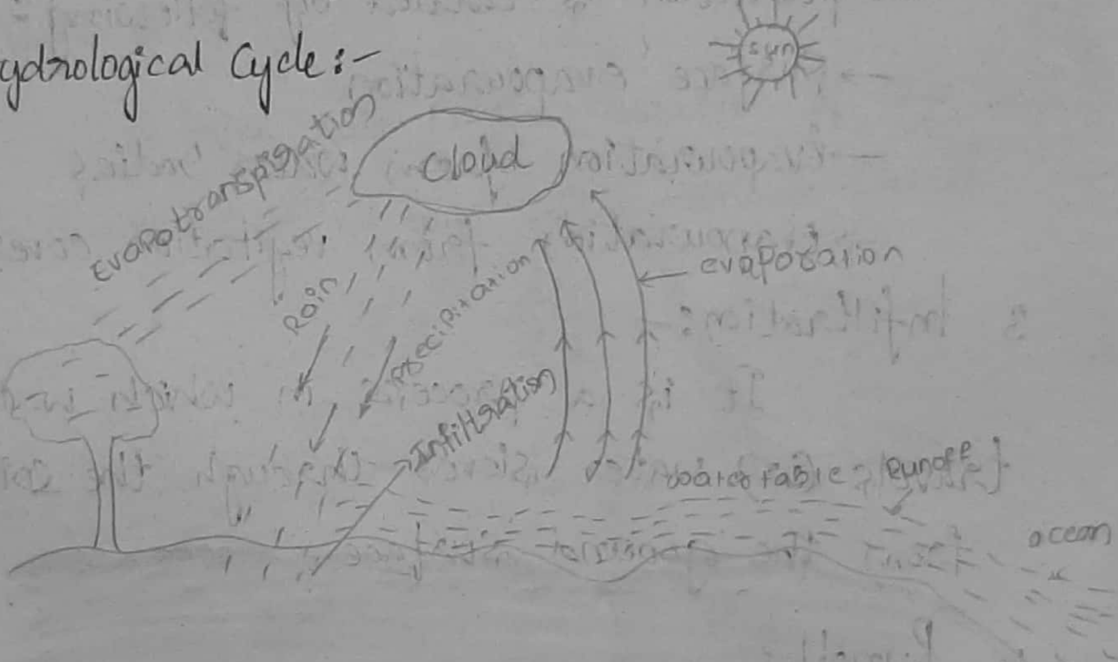
UNIT-1 Introduction

Hydrology :-

It is a Science which deals with occurence, movement and distribution of water. The main source of water is "rain".

Hydrological Cycle :-



Various terms Involved in hydrology:

1. precipitation
2. Evaporation
3. Evapotranspiration
4. Infiltration
5. runoff

1. precipitation:- The Various forms of water which reaches the ground from atmosphere is known as precipitation.

ex: rain, snow, fog, sleet, hail etc.,

2. Evapouration:-

The process of heading of water from ground to atmasphere is known as evapouration.

evapouration is carried by following:

→ surface evapouration

→ evapouration from water bodies

→ evapouration from vegitation cover.

3. Infiltration:-

It is a process in which water travels (or) water sieves through the soil from the ground surface.

4. Runoff:-

It is the process of moving of water on ground is known as Runoff.

→ surface runoff

→ Subsurface runoff

→ Ground water.

5. Evapotransportation:-

It is a combination of evaporation and transportation. It is the process of getting water evaporating from the roots, leaves, steams of the trees.

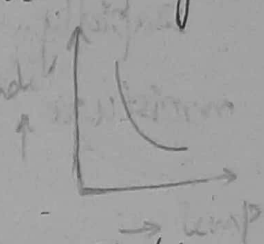
Types of precipitation:-

Lapse rate:

The lapse rate is defined as the rate of decrease with height for an atmospheric variable.

A lapse rate is the negative of the rate of temparature change with altitude change

$$\gamma = \frac{-dT}{dz}$$



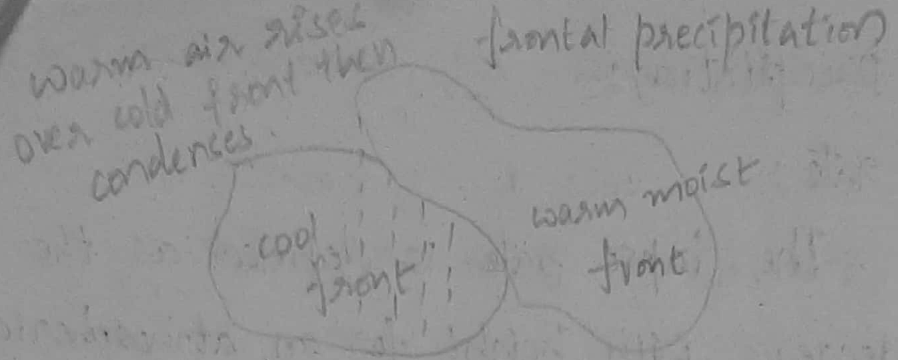
Necessary mechanism to form precipitation:-

1. Lifting mechanism to cool the air
2. formation of cloud elements
3. Growth of Cloud elements
4. Sufficient accumulation of Cloud elements.

Types of precipitation:-

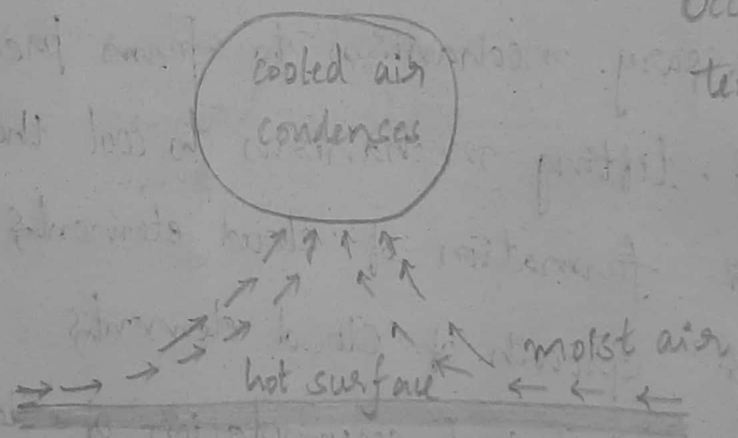
1. Cyclonic precipitation: (frontal / Non frontal)

frontal precipitation results when the leading edge (front) of a warm air mass meets a cool air mass. The warmer air mass is forced up over the cool air. As it rises the warm air cools, moisture in the air condenses, clouds and precipitation result.



2. Convective precipitation:

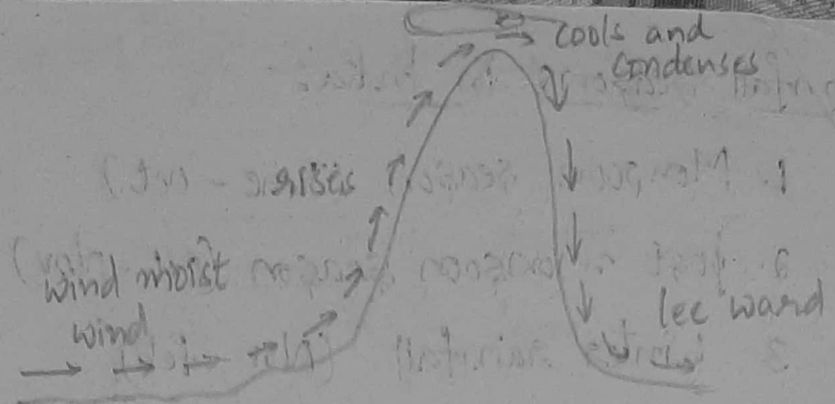
It results from the heating of the earth's surface that causes air to rise rapidly. As the air rises, it cools and moisture condenses into clouds and precipitation.



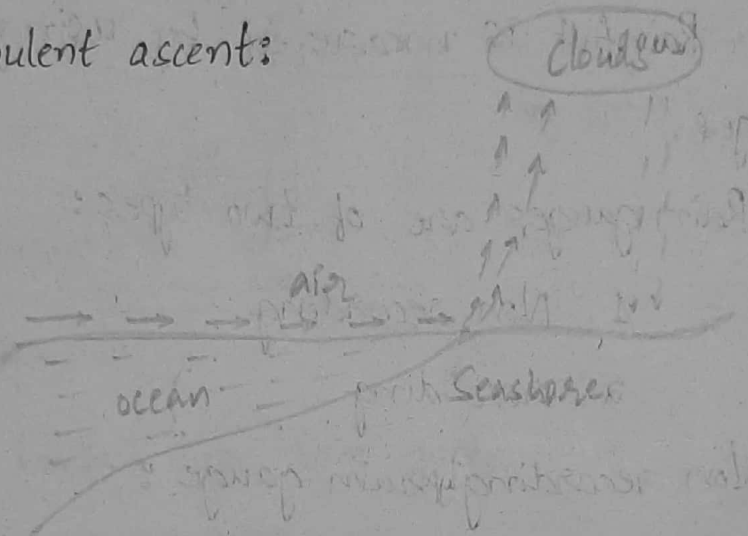
Occur due to temp. diff.

3. Orographic precipitation:-

It results when warm moist air of the ocean is forced to rise by large mountains. As the air rises it cools, moisture in the air condenses and clouds and precipitation result on the windward side of the mountain while the leeward side receives very little. This is common in british Columbia.



4. precipitation due to turbulent ascent:



air mass is lifted up due to the greater friction of earth surface after it's travels over the Ocean. The air mass is raised up due to the turbulents and friction after it ultimately condensed and precipitation occurs.

* Rainfall Seasons in India:-

1. Monsoon season (June - oct)
2. post monsoon season (Oct - Nov)
3. Winter rainfall (Nov - feb)
4. Summer rainfall (March - may)

* Measurement of rainfall:-

Rainfall is measured by using rain gauges.

Rain gauges are of two types:

1. Non recording
2. recording

Non recording type rain gauge :-

Symon's

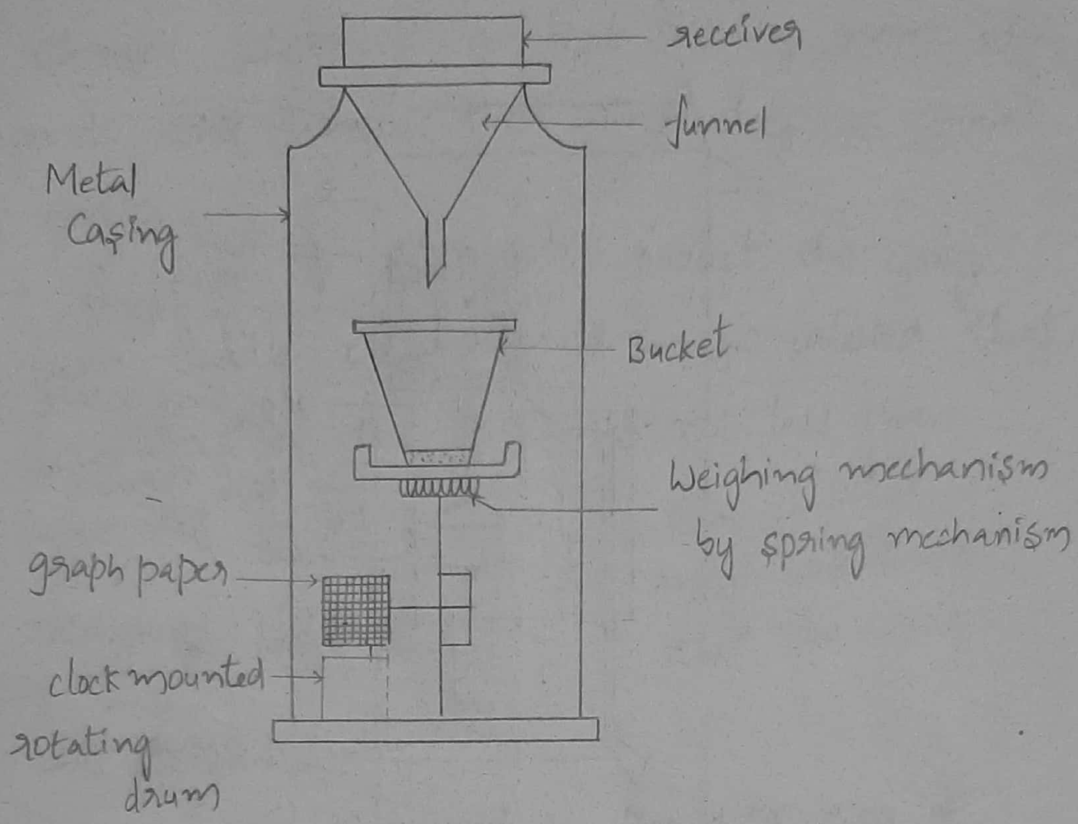
recording type rain gauge :-

a) weighing bucket type
b) tipping bucket type
c) Float type.

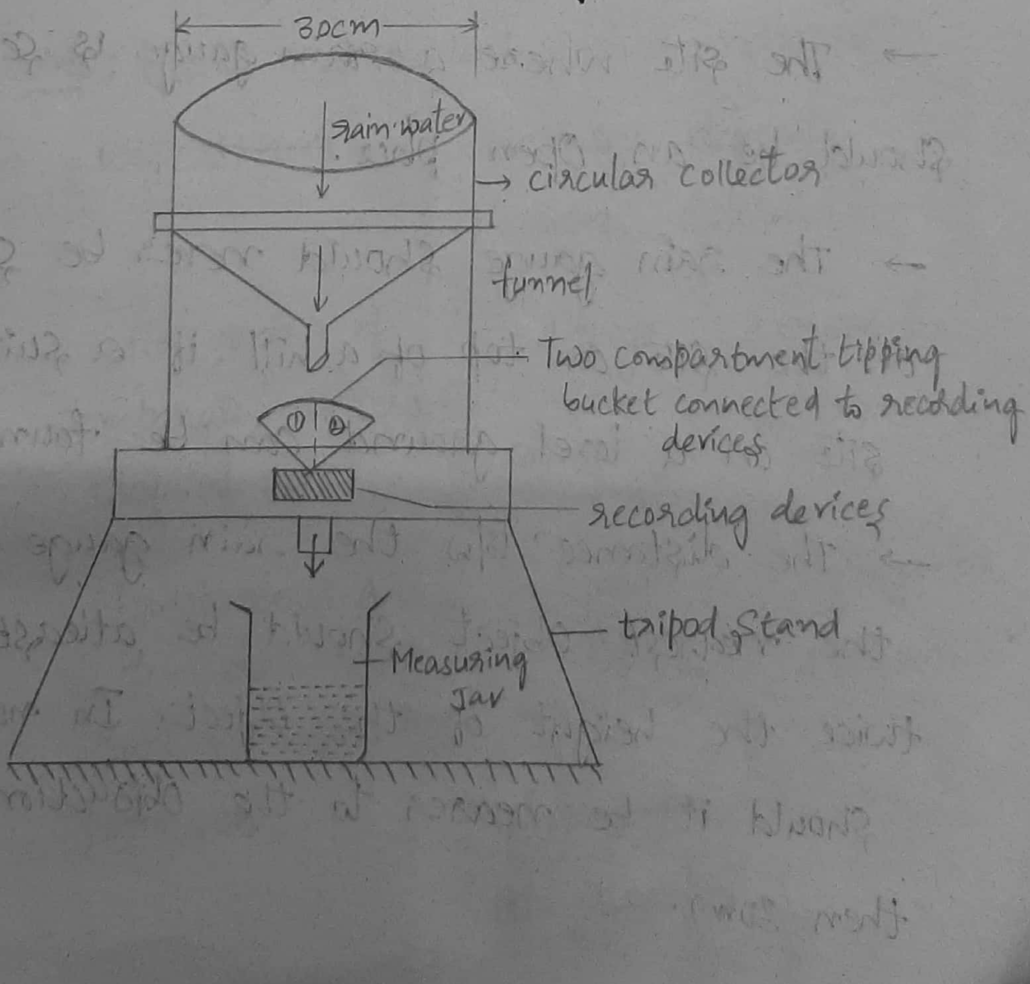
Symon's rain gauge :-

Symon's rain guage - level surface,

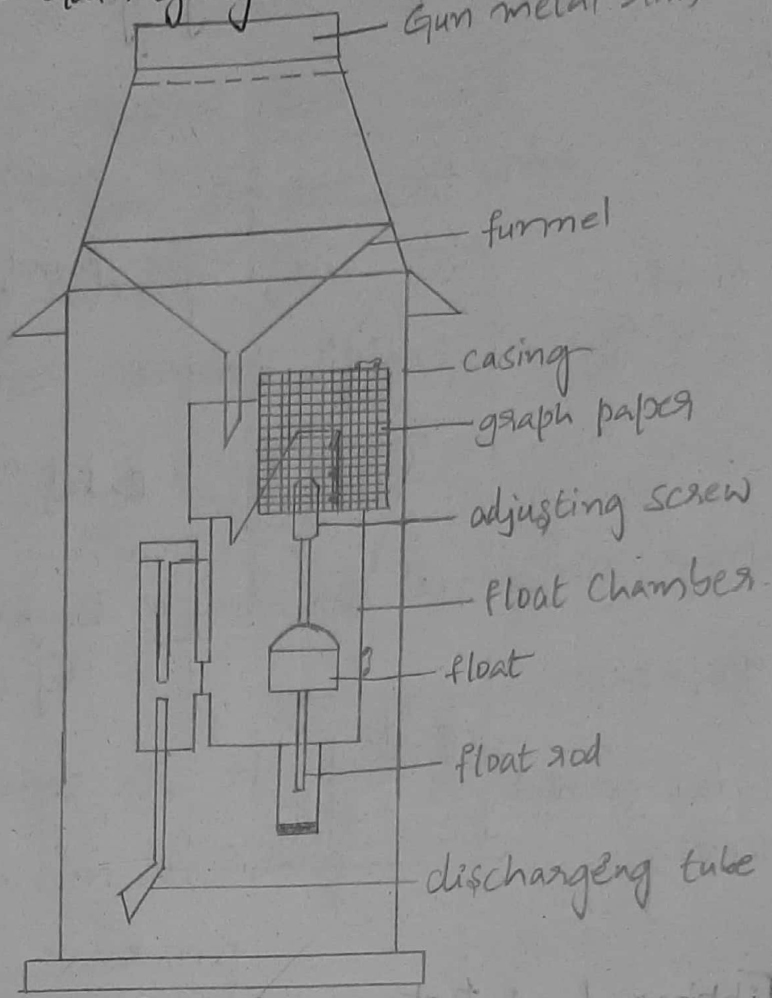
Weighing bucket type rain gauge :-



Tipping bucket type rain gauge :-



Float type rain gauge:-



Selection of site for rain gauge :-

→ The site where a rain gauge is set up should be an open place.

→ The rain gauge should never be situated on the site or top of a hill. if a suitable site on a level ground can be found.

→ The distance b/w the rain gauge and the nearest object should be atleast twice the height of the object. In no case should it be nearer to the obstruction then 30m.

→ In the hills, where it is difficult to find level space, the site for the gauge should be choosen where it is best shielding from high winds and where the wind does not causes eddies.

→ A fence, if erected to protect the gauge from caddle etc, should be so lalated that distance of the fence is not less than twice its height.

④ Rainguage Network:

Rainguage density:-

It is defined as the total area of the catchment to the total no of raingauges.

WMO: (World meterological recommendations)

region	Description	Network density min	tolerable
1.	flat region of temparate, melterant & tropical zones.	1 guage for 600-900 km^2	1 guage for 900-3000 km^2
2.	Mountaneous areas of temparate, melterant & tropical zone	1 guage for 100-250 km^2	1 guage for 250-1000 km^2
3.	polar zones.	1 guage for 1500-10,000 km^2	—

IS 4987 : 1968 :

→ 1 guage for 520 km^2 in plane areas, with denser network for the area lying in the path of low pressure systems.

→ 1 guage for 260 km^2 to 390 km^2 in regions with avg elevation of 1000m above MSL.

→ 1 guage for 130 km^2 in predominately hilly region with heavy rainfall; higher density being preferred where ever possible.

→ It is also recommended that 10% of the gauges are recording type.

→ The optimum no. of rain guages (N)

$$N = \left(\frac{C_v}{p}\right)^2$$

where,

→ C_v is the co-efficient of variation of the rainfall values of existing stations

$$C_v = \frac{S_x}{\bar{x}} \times 100$$

S_x is the standard deviation.

$\bar{x}$ is the mean of rainfall values of existing stations.

→ p is the desired degree of error in estimating mean rainfall.

C_v and p are expressed in percentages.

$$S_x = \frac{\Sigma(x_i - \bar{x})^2}{(n-1)}.$$

Q) A Catchment has 5 rainguage stations in a year, the annual rainfall recorded by the guages are 78.8cm, 90.2cm, 98.6cm, 102.4cm and 70.4cm. for a 6% error in the estimation of mean rainfall. Determine the additional no. of rain guages needed.

A) Optimum no. of rain guages

$$N = \left(\frac{C_v}{p}\right)^2$$

$$C_v = \frac{S_x}{\bar{x}} \times 100.$$

Where,

$$\bar{x} = \frac{78.8 + 90.2 + 98.6 + 102.4 + 70.4}{5}$$

$$\bar{x} = 88.08 \text{ cm}.$$

Standard deviation

$$S_x^2 = \frac{(78.8 - 88.08)^2 + (90.2 - 88.08)^2 + (98.6 - 88.08)^2 + (102.4 - 88.08)^2 + (70.4 - 88.08)^2}{5-1}$$

$$S_x = 13.40 \text{ cm}$$

Then,

$$C_v = \frac{S_x}{\bar{x}} \times 100$$

$$= \frac{13.40}{88.08} \times 100$$

$C_v = 15.2$

Optimum no. of rainguages

$$N = \left(\frac{C_v}{p}\right)^2$$

$$= \left(\frac{15.2}{6}\right)^2$$

$\boxed{N = 6.41} \simeq 7.$

Total No. of rainguages are provided in that Catchment = 7.

Then,
Additional no. of rainguages needed

$= 7 - 5$

$= 2.$

(*) Normal Annual rainfall Values in cm
120, 95, 96, 60, 65, 70, 45, 21.
How many additional rain guage Stations will be required. if the desired limit of error in the mean Value of rainfall is not to exceed 10cm.

$$\bar{x} = \frac{120+95+96+60+65+70+45+21}{8}$$

$\bar{x} = 71.5$ cm

$S_x = 31.47.$

$$p = \frac{10}{\bar{x}} \times 100$$

$$= \frac{10}{71.5} \times 100$$

$$= 13.98\%$$

$$N = \frac{(C_v)^2}{p^2}$$

$$= \frac{\left(\frac{S_x}{\bar{x}} \times 100\right)^2}{p^2}$$

$$= \frac{\left(\frac{31.47}{71.5} \times 100\right)^2}{(13.98)^2}$$

$$\boxed{N = 9.91} \simeq 10.$$

additional rain guages = 2.

⊛ Estimation of missing rainfall data:-

1. Arithematic mean
2. Normal ratio
3. Inverse distance.

The following 3 methods are adopted for the estimation of missing rainfall data:

① Arithematic mean method:-

$$P_x = \sum_{i=1}^{n} \frac{P_i}{n}$$

where,

n is the no. of Index stations. (near by stations).

p_x = missing rainfall of stations.

This method is used under the following Conditions:-

1. The normal ~~angular~~ anual rainfall of missing station is with in 10% of the normal anual rainfall of the Index Station.

2. Data of atleast 3 Index stations should be Available.

3. the Index station should be evenly spaced around the missing station should be as close as possible.

② Normal ratio method:-

$$p_x = \frac{N_x}{n}\left[\frac{p_1}{N_1} + \frac{p_2}{N_2} + \cdots + \frac{p_n}{N_n}\right]$$

where,

$N_1, N_2, N_3 \cdots N_n$ are the normal angular rainfall of Index stations.

N_x is Normal anual rainfall of missing stations.

n is no. of Index stations

③ Inverse Distance method:-

$$W_i = \frac{1}{D_i} = \frac{1}{x_i^2 + y_i^2}$$

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$$p_x = \frac{\sum_{i=1}^{n} P_i w_i}{\sum_{i=1}^{n} w_i}$$

Where,

. x_i, y_i = Co-ordinates.

(*) A watershed has 4 raingauge station A, B, C, D. during a storm raingauge station A was Inoperative while stations B, C and D surrounding A recorded rainfall of 48 mm, 51 mm and 45 mm respectively. Estimate the missing storm precipitation of station A using Arithematic mean method.

(A) $$p_x = \sum_{i=1}^{n} \frac{p_i}{n}$$

$$p_x = \frac{48+51+45}{3} = 48 \text{ mm}$$

~~$p_x = \sum_{i=1}^{n} \frac{p_i}{n}$~~

~~$n = 3$.~~

~~$p_x =$~~

(*) A precipitation station 'x' was Inoperated for some time during which a storm occured. The storm station at 3 stations A, B and C surrounding 'x' were respectively 6.60, 4.80, 3.70 cm. The Normal anual precipitation Amounts at stations X, A, B & C are respectively 65.8, 72.6, 51.8 and 38.2 cm Estimation the storm precipitation for station 'X'.

(A) Normal anual rainfall of missing station $N_x = 65.8$.

$n = 3$.

Normal anual rainfall of Index stations

$N_1 = 72.6$ cm

$N_2 = 51.8$ cm

$N_3 = 38.2$ cm

$P_1 = 6.60$ cm

$P_2 = 4.80$

$P_3 = 3.70$

$$P_x = \frac{65.8}{3}\left[\frac{6.60}{72.6} + \frac{4.8}{51.8} + \frac{3.70}{38.2}\right]$$

$P_x = 6.15$ cm

(*) In a river basin a station A was Inoperative during a storm while stations B, C, D and E surrounding A. were in Operation, registing 74mm, 88mm, 91mm and 80mm of precipitation. The Co-ordinates of B, C, D and E are (9, 6) (12, -9) (-11, -6) and (-7, 7) respectively. with co-ordinates of A as (0,0). estimate the missing strom precipitation of station 'A' by Inverse distance method.

(A) $W_B = \frac{1}{x_i^2 + y_i^2}$

$= \frac{1}{9^2 + 6^2} = 8.547 \times 10^{-3}$

$W_C = \frac{1}{12^2 + (-7)^2} = 4.444 \times 10^{-3}$

$W_D = \frac{1}{(-11)^2 + (-6)^2} = 6.369 \times 10^{-3}$

$W_E = \frac{1}{(-7)^2 + (7)^2} = 0.010$

$P_B = 74mm$; $P_C = 88mm$; $P_D = 71mm$

$P_E = 80mm$.

$P_x = \frac{\sum_{i=1}^{n} P_i W_i}{\sum_{i=1}^{n} W_i}$

$= \frac{(74 \times 8.547 \times 10^{-3}) + (88 \times 4.444 \times 10^{-3}) + (71 \times 6.369 \times 10^{-3}) + (0.010 \times 80)}{(8.547 \times 10^{-3}) + (4.44 \times 10^{-3}) + (6.369 \times 10^{-3}) + 0.010}$

$= 77.52$ mm

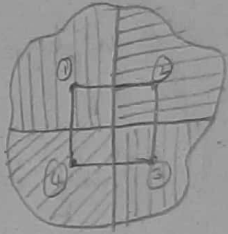
Estimation of avg rainfall (or) precipitation data:

1. Arithematic avg (or) mean method
2. Theisson polygon method
3. Isohyetal method. (line joining of equal rainfall values)

1. Arithematic avg (or) mean method:

The avg rainfall value $P_{avg} = \frac{\sum_{i=1}^{n} P_i}{n}$

2. Theisson polygon method:



→ Join the adjacent rainguage stations 1,2,3,4 etc, by straight lines.

→ construct the perpendicular bisectors of each of these lines.

→ A theisson network is thus constructed.

→ the polygon formed by the ⊥lar bisectors around a station encloses an area which is everywhere closer to that station then do any other station.

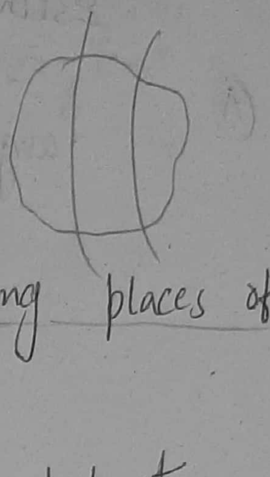
→ find the area of each polygons hatch as shown in figure.

→ multiply the area of each theisson polygon by the raingauge value of the enclosed station.

→ find the total area of the basin.

→ compute the avg precipitation by the following formula.

$$P_{avg} = \frac{\sum_{i=1}^{n} p_i A_i}{\sum_{i=1}^{n} A_i}$$



3. Isohyetal method:

Def: An Isohyete is a line, on a rainfall map of the basin joining places of equal rainfall readings.

→ from the rainfall values recorded at various rainguage stations prepared the Isohyetal map for the storm causing the rainfall over the area.

→ measure the areas enclosed between successive Isohyets with the help of planimeter.

→ Multiply each of these areas by the avg rainfall between the Isohyetes.

→ The avg rainfall is computed by the following formula.

$$P_{avg} = \frac{\sum_{i=1}^{n} A\left(\frac{P_1+P_2}{2}\right)}{\sum_{i=1}^{n} A}$$

(*) Rainfall Values:

12.6, 18.8, 14.8, 10.4, 16.2 mm

Estimating the avg rainfall value.

(A) $$P_{avg} = \frac{\sum_{i=1}^{n} P_i}{n}$$

$$= \frac{12.6 + 18.8 + 14.8 + 10.4 + 16.2}{5}$$

$$P_{avg} = 14.56\ mm$$

(*) A theisson polygon areas enclosed by rainguage stations and the rainfall values are tabulated below: estimate the avg rainfall value.

rainguage stations	area of theisson polygon km^2	Precip
A	45	30.8mm
B	38	34.6
C	30	32.6
D	40	24.6

(A) $$P_{avg} = \frac{\sum_{i=1}^{n} P_i A_i}{\sum_{i=1}^{n} A_i}$$

$$= \frac{(30.8)(45) + (34.6)(38) + (32.6)(30) + (24.6)(40)}{(45) + 38 + 40 + 30}$$

$$P_{avg} = 30.47\ mm$$

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(*) for a drainage basin of area 640 km^2, Isohyetals based on a strong event in the following data.

Isohyetal Intervals (cm)	Inner Isohyetal area km^2
14 - 12	90
12 - 10	140
10 - 8	125
8 - 6	140
6 - 4	85
4 - 2	40
2 - 0	20

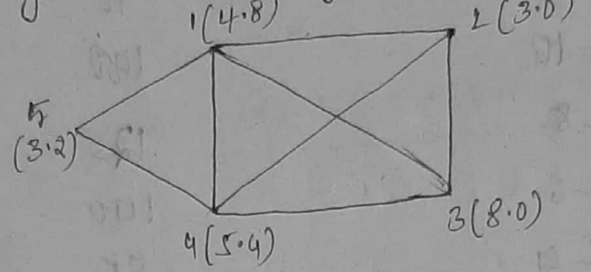
Estimate the avg depth of precipitation over the basin.

(A) $$P_{avg} = \frac{\sum_{i=1}^{n} A_i \left(\frac{P_1 + P_2}{2}\right)}{\sum_{i=1}^{n} A}$$

$$= \frac{90\left(\frac{14+12}{2}\right) + 140\left(\frac{12+10}{2}\right) + 125\left(\frac{10+8}{2}\right) + 140\left(\frac{8+6}{2}\right) + \left(\frac{6+4}{2}\right)85 + 40\left(\frac{4+2}{2}\right) + 20\left(\frac{2+0}{2}\right)}{640}$$

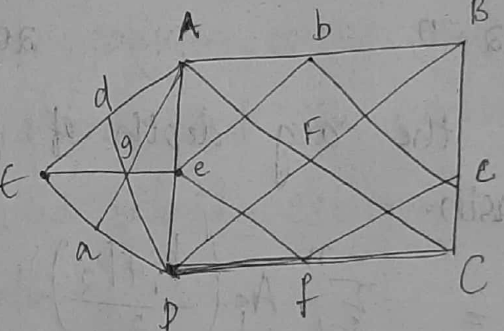
$P_{avg} = 8.40cm.$

* find the mean precipitation for the area sketched in figure by theisson method. the area is composed of a square plus an equilateral triangle plot of side 4km rainfall readings in cm. at the various station are also given in the figure.

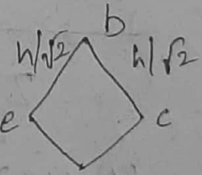


⊥le bisectors:

Dd
Aa
Ee
eb
bc
cf
fe



(A) station 'F' (bcfe)



length of bc $= \frac{1}{2} AC$

$= \frac{h}{\sqrt{2}}$

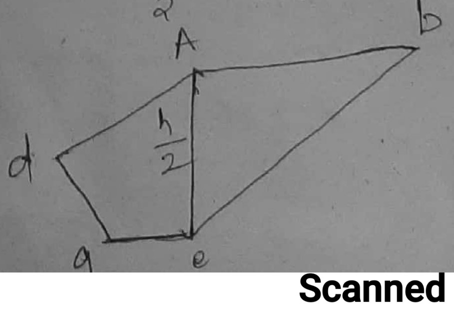
length of AC $= 2\frac{h}{\sqrt{2}}$

$= \sqrt{2}h$

area of portion bcfe $= \frac{h}{\sqrt{2}} \times \frac{h}{\sqrt{2}} = \frac{h^2}{2}$

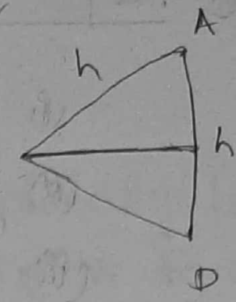
$= \frac{4^2}{2} = 8\ km^2$

(B) station A (begd)



area of triangle Abe $= \frac{1}{2} \times \frac{h}{2} \times \frac{h}{2}$

$A_2 = \frac{h^2}{8} \Rightarrow 2\,Km^2$



Area of (Aegd) $= \frac{1}{3}$ of area of ΔADE.

ΔADE (area) $= \frac{1}{2} \times h \times \frac{\sqrt{3}h}{2}$

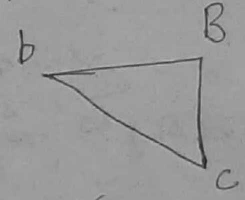
area of (Aegd) $= \frac{1}{3} \times \frac{1}{2} \times h \times \frac{\sqrt{3}h}{2}$

$A_4 = \frac{h^2}{4\sqrt{3}}$

area considered by station 'A' = area of ΔAbe + area of sector Adge

$= \frac{h^2}{8} + \frac{h^2}{4\sqrt{3}}$

$= \frac{(4)^2}{8} + \frac{(4)^2}{4\sqrt{3}} = 4.30\,Km^2$



area Enclosed by station 'B'

$A_2 = A_3 = \frac{1}{2} \times \frac{h}{2} \times \frac{h}{2} = \frac{h^2}{8} = 2\,Km^2$

area Enclosed by station 'e'

A_5 = area of sector edge

$= \frac{1}{3} \Delta^{le}\,ADE = \frac{h^2}{4\sqrt{3}} = 2.3\,Km^2$

The Avg precipitation is

$$P_{avg} = \frac{P_1A_1 + P_2A_2 + P_3A_3 + P_4A_4 + P_5A_5 + P_6A_6}{A_1 + A_2 + A_3 + A_4 + A_5 + A_6}$$

$$= \frac{(4.8 \times 4.3) + (2 \times 3) + (8 \times 2) + (4.3 \times 5.4) + (2.3 \times 3.5) + (8 \times 9.4)}{4.3 + 2 + 2 + 4.30 + 2.3 + 8}$$

$= 6.51\,cm$.

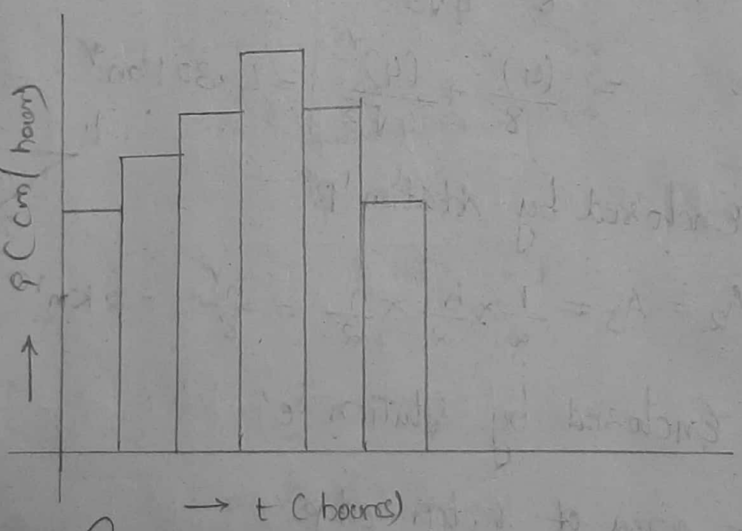
* Precipitation of rainfall:

(i) hyetograph.
(ii) mass Curve.
(iii) point rainfall.

① hyetograph

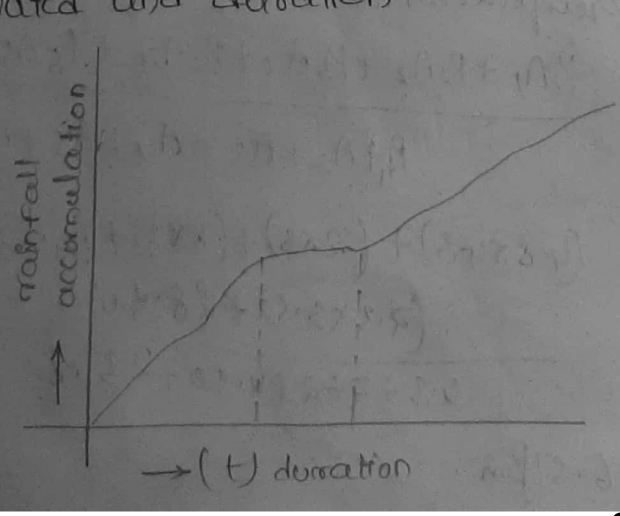
It is a graphically representation between duration and intensity of rain fall with is represented in bar charts. -

→ It is obtained from mass Curve of rainfall.



② Mass Curve

The graphical mass Curve is representation accumulated and duration.



horizontal Curve - No. of rainfall in that particular Section.

③ point rainfall method

The point rainfall is presented graphically has plots of magnitude Vs clonological time in the form of a bar diagram. The data can be presented as daily, weakly, monthly, seasonal, annual values.

Interpretation of rainfall data

Generally the precipitation information may be required under the fallowing headings.

① Intensity (i)

The intensity of rainfall is defined as the rate at which rain fall is occurs, that is expressed in (cm/hour).

$$i = P/t$$

P is precipitation
t is duration.

The intensity of the rainfall can be grouped as fallows that are,

(i) light intensity rainfall 2.5 mm/hour.
(ii) moderate intensity rain fall 2.5 to 7.5 mm/hour.
(iii) heavy intensity rainfall > 7.5 mm/hour.

② duration

duration is nothing but time which is represented by (t)

③ frequency (f)

The probability of occurrence of an event expressed as a %. is known as frequency (f)

$$\therefore f = \frac{1}{P} \times 100.$$

* The designe of hydraulic structures such as flood control structures, soil conservation structures, drains, culverts is based on the probability of the occurence of extream rain fall and their for the run off.

④ reccurrence interval

It is the interval in year for occurrance of the event of the same magnitude and is the reciprocal of frequency

$$T = \frac{1}{P_{rr}}$$

P_{rr} is the probability of occurrence can be calculated by the fallowing formulas:

(i) California formula

$$P_{rr} = \frac{M}{N} = \frac{m}{N}$$

(or)

$$t = \frac{N}{m}$$

(ii) hazen formula,

$$P_{ro} = \frac{(2m-1)}{2N}$$

(iii) weibull event

$$P_{ro} = \frac{m}{N+1}$$

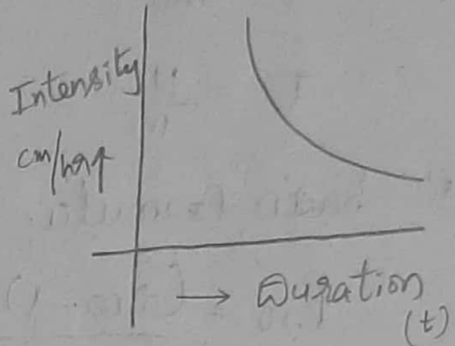
m = event of occurrence

N = no. of years record.

— o —

⊛ Intensity Duration Curve:

as the Duration of particular catchment area the Intensity of rainfall will be decreased.

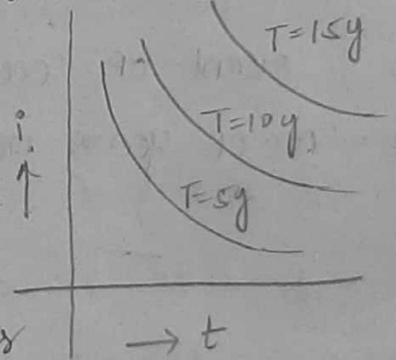


$$i = \frac{a}{(t+b)^n}$$

Sherman proposed a relation b/w I & t.

⊛ Intensity Duration frequency curve:

$$i = \frac{KT^x}{(t+b)^n}$$



t = ~~frequency~~ duration

i = Intensity

b, n, x, K are the constants for particular catchment area

⊛ Depth Area relation:

$$\bar{P} = P_n E^{-KA^n}$$

Where

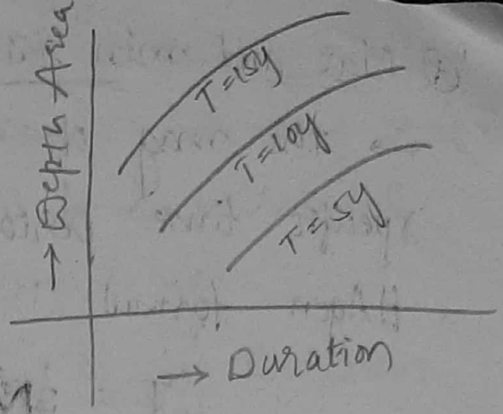
P_n is the heighest amount of rainfall

$\bar{P}$ is the avg Depth of rainfall

A represent catchment area where rainfall is to be occured.

K, A, n are the Constants.

(*) Depth Area Duration Curves:



(*) probable max precipitation (PMP):

It is the greatest (or) extreme rainfall for a given Duration i.e., physically possible over a station.

(or)

It is the rainfall over a basin which would produce a flood flow with virtually no rise of being exceeded.

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

It can be Obtained by considering 2 approaches that are

→ materological approach

→ ~~Statically appr~~ statistical Approach.

Where,

$\bar{P}$ is the mean of Annual max rainfall

K is the frequency factor

σ is the

(*) Max and min rainfall :-

→ The mag of max & min rainfall with in specific time period can be determined by HAgen formul

$$T = \frac{2N}{2m-1}$$

Where,

T = reccurence Interval with in which the event is either equal to or greater than the specified Amount.

m = rank number assign to the event.

Procedure for Determination of max rainfall :-

→ Arrange the rainfall data in decending order and assign rank number (m) to each rainfall event, the total no. of event being = N

→ Compute reoccurence Interval (T) by the Above eq'n

→ plot a graph b/w reccurence interval as abcissa and corresponding rainfall as Ordinate.

→ Determine the expected max rainfall magnitude for any desired value of 'T' from this graph.

* procedure for Determination of min rainfall:-

→ Arrange the rainfall Data in Ascending order and assign rank number (m) to each rainfall event, the total no. of event being =

→ Compute reccurence interval (T) by the above eq'n.

→ plot a graph b/w reccurence interval as abscissa and corresponding rainfall as ordinate.

→ Determine the expected min rainfall mag for any desired value of 'T' from this graph.

* The rainfall Data recorded at a rain guage station are given below. Compute the values of max & min rainfall values at 15 years reccurence interval.

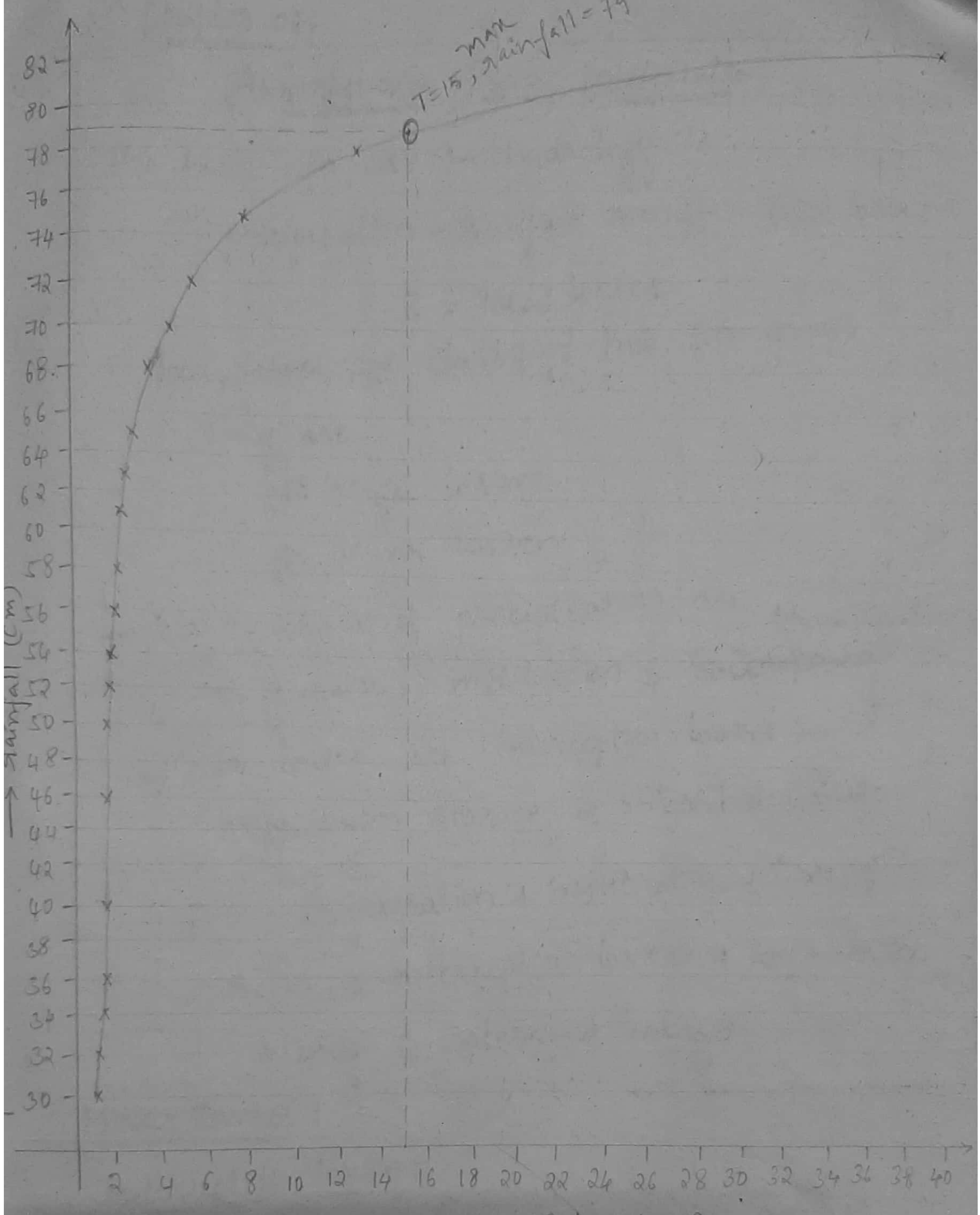
Year	rainfall (cm)	year	rainfall
1951	61	1961	54
1952	50	1962	70
1953	75	1963	34
1954	32	1964	63
1955	36	1965	68
1956	30	1966	82
1957	46	1967	78
1958	52	1968	58
1959	22	1969	56
1960	40	1970	65

max rainfall:

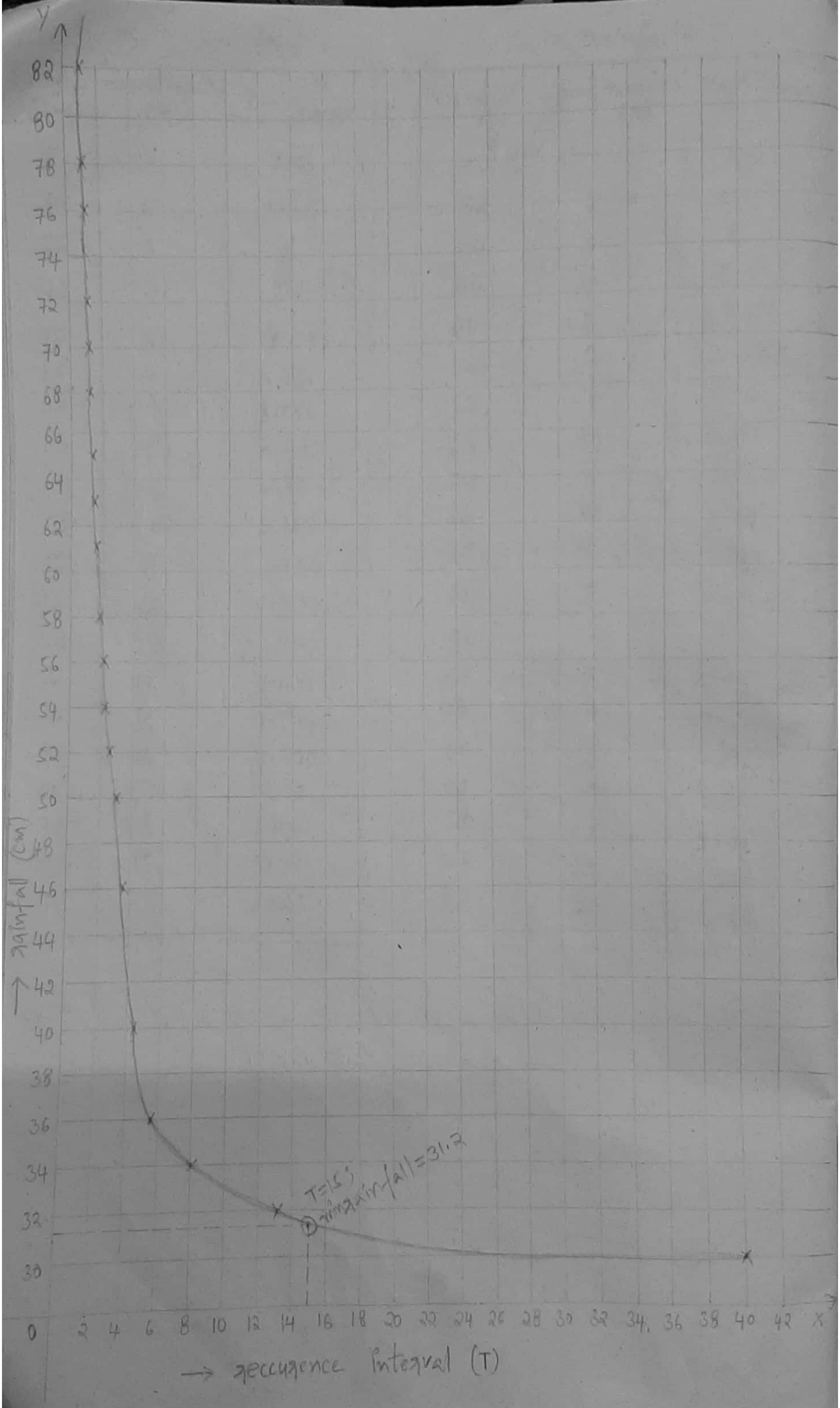
Rainfall (cm)	Rank number (m)	$T = \frac{2N}{2m-1}$
82	1	40
78	2	13.33
75	3	8
72	4	5.71
70	5	4.44
68	6	3.636
65	7	3.076
63	8	2.67
61	9	2.352
58	10	2.105
56	11	1.904
54	12	1.739
52	13	1.6
50	14	1.481
46	15	1.379
40	16	1.290
36	17	1.212
34	18	1.142
32	19	1.081
30	20	1.025

min rainfall:

rainfall	rank number (m)	$T = 2N/2m-1$
30	1	40
32	2	13.33
34	3	8
36	4	5.71
40	5	4.44
46	6	3.636
50	7	3.076
52	8	2.67
54	9	2.352
56	10	2.105
58	11	1.904
61	12	1.739
63	13	1.6
65	14	1.481
68	15	1.379
70	16	1.290
72	17	1.212
75	18	1.142
78	19	1.081
82	20	1.025



T=15, max rainfall = 79
rainfall (cm)
recurrence interval (T)



Y
82
80
78
76
74
72
70
68
66
64
62
60
58
56
54
52
50
48
46
44
42
40
38
36
34
32
30
0
2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 X
T=15; rainfall=31.2
↑ rainfall (cm)
→ reccurence interval (T)

09.12.2019 Chapter-02:

Abstractions from precipitation

The basic eq'n use in hydrology is

precipitation - surface runoff = Total losses

P-R = Total losses.

Total losses are classified into two groups

They are

(i) Major losses

(ii) Minor losses

→ Major losses of precipitation are evapouration, infiltration & transpiration

→ Minor losses are interception losses, Depression storage & watershed leakages

∴ P-R = Evapouration + infiltration + transpiration + Interception losses + Depression storage & watershed leakages.

MINOR LOSSES:

Interception losses:

Whenever the precipitation occurs the total amount of precipitated water doesn't reach the ground due to obstructions such as trees, buildings etc., present on the Ground surface. ∴, the amount of precipitated water is losses due to obstructions is nothing but Interception losses

Depression storage:

The precipitation water store in the depression treches present in the ground surface is nothing but depression storage.

Watershed Leakage:

Watershed basin – The boundary enclosed by a all the tributuries (or) branches of a water body is known as its watershed basin.

The watershed basins are seperated by ridge lines.

Def: The leakage of water from one watershed basin to the another watershed through the ridge line is known as watershed leakage.

* Various factors which influences Inteception losses:-

1. storm factors.
2. plant factors
3. season of the year
4. prevailing wind.

* Depression storage:-

1. Land form
2. soil Characteristics

3. Topography

4. Anti precipitation Index, manmade disturbances like terrace forming.

The depression storage is expressed as

$$V_{ds} = K\left(1 - e^{-P_e/K}\right)$$

V_{ds} = Volume of water stored in the depressions.

P_e = rainfall excess (excess of infiltration and interceptions).

k = depression storage capacity factor.

(*) Evapouration:

It is the process of changing of water from liquid state to gaseous state at the free surface, below the boiling point through the transfer of heat energy.

The main reason behind the evapouration is solar radiation.

Rate of evapouration depends upon the following factors.

1. Vapour pressure at the water surface and air above.
2. air and wind, temparature
3. solar radiation.
4. wind speed.
5. atmospheric pressure.

6. nature & size of evapourating surface.

7. Quality of water.

Dalton's law of Evapouration :

$$E = C(e_s - e_a)$$

Where

$C = a + bv$

$$\therefore E = (a+bv)(e_s - e_a)$$

Where

E is the evapouration loss (mm/day)

e_s is the saturated vapour pressure at water surface temparature in millibars

e_a is the actual Vapour pressure of the air above.

C is a constant whose value depends upon various factors such as barometric pressure, wind velocity, humidity

V is the wind speed in km/hr

a, b are constants.

- The avg rainfall in India is 119cm.
- The base flow is 55cm.

Factors affecting evapouration :-

* ~~Latent heat (radiation)~~

Daltons law E↓ ↑Pa ea↑ ↓Pa ↑E altitude Pa↓ E↑

1. Atmospheric pressure :

If atmospheric pressure is more, according to "Dalton's law" e_a is more, hence less evapouration. "Thus, decreases in atmospheric pressure can Increase evapouration." At higher altitude atmospheric pressure is low : hence evapouration should have been more. But this is not necessary because temparature at higher altitude is low which reduces evapouration.

2. Area of water surfaces :

A∝E

evapouration is directly proportional to the area exposed". Hence if area is more, evapouration is more.

3. Quality of water :

It also effects the rate of evapouration." If water contents dissolved salts, it reduces the saturated Vapour pressure e_s and by Dalton's law, E decreases. Also turbidity of water has some indirect effects. ↓e_s E↓

4. radiation :-

radiation is the most imp factors of evapouration. solar radiation supplies continuous

energy, which is essential for evapouration.
"Evapouration is directly proportional to radiation." solar energy near the equator is more, therefore, evapouration is much more.

$E \propto$ solar radiation

5. Vapour pressure:-

"Evapouration rate varies directly with difference of Vapour pressure between air and water". If E is the rate of Evapouration (mm/day) and e_w, e_a are the Vapour pressure in water and in air, then

$$E = c\,(e_w - e_a) \quad \text{—— (1)}$$

Here c is constant.

equation (1) is called "Dalton's law".

6. Temparature:-

"Increase in air temp, increases evapouration" when other factors remaining Same yet the high Correlation coefficient b/w the two does not exit. In cold dry season also although temp is less rate of evapouration is more because Some of heat energy absorbed at lower depth in hot water is released in cold season.

$\uparrow t \uparrow E$ heat Energy absorbed

7. Wind Velocity:

"The increase in wind velocity increases evapouration". Wind removes the evapourated water vapour and thereby creates space for new evapourated water vapour. When there is no wind above the water body where the evapourated water vapour is still condition, further evapouration ceases to take place. If wind velocity over the water body is high, it doesn't increases correspondingly the evapouration. There is always a critical velocity of wind beyond which evapouration does not increase". ↑W ↑E

8. Humidity :-

High humidity decreases ability of air to absorb more water vapour and reduce evapouration rate.

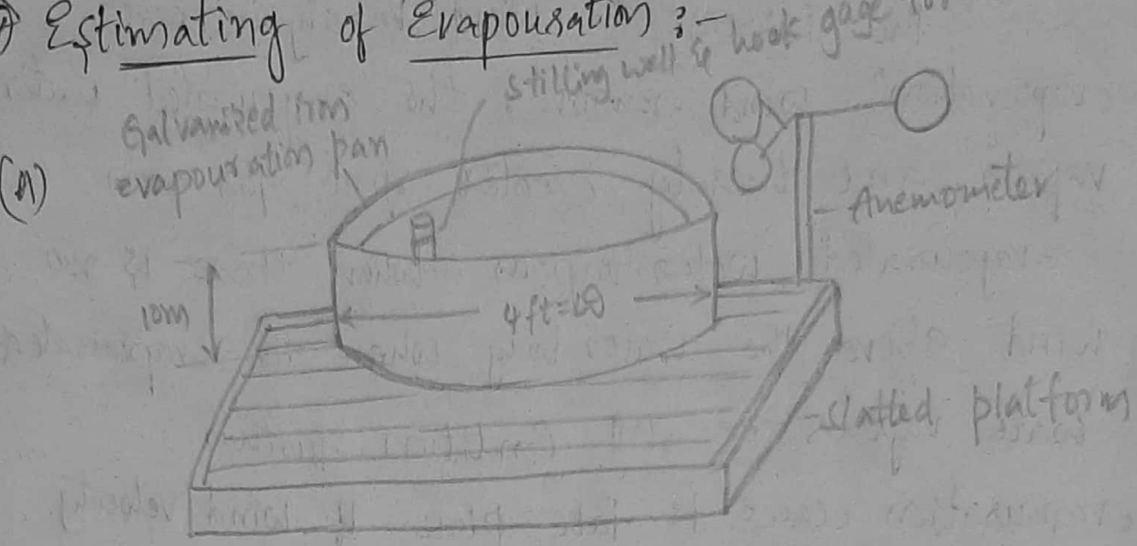
↑H ↓ ability of air to absorb more water vapour ↓ E rate

9.

~~Evapouration~~ of the liq

(v) Estimating of Evapouration :-

(A)



→ evapouration pan is filled to 8 inches and Observed daily. plus a rain gage, thermometer for water temp, and psychrometer for air temp and wet bulb temp. (cal'n reveal dewpoint T_d).

(B) ISI Standard pan:

→ In the enclosed figure, " ISI Standard pan has been sown". It is also known as modified Class A pan. Dimensions of the pan are Shown in fig.

→ It is placed in the vicinity of the Lake or reservoir to determine the evapouration of the Lake. " It is covered with wire mesh of GI to protect the water in the pan from birds". Pan is made of Cu sheet of 0.9mm thickness. The pan has a stilling well with a point gauge and thermometer.

→ Amount of water lost can be measured by the point gauge. water is added to bring it back to the Original level. readings are measured normally twice a day. The Annual pan Coefficient is 0.7.

⑧ <u>Estimation</u> of <u>evapouration</u> by <u>Meyer's formula</u>:

$$E_L = K_m (e_w - e_a)\left(1 + \frac{U_9}{16}\right) \quad \text{—— (2)}$$

Where,

E_L = lake evapouration (mm/day)

e_w = saturation vapour pressure at the water surface temparature (mm of mercury).

e_a = actual Vapour pressure of over laying air at a specified height (mm of mercury)

U_9 = monthly mean wind velocity (kmph) at a height of 9m above the ground.

K_m = co-efficient accounting for other factors (0.36 for large deep waters and 0.50 for small shallow lakes).

Mere Gabuji Thum se pyar karta hu

<u>Rohwer's equation</u>:

$$E = 0.771\,(1.456 - 0.000732\,P_a)\,(0.44 + 0.0733\,V)\,(e_s - e_a) \quad \text{—— (3)}$$

<u>Horton's equation</u>:

$$E = 0.4\left(2 - e^{-0.124V}\right)(e_s - e_a) \quad \text{—— (4)}$$

The values of E, e_s, e_a and V have the same significance has explained.

Lake mead's equation:

$$E = 0.0331\,V(e_s - e_a)(1 - 0.03(T_a - T_w)) \quad \text{— (5)}$$

here,

Ta and Tw are avg temp in °c of air and water surface respectively.

(*) Water Balance method:

Apply the water balance eq'n to the water body of interest over a time period Δt and solving the eqn for evaporation, E

$$E = W + SW_{in} + GW_{in} - SW_{out} - GW_{out} - \Delta V$$

W = precipitation on the lake

SW_{in} and SW_{out} = Inflows and outflows of surface water.

GW_{in} and GW_{out} = inflows and outflows of ground water.

ΔV = Change in the amount of stored in the lake during Δt.

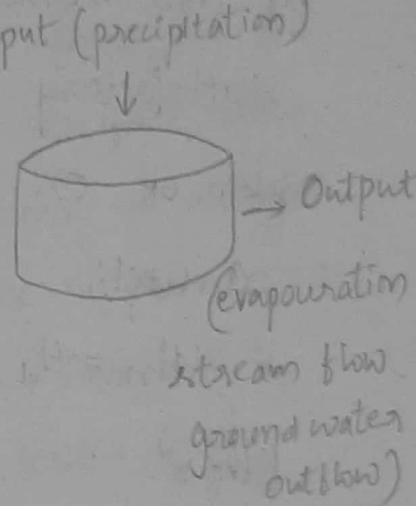
But,

→ Difficult to measure the terms.

→ large uncertainity in individual terms gives high uncertainity in E.

→ can however, give a rough estimate, in particular where E and Δt its relatively large.

Water budget:



Water balance eq'n

$$P - Q - E - \Delta s = 0$$

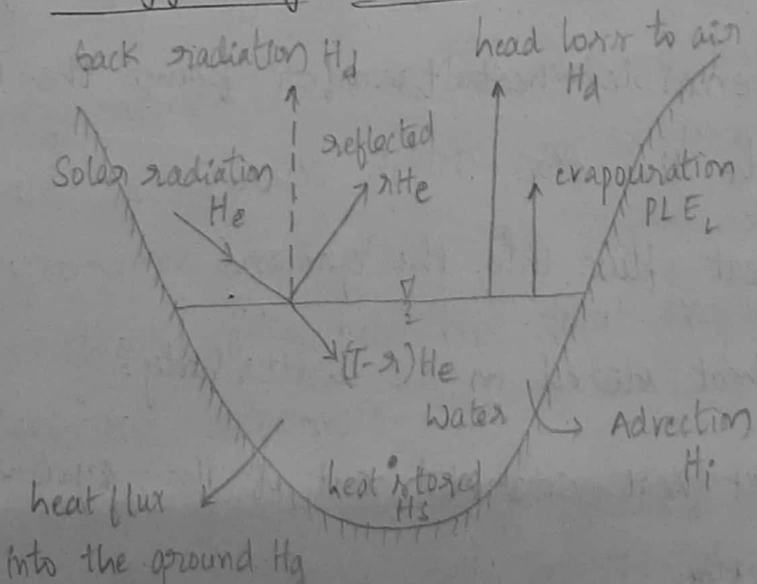
where, P = precipitation

Q = runoff

E = evapouration

Δs = Change in storage

④ Energy Budget method:



→ It involves application of the law of Conservation of energy.

→ Energy available for evapouration is,

determined by Considering the incoming energy, outgoing energy and water energy stored in the water body over a known time interval.

→ Estimation of evapouration from a lake by this method has been found to give satisfactory results, with errors of the order of 5%. when applied to periods less than a week.

$$H_n = H_a + H_e + H_g + H_s + H_i$$

Where,

H_n = net head energy received by the water surface $= H(1-r) - H_b$

H_b = back radiation from the water body

H_a = sensible heat transfer from the water surface to the air.

H_g = heat flux into the ground

H_s = heat stored in the water body.

H_i = net heat conducted out of the system by water flow

H_e = heat energy use up in evapouration

$= \rho L E_L$

L = latent head of evapouration

ρ = mass density of the fluid

(8) Evapouration Control method:

Min surface area: water is evapourated through the surface which interacts with the atmosphere. All factors remaining to be the same. if Choice is available between two possible sites for a reservoir, site in deep george, where for the same volume of storage, the surface area open to atmosphere is much less, is always preferrable compared to the one in plain areas where open surfaces are large. This will be considerably reduce the total water losses

Altitude of reservoir site: reservoir in mountainous georges at higher altitudes are preferably. firstly, the air and water surface temparatures will be low and is close vicinity. ∴ the saturation deficit will be less and evapouration rate from the waterbody will be less. This will reduce the total evapouration loss from the reservoir.

secondly, the surrounding high mountains act at wind barriers. Air in the absence of an efficient wind transport, gets saturated with evapourated moisture in the near vicinity of water surface. this reduces rate of evapouration and eventually the total water losses due to evapouration is reduced. contrary to it, in plain areas temp are expectedly more in tropical conditions and accordingly wind activity is intense. This promotes the evapouration rates and total loss of water due to evapouration.

Planning or underground reservoir:- If impounding of huge vol are not involved. as in case of municipal reservoirs, it may be desirable to plan ground water storage reservoirs. for these reservoirs interaction with open atmosphere is curtailed. No wind transport is available. Hardly any saturation deficit exists as the reservoir surface water temp. of small air above it remains sand and air remains completely saturated with moisture. loss of water due to evapouration is thus negligible.

Mechanical Covers: At the surface of water mechanical covers are provided which serve the purpose of a barrier b/w the water surface and the atmosphere. A wooden mesh or a mesh made out of interwoven bamboos have reportly given golden results. Near ten to fifteen % cut in evapouration loss has been reported through the use of such covers.

Thin film of Oils: Among all methods, use of thin film of oil has been found to be the most effective method in checking the loss due to evapouration. If the film of oil remains without break, the evapouration loss can be fully curtailed. However, desirability of its use is highly Questionable.

Use of Mono molecular layers: Under this head comes application of mono molecular layer of fatty acids and cetyl alcohol. The higher series of alcohols are found in solid state. When crushed and powdered they attain very small particle size almost close to molecular sized particle. Through special techniques when spread over the water surface, the powdered cetyle alcohol provides a near mono layer on the surface of water and provides a complete barrier b/w the water surface and the atmosphere. practical difficulty lies with the problem that the wind and wave action does not permit the spread and it accumulates in pockets of reservoir. This was tried in the case of AJI lake in gujarat and success was to the tune of 15 to 30% reduction in loss due to evapouration.

(7) Evapotranspiration :

ET is the Quantity of water transpired by the plants during their growth or retained in plant tissue, plus the moisture evapourated from the surface of the soil and the vegetation.

It accounts for the movement of water to the air from sources such as the soil, canopy interception and water bodies.

factors affecting Evapotranspiration :-

→ water availability - ET occurs only if water is available.

→ Energy availability - The more energy, the greater the rate of ET.

→ Wind speed higher the wind speed, greater will be rate of ET.

→ Humidity gradient - The rate and Quantity of water vapour entering into the atmosphere both become higher in dried air.

→ physical attributes of the vegetation - as vegetative cover, plant height and reflectivity surfaces, shape and area of the leaf

→ Soil characteristics - include its heat capacity, and soil chemistry and albedo.

Def:

potential evapotranspiration: PE is the rate at which ET would occur from a large area completely and uniformly covered with growing vegetation which has access to an unlimited supply of soil water and without advection or heat-storage effects.

(i.e., rate is dependent on the vegetation).

Actual evapotranspiration: AE is the rate at which ET occurs (i.e., describes all the processes by which liquid water at or near the land surfaces becomes atmospheric water vapour).

* factors affecting ET:

1. environmental factors
2. geographical factors
3. soil factors
4. plant & crop factors

1. Environmental factors:

→ colour of surface albedo :- lighter colours reflect heat away as there is less evapouration.

→ Temparature :- the warmer it is, more is ET.

→ wind speed

→ Humidity

→ water available.

2. plant & crop factors:

→ physical attributes of the plant

* vegetative cover
* leaf area index
* leaf shape & size
* Type of plant.

→ Stomatal resistance

plants regulate transpiration through adjustment of small openings in the leaves called stomata. As stomata close, the resistance of the leaf to loss of water vapour increases, decreasing to the diffusion of water vapour from plant to the atmosphere.

3. <u>Geographical factors:</u>

→ ET rates are also depending upon geography, an area's latitude and Climate.

→ Regions on the globe with the most solar radiation experience more ET.

→ ET rates are also highest in areas with a hot and dry Climate.

→ Evapouration is less at higher Latitude.

4. <u>Soil factors:</u>

→ Soil Characteristics:

* soil capillary character
* water table depth
* soil moisture content ↑ → ET ↑

When soil is lacking moisture, plants begin to transpire less water in an effort to survive, this is turn decreases ET.

Muje Mere

(*) Methods of Estimation of ET:

Estimation of ET

- Direct method
  - Lysimetry method
- Indirect method
  - Catchment water balance
  - energy balance.

Indirect method:

Catchment water balance:

ET may be Estimated by creating an equation of the water balance.

$$ET = P - \Delta S - Q - D.$$

P = precipitation

ΔS = Change in storage

Q = stream flow

D = groundwater recharge

ET = evapotranspiration.

Energy water balance:

The Actual ET is estimated by the energy balance.

$$\Delta E = R_n - G - H$$

ΔE = The energy needed to Change the phase of water from liquid to gas = ET.

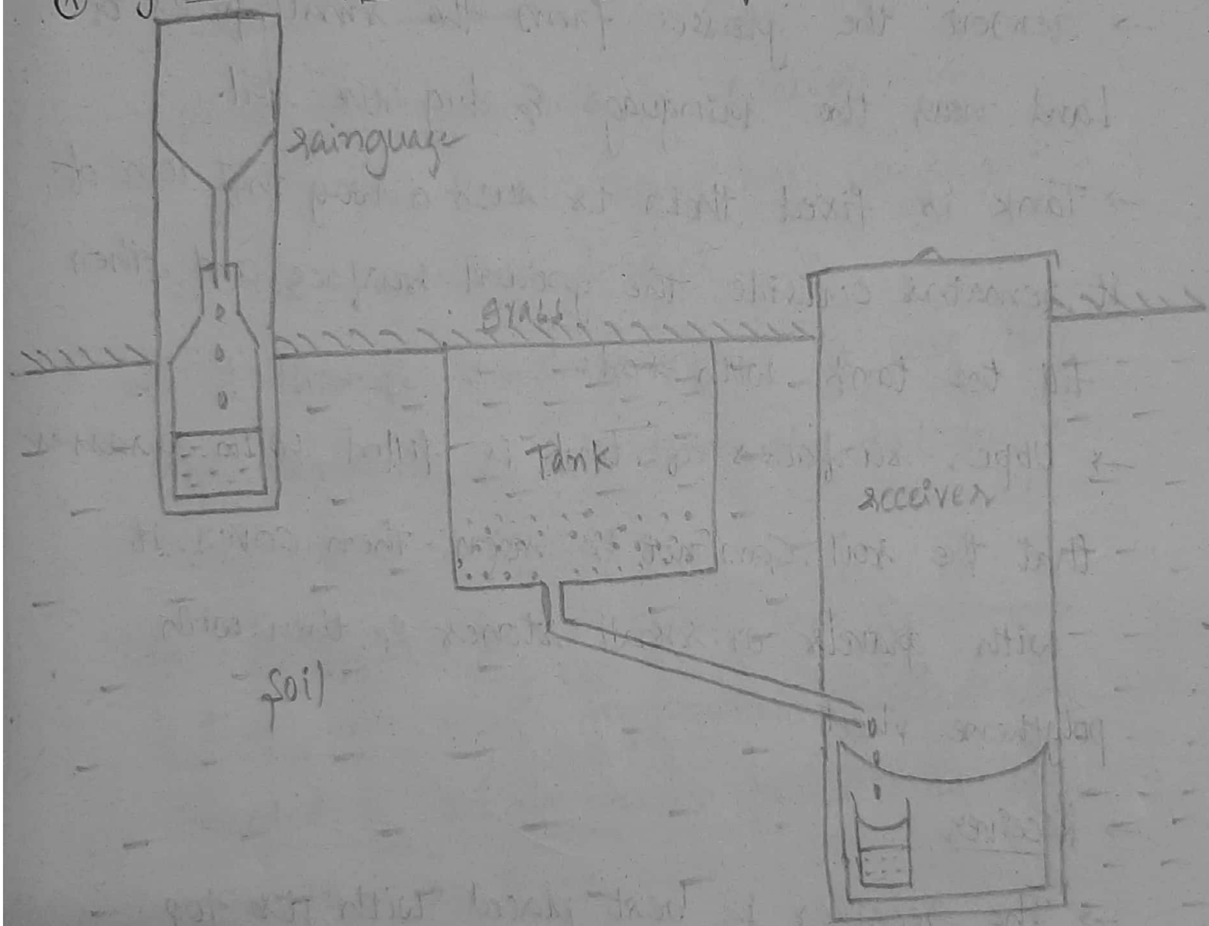
R_n = net radiation

G = soil heat flux

H = sensible heat flux.

⊛ ~~Using~~ ~~[illegible]~~ Direct method:-

⊛ lysimeter Apparatus for measuring ET:



A lysimeter is a measuring device which can be used to measure the amount of actual ET. which is released by plants, usually crops or trees. By recording the amount of precipitation that an area receives & the amount lost through the soil, the amount of water lost by evapotranspiration can be calculated.

Construction Method:

select a piece of ground

→ fix the rainguage for measuring the precipitation value in ml.

→ remove the grasses from the small pieces of Land near the rainguage & dug the soil.

→ Tank is fixed their is such a way that 10cm of it remains outside the ground surface and then fill the tank with soil.

→ Upper surfaces of tank is filled with grasses that the soil can not be seen. Then cover it with gravels or small stones & then with polythene sheet.

→ Receiver

→ The receiver is best placed with its top about 5cm above ground so that surface w.c enter.

→ pack soil around the Apparatus, relay turf and apply water to bed in the turf & settle the soil when construction is complete.

→ Measurements can begin in a few days, experiment may continue for few months or even for a year.

→ In dry season, add water to the experimental area but if the precipitation rate is sufficient, no need of water.

ET = water added – percolated water.

Significance of ET:

→ plays a major role in precipitation

→ It is the most significant component of the hydrologic budget.

→ A through knowledge of ET is very Imp for planning & adjusting the distribution of water resources

→ Managers of the crops can determine that how much supplemental water is needed to achieve max productivity by estimating P.E & AE.

⊛ Infiltration:

* The process of entering rain water into soil strata of earth is called INFILTRATION.

* The infiltrated water first meets the soil moisture deficiency if any & excess water moves vertically downwards to reach the groundwater table. This vertical movement is called PERCOLATION.

Infiltration Capacity:

The Infiltration Capacity of soil is defined as the max rate at which it is capable of absorbing water and is denoted by f.

If $i \geq f$ then $f_a = f$ (depend upon soil capacity)

If $i < f$ then $f_a = i$ (depend upon rainfall intensity)

Where,

f_a = actual Infiltration Capacity

f = Infiltration capacity

i = rate of rainfall.

→ for Dry soil - (Infiltration rate) f is more

Moist soil - f is less

→ Max rate of water absorption by soil – f

→ Max capacity of water absorption by soil - field capacity.

Infiltration rate:

→ The rate at which soils is able to absorb rainfall or irrigation

→ It is measured in (mm/hr) or (inches/hr)

→ Infiltrometer is used for measurement of infiltration.

→ If (i>f) runoff occurs

→ Infiltration rate is connected to hydraulic conductivity.

Hydraulic Conductivity:

It is ability of a fluid to flow through a porous medium.

It is determined by the size and shape of the pore spaces in the medium & viscosity of fluid.

(OR)

It is expressed as the volume of fluid that will move in unit time under a unit hydraulic gradient through a unit area measured ⊥le to the direction of flow.

* factors affection Infiltration Capacity :-

→ Slope of the Land: The steeper the slope (gradient) the less the infiltration (or) seepage.

→ Degree of saturation: The more saturated the loose earth materials are, the less the infiltration.

→ porosity: Porosity is the % of open space (pores and cracks) in a earth surface. The greater the porosity, the greater the amount of infiltration.

→ Compaction:- The clay surfaced soils are compacted even by the impact of rain drops which reduce infiltration. This effect is negligible in sandy soils.

→ Surface cover Conditions:

Vegetation: Grasses, trees and other plant types capture falling precipitation on leaves and branches, keeping that water from being absorbed into the earth & take more time to reach in to the ground. More the vegetation SLOWER the infiltration.

→ Land Use:

Roads, parking ~~pots~~ lots, and buildings create surfaces that are not longer permeable. Thus infiltration is less.

→ Temparature: At high temp. viscosity decreases and infiltration increases.

Summer — infiltration ↑ increases.
Winter — infiltration ↓ Decreases.

→ Other factors:

entrapped air in pores: entrapped air can greatly affect the hydraulic conductivity at or near saturation.

Quality of Water: Turbidity by Colloidal water.

Freezing: freezing in winter may lock pores.

Annual & Seasonal Changes: According to Change in Land use pattern. except for massive deforestation & agriculture.

(*) Measurement of Infiltration:

Infiltrometer: It is a device used to measure the rate of water infiltration to the soil.

Horton's eq'n:

$$f(t) = f_c + (f_0 - f_c)\, e^{-kt}$$

Where,

f_t = Infiltration Capacity (inches/hr)

f_c = min infiltration Capacity

f_0 = initial infiltration Capacity

t = time since the start of rainfall

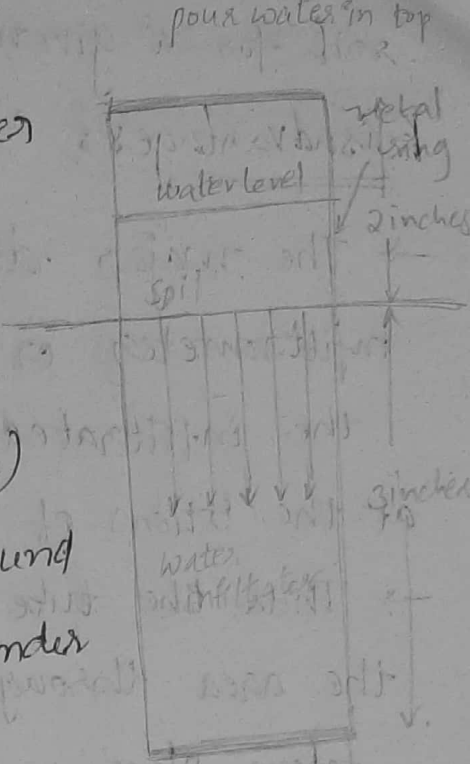
k = constant depending upon soil type & Vegetable cover.

Note: f_c is directly depend upon hydraulic conductivity.

Type of Infiltrometer

- flooding type infiltrometer
  - single ring infiltrometer
  - double ring infiltrometer
- rainfall simulators

⊛ Single ring Infiltrometers:



→ This consist of metal cylinder of dia 25 to 30cm and length of 50cm to 60cm with both ends open.

Length of cylinder = (2×dia)

→ It is driven into a level ground such that about 10cm of cylinder is above the ground.

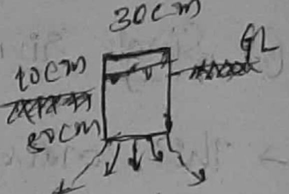
→ water is poured into the top apart to a depth of 5cm & pointer is set inside the ring to indicate the water level to be maintained.

→ The single ring involves driving a ring into the soil and supplying water in the ring either at constant head or falling head condition.

⊛ constant head refers to condition where the amount of water in the ring is always held constant means the rate of water supplied corresponds to the Infiltration Capacity.

* falling head refers to Condition where the water is supplied in the ring and the water is allowed to drop with time. The Operator records how much water goes into the

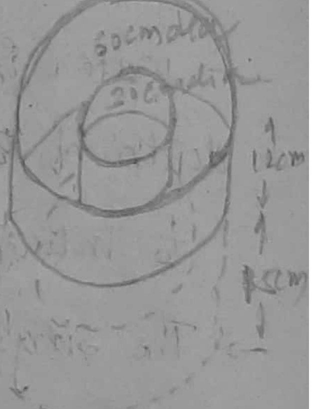
soil for a given time period.



Disadvantages:

→ The major drawback of the single ring infiltrometer or tube infiltrometer is that the infiltrated water percolates Laterally at the bottom of the ring.

→ Thus the tube is not truly representing the area through which infiltration is taken place



* Double ring Infiltrometer:

→ This is most Commonly used flooding type infiltrometer

→ It consists of two concentric rings driven into soil uniformly without disturbing the soil to the least of to a depth of 15cm. The dia of rings may vary between 25cm to 60cm.

→ An inner ring is driven into the ground, and a second bigger ring around that to help control the flow of water through the first ring. water is supplied either with a Constant or falling head condition, and the operator records how much water infiltrates from the inner ring into the soil over a given time period.

Chapter-03

Runoff: It is the process of moving water on the ground surface.

runoff is classified into three types.

They are

1. surface runoff
2. sub surface runoff
3. Base flow or groundwater flow

Basic terms used in hydrology:

Basin: A basin also called a drainage basin, Catchment or watershed is the area bounded by the highest contour called ridge line from where precipitated water is collected by surface and subsurface flows and drained out through a natural stream or river. The adjacent basins are divided by ridge lines. The total area of the basin is known as Catchment area.

Stream: Stream is a natural flow Channel towards which the water from a basin flows.

Overland flow: Overland flow is the portion of rainwater which flows over the land surface in the form of sheet of water to join the nearest stream.

Surface runoff: Surface runoff is the part of precipitation and other drainage water of a basin which moves over the natural land surface and then through a network of channels of gradually large sections.

Stream flow: Stream flow are the total runoff consists of surface flow, subsurface flow, GW flow and the flow due to precipitation falling directly on the stream.

Drainage density: (D_d)

It is defined as the ratio of the total length of all streams of the catchment divided by its area.

$$D_d = \frac{L_s}{A}$$

Where,

L_s is the total length of all streams in a basin

A = drainage area of basin.

Stream density: (D_s)

It is defined as the no. of streams of given order per km^2 of the catchment area.

$$D_s = \frac{N_s}{A}$$

Centroid of the basin: It is the point of weight centre of watershed.

form factor:-

It is the ratio of watershed area to the square of its length.

~~form fact~~

Compactness coefficient:-

It is the ratio of perimeter of the basin to the circumference of a circle whole area is the area of basin.

$$C_c = \frac{P}{\sqrt{4\pi A}}$$

Elongation ratio:

It is the ratio of diameter of a circle of the same area of the basin to the man length of the basin.

Circularity ratio:

It is the ratio of the ~~bas~~ area of the basin to the area of the circile having the same perimeter as the basin.

Factors affecting runoff:

runoff rate and Volume from an area are mainly inf

1. Climate factors
2. physiographic factors.

A. Climate forms:

rainfall Characteristics:

1. forms of Precipitation:-

It has great effect on the runoff. eg: A precipitation which occurs in the form of rainfall starts immediately as surface runoff depending upon rainfall intensity while precipitation in the from of snow doesn't result in surface runoff.

2. Rainfall Intensity:

If the rainfall intensity is greater than infiltration rate of soil runoff starts Immediately after rainfall.

While in case of Low rainfall intensity runoff starts Later.

Thus high intensities of rainfall yield higher runoff.

3. Duration of rainfall:

It is directly related to the volume of runoff because infiltration rate of soil decreases with duration of rainfall.

Therefore medium intensity rainfall even results in considerable amount of runoff if duration is longer.

4. Rainfall Distribution:

Runoff from a watershed depends very much on the distribution of rainfall.

It is also expressed as "distribution coefficient".

Near the outlet of watershed, runoff will be more.

5. Direction of Prevailing wind:

If the direction of prevailing wind is same as drainage system, it results in peak flow.

A storm moving in the direction of stream slope produce a higher peak in shorter period of time than a storm moving in opp. direction.

6. Other Climate factors:

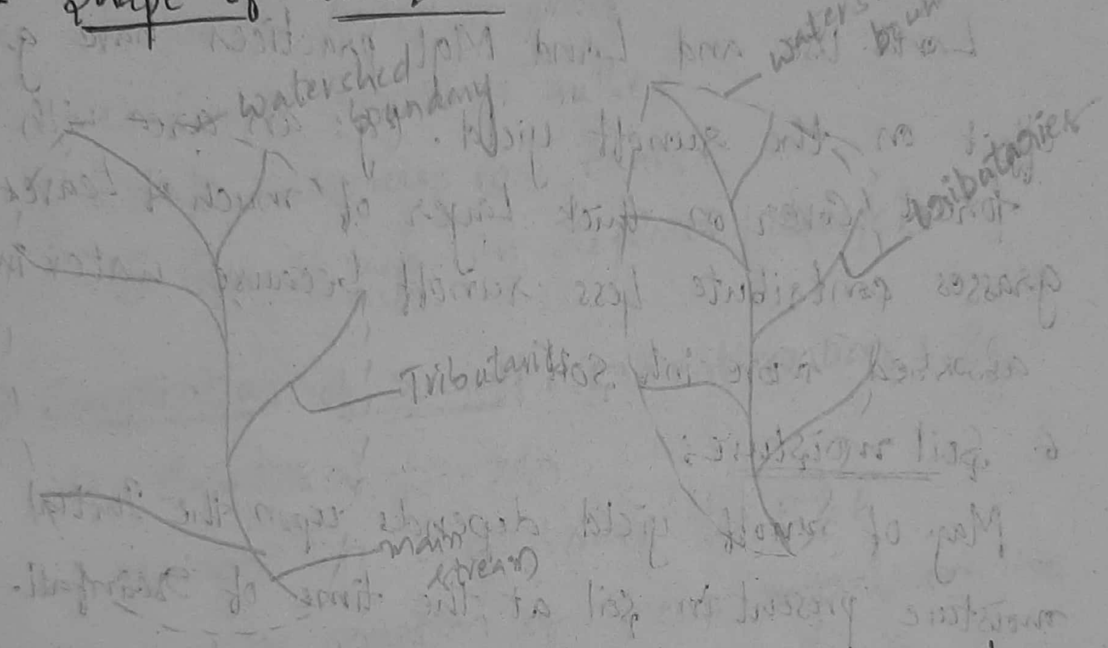
Other factors such as temp wind velocity, relative humidity, annual rainfall etc, affect the water losses from watershed area.

B) Physiographic factors:

1. size of watershed:

A Large watershed takes Longer time for draining the runoff to outlet than smaller watershed and Vice-versa.

2. Shape of watershed:



runoff is greatly affected by shape of watershed. Shape of water shed is generally expressed by the term "form factor" and

3. Slope of watershed: It has complex effect. It controls the time of overland flow and time of concentration of rainfall. Eg: sloppy watershed results in greater runoff due to greater run-off Velocity and Vice-Versa.

4. Orientation of Watersheds:
This affects the evapouration and transpiration losses from the area. The North and South Orientation, effects the time of melting of collected snow.

5. Land Use:
Land Use and Land Mgt practices have great effect on the runoff yield. Eg: an area with forest cover on thick layer of much of Leaves and grasses contribute Less runoff because water is absorbed more into soil.

6. Soil moisture;
Mag. of runoff yield depends upon the Initial moisture present in soil at the time of rainfall.
If the rain occurs after along dry spell then infiltration rate is more, hence it contributes less runoff.

7. Soil type:
Infiltration rate vary with type of soil. So runoff is great affected by soil type.

8. Topography characteristics:
It includes those topographic features which affects the runoff.
Undulating land has greater runoff than flat Land.

9. **Drainage Density:**

Greater drainage density gives more runoff.

10. **Storage Characteristics:**

a) Depressions
b) stream
c) Channels
d) Ponds, Lakes & pools
e) Check dams in gullies
f) u/s reservoirs (or) tanks
g) GW storage in deposits / aquifers.

⊛ **Computation of runoff: (or) estimation: By**

(i) Empirical formula

→ straight line regression b/w P & R.

The equation of linear regression line between observed values of R and P is

$$R = ap + b$$

Where,
a and b are constants representing obstructions.

The values of a and b are given by the following equations

$$a = \frac{N(\Sigma PR) - (\Sigma P)(\Sigma R)}{N(\Sigma P)^2 - (\Sigma P)^2}$$

$$b = \frac{\Sigma R \& \Sigma P}{N}$$

co-efficient of correlation

$$\gamma = \frac{(\Sigma PR)N - (\Sigma P)(\Sigma R)}{\sqrt{\left(N(\Sigma P^2) - (\Sigma P)^2\right) \times \left(N(\Sigma R^2) - (\Sigma R)^2\right)}}$$

→ exponential regression between P and R.
for large catchments it is advantages to use the following exponential relationship.

$$R = \beta P^m$$

Where,
β and m are constants.

$$\log_e R = m \log_e P + \log_e \beta$$

Runoff coefficient

The runoff and rainfall can be inter-related by runoff Coefficient by the expression

$$R = KP$$

where,
R is the runoff in cm
P is the rainfall in cm.
K is the runoff coefficient.

The runoff Co-efficient depends upon all the factors which effects the runoff. This method is used for small water control projects. The values of K are given below.

area	'K' values
→ urban residentials single houses and garden apartments	0.3, 0.5
→ commercial and Industrial.	0.9
→ forest areas depending on soil.	0.05 to 0.2.
→ farm land, parks	0.05 to 0.3.
→ Asphalt or concrete pavements	0.85

⊗ Barlow's Table: studied under 140 km^2 in the united province

Class	Description of catchment	runoff percent.
A.	flat, cultivated & black cotton soil	10
B.	flat partly cultivated various soils	15
C.	Average	20
D.	Hills and plains with cultivation	35
E.	very ~~high~~ hill & steep, with hardly any cultivation	45

The above values of runoff percentages are for avg monsoons. These are to be multiplied by the following coefficients according to the nature of season.

Barlow's co-efficient:

Nature of season	Class of Catchment A	B	C	D	E
1. light rain upto 25 mm/day no be any damper	0.7	0.8	0.8	0.8	0.8
2. Avg (or) varying rainfall (25–75 mm/day) no continuous damper.	1.0	1.0	1.0	1.0	1.0
3. Continuous dampers 75 mm/day	1.5	1.5	1.6	1.7	1.8

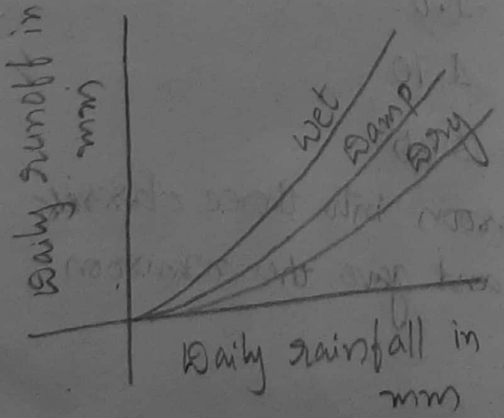
Strange's table & curves

strange gave tables and curves for runoff resulting from rainfall in the plains of south India.

The following tables & graphs are for the konkan region of Maharastra.

These curve & tables give runoff for daily rainfall and taken into account three types of Catchments (good, avg, bad) and three surface conditions (dry, damp, wet) prior to the rain.

Daily runoff	runoff % of yield when the original state of ground					
	Dry		Damp		Wet	
	%	yield (mm)	%	yield (mm)	%	yield
6.25	–	–	–	–	8	0.5
12.5	–	–	6	0.75	12	1.5
18.75	–	–	8	1.50	16	3.0
25	3	0.75	11	2.75	18	4.5
31.25	5	1.56	14	4.39	22	6.88
37.5	6	2.25	16	6.00	25	9.37
43.75	8	3.5	19	8.31	30	13.1
50	10	5.0	22	11.00	34	17.0
62.5	15	9.37	20	18.15	43	26.9
75	20	15.00	37	27.75	55	41.25
100	30	30.00	50	50.00	70	70.00



Ingli's formula:

Derived from Data Collected from 37 catchments.

→ Ghat areas (western ghats)

$$R = 0.85P - 30.5 \quad (R \,\&\, P \text{ are in cm})$$

→ Non ghat areas (plain region)

$$R = 0.00394P^2 - 0.0701P \quad (R \,\&\, P \text{ are in cm})$$

(iii) Lacey's formula:

$$R = \frac{P}{1 + \left(\frac{304.8F}{PS}\right)} \quad (R \,\&\, P \text{ are in cm})$$

Where,

S = Catchment factor

F = monsoon factor

Class of Catment	Values of S
for class A	0.25
B	0.60
C	1.0
D	1.70
E	3.45

Lacey also divide the monsoon into three classes depending upon its duration and gave the monsoon duration factors.

class of mansoon	'F' value
Very short	0.50
standard Length	1.0
very long	1.50

(iv) **Khosla's formula:**

$$R_m = P_m - 0.48\ T_m$$

R_m is the monthly runoff in cm

T_m = mean temp in °c on the entire catchment

P_m = monthly precipitation in cm

(v) **ICAR formula:**

$$R = 1.511\ (P^{1.44})\ (T_m^{-1.34})\ (A^{-0.0613})$$

A is the watershed area in km^2

(vi) RAIR Ahuja and Majundar formula:

$R = 120P - 4945$ (rajasthan) Chambal

$R = 435P - 17200$ (Gujarat) (Tapi)

$R = 13400P - 5750000$ (Bengal)

$R = 234.6P - 1510$ (M.P) Tawa

$R = 1318P + 86$ (A.P)

UP Irrigation rearearch Institute formula

$R = 5.45\ P^{0.06}$ (for ganga, Haridwar)

$R = 0.35\ P^{1.1}$ (Tejawala)

$R = 2.7\ P^{0.8}$ (sarda at Banabasa)

Measurement of runoff: (in streams, rivers (or) any water bodies)

River discharge, the volume flow rate through a river cross section, is perhaps the most important single hydrologic Quantity.

Measurements of river discharge are required for flood hazard mgt, water resource planning, climate and ecology studies, and compliance with transboundary water agreements.

~~the discharge~~

Stream flow measurement:-

It techniques can be broadly classified into two categories as

(i) direct determination

(a) area-velocity methods

(b) Dilution techniques

(c) Electromagnetic methods

(d) Ultrasonic methods

(ii) Indirect determination of stream flow:

(a) Hydraulic structures, such as wiers, flumes and gated structures.

(b) slope-area method,

Barring a few exceptional cases, continuous measurement of stream discharge is very difficult to obtain.

As a rule, direct measurement of discharge is a very time-consuming and costly procedure. Hence a two step procedure is followed.

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first, the discharge in a given stream is related to the elevation of the water surface (stage) through a series of careful measurements.

In the next step the stage of the steam is observed routinely in a relatively inexpensive manner and the discharge is estimated by using the previously determined stage - discharge relationship.

The observation of the stage is easy, inexpensive, and if desired, continuous readings can also be obtained.

stage = depth of water

Stream Gauging:

stream gauging is the technique used to measure the volume of water flowing through a channel per unit time, generally referred to as discharge. stream discharge is determined by the relationship between stream velocity and channel area.

Quantifying the relationship between these variables allows continuous records of discharge to be estimated.

The first step towards this is the measurement of stage.

stage measurement and rating curves:-

stage describes the depth of water with in a channel & is quantified by the ht of water at a gauging site above an arbitrary datum.

The Velocity-area method:

The most common and direct method of estimating discharge is the velocity-area method. This technique requires measurements of stream velocity, Channel width and depth of water flow at a stream vertical section. The measurement of velocity in rivers is achieved using instruments such as current meters.

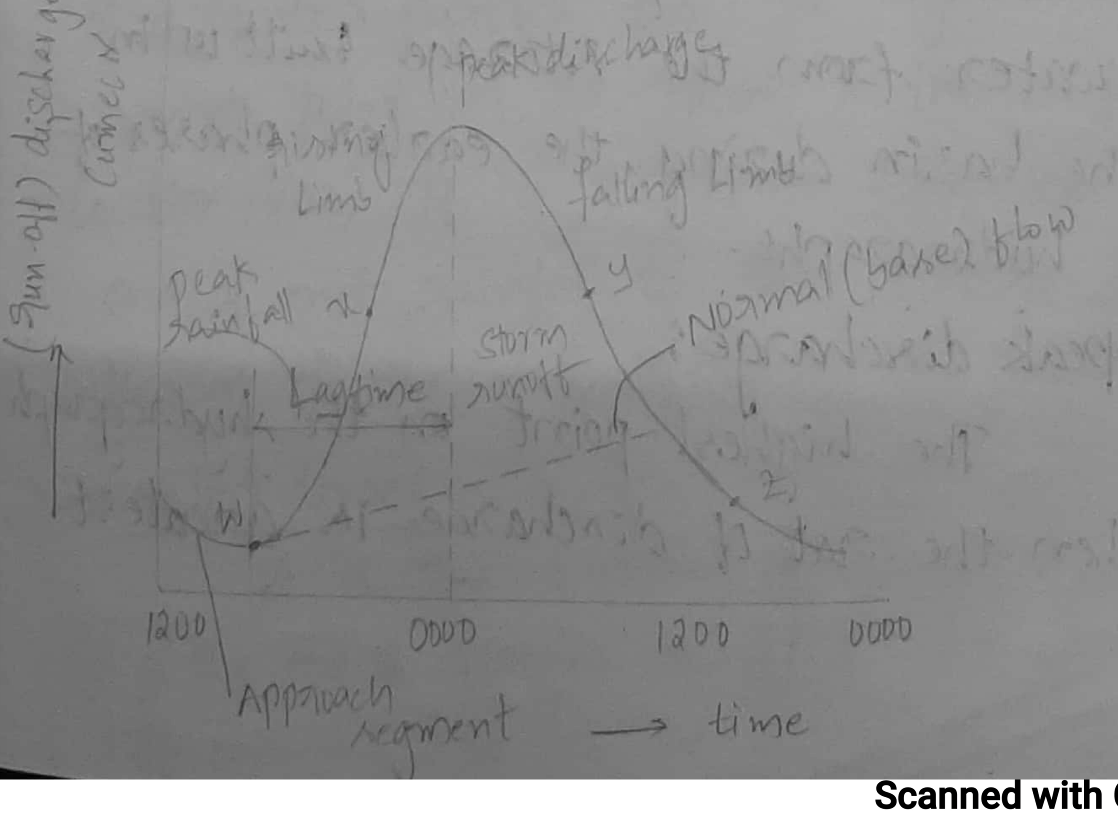
⊛ Estimation of runoff by hydrographs:

Hydrograph is a graphical representation between discharge Vs time. past a specific point in a river, or other channel or conduit carrying flow.

It can also refer to a graph showing the volume of water reaching a particular outfall.

purpose or uses of hydraphs drawing:

graphs are commonly used in the design of sewerage, more specifically, the design of surface water sewerage systems and combined sewers.



Components of a hydrograph:

1. rising Limb:

The rising Limb of hydro graph also known as concentration curve, reflects a prolonged increase in discharge from a Catchment area, typically in response to a rainfall event.

2. falling Limb or recession Limb:

The recession Limb extends from the peak flow rate onward. The end of stormflow and the return to gw derived flow is often taken as the point of inflection of the recession Limb. The recession Limb represents the withdrawal of water from the storage built up in the basin during the earlier phases of the hydrographs.

3. peak discharge:

The highest point on the hydrograph when the rate of discharge is greatest.

4. Lag time:- The time interval from the centre of mass of rainfall excess to the peak of the resulting hydrograph.

5. Time to peak: Time interval from the start of the resulting hydrograph.

6. Discharge:- The rate of flow passing a specific location in a river or other channel.

Effective time Duration:

It is the net duration of precipitation during which rainfall rates are more than infiltration rates.

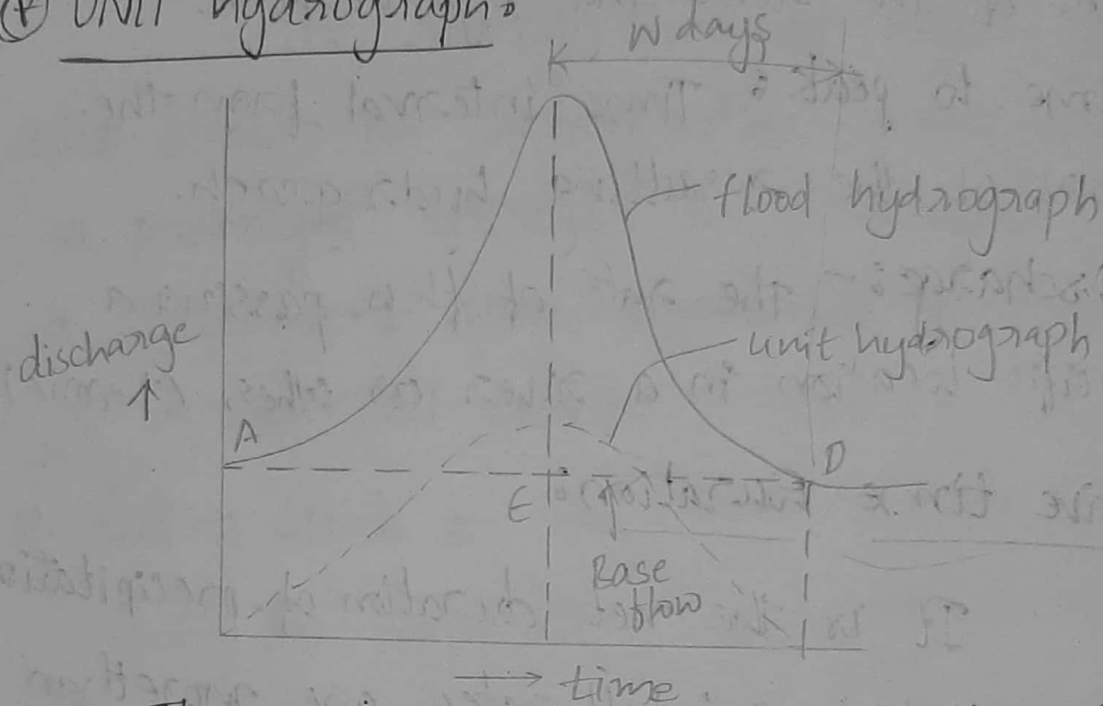
Time of Concentration:

It is defined as the travel time of a water particle from the hydraulically remote point in the Basin to the outflow location. (or) It is the time from the end of net rainfall to the point of inflection of the falling limb in the hydrograph

Recession time:

It is the Duration of Direct runoff after the end of effective rainfall duration. It is the difference in time b/w the end of effective rainfall & Lowest point of the recession Limb.

⊛ UNIT hydrograph:



→ The amount of runoff resulting from 1unit (1cm, 1mm, 1ft etc.) of rainfall excess.

→ is essentially a tool for determining the Direct runoff response to rainfall.

→ Once you know the watershed's response to one storm, you can predict what its response for Another will Look like.

⊛ Basic Assumptions of UH:

1. The effective rainfall is uniformly distributed with in its duration.

2. The effective rainfall is uniformly

distributed over the whole drainage basin.

3. The base duration of direct runoff hydrograph due to an effective rainfall of unit duration is

4. The ordinates of DRH are directly proportional to the total amount of DR of each hydrograph.

5. for a given basin, the runoff hydrograph due to a given period of rainfall reflects all the combined physical

① ⊛ Table below gives the time distribution of rainfall N plasting for 9 hours if the direct runoff is 9.3cm determine the index of the storm & time index of rainfall excess.

Time from start (hr)	1	2	3	4	5	6	7	8	9
Incremental rainfall in each hr (cm)	0.7	1.4	2.4	3.7	2.9	2.6	1.7	0.8	0.5.

Ⓐ Given data,

runoff = 9.3 cm

plasting = 9 hrs

$P = 0.7 + 1.4 + 2.4 + 3.7 + 2.9 + 2.6 + 1.7 + 0.8 + 0.5$

$= 16.7$ cm

$R = 9.3$ cm.

$$W_i = \frac{P-R}{t} = \frac{16.7-9.3}{9} = 0.82 \text{ cm/hr}$$

$P = 16.7 - (0.7 + 0.8 + 0.5) = 14.7$ cm

$$\phi_i = \frac{P-R}{t} = \frac{14.7-9.3}{6} = 0.9 \text{ cm/hr}$$

rainfall excess = 6 hrs

* Computation of direct runoff (or) rainfall excess from storm hydrograph:-

Procedure:

① find the Ordinates of storm hydrograph representing total discharge Q at a given time internal, say t hours.

② seperate the ground water flow. find the orginates of the base flow at the same time interval.

③ find the Ordinates of direct runoff by subtracting the Ordinates of base flow from total discharge Ordinates.

④ The direct run-off in depth of water (in cm) is found from the expression

$$\text{Direct runoff} = \frac{\text{Total Volume of direct runoff}}{\text{area of basin}}$$

$$= \left(\frac{(\Sigma O) \times t \times 60 \times 60}{A \times 10^6}\right) \times 100$$

Where,

$$= \frac{0.36 \times \Sigma O \times t}{A}$$

t = time interval b/w successive Ordinates in hr.

A = area of basin in sq. km

Q = discharge in cumecs

ΣO = sum of discharge Ordinates (direct runoff) in cumecs.

(1) The Ordinates of 3 hr storm hydrograph and its base flow are given below. find out direct runoff depth. A = 30 km²

Time	5	8	11	14	17	20	23
Ordinates of hydrograph in cumecs	14	25	51	65	54	28	14
Base flow in cumecs	14	12	11	10	11	13	14
O of Direct runoff	0	13	40	55	43	15	0

ΣO = 166

(A) Ordinates of direct runoff

= Total discharge Ordinates − Base flow.

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The Direct runoff depth

$$= \frac{(\Sigma 0) \times t \times 0.36}{A}$$

$$= \frac{166 \times (3) \times 0.36}{30}$$

$$= 5.976 \text{ cm}$$

(*) Construction of Unit hydrographs:

(2) A 12hrs storm rainfall has the following depth in cm for each hr occuring over a basin

depth 1.8 2.6 7.8 3.9 10.6 5.4 7.8 9.2 6.5 4.4 1.8 1.6

the surface R resulting from the above storm is found to be 24.4cm depth over the basin. Determine the avg infiltration index for the basin.

(A) Given $t = 12$ hr

$R = 24.4$

$p = 63.4$ cm

$$W_i = \frac{P - R}{t} = \frac{63.4 - 24.4}{12} = 3.25 \text{ cm/hr}$$

$$P = 63.4 - (1.8 + 1.8 + 1.6 + 2.6)$$

$$= 55.6$$

$$\phi_i = \frac{55.6 - 24.4}{8} = 3.9 \text{ cm/hr.}$$

(3) A storm with 15 cm precipitation produced a direct runoff of 8.7cm the time distribution of the storm is follows.

Time from start (hr)	1	2	3	4	5	6	7	8
Incremental rainfall in each hr (cm)	0.6	1.35	2.25	3.45	2.7	2.4	1.5	0.75

(A) $R = 8.7\,cm$

$P = 15\,cm$

$$W_i = \frac{P-R}{t}$$

$$= \frac{15-8.7}{8} = 0.787\ cm/hr$$

$$P = 15-(0.6+0.75) = 13.65\,cm$$

$$\phi_i = \frac{15-8.7}{6} = 1.05\ cm/hr$$

(4) Table below gives the Observed Values of yearly precipitation & corresponding yearly runoff for a catchment for 16yrs & develop a linear correlation eq'n b/w P&R.

year	P(cm)	PR	R(cm)	P^2
1970	70.2	1691.82	24.1	4928.04
1971	70.1	1591.27	22.7	4914.01
1972	73.3	1876.48	25.6	5372.89
1973	42.5	480.25	11.3	1806.25
1974	81.3	2308.92	28.4	6609.69
1975	50.6	642.62	12.7	2560.36
1976	52.9	708.86	13.4	2798.41
1977	59.4	932.58	15.7	3528.36
1978	60.3	976.86	16.2	3636.09
1979	64.3	1138.11	17.7	4134.49
1980	68.8	1320.96	19.2	4733.44
1981	56.7	844.83	14.9	3214.89
1982	77.2	1960.88	25.4	5959.84
1983	40.5	429.3	10.6	1640.25
1984	44.1	515.97	11.7	1944.81
1985	65.5	1172.45	17.9	4290.25
	$\Sigma P = 977.7$	$\Sigma PR = 18592.16$	$\Sigma R = 287.5$	$\Sigma P^2 = 62072.07$

$$a = \frac{N(\Sigma PR) - (\Sigma P)(\Sigma R)}{N(\Sigma P^2) - (\Sigma P)^2}$$

$$a = \frac{16(18592.16) - (977.7)(287.5)}{16(62072.07) - (62072.07)}$$

$a = 0.43$

$$b = \frac{\Sigma R - a\Sigma P}{N}$$

$$= \frac{287.5 - (0.43)(977.7)}{16}$$

$$b = -8.3$$

$$R = ap + b$$

$$= 0.43(977.7) + (-8.3)$$

$$\boxed{R = 25.75}$$

* Construction of Unit hydrograph:

1. from the past records, select some unit period of intends rainfall direction corresponding to an isolated storm uniformly distributed over the aired.
2. from the past records at the river discharge for that storm, plot the storm hydrograph for some days before & after the period of rainfall of that Unit hyduration.
3. By the method indicated in seperate the GW flow from the Direct runoff.

4. Subtract the Ordinates of baseflow from the total Ordinates, find the Ordinates of direct runoff.

5. Cal direct runoff, n (in cm) by the expression.

$$n = \frac{0.36\,(\Sigma O)\,t}{A} \text{ in cm.}$$

6. Cal the Ordinates of UH by the relation.

Ordinates of UH

$$= \frac{\text{Ordinates of direct runoff}}{\text{direct runoff } n \text{ in cm.}}$$

(*) A 2hr storm hydrograph of the ordinates and base flow are tabulated below. for a catchment of 25km². Derived ordinates of unit hydrograph.

14. Aug

Day	hour	Total discharge Q	Base flow cumecs	Ordinates of storm hydrograph	O of unit hydrograph
12. Aug	6	6	6	0	0
	8	8	6	2	0.08
	10	10	5.5	4.5	0.19
	12	16	5	11	0.46
	14	28	4.5	23.5	0.99
	16	42	4.0	38	1.60
	18	60	3.5	56.5	2.38
	20	80	3.0	77	3.25
	22	110	2.5	107.5	4.54
13. Aug	24	100	2.5	97.5	4.12
	2	90	2.5	87.5	3.69
	4	80	3.0	77	3.25
	6	68	3.0	65	2.74
	8	56	3.5	52.5	2.21
	10	45	3.5	41.5	1.75
	12	35	4.0	31	1.31
	14	26	4.0	22	0.93
	16	18	4.5	13.5	0.57

	18	11	4.5	6.5	0.27
	20	9	5.5	3.5	0.14
	22	8	5.5	2.5	0.10
14 Aug	24	7	5.5	1.5	0.06
	2	6	6.0	0	0
				~~820.5~~ 82.5	

$$n = \frac{0.36 \times \Sigma O \times t}{A}$$

Ordinates of Unit hydrograph

$$= \frac{\text{Ordinates of direct runoff}}{\text{Direct runoff depth } (n)}$$

$$n = \frac{0.36 \times 82.5 \times 3}{25} = 23.6$$

(*) $n = 8$.

Day	hour	O of unit hydrograph cumec ($\frac{SH}{n}$)	Base flow	O of direct ~~storm~~ ~~hydrograph~~ runoff	Total discharge
22. Aug	6	0	4	0	4
	9	0.12	3.5	0.96	4.46
	12	0.35	3.0	2.8	5.8
	15	0.88	2.5	7.04	9.54
	18	1.50	2.0	12	14
	21	2.80	1.5	22.4	23.9
	24	2.0	1.8	16	17.8
23. Aug	3	1.85	2.1	14.8	16.9
	6	1.53	2.4	12.24	14.64
	9	1.26	2.7	10.08	12.78
	12	0.84	3.0	6.72	9.72
	15	0.50	3.3	4	7.3
	18	0.35	3.6	2.8	6.4
	21	0.12	~~4.0~~ 3.8	0.96	4.76
	24	0	4.0	0	4

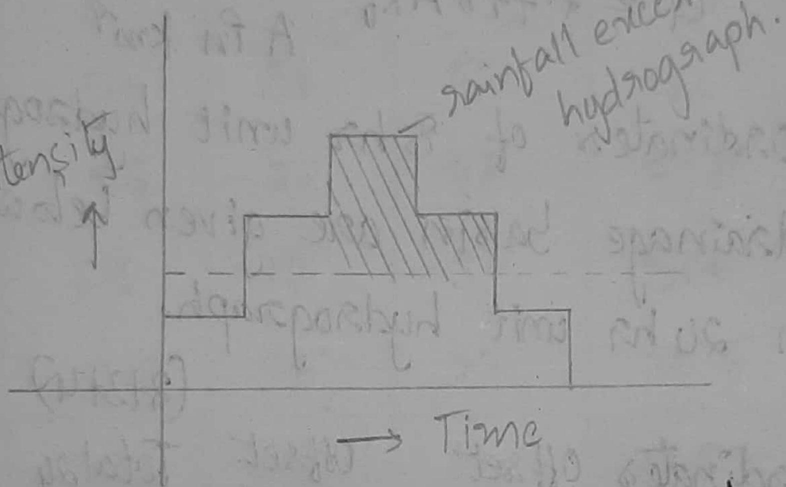
Ordinates of UH = $\frac{\text{SH (or) Direct runoff}}{n}$

Total discharge = base flow + Direct runoff

④ Effective rainfall hydrograph:- (ERH)

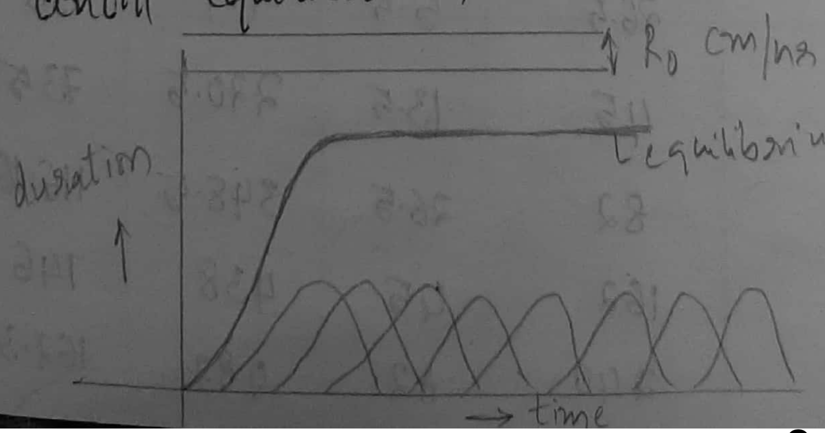
It is the hytograph which is obtained from deducting losses (initial loss and infiltration) from the hytographs.

It is also called as hyteograph of rainfall excess.



④ S-hydrograph: (or) summation hydrograph:-

S-hydrograph is a hydrograph i.e., produced by a continuous effective rainfall at a constant rate for indefinite period. It is in the form of S-curve and indicates continuous rising curve until equilibrium is achieved.



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at the time of Equilibrium it will
a constant rate of effective rainfall
R_0 cm/hr.

The effective runoff Q can be estimated by

$$Q = \frac{AR_0}{36} \quad \text{A in hect.}$$

$$Q = 2.778\, AR_0 \quad \text{A in km}^2$$

(*) The ordinates of 8 hr unit hydrograph for a drainage basin are given below. Obtain 24 hr unit hydrograph.

Time in hrs (1)	Ordinates of 8hr Unit hydrograph (2)	Offset ordinates for sec 8hr U.H (3)	Offset ordinates for third 8hr U.H (4)	Total 24 hr U.H Ordinates (5) (2+3+4)	Ordinates of 24hr UNIT hydrograph (6) (5)/3
0	0	–	–	0	0
4	5.5	–	–	5.5	1.83
8	13.5	0	–	13.5	4.5
12	26.5	5.5	–	32	10.67
16	45	13.5	0	58.5	19.5
20	82	26.5	5.5	114	38
24	162	45	13.5	220.5	73.5
28	240	82	26.5	348.5	116.16
32	231	162	45	438	146
36	165	240	82	487	162.33

40	112	231	162	505	168.33
44	79	165	240	484	161.33
48	57	112	231	400	133.33
52	42	79	165	286	95.33
56	31	57	112	200	66.67
60	22	42	79	143	47.66
64	14	31	57	102	34
68	9.5	22	42	73.5	24.5
72	6.6	14	31	51.6	17.2
76	4.0	9.5	22	35.5	11.83
80	2.0	6.6	14	22.6	7.53
84	1	4.0	9.5	14.5	4.83
88	0	2.0	6.6	8.6	2.86
92		1	4.0	5	1.67
96		0	2.0	2	0.66
100			1	1	0.33
104			0	0	0

⊛ find the Ordinates of a storm hydrograph resulting from a three hrs storm with a rainfall of 2, 6.75, & 3.75 cm during subsequent 3hr intervals. The Ordinates of 3hr unit hydrograph are given in the following table.

hrs	O of Unit Hydrograph
3	0
6	110
9	365
12	500
15	390
18	310
21	250
24	235
3	175
6	130
9	95
12	65
15	40
18	22
21	10
24	0

(A)

(i) rainfall Excess for the first 3hrs.

$$w_i = \frac{P-R-S_g}{t_e}$$

$$2.5 = \frac{20-R-5}{3}$$

$R = 0.75\text{cm}$

(ii) rainfall Excess for the second 3hrs

$$\phi_i = \frac{P-R}{t_e}$$

$$2.5 = \frac{6.75-R}{3}$$

$R = 6\text{cm}$.

(iii) rainfall Excess for the third (or) last 3hrs

$$\phi_i = \frac{P-R}{t_e}$$

$$2.5 = \frac{37.5-R}{3}$$

$R = 30\text{mm}$ (or)

$R = 3\text{cm}$.

Assume an intial loss of 5mm, infiltration index of 2.5 mm/hr & base flow of 10 cumec.

Time (hr)	O of Unit hydrograph (1)	rain fall Excess (2)	Surface runoff from rainfall excess during successive Periods				Base flow	storm hydrograph
			0.75	6	3	sum		
3	0	0.75	0	–	–	0	10	10
6	110	6	82.5	0	–	82.5	10	92.5
9	365	3	273.75	660	×	933.75	10	943.75
12	500		375	2190	0	2895	10	2905
15	390		292.5	3000	330	4387.5	10	4397.5
18	310		232.5	2340	1095	4072.5	10	4082.5
21	250		187.5	1860	1500	3217.5	10	3227.5
24	235		176.25	1500	1170	2606.25	10	2616.25
3	175		131.25	1410	930	2291.25	10	2301.25
6	130		97.5	1050	750	1852.5	10	1862.5
9	95		71.25	780	705	1376.25	10	1386.25
12	65		48.75	570	525	1008.75	10	1018.75
15	40		30	390	390	705	10	715
18	22		16.5	240	285	451.5	10	461.5
21	10		7.5	132	195	259.5	10	269.5
24	0		0	60	120	126	10	136
				0	66	30	10	40
					30	0	10	10
					0			

(*) find the Ordinates of a storm hydrograph resulting from a three hours - storm with a rainfall of 2, 6.75 & 3.75 cm during subsequent 3hrs intervals. The Ordinates of 3hr unit hydrograph are given in the following table. Assume $S_r = 5mm$; $W_i = 2.5 mm/hr$; Base flow =

(A) rainfall Excess for the 1^{st} 3hr

$$W_i = \frac{P - R - S_r}{t_e}$$

$$W_i = 2.5; \quad 2.5 = \frac{20 - R - 5}{3}$$

$$R = 0.75 cm$$

rainfall Excess for the 2^{nd} 3hr

$$\phi_i = \frac{P - R}{t_e}$$

$$2.5 = \frac{67.5 - R}{3}$$

$$R = 6 cm.$$

rainfall Excess for the last 3hr.

$$\phi_i = \frac{P - R}{t_e}$$

$$2.5 = \frac{37.5 - R}{3}$$

$$R = 30 mm \simeq 3 cm$$

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Time (hr)	O of Unit hydrograph	rain fall Excess	surface runoff from rain fall Excess during successive Period. 0.75	6	3	sum	Base flow	storm hydrograph
3	0	0.75	0	–	–	0	10	10
6	110	6	82.5	0	–	82.5	10	92.5
9	365	3	273.75	660	0	933.75	10	943.75
12	500		375	2190	330	2895	10	2905
15	390		292.5	3000	1095	4387.5	10	4397.5
18	310		232.5	2340	1500	4072.5	10	4082.5
21	250		187.5	1860	1170	3217.5	10	3227.5
24	235		176.25	1500	930	2606.25	10	2616.25
3	175		131.25	1410	750	2291.25	10	2301.25
6	130		97.5	1050	705	1852.5	10	1862.5
9	95		71.25	780	525	1376.25	10	1386.25
12	65		48.75	570	390	1008.75	10	1018.75
15	40		30	390	285	705	10	715
18	22		16.5	240	195	451.5	10	461.5
21	10		7.5	132	120	259.5	10	269.5
24	0		0	60	66	126	10	136
				0	30	30	10	40
					0	0	10	10

(*) A storm with 15.0cm Precipitation produces a direct runoff of 8.7 cms. The time distribution of the storm is as follows: Determine Infiltration Indices:

Time from start (hr)	1	2	3	4	5	6	7	8
Incremental rainfall in each hr (cm)	0.6	1.35	2.25	3.45	2.70	2.40	1.5	0.75

(A)

$P = 0.6 + 1.35 + 2.25 + 3.45 + 2.70 + 2.40 + 1.5 + 0.75$

$= 15\ cm$

$t = 8\ hr$

$R = 8.7\ cms$

$W_i = \frac{P-R}{t}$

$= \frac{15-8.7}{8} = 0.7875\ cm/hr$

$\phi_i = \frac{P-R}{t}$

$P = 15 - (0.6 + 0.75)$

$= 13.65\ cm$

$\phi_i = \frac{13.65 - 8.7}{6} = 0.825\ cm/hr$

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Derive a 9 hr UH for the given 6 hr UH:

Time (hr) (1)	'O' of 6 hr Unit hydrograph (2)	Offset Ordinate (3)	'O' of S-curve hydrograph (4)	'O' of offset S-curve (5)	Δy (6)=(5)-(4)	'O' of 9-hr S-hydrograph $O = \Delta y \times \frac{6}{9}$
0	0	–	0	–	0	0
3	9	–	9	–	9	6
6	20	0	20	–	20	13.33
9	35	9	44	0	44	29.33
12	49	20	69	9	60	40
15	43	44	27	20	67	44.66
18	35	69	104	44	60	40
21	28	87	115	69	46	0.85
24	22	104	126	27	39	26
27	17	115	132	104	28	18.66
30	12	126	138	115	23	15.33
33	9	132	141	126	15	10
36	6	138	144	132	12	8
39	3	141	144	138	6	4
42	0	144	144	141	3	2
		0	144	144	0	0
		0				

Chapter-04

Floods

* flood Overflow of excess water that submerged land & inflow of tide onto Land.
* most frequent & deadliest occurs when the geomorphic Equilibrium in the river system is disturbed because of
  → intrinsic threshold
  → Extrinsic threshold.

* Causes of flood:

Natural:

→ heavy rainfall

→ melting of ice during Volcano Eruption

→ Undersea earthQuake

→ marine landslip.

Manmade:

→ Bank Erosion

→ Break of dam / bridge / Embankment.

→ Improper maintainence of drainage system

⊛ Effects of flood:

Primary	secondary	Tertiary
↓	↓	↓
Due to direct contact of flood water	Due to result of primary effect	Due to Combine Effect of primary & secondary
physical damage	disruption of essential services	long term Effect

⊛ Flood Management:

Cannot be absolutely controlled only managed.

Aims of Flood management:

→ protection of people & property

→ reduction of flood risk

→ monitoring, research, fore casting & warning.

⊛ Estimation of flood discharge by Empirical formulas-

flood discharge is estimated by

$$Q = CA^{n}$$

Where, Q = flood discharge

A is the Catchment area
n is the flood index
C is the flood Coefficient.

The values of C & n are depend upon various factors such as

→ size, shape & location of Catchment area
→ Topography of the Catchment
→ Intensity & duration of rainfall
→ Distribution pattern of the storm over the basin.

(*) Dicken's formula :

$$Q = CA^{3/4}$$

Where, Q in cumecs
A in sq.km

The Constant 'c' depend upon the Catchment & may be Obtained from the following data.

Region	'C'
Northern India	11.4
Central India	13.9 to 19.5
Western India	22.2 to 25.

Ryves formula:

for madras Catchment

$$Q = CA^{2/3}$$

→ area with in 24 km from the coast the value of 'C' is 6.75.

→ area within 24 km to 161 km from the Coast the value of C is 8.45

→ The value of C is 8.45 limited areas near the hill C is 10.1

Inglis formula:

$$Q = 123\, A^{1/2}$$

applicable for catchment of former Bombay presidency.

Naval Jang Bahadur formula:-

for Catchment of Old hyderabad

$$Q = CA^{\left(0.993 - \frac{1}{14}\log A\right)}$$

Where,

C varies from 4.5 to 60

Fannings formula:

for American Catchment

$$Q = CA^{5/6}$$

avg value of 'C' may be taken = 2.54.

* **Creager's formula:**

Applicable for american Catchment Expressed in F.P.S units

$$Q_1 = 4.6\, C_1 A_1^{(0.8904 A_1^{-0.048})}$$

The constant varies from 30 to 100.

* **Fuller's formula:**

The formula takes into account the flood frequency also

$$Q_{max} = CA^{0.8}(1+0.8 \log T)(1+2.67A^{-0.3})$$

↓ metric units.

Where,

T = no. of years after which such a flood is to reccure

Q = max flood (in cm^3) during any part of day that could occur in T-years

A = area of drainage basin in km^2

C = Constant varying from 0.185 to 1.3.

⊛ flood frequency analysis :-

Gumbels distribution method :-

~~proce~~ It is used for Estimation of flood discharge for any return period.

procedure :-

step 1 : from the given data on flood peaks for 'n' years, the mean $\bar{x}$ & standard deviation S_x are computed from the following formula.

$$\text{Mean } \bar{x} = \frac{\Sigma x_i}{n}$$

$$\text{S.d } S_x = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (x_i - \bar{x})^2}$$

Step 2 : for the known sample size 'n', the values of $\bar{y}_n$ & σ_n are obtained from the reduced Extremes of Gumble's distribution table.

step 3 : for the given return period T_r the reduced varient y_T is found from the Eq'n

$$y_T = -\ln\left[\ln\left(\frac{T_r}{T_r - 1}\right)\right]$$

step 4 : with the values of $\bar{y}_n$ & σ_n obtained in step 2, and y_T obtained in step 3.

The frequency factor K_T is Calculated by the following formula

$$K_T = \left(\frac{y_T - \bar{y}_n}{\sigma_n}\right)$$

Step 5: with the Values of $\bar{x}$ & S_x Obtained in step 1 & K_T Obtained in step 4. The magnitude of flood Can be estimated by the following formula

$$x_T = \bar{x} + K_T S_x$$

(1)

(Q) The Observed Annual flood peaks of a stream for a period of 40 years from 1941 to 1980 in m^3/sec are given below.

395, 619, 766, 422, 282, 990, 705, 528, 520, 436, 697, 624, 496, 589, 598, 359, 686, 726, 527, 310, 408, 721, 814, 459, 440, 632, 343, 634, 464, 373, 289, 371, 522, 342, 446, 366, 699, 560, 450, 610.

Estimate the 100yr & 200yr flood.

(A) $n = 40$

Step 1: Mean $\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}$

$$\bar{x} = \frac{395+619+766+422+282+990+705+528+520+436+697+624+496+589+598+359+686+726+527+310+408+721+814+459+440+632+843+634+464+373+289+371+522+342+446+366+699+560+450+610}{40}$$

$\bar{x} = 530.45\ m^3/sec$

standard deviation (S_x):-

$$S_x = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i-\bar{x})^2}$$

$S_x = 160.80.$

Step 2: for $n = 40$ years

$\bar{y}_n = 0.54362$

$\sigma_n = 1.14132.$

Step 3: reduced Varient:

$$y_T = -L_n\left[L_n\left(\frac{T_r}{T_r-1}\right)\right]$$

for 100 years,

$$y_{100} = -\ln\left[\ln\left(\frac{100}{100-1}\right)\right]$$

$= +4.610$

for 200 years,

$$y_{200} = -Ln\left(Ln\left(\frac{200}{200-1}\right)\right)$$

~~-0.0025 ln~~ $y_{200} = 5.295$

step 4: frequency factor (K_T)

$$K_T = \frac{y_T - \bar{y}_n}{\sigma_n}$$

for $K_{100} = \frac{4.610 - 0.54362}{1.14132}$

$K_{100} = 3.5628$

for $K_{200} = \frac{5.295 - 0.54362}{1.14132}$

$= 4.163.$

step 5: Magnitude of flood :-

$x_{100} = \bar{x} + K_T S_x$

$x_{100} = 530.45 + 3.5628 \times 160.80$

$= 1103.34\ m^3/sec$

$x_{200} = 530.45 + 4.163 \times 160.80$

$= 1199.86\ m^3/sec$

(*) from the Analysis of Available data on annual flood peaks of a small stream for a period of 35 years, the 50yr & 100yr flood have been Estimated to be 660 m3/sec & 740 m3/sec using Gumbles method. Estimate the 200yr flood for the stream.

for 50years flood :-

$$x_T = 660 \, m^3/sec$$

$$x_T = \bar{x} + K_T S_x$$

$$K_{50} = \frac{y_T - \bar{y}_n}{\sigma_n}$$

$$y_{50} = -Ln\left[Ln\left(\frac{T_r}{T_r - 1}\right)\right]$$

$$= -Ln\left[Ln\left(\frac{50}{50-1}\right)\right]$$

$$y_{50} = 3.901$$

for 35 years ; $\bar{y}_n = 0.54034$

$$\sigma_n = 1.12847$$

$$K_{50} = \frac{3.901 - 0.54034}{1.12847}$$

$$K_{50} = 2.978$$

$$x_{50} = \bar{x} + K_T S_x$$

$660 = \bar{x} + 2.978 S_x$ —— ①

for 100 yrs flood:

$x_T = 740 \ m^3/sec$

$y_{100} = -L_n\left[L_n\left(\frac{100}{99}\right)\right]$

$= 4.600$

$K_{100} = \frac{4.600 - 0.54034}{1.12847}$

$= 3.597$

$x_{100} = \bar{x} + K_T S_x$

$740 = \bar{x} + 3.597 S_x$ —— ②

from Eq'n ① & ②

$660 = \bar{x} + 2.978 S_x$

$740 = \bar{x} + 3.597 S_x$

$- \quad - \quad -$

$-80 = -0.619 S_x$

$S_x = 129.240$ —— ③

sub Eq'n ③ in ①

$660 = \bar{x} + 2.978(129.240)$

$660 = \bar{x} + 384.87$

$\bar{x} = 275.123$

for 200 yr flood:

$$y_{200} = -\ln\left(\ln\left(\frac{200}{199}\right)\right)$$

$$= 5.295$$

$$K_{200} = \frac{5.295 - 0.54034}{1.12847}$$

$$= 4.213$$

$$x_{200} = \bar{x} + K_{200} S_x$$

$$= 275.123 + 4.213(129.240)$$

$$\boxed{x_{200} = 819.611\ m^3/sec}$$

(*) for a river the Estimated flood Peaks for 2 return periods by the use of gumbles method is given below:

return period (T)	peak flood
40	27,000
80	31000

Estimate the flood magnitude with a return period of 240 years.

(A)

$$x_{40} = \bar{x} + K_{40} S_x$$

$$27{,}000 = \bar{x} + K_{40} S_x. \quad \text{—— (1)}$$

$x_{80} = \bar{x} + K_{80} S_x$

$31{,}000 = \bar{x} + K_{80} S_x$ — (2)

from (1) & (2)

$31000 = \bar{x} + K_{80} S_x$

$27{,}000 = \bar{x} + K_{40} S_x$

$4000 = (K_{80} - K_{40}) S_x$ — (3)

$y_{40} = -\ln\left(\ln \frac{40}{39}\right)$

$= 3.676$

$y_{80} = -\ln\left[\ln\left(\frac{80}{79}\right)\right]$

$= 4.375$

$K = \frac{y_T - \bar{y}_n}{\sigma_n} \Rightarrow \frac{y_T}{\sigma_n} - \frac{\bar{y}_n}{\sigma_n}$

from (3)

$4000 = \left(\frac{y_{80}}{\sigma_n} - \frac{\bar{y}_n}{\sigma_n} - \frac{y_{40}}{\sigma_n} + \frac{\bar{y}_n}{\sigma_n}\right) S_x$

$4000 = \left(\frac{y_{80}}{\sigma_n} - \frac{y_{40}}{\sigma_n}\right) S_x$

$4000 = (4.375 - 3.676) \frac{S_x}{\sigma_n}$

$\frac{S_x}{\sigma_n} = 5722.460$ — (4)

for T = 240 yrs

$y_{240} = -\ln\left(\ln \frac{240}{239}\right)$

$= 5.478$

$x_{240} = \bar{x} + K_{240} S_x$ — (5)

from eq'n (5) & (2)

$x_{240} = \bar{x} + K_{240} S_x$

$x_{80} = \bar{x} + K_{80} S_x$

$(x_{240} - x_{80}) = (K_{240} - K_{80}) S_x$

$(x_{240} - x_{80}) = (y_{240} - y_{80}) \frac{S_x}{\sigma_n}$

$(x_{240} - 31000) = (5.478 - 4.375)\, 5722.460$

$x_{240} = 37311.87 \frac{m^3}{sec}$

(*) Log pearson type III distribution method:-

1. The given flood discharge to data series is converted into their logarithms.

2. The mean, S.deviation & the skewness coefficient of the y-series are Estimated by the following formula.

(i) $y_i = \log(x_i)$

(ii) $\bar{y} = \frac{\sum_{i=1}^{n} y_i}{n}$

$S_y = \sqrt{\frac{\sum_{i=1}^{n} (y_i - \bar{y})^2}{n-1}}$

$g = \frac{n \sum_{i=1}^{n} (y_i - \bar{y})^3}{(n-1)(n-2) S_y^3}$

3. for the given return period 'P_r' and the Estimated skewness coefficient 'g'. The value of 'K_T' is selected from the log pearson type III distribution table.

4. The log of the design flood is Calculated from $y_T = \bar{y} + K_T S_y$

5. The design flood its self is Obtained by $x_T = \text{antilog}(y_T) = 10^{y_T}$

① **step 1:** Logarithms values:-

2.596, 2.791, 2.884, 2.625, 2.450, 2.995,
2.848, 2.722, 2.716, 2.639, 2.843, 2.795,
2.695, 2.770, 2.776, 2.555, 2.836, 2.860,
2.721, 2.491, 2.610, 2.857, 2.910, 2.661, 2.643,
2.800, 2.535, 2.802, 2.666, 2.571, 2.460, 2.569,
2.717, 2.534, 2.649, 2.563, 2.844, 2.748,
2.653, 2.785.

step 2:

Mean $\bar{y} = \frac{\sum_{i=1}^{n} y_i}{n}$

$= 2.704$.

standard deviation

$S_y = \sqrt{\frac{\sum_{i=1}^{n} (y_i - \bar{y})^2}{n-1}}$

$= 0.132$.

skewness coefficient

$g = \frac{n \sum_{i=1}^{n} (y_i - \bar{y})^3}{(n-1)(n-2) S_y^3}$

$= -0.034$

step 3:

for $g = -0.034$

$T = 100yr$

Table-14.4: recurrence Interval $T = 100yr$

g	T	K
~~0~~	~~25~~	~~1.751~~
~~-0.1~~	~~50~~	~~1.716~~ 1.716
~~-0.034~~	~~40~~	?

g	K
0	2.326
-0.1	2.252
-0.034	$2.326 - \frac{(-0.034-0)}{(-0.1-0)}(2.326-2.252)$

$K_{100} = 2.300$

reccurence interval $T = 200yr$

g	K
0	2.576
-0.1	2.482
-0.034	$2.576 - \frac{(-0.034)}{(-0.1)}(2.576-2.482)$

$K_{200} = 2.544$

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step4: Logarithm of the design flood :-

$$y_T = \bar{y} + K_T s_y$$

$$y_{100} = 2.704 + 2.300(0.132)$$
$$= 3.007$$

$$y_{200} = 2.704 + 2.544(0.132)$$
$$= 3.039$$

step5: design flood :-

$$x_{100} = \text{anti log}(y_T) = 10^{y_T}$$
$$= \text{anti log}(3.007) = 10^{3.007}$$
$$= 1016.24\ m^3/sec$$

$$x_{200} = \text{anti log}(3.039) = 10^{3.039}$$
$$= 1093.956\ m^3/sec$$

④ **flood routing:**

flood routing is a technique to determine the storage Level. Volume of water stored in reservoir & its out flow Values & in flow flood hydrograph.

The basic Equation usage in flood routing techniques is

$$\bar{I} - \bar{O} = \Delta S.$$

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Inflow - Outflow = Change in storage Level

$$\left(\frac{I_1+I_2}{2}\right)t - \left(\frac{O_1+O_2}{2}\right)t = S_2 - S_1 \quad \text{---(1)}$$

The following are the methods of flood routing.

(i) muskingum method

(ii) Modified pulse method.

(i) <u>Muskingum method</u>:-

The basic Eq'n use In muskingum method is

$$S = K(xI + (1-x)O)$$

I is the Out flow value

O is the inflow value.

$$S_1 = K(xI_1 + (1-x)O_1)$$

$$S_2 = K(xI_2 + (1-x)O_2)$$

substitute S_1 & S_2 values in Eq'n (1)

$$\Rightarrow \left(\frac{I_1+I_2}{2}\right)t - \left(\frac{O_1+O_2}{2}\right)t = K(xI_2 + (1-x)O_2) - K(xI_1 + (1-x)O_1)$$

$$\Rightarrow \left(\frac{I_1+I_2}{2}\right)t + K(xI_1 + (1-x)O_1) = \left(\frac{O_1+O_2}{2}\right)t + K(xI_2 + (1-x)O_2)$$

$$\Rightarrow \frac{t}{2}(I_1+I_2) + K(xI_1+(1-x)O_1) = \frac{t}{2}(O_1+O_2) + K(xI_2+(1-x)O_2)$$

$$\Rightarrow \frac{t}{2}\left[(I_1+I_2) + \frac{2K}{t}(xI_1+(1-x)O_1)\right] = \frac{t}{2}\left[(O_1+O_2) + \frac{2K}{t}(xI_2+(1-x)O_2)\right]$$

$$\Rightarrow (I_1+I_2) + \frac{K}{0.5t}(xI_1+(1-x)O_1) = (O_1+O_2) + \frac{K}{0.5t}(xI_2+(1-x)O_2)$$

$$\Rightarrow I_1 + \frac{K\cdot x\cdot I_1}{0.5t} + \frac{k(1-x)}{0.5t}O_1 - O_1 + I_2 - \frac{kxI_2}{0.5t} = O_2 + \frac{K(1-x)}{0.5t}O_2$$

$$\Rightarrow I_1\left(\frac{0.5t+kx}{0.5t}\right) + O_1\left(\frac{K(1-x)-0.5t}{0.5t}\right) + I_2\left(\frac{0.5t-kx}{0.5t}\right) = O_2\left(\frac{0.5t+K(1-x)}{0.5t}\right)$$

$$\Rightarrow I_1\left(\frac{0.5t+kx}{0.5t+k(1-x)}\right) + O_1\left(\frac{K(1-x)-0.5t}{0.5t+K(1-x)}\right) + I_2\left(\frac{0.5t-kx}{0.5t+k(1-x)}\right) = O_2$$

$$\boxed{O_2 = C_0I_2 + C_1I_1 + C_2O_1}$$ $/\because C_1+C_2+C_0=1$

$$C_1 = \frac{0.5t + kx}{0.5t + k(1-x)}$$

$$C_2 = \frac{k(1-x) - 0.5t}{0.5t + k(1-x)}$$

$$C_0 = \frac{0.5t - kx}{0.5t + k(1-x)}$$

(*) The storage in a stream reach has been studied 'x' & 'K' have been indentified as 0.28 & 1.6 days. if the inflow hydrograph in the stream reach as the flood starts coming in & passes is given by the following table. Compute the outflow hydrograph.

Time	inflow Values
0	35
6	55
12	92
18	130
24	160
30	140

Scanned with CamScanner

$x = 0.28$

$k = 1.6$ days $= 1.6 \times 24 = 38.4$

$\because C_0 + C_2 + C_1 = 1$

$$C_1 = \frac{0.5t + kx}{0.5t + k(1-x)}$$

$$= \frac{0.5 \times 6 + 1.6(0.28)}{0.5 \times 6 + 1.6(1-0.28)}$$

$= 0.830$ $\quad$ 38.4 $= 0.448$

$$C_2 = \frac{k(1-x) - 0.5t}{0.5t + k(1-x)}$$

$$= \frac{1.6(1-0.28) - 0.5(6)}{0.5(6) + 1.6(1-0.28)}$$

$= -0.445$ $\quad$ 0.804

$$C_0 = \frac{0.5t - kx}{0.5t + k(1-x)}$$

$$= \frac{0.5(6) - 1.6(0.28)}{0.5(6) + 1.6(1-0.28)}$$

$= 0.614$ $\quad$ -0.252.

$C_0 + C_1 + C_2 = 0.614 + 0.830 + (-0.445)$

$= 0.999 \simeq 1 = 1$

Time	Inflow values	C_0I_2	C_1I_1	C_2O_1	$O_2 = C_0I_2 + C_1I_1 + C_2O_1$
0	35	–	–	–	35
6	55	$(-0.252 \times 55) = -13.86$	$(0.448 \times 35) = 15.68$	$(0.804 \times 35) = 28.14$	29.96
12	92	$(-0.252 \times 92) = -23.184$	$(0.448 \times 55) = 24.64$	$(0.804 \times 29.96) = 24.08$	25.536
18	130	$(-0.252 \times 130) = -32.76$	$(0.448 \times 92) = 41.216$	$(0.804 \times 25.536) = 20.530$	28.986
24	160	$(-0.252 \times 160) = -40.32$	$(0.448 \times 130) = 58.24$	$(0.804 \times 28.986) = 23.304$	41.224
30	140	$(-0.252 \times 140) = -35.28$	$(0.448 \times 160) = 71.68$	$(0.804 \times 41.224) = 33.144$	69.544

Methods of flood routing:-

Another methods for doing flood routing are

(i) Calculus.

(ii) Graphical method

And again in graphical methods are of two types.

(i) step by step

(ii) trial & Error method.

for flood routing operations in Calculus method is complecated by neither the flood inflow hydrograph nor the storage & Outlet discharge can be Expressed by algebraic Equations. so, mostly graphical are used for flood routing techniques.

⊛ Graphical method :-

step by step method: (inflow-storage-discharge curve method).

(i) Inflow flood hydrograph

(ii) Elevation outflow curve

(iii) Elevation Storage curve.

The basic Eq'n used in this method

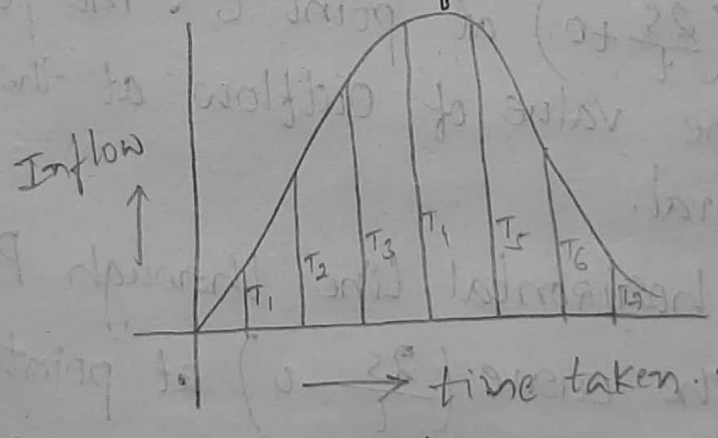
$$\bar{I} - \bar{O} = \Delta S \quad \text{—} (1)$$

$$\left(\frac{I_1+I_2}{2}\right)t - \left(\frac{O_1+O_2}{2}\right)t = S_2 - S_1 \quad \text{—} (2)$$

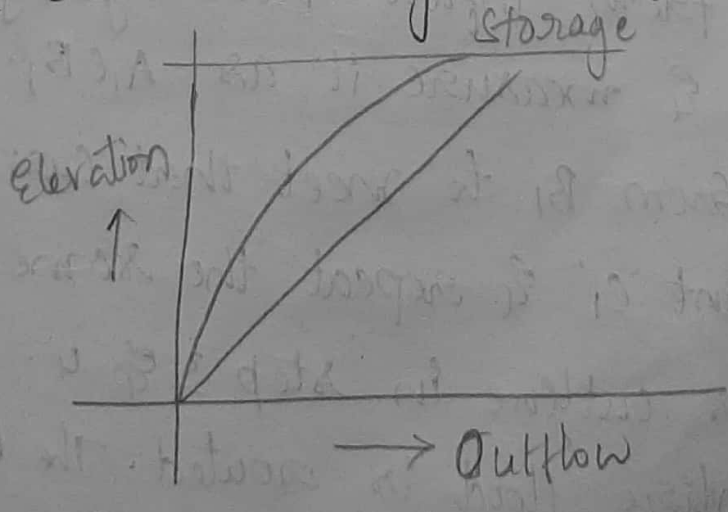
$$(I_1+I_2) + \left(\frac{2S_1}{t} - O_1\right) = \left(\frac{2S_2}{t} + O_2\right) \quad \text{—} (3)$$

To go for furthur Analysis the following graphs are required

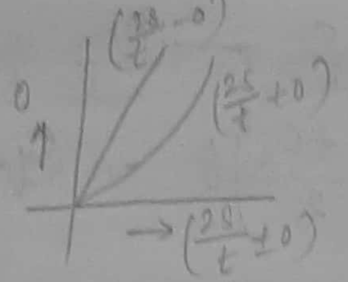
(i) Inflow flood hydrograph from which ordinates $I, I_2, I_3 \ldots$ can be found at Choosen interval of time Period.



(ii) Elevation outflow curve of the reservoir & Elevation storage curve of the reservoir.



In addition to those curves $\left(\frac{2S}{t} \pm O\right)$ vs outflow curves are desired.



procedure:

1. Calculate the total inflow from inflow hydrograph for the time interval 't' & Enter it on $\left(\frac{2S}{t} \pm O\right)$ vs (O) curves & Draw a line as AB.

2. Draw a vertical line from 'B' to meet that curve $\left(\frac{2S}{t} + O\right)$ at point 'C'. The point 'C' gives the value of outflow at the end of interval.

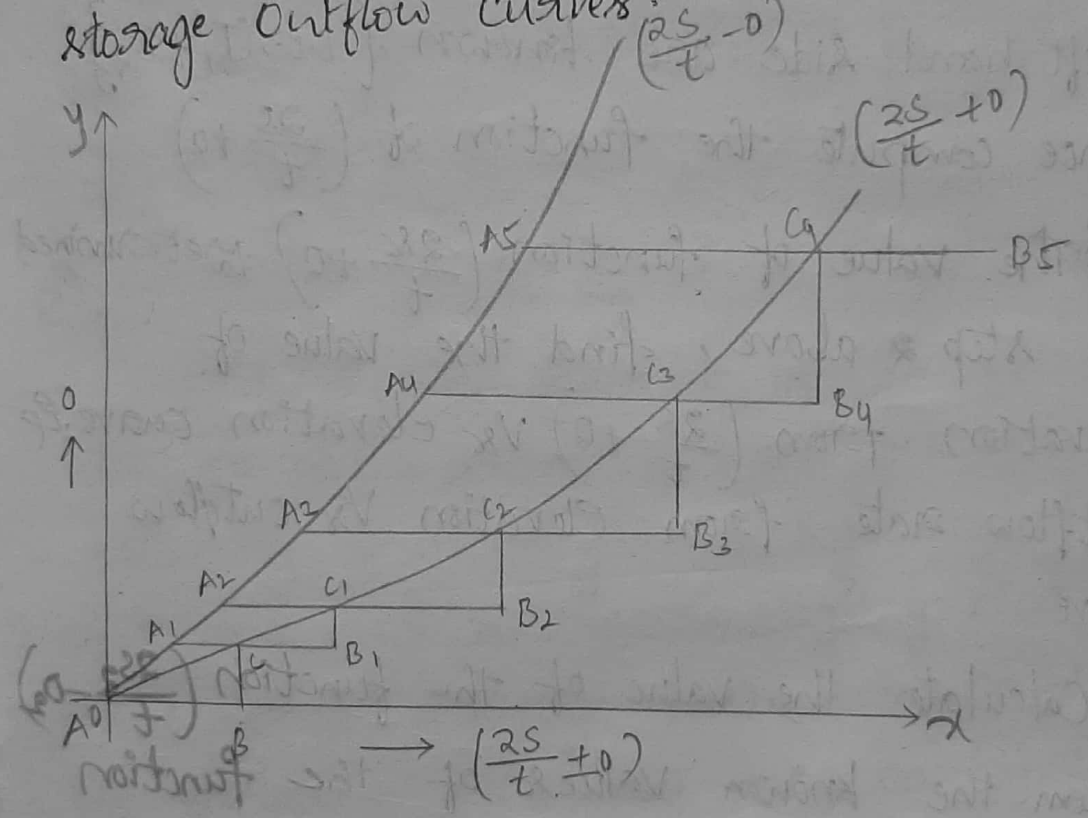
3. Draw a horizontal line through Point 'C' to cut the curve $\left(\frac{2S}{t} - O\right)$ at point 'A_1'.

4. Calculate the total inflow during the next period from inflow flood hydrograph & mark it & measure it as A_1CB_1.

5. Erect a ⊥ from B_1 to meet that curve $\left(\frac{2S}{t} + O\right)$ at point 'C_1' & repeat the same procedure as outline in step 3 & 4. Until the Entire flood is routed. The Outflow discharge at any time interval is given by the total vertical Ordinates.

The biggest of these ordinates will give the peak outflow rate for which the spillway is to be designed.

6. The outflow discharge at various time intervals has been determined as discussed above, the reservoir water surface elevation for these can be determined from elevation storage outflow curves.



⊛ Modified pulse method :-

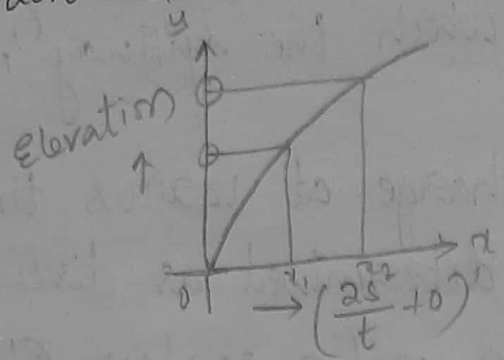
The basic Eq'n used for modified puls method is

$$\bar{I}_1 - \bar{O} = \Delta S$$

$$(I_1+I_2) + \left(\frac{2S_1}{t} - O_1\right) = \left(\frac{2S_2}{t} + O_2\right) \quad \text{—— (1)}$$

1. Choose a suitable interval of time 't' & prepare a curve b/w $\left(\frac{2S}{t}+O\right)$ as abscissa &

Elevation as Ordinate.



2. At the beginning of routing process, S_1 & O_1 are '0'. Hence all the terms on the left hand side are known [i.e., (I_1+I_2)]. Hence compute the function of $\left(\frac{2S}{t}+O\right)$

3. For the value of function $\left(\frac{2S}{t}+O\right)$ determined in step 2 above, find the value of Elevation from $\left(\frac{2S}{t}+O\right)$ Vs elevation curve. & outflow rate from Elevation Vs outflow curve.

4. Calculate the value of the function $\left(\frac{2S_2}{t}-O_2\right)$ from the known values of the function $\left(\frac{2S_2}{t}+O_2\right)$ & O_2 using the following eq'n

$$\text{i.e., } \left(\frac{2S_2}{t}-O_2\right)=\left(\frac{2S_2}{t}+O_2\right)-2O_2$$

5. Compute the value of $\left(\frac{2S_3}{t}+O_3\right)$ by using the following eq'n

$$(I_2+I_3)+\left(\frac{2S_2}{t}-O_2\right)=\left(\frac{2S_3}{t}+O_3\right)$$

In the above eq'n, all the terms in the left hand side are completely known.

Then the Value of $\left(\frac{2S_3}{t} + O_3\right)$ is known, corresponding due to which the Elevation is found from above graph & O_3 is found from elevation - Outflow curve.

6. Repeat the above procedure till the entire inflow hydrograph is routed.
7. Determine the max WL & max outflow rate from the values obtained an Above procedure.

⊛ Standard project flood:

This is the Estimate of the flood likely to occur from the most severe combination of materiological & hydrological conditions, which are reasonably characteristic of the drainage basin being consider but Excluding extremely rare combination.

⊛ Max propable flood:

This is differs from the standard project flood in that it includes the extremely rare & catastrophic floods & is usually confined to Spillway design of very high dams. The std project flood is usually around 80% of the max Propable flood for the basin.

⊛ Design flood:

It is the flood adopted for the design of hydraulic structures like spillways, bridge openings etc.,

⊛ Flood Control methods:

1. Introduce better flood warning systems
2. modify home & businesses to withstand the floods.
3. Construction of buildings above flood levels
4. Tackle Climate Change.
5. Increase Spending on flood defenses
6. protect bed plants & introduce plant trees statistically
7. restore, reverse to their natural courses
8. Introduce water storage areas
9. Improve soil Conditions
10. put up more flood barriers

5. Ground Water hydrology

It is the science which deals with Occurence, movement & distribution of water below the ground source.

The main source for GW is precipitation & the discharge of GW carried in two ways i.e., natural ways (ex: rivers, lakes, reservoirs etc.,) & Artificial ways (pumpage of water from wells).

Where the rainwater falls from Grsurface which infiltrates & moves down, checked by the impervious layer & further moves down & reach the GW table.

Basic Definitions:

Aquifer: Aquifer are the permeable formations having structures which permitt appreciable Quantity of water to move through them under Ordinary field Conditions.

Ex: sand bed, gravel etc.

Aquiclude: These are the impermeable formations which contain water but aren't capable of transmitting on supplying a significant Quantity ex: clay.

Aquifuges: These are the Impermeable formations which neither contain water nor transmitts water. Ex: rocks.

Porosity: It is defined as the ratio b/w the volume of voids to the Total Volume. It is expressed as percentage.

$$n = \frac{V_v}{V} \times 100$$

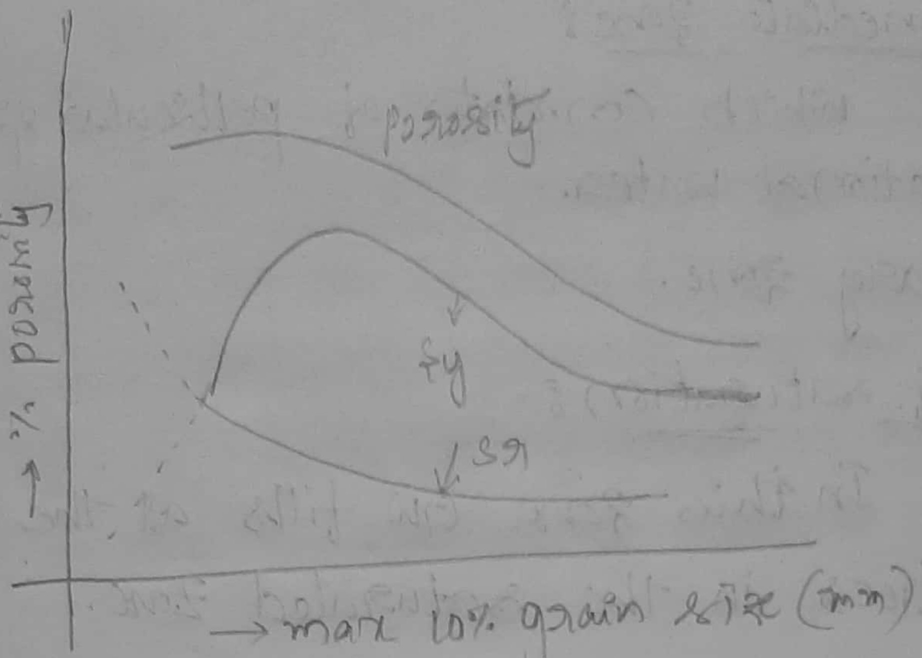
Specific yield: It is the ratio Expressed as percentage of the volume of water which after being saturated, can be drain by gravity to its own volume. (S_y)

$$S_y = \frac{\text{Volume of water drain by gravity}}{\text{Total volume}} \times 100$$

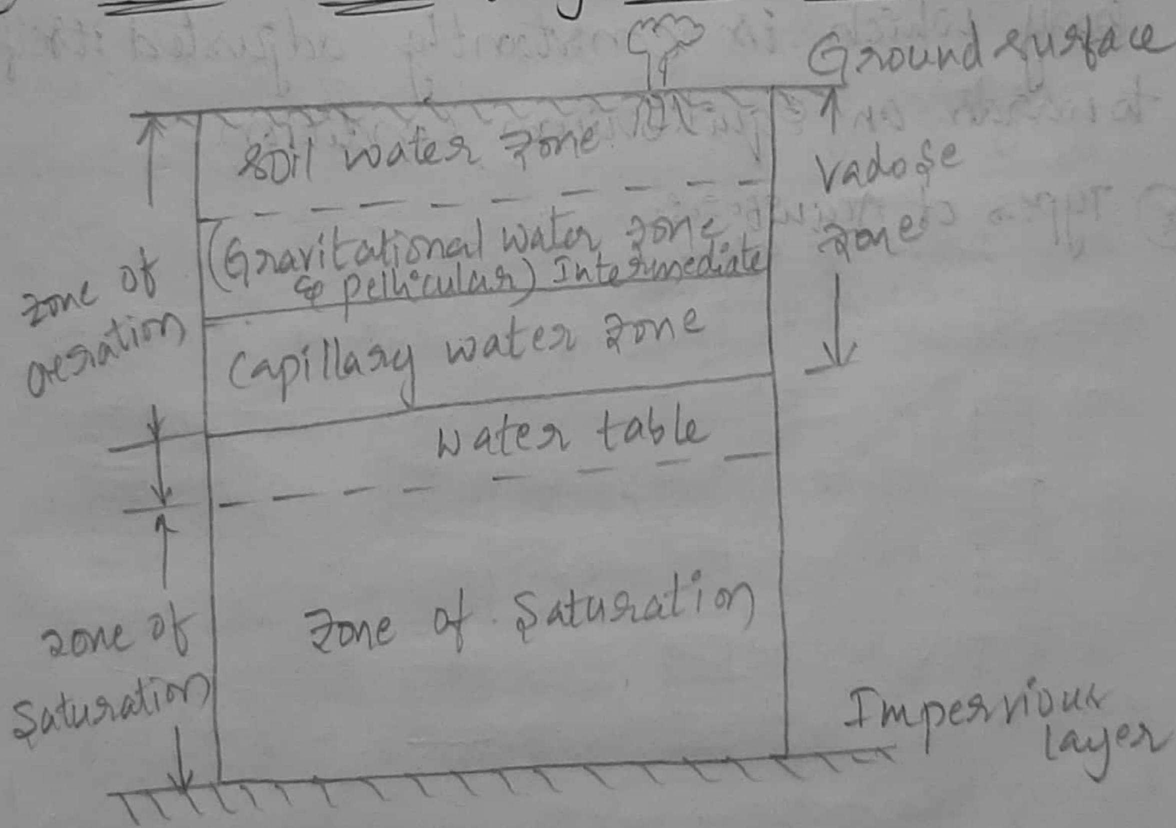
Specific retension: (S_r)

It is the ratio of vol of water it will retain after saturation against the force of gravity to its own volume in percentages.

Saturation



⊛ Various zones of groundwater:



GW carries in 2 zones. That are

1. Zone of aeration
2. Zone of saturation.

Zone of aeration:-

1. Soil water: which consists of soil water zone which lies just below the ground surface.

2. Intermediate zone:

which consists of pellicular & gravitational water.

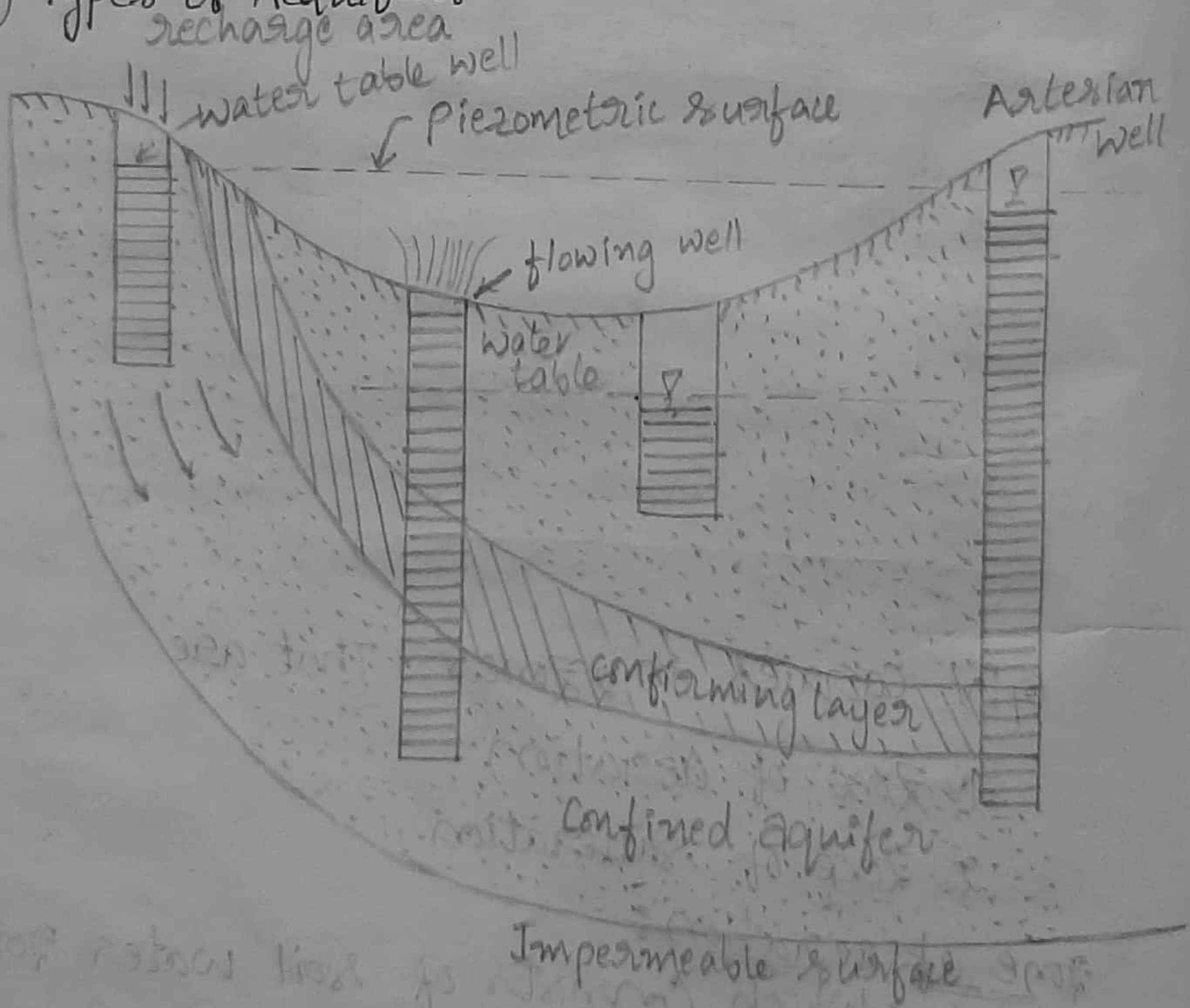
3. Capillary zone.

Zone of saturation:-

In this zone GW fills all the Interstices in the saturated zone.

Water table: It is the surface of water body which is constantly adjusted itself towards an Equilibrium Condition.

(*) Types of Acquifer:-



Unconfined Aquifer:-

It is the aquifer in which water table serves as the upper surface of zone of saturation. It is also termed as water table aquifer, free, phreatic (or) non artesian aquifer. In this type of aquifers water table varies in undulating form & in slope.

Confined aquifer:

It is the one in which ground water is confined under pressure greater than atmospheric pressure by overlying relatively impermeable strata.

These are similar to pipe lines.

flowing well:

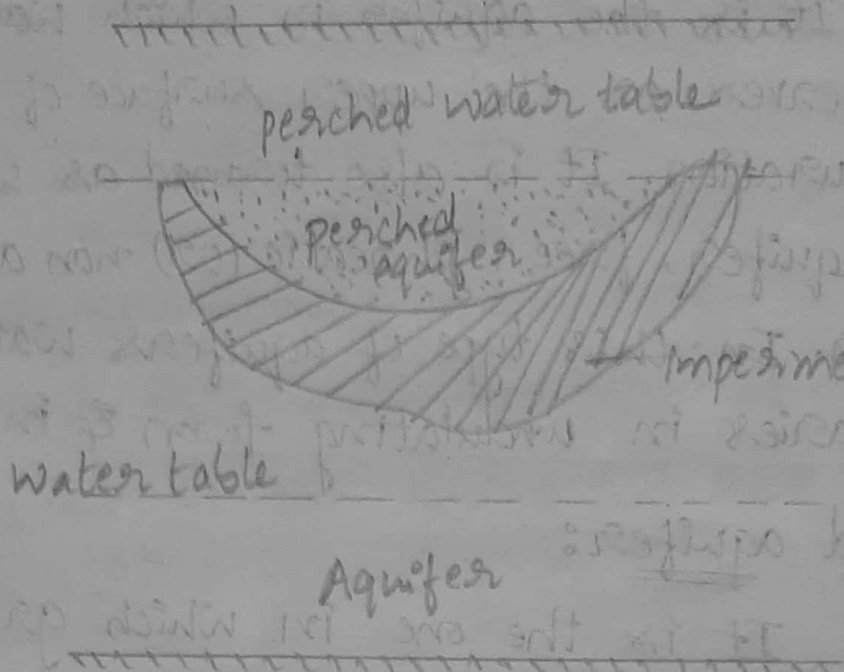
When a well penetrates a confined aquifer, water level in that well rises to the level of local stratic pressure. If this pressure is sufficient to rise the water above the groundlevel, a flowing well occurs.

crystal palace
skyscraper

Artesian well:

If the water level in a well is below the ground level but above the local water table then that well is known as artesian well.

perched Aquifer:-



It is a special type of unconfined aquifer & It occurs where a gw body is seperated from the main GW by a relatively impermeable strata of small axial extend & by the zone of aeriation above the main body of gwater.

(*) storage Co-efficient:-

It is the water yielding capacity of a Confined aquifer. & It can be defined as volume of water that an aquifer releases from (or) takes into storage per unit surface area of aquifer per unit change in the Component of head normal to the surface.

Coefficient of permeability : (K)

It is the velocity of flow which will occur through the total c/s area of the soil under unit hydraulic gradient.

$$K = \frac{V}{i}$$

Co-efficient of Transmissivity : (T)

It is the rate of flow of water in m^3/day through a vertical strip of aquifer of unit width. & Extending the full saturation ht under unit hydraulic gradient at a temp of 60°F.

$$T = Kb$$

b = thickness of Aquifer.

⊛ Permeability of soil:

permeability is the measure of the soil's ability to permit water to flow through its pores or voids. Knowledge of the permeability properties of soil is necessary to:

→ Estimating the Quantity of underground seepage.

→ solving problems involving pumping seepage water from Construction excavation.

factors:

1. Grain size: smaller the grain size smaller the voids and thus lower the permeability.
2. Void ratio: Increase in the porosity leads to an increase in the permeability.
3. Composition: The influence of soil composition on permeability is generally insignificant in the case of gravels, sands & silts, unless mica & organic matter are present.
4. soil structural: fine grained soils with a flocculated structure have a higher coefficient of permeability than those with a dispersed structure.
5. Degree of saturation:

   Higher the degree of saturation, higher the permeability.
6. Presence of Entrapped air & other foreign matter reduces the permeability of a soil. Organic foreign matter may choke flow channels thus decreasing the permeability.

* Measurement of Coefficient of permeability of soil :-

1. Laboratory tests (using darcy's law)

(a) Constant head permeability test - suitable for Coarse grained soils.

(b) falling or Variable head permeability test - suitable for fine grained soils.

2. Field tests :

(a) pumping out test

(b) pumping in test.

3. Indirect methods :

(a) Computation from the particle size

(b) Computation from Consolidation test.

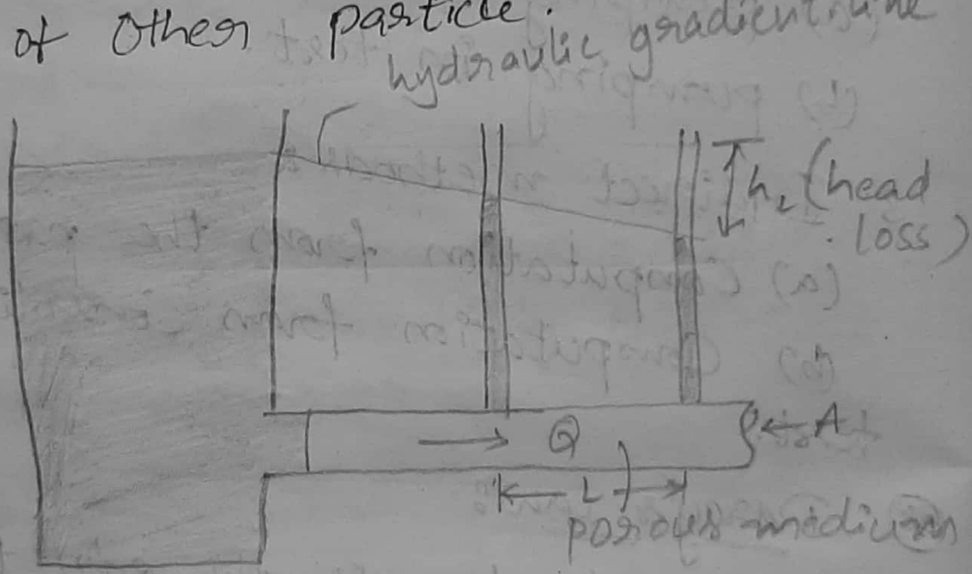
* Darcy's law :

Darcy's law is the eq'n that describes the flow of a fluid through a porous medium. The law was formulated by Henry darcy (1856) based on the results of experiments on the flow of water through beds of sand.

for Laminar flow through saturated soil mass, the discharge per unit time is proportional to the "i".

Assumptions:

1. The soil is saturated.
2. The flow is steady state i.e., flow Condition do not Change with time.
3. water & soil are incompressible i.e., Continuity eqn is assumed to be Valid.
4. The flow is laminar i.e., flow follows a definite path & does not cross the path of other particle.



$$Q = KA\frac{h_L}{L}$$

Darcy's law Apparatus.

Where,

$i = \frac{h_L}{L}$ = hydraulic gradient.

K = Coefficient of permeability.

⊛ Pumping Out tests:

Assumptions:

1. The Aquifer is homogeneous
2. Darcy's law is Valid
3. The flow is horizontal
4. The well penetrates the entire thickness of the Aquifer
5. Natural GW regime remains constant with time.
6. Dupuit's theory is valid i.e., $i = \frac{dz}{dr}$.

⊛ Unconfined Aquifer:- GT.

⊛ Confined aquifer: GT.

⊛ A tube well of 30cm dia penetrates fully in an artesian Aquifer. the strainer length is 15m. Calculate the yield from the well under a drawdown of 3m. The Aquifer consists of sand of effective size of 0.2mm having co-efficient of permeability = 50 m/day. Assume radius of drawdown = 150m.

Ⓐ $b = 15m \quad k = 50 m/day \; ; R = 150m$

$s = 3m \qquad r = 0.15m$

$$Q = \frac{2.73\, kbs}{\log_{10}(R/r)}$$

$$= \frac{2.73 \times 50 \times 15 \times 3}{\log_{10}(150/0.15)}$$

$Q = 2047.5 \; m^3/day.$

(*) A tube well penetrates fully an unconfined Aquifer. Calculate the discharge from the tube well under the following conditions.

dia of well = 30cm, draw down = 2m; effective length of the strainer under the above drawdown = 10m

K = 0.05 cm/sec; radius of '0' drawdown is 300m.

(A) K = 0.05 cm/sec; S = 2m; L = 10m

= 0.05×10^{-2} m/sec = ~~100000 m~~

r = 15cm = 0.15m; R = 300 m =

$$Q = \frac{1.36 K S (S + 2C)}{\log_{10}(R/r)}$$

$$= \frac{1.36 \times 0.05 \times 10^{-2} \times 2 (2 + (2 \times 10))}{\log_{10}(300/0.15)}$$

$$\boxed{Q = 9.063 \times 10^{-3}\ m^3/sec}$$

(*) Design a tube well for the following data

yield required = 0.08 cumecs

Thickness of confined aquifer = 30m

radius of circle of influence = 300m

K = 60m/day; S = 5m

(A)

$$Q = \frac{2.73 kbs}{\log_{10}(R/r)}$$

~~0.08 m³/sec~~

~~= $\frac{0.08}{60 \times 60 \times 24}$ m²/day~~

~~Q = 9.25×10^{-7}~~

6912

$$\frac{~~0.08~~}{~~9.25 \times 10^{-7}~~} = \frac{2.73 \times 60 \times 30 \times 5}{\log_{10}(300/r)}$$

$$\log_{10}\left(\frac{300}{r}\right) = ~~7.656 \times 10^{10}~~$$

$$\boxed{r = 0.083}$$

* Determination of Aquifer constant (T):

Confined aquifer:

pumping out test under steady steady state condition.

$$Q = \frac{2.73\, kb\,(h_2 - h_1)}{\log_{10}\left(\frac{r_2}{r_1}\right)}$$

$[\because T = kb.$

$$Q = \frac{2.73\, T\,(h_2 - h_1)}{\log_{10}(r_2/r_1)}$$

$$h_1 = H - S_1 \; ; \; h_2 = H - S_2$$

$$h_2 - h_1 = H - S_2 - H + S_1 \Rightarrow S_1 - S_2.$$

$$Q = \frac{2.73\, T\,(S_1 - S_2)}{\log_{10}(r_2/r_1)}$$

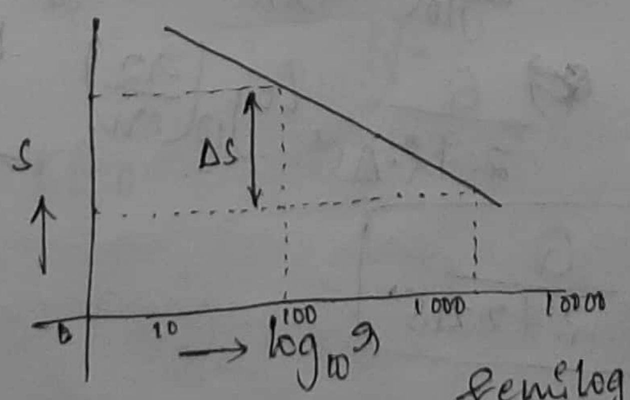
$$T = \frac{Q}{2.73T(S_1 - S_2)} \log_{10}\left(\frac{r_2}{r_1}\right)$$

$$T = \frac{Q}{2.73T\,\Delta S} \log_{10}\left(\frac{r_2}{r_1}\right)$$

$[\because \Delta S = S_1 - S_2$

$[\because r_2 = 10 r_1.$

$$\boxed{T = \frac{Q}{2.73T.\Delta S}}$$



Semilog graph.

Unconfined aquifer:

$$Q = \frac{1.36 K (h_2^2 - h_1^2)}{\log_{10}(r_2/r_1)}$$

$$Q = \frac{1.36 K (h_2^2 - h_1^2)}{\log_{10}(r_2/r_1)}$$

$$h_2^2 - h_1^2 = (H - S_2)^2 - (H - S_1)^2$$

$$= H^2 - 2HS_2 + S_2^2 - H^2 + 2HS_1 - S_1^2$$

$$= 2HS_1 - 2HS_2 + S_2^2 - S_1^2$$

$$= 2H\left(S_1 - S_2 + \frac{S_2^2}{2H} - \frac{S_1^2}{2H}\right)$$

$$= 2H\left[\underbrace{\left(S_1 - \frac{S_1^2}{2H}\right)}_{S_1'} - \underbrace{\left(S_2 - \frac{S_2^2}{2H}\right)}_{S_2'}\right]$$

$$Q = \frac{1.36 K \times 2H (S_1' - S_2')}{\log_{10}(r_2/r_1)}$$

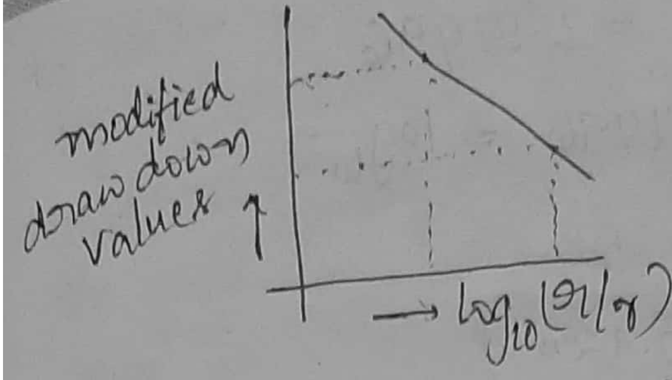
$$Q = \frac{2.72 KH (S_1' - S_2')}{\log_{10}(r_2/r_1)}$$

$$Q = \frac{2.72 T (S_1' - S_2')}{\log_{10}(r_2/r_1)}$$ $\therefore S_1' - S_2' = \Delta S'$

$\log_{10}\frac{r_2}{r_1} = \log_{10}\frac{10 r_1}{r_1} = 1$

$$T = \frac{Q}{2.72 \cdot \Delta S'} \log_{10}\left(\frac{r_2}{r_1}\right)$$

$$\boxed{T = \frac{Q}{2.72 \cdot \Delta S'}}$$



$\left(S_1 - \frac{S_1^2}{2H}\right)$ & $\left(S_2 - \frac{S_2^2}{2H}\right)$ are the modified drawdown values.

(*) A horizontal Aquifer is of 10m thickness & infinite areal extent with its top level 25m below ground level static piezometric surface is 10m below GL during steady rate of pumping from the well at 5000 m³/day. the steady drawing at the well is 12m. permeability of aquifer formation is 48 m/day. Assume the radius of influence as 500m find the effective well dia in m

(A) $Q = 5000\ m^2/day$

$k = 48\ m/day$

$R = 500m$

$s = 12m$

$b = 10m$; $r = ?$

$$Q = \frac{2.73 k b s}{\log_{10}(R/r)}$$

$$5000 = \frac{2.73 \times 48 \times 10 \times 12}{\log_{10}(500/r)}$$

$\log_{10}(500/r) = 3.14496$

$$\log_{10} 500 - \log_{10} r = 3.14496$$

$$\log_{10} 500 - 3.14496 = \log_{10} r$$

$$r = 0.358$$

$$\boxed{d = 0.72m}$$

(*) <u>Yield of Open well:</u>

Open well : large diameter well

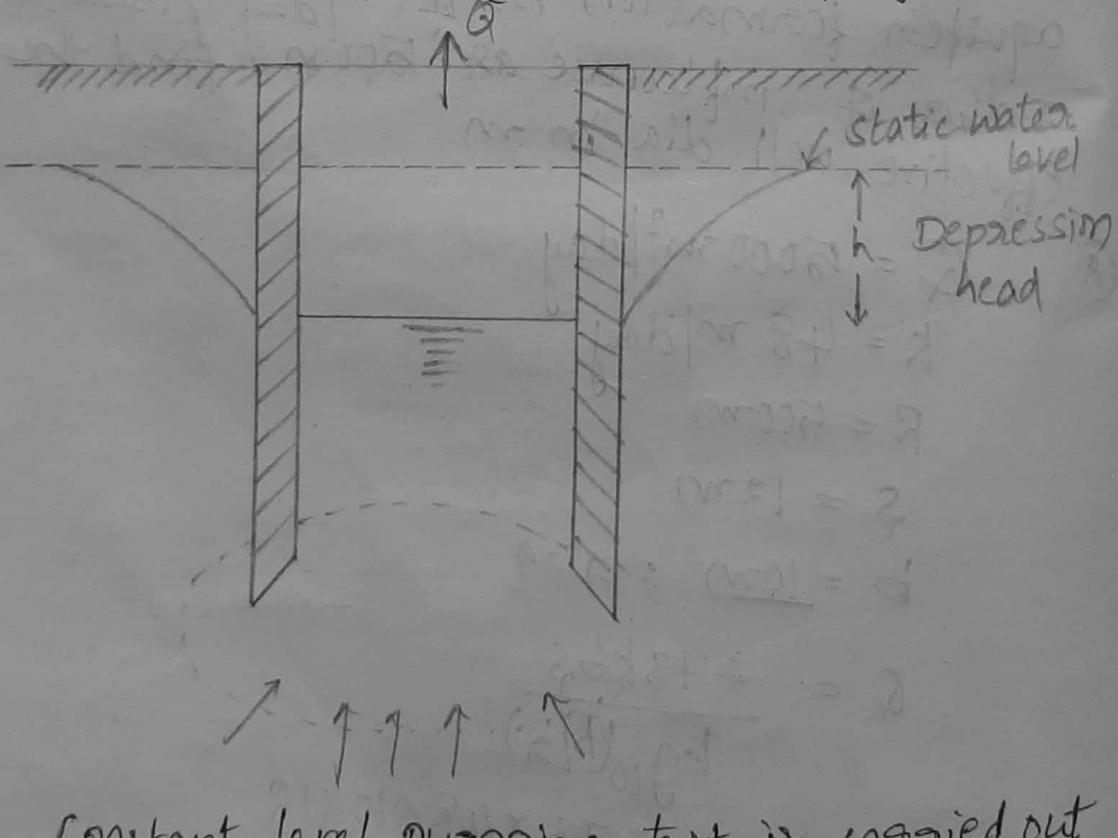
tests for determination of discharge

(i) pumping test

ii) recuperation test.

i) <u>pumping test:</u>

constant head (or) level pumping test:



Constant level pumping test is carried out by suitable pump arrangement. whenever the pumping is started from an open well the water level is depressed as shown in fig. by mataining this depressed level to be constant by regulating the pump arrangement the yield can be determine from V-notch (or) any other suitable discharge measuring devices.

The yield can be obtained from the following formula

$$Q = VA$$

$$Q = CAh$$

Where,

Q is the discharge in m^3/sec

A is the C/s area of flow into the well at its base in m^2.

h is the depression head in m

V is the mean velocity of water percolating into the well in m/sec

c is the percolation intensity coefficient.

This formula can be derived from darcy's law also

$$Q = KiA$$

$$Q = K\frac{h}{L}A$$

$$Q = \frac{K}{L}hA$$

$$\boxed{Q = CAh}$$

Where,

i is the hydraulic gradient.

due to cavity formation, 'A' is considered as four-third of actual c/s area of the flow.

from the above expression, the yield value is increases with increase in the percolation head.

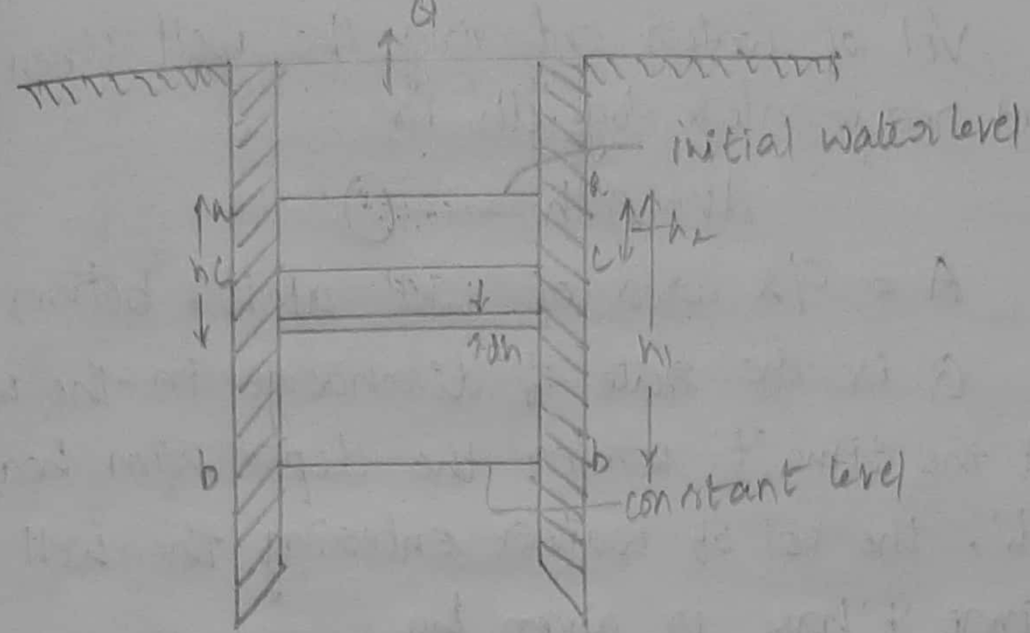
However the percolation head cannot be increased beyond a critical value. The critical value of 'h' at which the velocity is critical is known as critical depression head.

The depression head = $\frac{1}{3}$rd of critical head.

Max yield is obtained at critical depression head & this head is known as working head.

The yield under working head is known as max safe yield.

(ii) Recuperation test:



from figure,

'aa' represents static WL in the well before the pumping started.

'bb' represents WL in the well when the pumping stopped.

'h_1' is the depression head in the well when the pumping stopped.

C-C is the WL in the well at a time 'T' after the pumping stopped.

'h_2' is the depression head in the well at the time 'T' after the pumping stopped.

'h' is the depression head in the well at the time 't' after pumping stopped.

'dh' is the decrease in depression head in a time 'dt'.

t & T are in hrs.

Vol of water entering the well when the head recuperates by 'dh' is

$$dv = A\,dh \quad \text{--- (1)}$$

A = C/s area of well at its bottom

Q is the rate of discharge in the well at the time 't' under the depression head 'h', the vol of water entering the well in time 't' has is given by

$$dv = Q\,dt \quad \text{--- (2)}$$

But $Q \propto h$

$$\Rightarrow Q = Kh$$

$$\therefore dv = Kh\,dt \quad \text{--- (3)}$$

by equating eqn (1) & (2)

$$A\,dh = -Kh\,dt$$

$$-\frac{dh}{h} = \frac{K}{A}\,dt$$

by integrating on both sides & apply the limits from 0 to T & h_1 to h_2

$$\int_{h_1}^{h_2} \frac{-dh}{h} = \int_{0}^{T} \frac{K}{A}\,dt$$

$$-\log h_2 + \log h_1 = \frac{K}{A} T$$

$$\frac{K}{A} = \frac{\log h_1 - \log h_2}{T}$$

$$\frac{K}{A} = \frac{1}{T}\log_e(h_1/h_2)$$

$$\boxed{\frac{K}{A} = \frac{2.303}{T}\log\left(\frac{h_1}{h_2}\right)}$$

$\frac{K}{A}$ is the specific yield (or) specific capacity of an open well in $m^3/hr/m^2$ of area thro which water penetrates under 'm' depression head.

$$Q \propto H$$

$$Q = KH$$

$$Q = \left(\frac{K}{A}\right).A.H$$

$$\therefore \boxed{Q = \frac{2.303}{T}\log\left(\frac{h_1}{h_2}\right)A.H} \; m^3/hr.$$

If 'T' is in hrs.

(*) Design an open well in fine sand to give a discharge of 0.003 cumecs. When worked under a depression head of 2.5m. Consider $\left(\frac{K}{A}\right)$ value for find sand is $0.5 \, m^3/hr/m^2$ of area under unit depression head.

(A) $Q = 0.003 \, m^3/sec$

$Q = 0.003 \times 60 \times 60$

$Q = 10.8 \, m^3/hr$; $H = 2.5m$; $\frac{K}{A} = 0.5 \, m^3/hr/m^2$

$Q = CAH$

$Q = \left(\frac{K}{A}\right) A \cdot H$

$10.8 = 0.5 \times A \times 2.5$

$A = 10.8 / 0.5 \times 2.5$

$\boxed{d = 3.316m} \simeq \boxed{d = 3.32m}$

(*) During a recuperation test, the water in an open well was depressed by pumping by 2.5m & it recuperated 1.8m in 80min. find (i) yield from a well of 4m dia. under a depression head of 3m.

(ii) The dia of the well to yield 8 lit/sec under a depression head of 2m.

(A) $h_1 = 2.5m$; $T = 80min = 80/60 \, hr$

$= 1.33$

$$Q = \left(\frac{K}{A}\right) \cdot A \cdot H$$

$$\frac{K}{A} = \frac{2.303}{T} \log \left(H_1 / H_2\right)$$

$$\frac{K}{A} = \frac{2.303}{1.3} \log_{10} \left(\frac{2.5}{2.5-1.8}\right)$$

$$= ~~2.65\times10^{-4}~~ \; 0.999$$

(i) $Q = \left(\frac{K}{A}\right) A \cdot H$

$$= ~~2.65\times10^{-4}~~ \; 0.999 \times \frac{\pi}{4} (4)^2 \times 3$$

$$= 36.90 \; m^3/hr$$

$Q = 8$ lit/sec

$Q = \frac{8}{1000} \times 60 \times 60$

$Q = 28.8 \; m^3/hr$

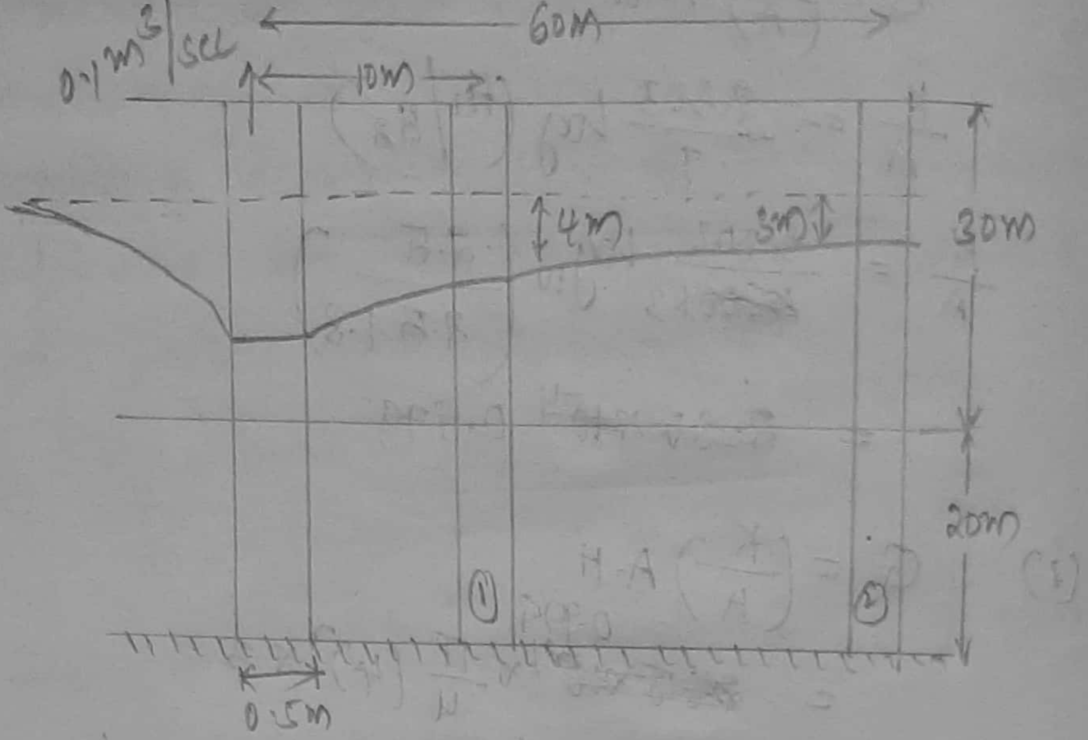
(ii) $Q = \left(\frac{K}{A}\right) A \cdot H$

$$28.8 = 0.999 \times A \times 2$$

$$\boxed{d = 4.32m}$$

(*) An aquifer of 20m avg thickness is overlaid by an impermeable layer of 30m thickness a test well of 0.5m dia & two observation wells at a distance of 10m & 60m from the test well are drilled through the aquifer after pumping at a rate of 0.1m³/sec for a long time, The following drawdowns are stabilized in these wells, In the 1st observation well 4m, second observation well 3m. show the arrangement in dia & determine the 'k' & drawdown in the test well.

(4)



(i) $Q = 0.1\ m^3/sec \Rightarrow 0.1 \times 60 \times 60$

$\Rightarrow 360\ m^3/hr$

$$Q = \frac{2.72 K b (S_1 - S_2)}{\log_{10}(r_2/r_1)}$$

$$0.1 = \frac{2.72 \times K (20)(4 - 3)}{\log_{10}(60/10)}$$

$$\boxed{K = 1.43 \times 10^{-3}}\ m/sec.$$

(ii) $S = ?$ by making $S_1 = S$ & $r_1 = r$

$$Q = \frac{2.72 K b (S - S_2)}{\log_{10}(r_2/r)}$$

$$0.1 = \frac{2.72 \times 1.43 \times 10^{-3} \times 20 (S - 3)}{\log_{10}(60/0.25)}$$

$\boxed{S = 6.05 m}$ $\approx$ $\boxed{6 m = S}$

(8) In order to determine the field permeability of a free aquifer, pumping out test was performed & following observation were made.

(i) dia of well = 20cm

discharge from the well = 240 m^3/hr

RL of original water surface before pumping started = 240.5 m

RL of water in the well at constant pumping = 235.6 m

RL of the impervious layer = 210m

RL of water in observation well = 239.8 m

radial distance of observation well from the tube well = 50m

Calculate 'K'. also calculate (i) the error in 'K' if observations are not taken in the observation well & radius of influence is assumed to be 300m.

(ii) actual radius of influence based on the observations of observation well.

(A)

$$Q = \frac{\pi K(h_1^2 - h_2^2)}{2.303 \log_{10}(r_1/r_2)}$$

$$240 = \frac{\pi K (4.9^2 - 0.7^2)}{2.303 \log_{10}(50/0.1)} \Rightarrow 20.18 \frac{m}{hr} = K$$

$K = 0.056$ m/sec

(ii) radius of influence $R = 300$.

$$K = \frac{2.303 \log_{10}(R/r)\, Q}{\pi (h^2 - h_1^2)}$$

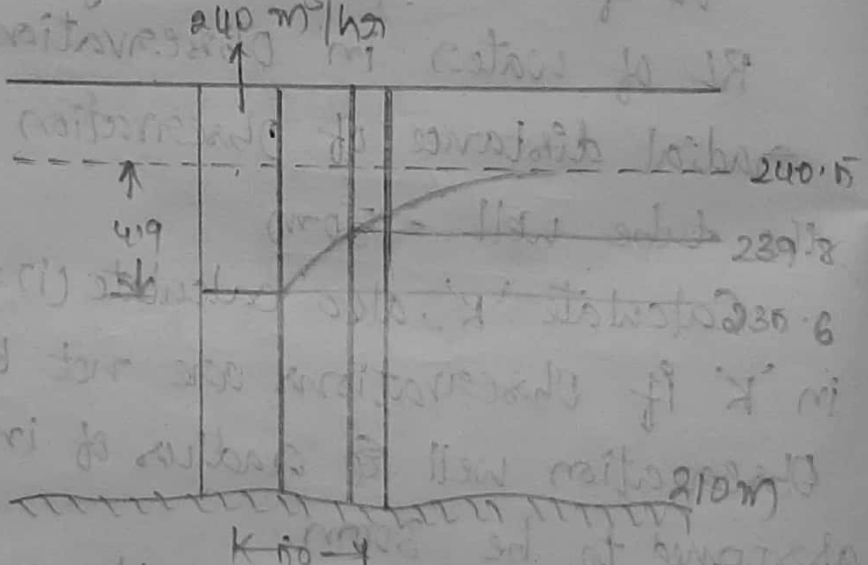
$$k = \frac{2.303 \log_{10}(300/0.1) \times 240}{\pi ((30.5)^2 - 4.9^2)}$$

~~$K = 5.24 \times 10^{-4}$ m/sec~~

~~$K = 2.812 \times 10^{-3}$ m/~~

$K = 1.875 \times 10^{-3}$ m/sec

(iii)



① $$Q = \frac{\pi K (h_1^2 - h^2)}{2.303 \log_{10}(r_1/r)}$$

$h_1 = 239.8 - 210 = 29.8$ m

$h = 235.6 - 210 = 25.6$

$$K = \frac{2.303 \times 240 \times \log_{10}\left(\frac{50}{0.1}\right)}{\pi (29.8^2 - 25.6^2)}$$

$k = 2.04\ m/hr$

$$\boxed{k = 5.66 \times 10^{-3}\ m/sec}$$

(i) radius of influence $R = 300m$

$$Q = \frac{1.36\,KS(S+2h)}{\log_{10}(R/r)}$$

$$240 = \frac{1.36 \times K \times 4.9\,(4.9 + 2 \times 25.6)}{\log(300/0.1)}$$

$$\boxed{K = 2.23\ m/hr}$$

(ii)

$$Q = \frac{1.36\,K\,(h_1^2 - h^2)}{\log_{10}(R/r)}$$

$h_1 = 240.5 - 210 = 30.5m$

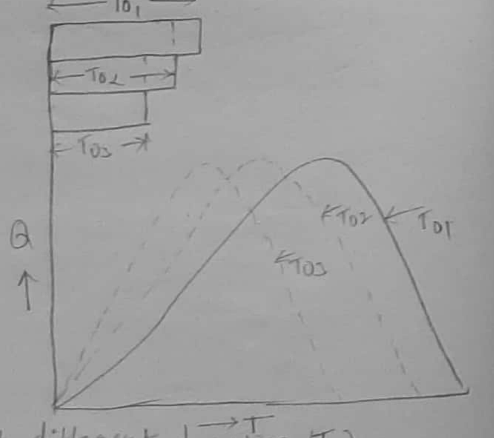
$h = 235.6 - 210 = 25.6m$

$$240 = \frac{1.36 \times 2.04\,(30.5^2 - 25.6^2)}{\log_{10} R/0.1}$$

$$\log \frac{R}{0.1} = 3.177$$

$$\boxed{R = 150.31\ m}$$

(*)



UH of different duration (To)

9.03.20

6. ADVANCED TOPICS IN HYDROLOGY

(*) Instantaneous unit hydrograph: (IUH)

for any catchment they can be a no. of unit hydrographs corresponding to varies values of unit duration T_0.

To obtain the runoff hydrograph resulting from a storm of varying duration & varying intensities, it is preferable to have a unit hydrograph of very short duration.

If the duration of rainfall excess becomes infinite small the resulting unit hydrograph is called instantaneous unit hydrograph & it represents the unit hydrograph the catchment due surface runoff from the catchment due to instantaneous precipitation of rainfall excess vol of 1cm.

IUH can be derived from s-hydrograph obtained from an available unit hydrograph of duration T_0.

If 2-S curves hydrographs are drawn at a time lag of t_0, the ordinates of unit hydrograph of t_0 hr unit duration at any time 't' is given by

$$u(t,t_0) = \frac{T_0}{t_0}\left(S_t - S_{t-t_0}\right)$$

from the above eqn $u(t, t_0)$ is the Ordinate of UH of Unit duration t_0.

T_0 is the Unit duration of UH from which S curve has been obtained.

S_t is the Ordinate of S-curve at any time 't'.

S_{t-t_0} is the Ordinate of shifted S-curve shifted by t_0.

If t_0 is taken as Δt, the ordinates of resulting UH of Δt unit duration is given by

$$u(t, \Delta t) = \frac{T_0}{\Delta t}\left(S_t^{T_0} - S_{t-\Delta t}^{T_0}\right)$$

$$= T_0 \frac{\Delta S_t^{T_0}}{\Delta t}$$

$S_t^{T_0}$ is the S curve obtained from UH of T_0 duration.

If we Apply the Limits Δt tends to 0. then we get instantaneous UH is given by

$$\underset{\Delta t \to 0}{Lt}\; u(t, \Delta t) = T_0 \frac{dS_t^{T_0}}{dt}$$

$$u(t) = T_0 \frac{dS_t^{T_0}}{dt}$$

$$= \frac{1}{R_0} \frac{dS_t^{T_0}}{dt}$$

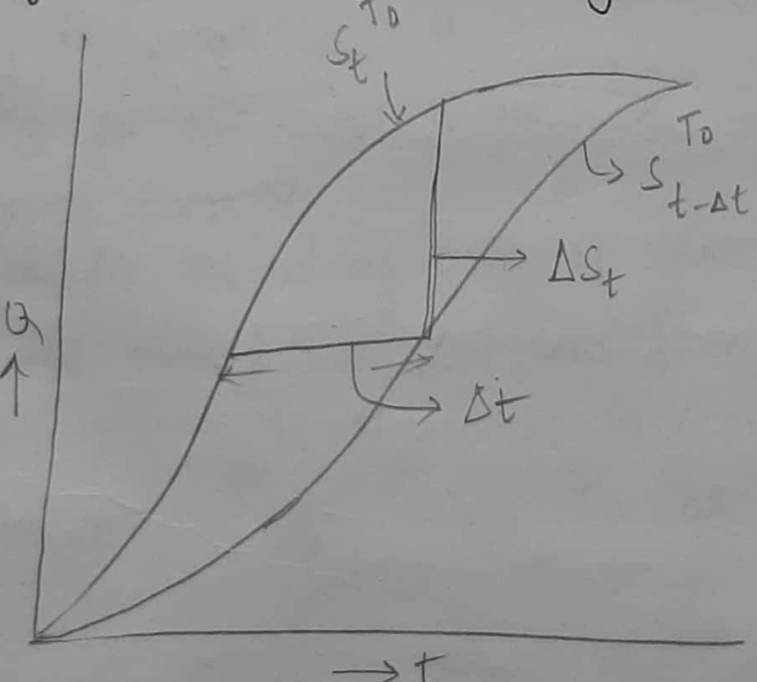
Hence, the Ordinate of IUH $u(t) = T_0 \times$ the slope of S-curve derived from T_0 hr UH at time t.

In the above expression R_0 is the intensity of rainfall excess i.e., given by

$$R_0 = \frac{1}{T_0}$$

If R_0 = 1cm; then $u(t) = \frac{dS_t^{T_0}}{dt}$

Where, S_t is the ordinate of S-curve of intensity 1cm per hr, the ordinate of Instantaneous UH at any time t is the slope of S-curve of intensity 1cm/hr.



IUH

As IUH is designated by u(t) is a single peaked hydrograph with a finite base width. it has following properties:

1. 0 ≤ u(t) ≤ a positive value of t > 0
2. u(t) = 0 at t ≤ 0
3. u(t) tends to 0 as 't' tends to ∞

4. $\int_0^\infty u(t).dt$ = unit depth over catchment.

5. Time to peak < time to centroid of the curve.

6. IUH is a graphical expression of the integration of all the parameters of the catchment such as length, slope, shape etc.,

7. The IUH can be developed either directly from the observed data or by adopting conceptual model. When the IUH is available for a catchment, UH of varies duration can be easily derive

Derivation of IUH from Nash model:

Nash derived the Ordinates of IUH formed by the catchment on an instantaneous rainfall is equavalent to a subset of routing through a no. of linear reservoirs. Hence, the considered entire catchment is equivalent to a series of linear reservoirs.

The storage characteristics expression is given by

$$S = kQ$$

Where,

'S' is the storage in the reservoir at any time 't'.

'Q' is the Outflow from the reservoir at same time 't'.

'k' is the delay time of reservoir.

He considered Outflow from one reservoir becomes inflow to the next reservoir.

The major eqn which is used for the routing process is

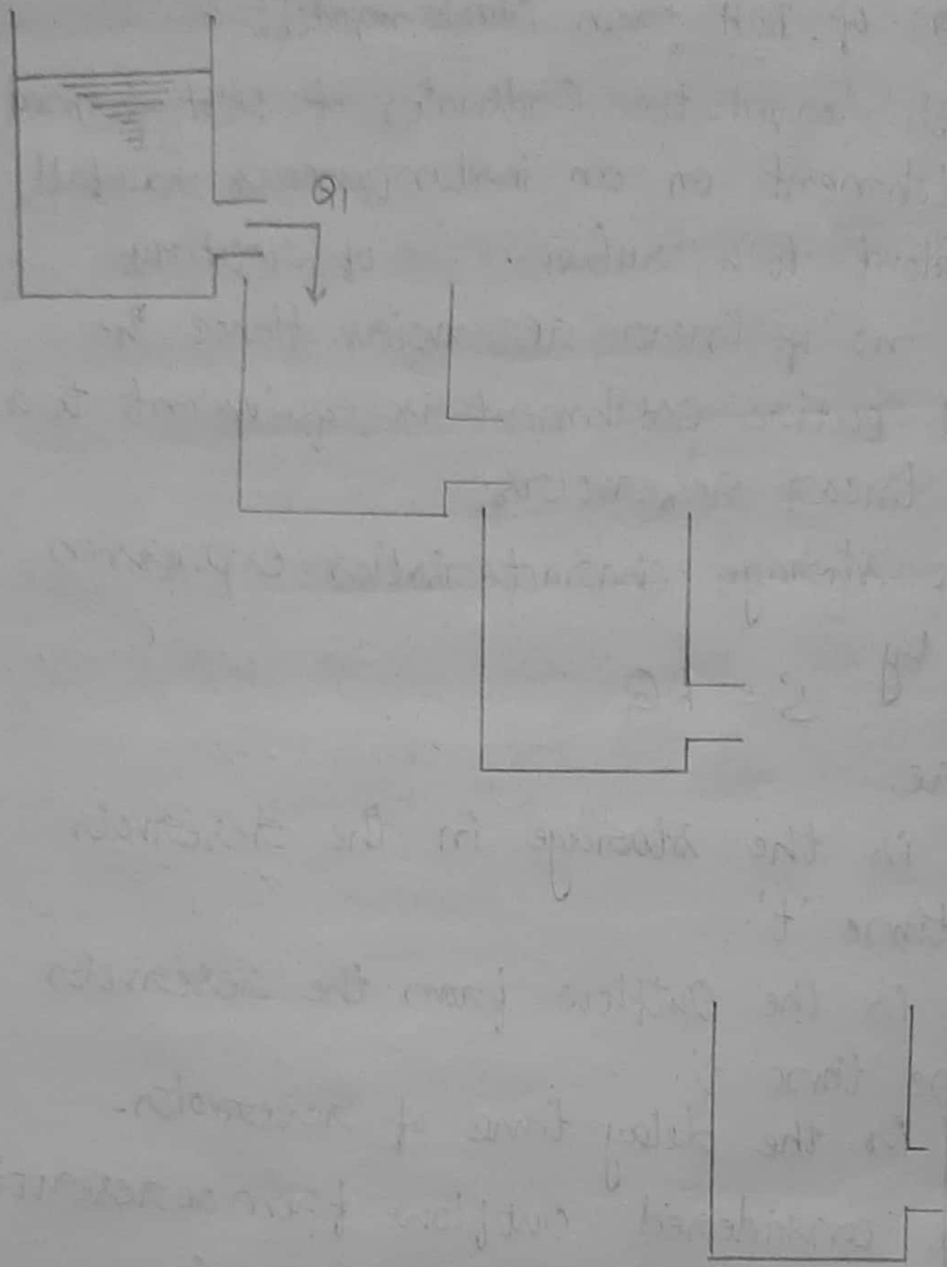
$$I - Q = \frac{ds}{dt}$$

where,

I is the rate of inflow into the reservoir at time 't'.

Q is the rate of outflow into the reservoir at time 't'.

$\frac{ds}{dt}$ is the rate of change of storage in the reservoir.



for incase of linear reservoirs

$$I - Q = \frac{d}{dt}(KQ)$$

$$S = KQ, \quad \frac{dS}{dt} = K\frac{dQ}{dt},$$

$$I - Q = K\frac{d}{dt}(Q)$$

$$I = Q + K\frac{dQ}{dt}$$

$$I = \left(1 + K\frac{d}{dt}\right)Q.$$

$$I = \frac{1}{K}e^{-t/K}\int e^{-t/K} I \, dt$$

for the 1st reservoir, when the input is applied Instantaneously, the inflow has the following Characteristics

i.e., $\int_{-\infty}^{\infty} I \cdot dt = V$

where V is the instantaneous input.

with this conditions the outflow from the 1st reservoir for an instantaneous input of V can becomes $Q_1 = \frac{V}{K} e^{-t/K}$

The Outflow from the second reservoir, is given by $Q = \frac{1}{K} e^{-t/K} \int e^{t/K} \cdot I \cdot dt$

where,

I is the know replaced by Q_1, as Q_1 becomes inflow to the 2nd reservoir.

Therefore $Q_2 = \frac{1}{K} e^{-t/K} \int_{0}^{t} e^{t/K} \cdot \frac{V}{K} e^{-t/K} \cdot dt$

$$Q_2 = \frac{V}{K^2} e^{-t/K} \cdot dt.$$

by successive routing of the flow n through an reservoirs, the yields from nth reservoir is

$$Q_n = \frac{V}{K} e^{-t/K} \cdot \left(\frac{t}{K}\right)^{n-1} \cdot \frac{1}{(n-1)!}$$

Instead of V cm of rainfall, if 1cm of rainfall is applied as the Instantaneous input to the 1st reservoir, the Outflow from the nth reservoir is nothing but IUH. i.e.,

$$u(t) = \frac{1}{K} e^{-t/K} \cdot \left(\frac{t}{K}\right)^{n-1} \frac{1}{(n-1)!}$$

if $\gamma_n = \frac{1}{(n-1)!}$

$$\boxed{u(t) = \frac{\gamma_n}{K} \cdot e^{-t/K} \cdot \left(\frac{t}{K}\right)^{n-1}}$$

(*) Clark's model for derivation of IUH:

Clark develop IUH by considering two aspects of drainage basins that are

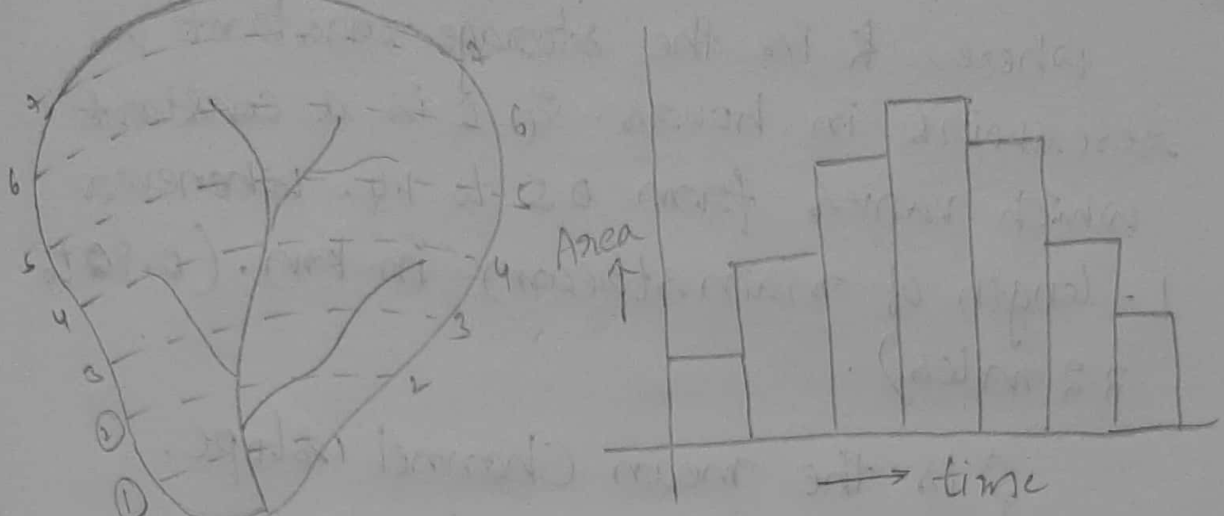
1. Transilation effect.
2. Storage effect

Transilation effect means travelling of water particles from one point to another point.

Storage effect means rising of storage levels by transilation effect.

As per the Clark model the basin may be divided into zones by drawing isochrones.

The area b/w successive Isochrones is measured & a time area concentration diagram is prepared.



The time area diagram is n through a linear reservoir whose storage eq'n is given by

$$S = Q \cdot K.$$

The ordinate of time area diagram can be readily converted into m^3/sec by multiplying with $\frac{2.778}{\Delta t}$.

where Δt is the time interval b/w successive isochrones.

The basic eq'n used for routing process is

$$\bar{I} - \bar{Q} = \Delta S$$

$$\left(\frac{I_1 + I_2}{2}\right)\Delta t - \left(\frac{Q_1 + Q_2}{2}\right)\Delta t = S_2 - S_1$$

$$Q_2 = \left(\frac{I_1 + I_2}{2}\right) C_0 + Q_1 C_1$$

where, $C_0 = \frac{\Delta t}{K + \frac{\Delta t}{2}}$; $C_1 = \frac{K - \Delta t/2}{K + \Delta t/2}$

$$k = \frac{CL}{\sqrt{S}}$$

where, k is the storage constant in reservoirs in hours. & c is a constant which varies from 0.5 to 1.4. whenever L - length of main stream in km. (0.89 to 2.2 miles).

S is the mean Channel slope.

$$K = \frac{bL\sqrt{A}}{\sqrt{S}}$$

Where, b is a constant which varies from 0.015 to 0.03 whenever L is varies from 0.04 to 0.08.

'A' is the area of the catchment in square miles.