c)^{0.3}$; L & L_c in km.

2. Peak Discharge, 'Q_p' (m^3/s) $= 2.78\, C_p \dfrac{A}{t_p}$; A in km^2, t_p in hr

3. Base time (or) time base, 't_b' $= 3 + \dfrac{t_p}{8}$; t_b in days

4. $W_{50} = 5.87 \left(\dfrac{Q_p}{A}\right)^{-1.08}$; $Q_p \rightarrow m^3/s$, $A \rightarrow m^2$

5. $W_{75} = \dfrac{W_{50}}{1.75}$ & $D = \dfrac{t_p}{5.5}$



42. $A = 400\ km^2$

$L = 45\ km$, $L_c = 25\ km$.

$C_t = 1.257$, $C_p = 0.576$

Time of concentration, $t_c = \frac{D}{2} + t_p$

Basin lag or lag time, $t_p = C_t (L\, L_c)^{0.3}$

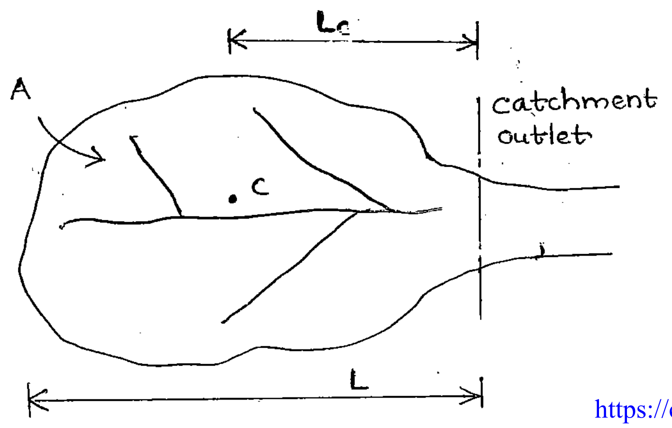
$= 1.257 (45 * 25)^{0.3}$

$= 10.34$ hrs

Peak discharge, $Q_p = 2.78\, C_p \dfrac{A}{t_p}$

$= 2.78 \times 0.576 \times \dfrac{400}{10.34} = 61.92\ m^3/s$

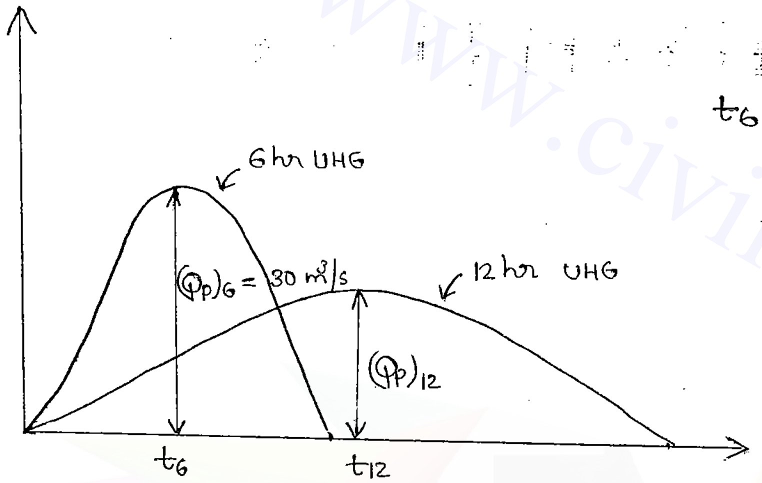
Base time, $t_b = 3 + \dfrac{t_p}{8} = 3 + \dfrac{10.34}{8} = 4.29$ days $= 103.02$ hours



(50)

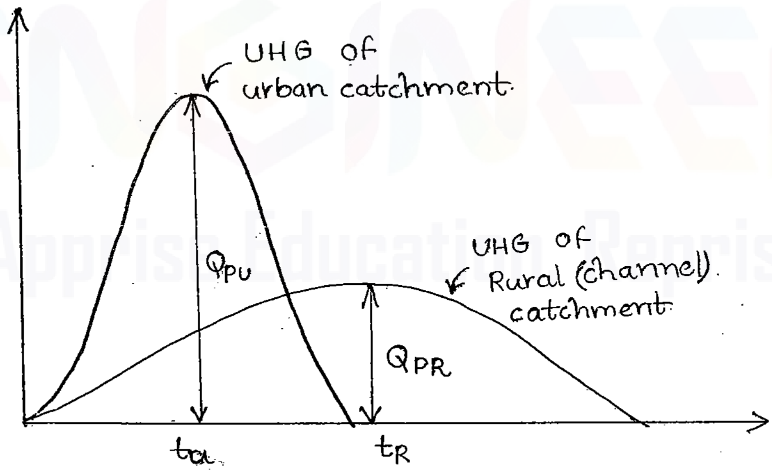
For ungauged catchments, to derive UHG, Snyder has proposed set of emperical equations. The hydrograph derived from empirical equations is known as 'Synthetic UHG'

43.



44. Line joining points of equal time of concentration are known as Isochrones (Iso – same, Chrone – time)

47.



→ Limitations of UHG

– Only direct runoff contributed by storms included in UHG. Direct runoff contributed by melting of ice (or) snow not included in UHG assesment.

– UHGs are valid only catchments whose area < 5000 km²

– UHGs are valid only for catchment without storage facility

– Valid only for uniform storm.

9th Dec,
WEDNESDAY

08. MAXIMUM FLOOD ESTIMATION

Flood is a usual stage (depth of flow) in a river, water accumulate to such a level that it overtop the banks and inundate (submerge) large area and cause loss of life and economic loss.

- Floods occur due to :
  (i) Heavy rainfall in a catchment
  (ii) Sudden melting
  (iii) Obstruction to the flow.

- Floods are estimated and data is used :
  (i) in the design of hydraulic structures
  (ii) in the design of 'levee' (flood protection wall)
  (iii) flood management

→ Methods to estimate flood Discharge:

1. Using past flood marks.

Wetted area, wetted perimeter, hydraulic mean radius 'R' are calculated and $Q = A \cdot V$.

2. Using emperical formula.

(i) Dicken's formula (North Indian Catchment)

$$Q = C_D A^{3/4}$$

(ii) Ryve's formula (South Indian Catchment)

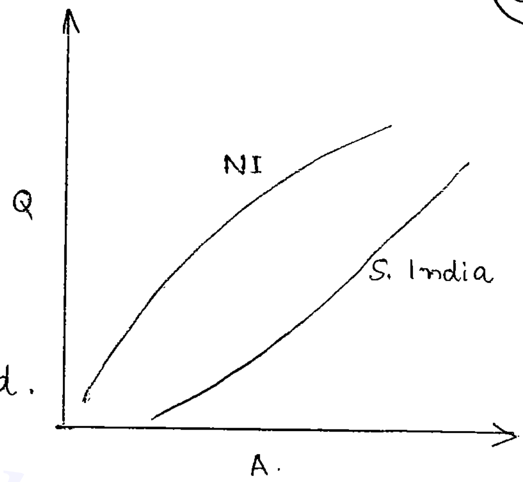
$$Q = C_R A^{2/3}$$

(iii) Inglis Formula

$$Q = \frac{124 A}{\sqrt{A + 10.4}}$$

3. Flood envelope curves

Q vs A plots are made for different parts of India by Central Water Commission (CWC).



Knowing the area of catchment (A), max. flood discharge can be calculated. (Q.)

4. Unit Hydrograph method.

UHG ⟶ DRH ⟶ FHG.

For short term flood forecasting, this method is used.

5. Flood Frequency Analysis.

Probable max. flood, PMF = X_T

$$X_T = \bar{X} + K\sigma$$

This method is used for long range (term) flood forecasting.

$\bar{x}$ → mean of flood data.

σ → standard deviation of flood data.

k → frequency factor.

$$K = \frac{y_t - y'}{s'}$$

y' & s' depends on sample size 'N', they are obtained from Gumbell's tables.

$$K = \frac{y_t - 0.577}{1.2825} \quad (\text{when sample size, } N = \infty)$$

$$y_t = -\ln(-\ln(1-p)) \;;\; \text{where } P = \frac{1}{T}$$

6. Rational Formula.

- It is an emperical formula but universal.
- best suitable for <u>urban catchments</u> whose catchment area < 5000 ha ($50\ km^2$).

$$\text{Max. flood discharge, } Q_{max} = \frac{AIR}{360}$$

where A → area of catchment (ha)

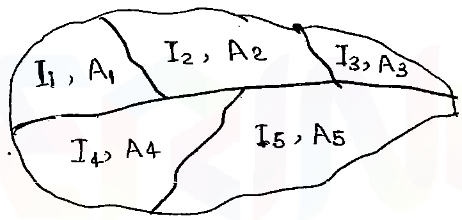
I → impermeability factor (or) runoff factor $\left(= \frac{\text{Runoff}}{\text{Rainfall}}\right)$

R → rainfall intensity (mm/hr) $\left\{= \frac{\text{depth of rainfall}}{\text{duration of rainfall}}\right\}$

$$R = \frac{P}{t}$$

when duration of rainfall, 't', is not given, it is taken as time of concentration, 't_c'

$$I = \frac{\Sigma A_i I_i}{A}$$



NOTE :

⊙ Rational formula is applicable only for such storms whose duration is $\geq t_c$. ie minimum time storm has to occur to produce max discharge is time of concentration, t_c.

$$Q \propto A, \quad Q \propto R, \quad Q \propto \frac{1}{t}$$

$$R \propto \frac{1}{t}$$

'-42

01 Run off coeffecient, $I = 0.4$ $\qquad$ $P = 45$ mm/hr.

Area of catchment, $A = 90$ ha.

$$Q_{max} = \frac{AIR}{360} = \frac{90 * 0.4 \times 45}{360} = \underline{4.5\ m^3/s}$$

02 $Q_{max} = \frac{AIR}{360} = \frac{60 \times 0.4 \times 30}{360} = 2\ m^3/s$

03. $A_1 = 30\%\ A$, $A_2 = 70\%\ A$.

$I_1 = 0.4$ $\qquad I_2 = 0.6$.

$I = \frac{\Sigma A_i I_i}{A} = 0.4 \times 0.3 + 0.6 \times 0.7 = 0.54$

04 $A = 1.5\ km^2 = 150\ ha$ $\qquad \{1\ km^2 = 100\ ha\}$

$I = 0.42$, $t_c = 28$ min.

$P = 48$ mm.

$R = \frac{48\ mm}{28/60} = 102.86$ (duration of rainfall t not given $\Rightarrow t = t_c$)

$Q_{max} = \frac{150 \times 0.42 \times 102.86}{360} = 18\ m^3/s$

05. Equivalent runoff coeffecient $= \frac{10 \times 0.7 + 20 \times 0.1 + 50 \times 0.3 + 20 \times 0.8}{10 + 20 + 50 + 20}$

$= 0.4$

06. $I = 0.3$, $A = 0.85\ km^2 = 85$ ha. $\{$Entire catchment starts contributing when $t \geq t_c\}$

$t_c = 30$ min., $P = 50$ mm

$R = \frac{50}{30/60} = 100$ mm/hr.

$Q_{max} = \frac{85 \times 0.3 \times 100}{360} = 7.0833\ m^3/s$

08. $Q_{max} = \frac{150 \times 0.4 \times 100/10}{360} = 1.667\ m^3/s$

$= 100\ m^3/min$

th dec,
HURSDAY

09. FLOOD ROUTING

Flood Routing is the method of generating flood hydrograph on d/s side by using the flood data available on the upstream side.

- Flood routing is carried out by two methods:

(i) Hydraulic Flood Routing
(ii) Hydrologic Flood Routing

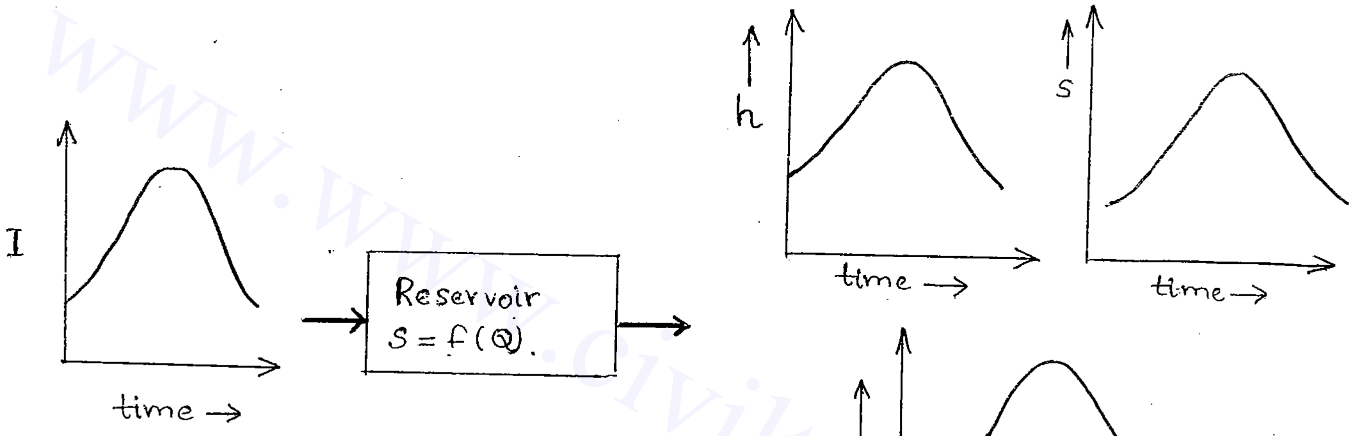
* Hydraulic Flood Routing:
  - This method is very complex but accurate.
  - It require high speed digital computer with advanced programming language.
  - This method uses
    (i) Continuity Equation.
    (ii) St. Venant's equation of motion of unsteady gradually varied flow.

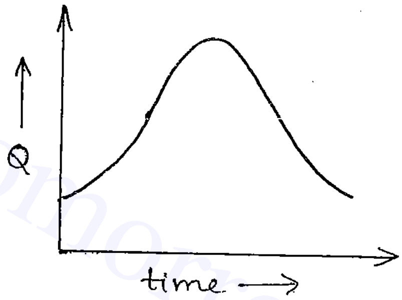
* Hydrologic Flood Routing:
  - This method is simple but approximate.
  - This method uses only continuity equation.

$$I - Q = \frac{ds}{dt}$$

- Hydrologic flood routing is applied :-
  (i) for channels with reservoir b/w u/s & d/s, known as 'Hydrologic Reservoir Routing'.
  (ii) for channels without reservoir b/w u/s & d/s, known as 'Hydrologic Channel Routing'.

→ Hydrologic Reservoir Routing





- Reservoir storage is a function of outflow only (Q)

$h \to$ depth of flow.

$S \to$ storage.

$$I - Q = \frac{ds}{dt}.$$

$$\frac{I_1 + I_2}{2} - \frac{Q_1 + Q_2}{2} = \frac{\Delta S}{\Delta t}.$$

$$\frac{I_1 + I_2}{2} - \frac{Q_1 + Q_2}{2} = \frac{S_2 - S_1}{\Delta t}.$$

- To find out flow from the above equation :-

(i) Modified Puls Method.

(ii) Good rich method

anyone is used.

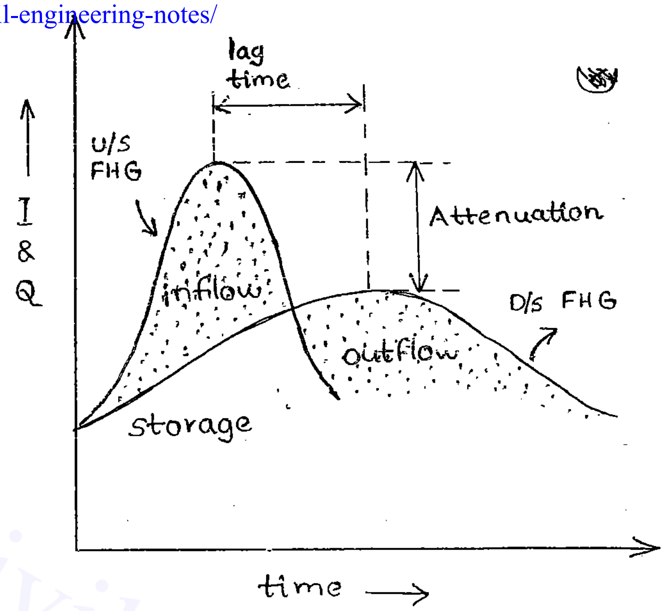
* Modified Puls Equation

$$\left(\frac{I_1 + I_2}{2}\right)\Delta t + \left(S_1 - \frac{Q_1}{2}\Delta t\right) = \underbrace{S_2 + \frac{Q_2}{2}\Delta t}_{\text{unknowns}}.$$

* Good rich method.

$$(I_1 + I_2) + \left(\frac{2S_1}{\Delta t} - Q_1\right) = \frac{2S_2}{\Delta t} + Q_2$$

Overlapped area b/w inflow curve and outflow curve represents storage.



→ Hydrologic Channel Routing

The effect of floodwave while passing from u/s to d/s is evaluated assuming that there is no lateral addition of flow by:

by * Muskinghum Method

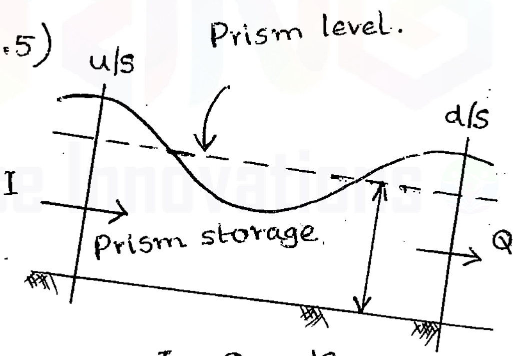
$$\text{Storage}, S = k\left(x I + (1-x) Q\right)$$

where K → storage time constant.

x → weightage factor (0 to 0.5)

I → inflow (u/s)

Q → outflow (d/s)



$$I - Q = \frac{dS}{dt}$$

— Solution to Muskingham equation for outflow, Q

$$Q_n = C_0 I_n + C_1 I_{n-1} + C_2 Q_{n-1}$$

where C_0, C_1 & C_2 are Muskingham constants.

$$C_0 + C_1 + C_2 = 1$$

time	u/s FHG (I)	d/s FHG (Q)
t_{n-1} } Δt	I_{n-1} →	Q_{n-1}
t_n	I_n ←	Q_n
t_{n+1}	I_{n+1}	Q_{n+1}

$$C_0 = \frac{-Kx + 0.5\,\Delta t}{K - Kx + 0.5\,\Delta t} \; ; \; C_1 = \frac{Kx + 0.5\,\Delta t}{K - Kx + 0.5\,\Delta t}$$

P-47

3.

time	I (m^3/s)	Q (m^3/s)
3^{rd}	18	15
4^{th}	42	$Q_4 = ?$

$C_0 = 0.042$

$C_1 = 0.538$

$C_2 = 1 - (0.042 + 0.538) = 0.42$.

$$Q_4 = 0.042 \times 42 + 0.538 \times 18 + 0.42 \times 15 = \underline{\underline{17.748}}\ m^3/s$$

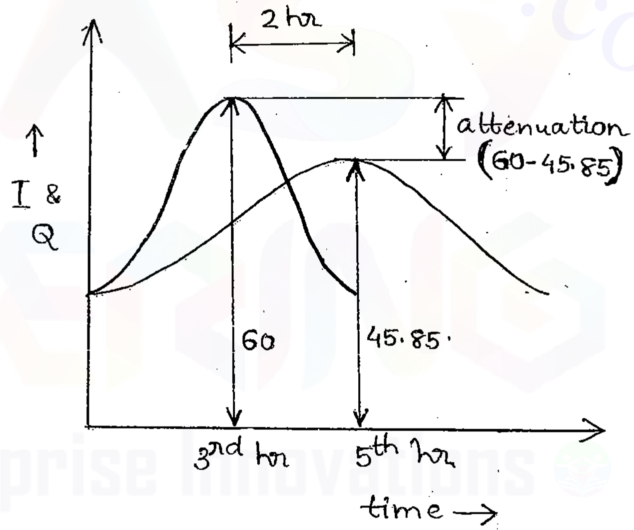
~~5.~~ 4.

$C_0 = 0.048$

$C_1 = 0.429$

$C_2 = 0.523$

time	u/s FHG (I) (m^3/s)	d/s FHG (Q) (m^3/s)
0	10	10
1	20	10.48
2	40	15.98
3	60	28.39
4	50	42.98
5	40	(45.85)
6	30	42.37



$Q_1 = 0.048 \times 20 + 0.429 \times 10 + 0.523 \times 10 = 10.48\ m^3/s$

$Q_2 = 0.048 \times 40 + 0.0429 \times 20 + 0.523 \times 10.48 = 15.98\ m^3/s$

$Q_3 = 0.048 \times 60 + 0.429 \times 40 + 0.523 \times 15.98 = 28.39\ m^3/s$

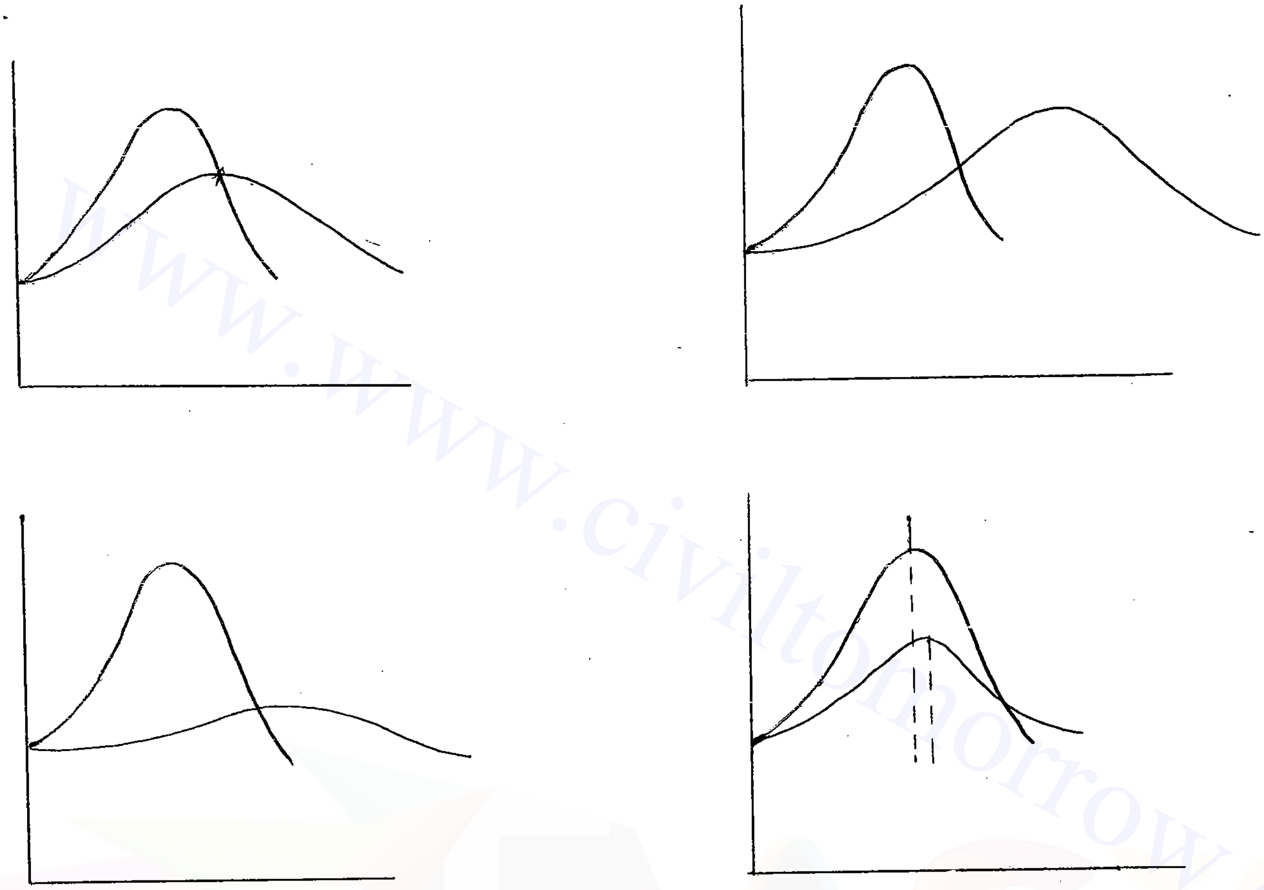
$Q_4 = 0.048 \times 50 + 0.429 \times 60 + 0.523 \times 28.39 = 42.98\ m^3/s$

$Q_5 = 0.048 \times 40 + 0.429 \times 50 + 0.523 \times 42.98 = 45.85\ m^3/s$

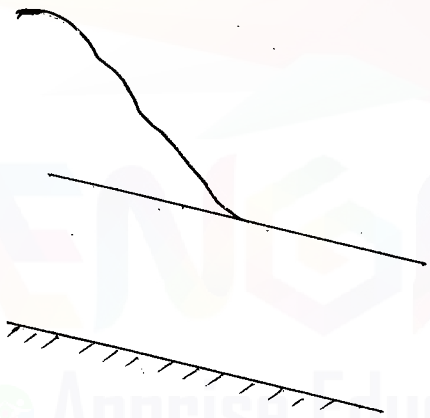
$Q_6 = 0.048 \times 30 + 0.429 \times 40 + 0.523 \times 45.85 = 42.37\ m^3/s$

Peak flood discharge on d/s $= \underline{\underline{45.85}}\ m^3/s$

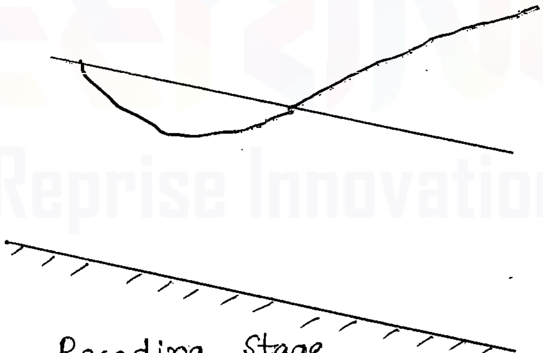
2



1.



Rising Phase
(Advancing stage)



Receding Stage
(falling phase of flood).

10. WELL HYDRAULICS

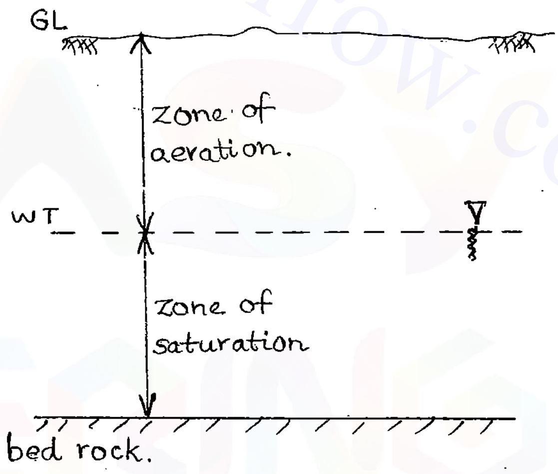
- Thirty percent of world's fresh water is available in the form of groundwater, compelled to use in the absence of surface water source.

- Before extraction and usage of groundwater it is necessary to know the groundwater potential.

- Water present in soil mantle is known as Groundwater. Based on the availability of water in the ground, ground is classified into:

(i) Zone of aeration.

(ii) Zone of saturation.



- Saturation formations of Earth further classified into:-

(i) Aquifer - formations which are porous and permeable. They only yield reliable amounts of water.

Eg: Sandy soils.

(ii) Aquitard - formations which are porous & semi permeable.

Eg: Sandy-clayey soils.

(iii) Aquiclude - porous and impermeable formations.

Eg: Clayey soils.

(iv) Aquifuge - formations which are neither porous nor permeable.

Eg: Granite, rock etc.

- Aquifers are further classified into:

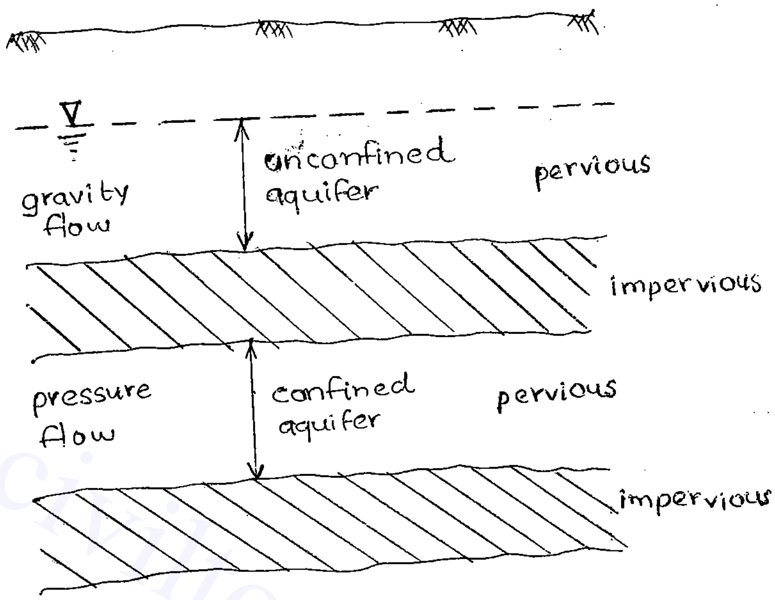
1. Unconfined Aquifer

2. Confined Aquifer.

Unconfined aquifer is also called as 'Water Table Aquifer'.

Confined aquifer is also called as 'Artesian Aquifer'.

Flow in unconfined aquifer is under gravity whereas that in confined aquifer is under pressure.



→ Aquifer Properties:

1. Porosity, 'n'
2. Specific Yield, 'Sy'
3. Specific retention, 'Sr'

* Porosity (n):

Storage capacity of soil depends on porosity.

$$n = \frac{V_v}{V}$$

$n > 20\%$ → adequate water

$5 < n < 20\%$ → moderate amounts of water

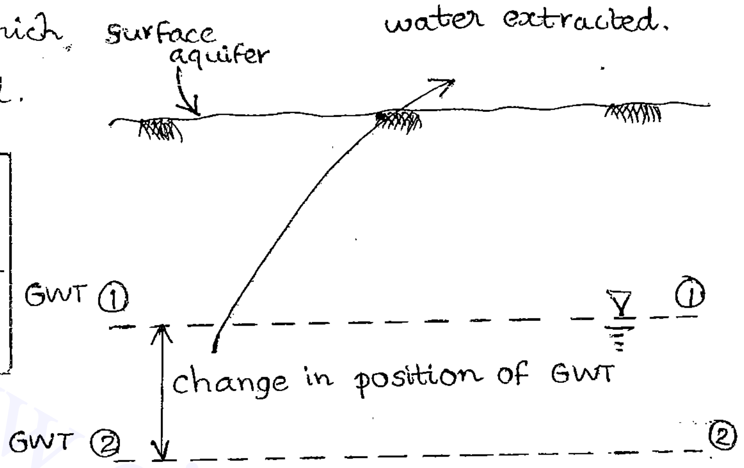
$n < 5\%$ → very less amount of water.

* Specific Yield (Sy):

Volume of water extracted by force of gravity from unit volume of aquifer is known as Specific Yield.

$$S_y = \frac{\text{volume of water extracted}}{\text{volume of aquifer}}$$

ΔGWT = thickness of aquifer from which water extracted.



Volume of aquifer = Surface area of aquifer * ΔGWT

Change in groundwater storage	=	volume of water extracted	=	Sy * volume of aquifer

* Specific Retention (Sr) :

Fraction of water retained by the soil against force of gravity is known as Specific Retention.

– Relation among Porosity, Specific Yield & Specific Retention

$$n = S_y + S_r$$

-54.

01. $n = 0.4$, $S_r = 0.15$

$\Rightarrow S_y = 0.4 - 0.15$
$= 0.25$

Volume of aquifer $= 150 \times 10^4 \times (23-20)$.
$= 112.5 \times 10^4 \; m^3 = 112.5 \times 25$ ha.m

Change in ground water storage of aquifer = Sy * volume of aquifer

$= 0.25 \times 150 \times 3 = \underline{\underline{112.5}}$ ha.m

02. Volume of water extracted $= 3 \times 10^6 \; m^3$

Volume of aquifer $= (102-99) \times 5 \times 10^6$.

Specific yield $= \dfrac{\text{volume of water extracted}}{\text{volume of aquifer}}$

$$= \frac{3\times10^6}{3\times10^6\times5} = \frac{1}{5} = \underline{0.2}$$

03. $n = 0.3$; $S_y = 0.2$, $\Delta GWT = 0.25\,m$, $A = 100\,km^2$

Volume of water lost = volume of water extracted

$= S_y * \text{volume of aquifer}$

$= 0.2 * 100\times10^6 \times 0.25$

$= 5\times10^6\ m^3 = \underline{5\ \text{million}\ m^3}$

- Groundwater flow is governed by 'Darcy's Law'.

$$\boxed{V = k\,i}$$

where $V \rightarrow$ apparent velocity of flow.

$i \rightarrow$ slope of HGL = slope of water table.

$$\boxed{Q = k\,i\,A}$$

where $A \rightarrow$ area perpendicular to flow direction.

$K \rightarrow$ permeability of soil. (horizontal hydraulic conductivity of soils)

- Infiltration is the vertical hydraulic conductivity of soils.

Actual flow velocity $= V_a = \dfrac{V}{n}$

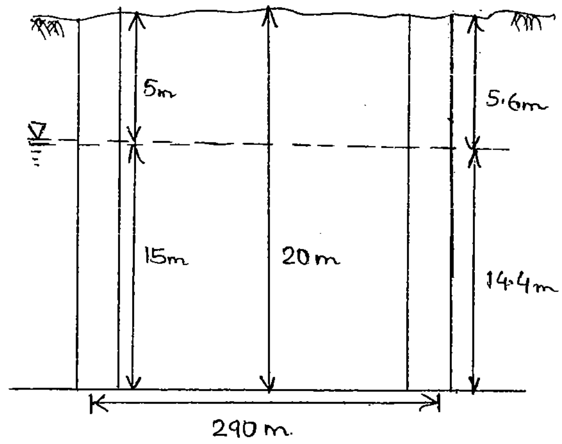
04. $K = 4\times10^{-3}$ cm/s $= \dfrac{4\times10^{-3}\times10^{-2}}{1/86400} = \underline{3.456\ m/day}$

$i = \dfrac{5.6-5}{290} = 2.069\times10^{-3}$

$$A = \left(\frac{15 + 14.4}{2} \times 1\right)$$

$$Q = 3.456 \times 2.069 \times 10^{-3} \times \left(\frac{15 + 14.4}{2}\right)$$

$$= 0.105 \ m^3/day/m$$



05. $i = \frac{50 - 25}{1500} =$

$K = 30 \ m/day.$

$V = ki = \frac{25}{1500} \times 30 = 0.5 \ m/day.$

$V_a = \frac{V}{n} = \frac{0.5}{0.25} = 2 \ m/day.$

Time of travel $= \frac{\text{Distance b/w wells}}{V_a}$

$= \frac{1500 \ m}{2 \ m/day} = 750$ days

09. $i = \frac{45 - 39.5}{2000} = \frac{5.5}{2000}$ Thickness $= 25$ m.

Width $= 2000$ m.

$k = 30$ m/day.

(i). Total daily flow through aquifer $= 30 \times \frac{5.5}{2000} \times (25 \times 2000)$.

$= 4125 \ m^3/day$

(ii) $i = \frac{45 - 39.5}{2000} = \frac{45 - h}{300}$

$\Rightarrow h = 44.175$ m