Introduction to Hydrology

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Hydrology :- It is the science which deals with the occurrence distribution and movement of water on the earth, including that in the atmosphere & below the surface of the earth.

Hydrologic cycle :-

The supply of water from earth to atmosphere and back to the earth. The Earth's water circulatory system is known as the "hydrologic cycle".

* The hydrologic cycle consists of the following processes.

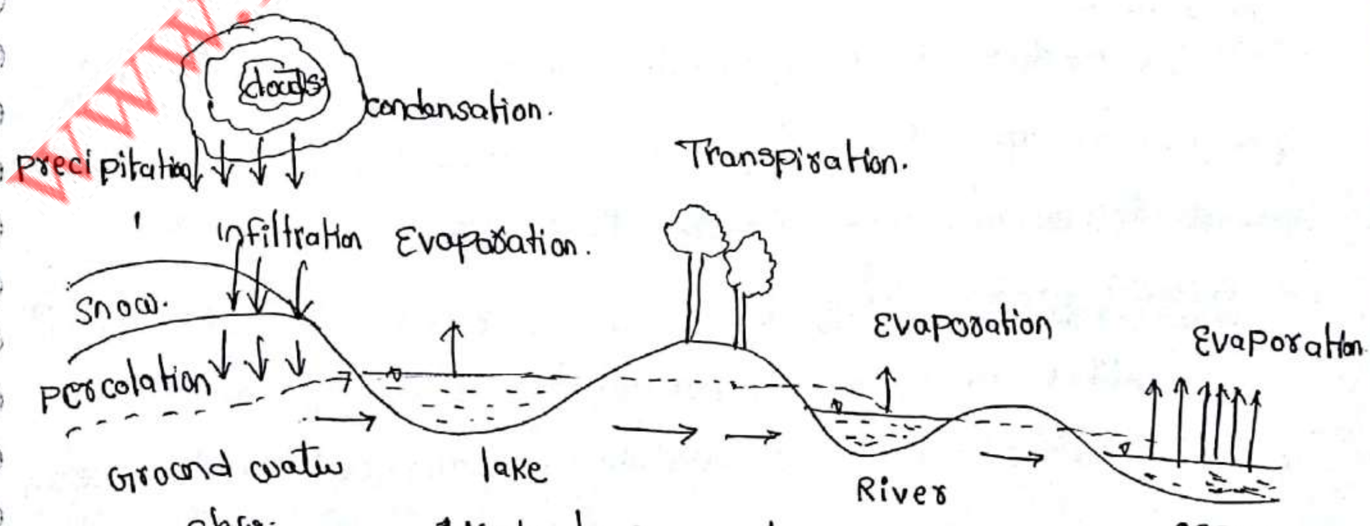
1. **Evaporation & Transpiration (E) :-**

The water from the earth surfaces of ocean, rivers, lake and also from the moist soil evaporates. The vapours are carried over the land by air in the form of clouds.

"Transpiration" is the process of water being lost from the leaves of plants from their pores.

→ The total evaporation consists of

1) surface evaporation.



Hydrologic cycle

ii) water surface evaporation from river surface & ocean
iii) Evaporation from plants & leaves.
iv) Atmospheric evaporation.

Precipitation :- (P)

It is defined as the fall of moisture from the atmosphere to the surface in any form. precipitation may be two forms.

a) liquid form :- Rain fall.

b) frozen form :- snow, Hail, sleet, freezing rain.

Run off :- (R) :-

Run off is the portion of precipitation that is not evaporated. when moisture falls to the Earth's surface as precipitation, a part of it is evaporated from the water surface soil & vegetation through transipiration by plants & reminder is the Runoff.

Run off may be classified as follows.

1. surface run off :-

The water flows over land & reach the streams & rivers and discharge the water to the sea.

2. sub surface run off :-

A portion of precipitation infiltrates into the surface soil & depending upon the geology of the basins, runs as sub surface runoff & reaches the streams & rivers.

3. Ground water flow :-

After infiltration, percolates down & joins the ground water reservoir which is connected to the ocean.

The hydrologic cycle may be expressed by using..

Precipitation (P) = Evaporation (E) + Run off (R).

Applications of Hydrology :-

The applications of Hydrology are.

i) Design of Hydraulic structures.
ii) Municipal & Industrial water supply.
iii) irrigation.
iv) Hydro Power.
v) Flood control.
vi) Navigation.
vii) Erosion & sediment control.

Design of Hydraulic Structures :-

Design of any structure related to water such as spillway, dam, culvert, highway bridge, rail bridge etc. are consist of three parts. hydrologic design, hydraulic design & structural Design.

Hydrologic design deals with the estimation of quantities of water. i.e their time distribution, time of occurrence & frequency of occurence.

Hydraulic design provides best suitable shape & section of the structure.

Structural design ensures the stability & safety of the section against water pressures & other pressures.

ii) Muncipal & Industrial water supply :-

The availability of water is often the most important factor in locating the major industries & it is effect on growth on muncipalities. Hydrologist to know the flow in the nearby stream is sufficient to meet the needs of the municipal city (or) the industry.

Irrigation :-

Hydrology of the basin provides the required information regarding the stream flows at various projects sites, their time distribution & frequency distribution which is essential in fixing the storage capacities for the cultivation of land

Hydro power :-

Hydrologic studies are essential for the planning of any water power development. Hydrology gives the information about soil conditions, flow conditions & floods. ~~Infor~~

Flood control :-

Reserviors, channel diversions, channel improvements (or) a combination of them are the most common-used flood control structures.

Navigation :-

Hydrologic problems in Navigation projects require answers to such questions as how much water will be required for lockgates & to maintain minimum draft, where from this water can be obtained & preserved and what will be the effect of the navigation structures on

...the stages in the river especially during floods etc.

Errosion & Sediment control :-

Excessive erosion in the catchment feeds sediment into the runoff. Hydrology of the catchment along with the knowledge of the existing watershed management pratices will help in finding out the effetive errosion contro measures suitable for the given soil conditions.

Pollution Abatement :-

A hydrologist can help the sanitary engineer regarding the level to which the stage of sewage has to be treated before it is disposed of into the stream & also the quanti of sewage that can be allowed into the river with-out cau any pollution to the down stream regions.

Forms of precipitation :-

The various forms of precipitation are Drizzle, rain, glaze, sleet, Snow, snow flakes & hail.

Drizzle :-

When the size of water droplets is under 0.5mm, & it's intensity is less than 1mm per hours. Because of th lightness, the droplets appear to be floating in air.

Rain :-

When the size of the drops is more than 0.5mm. The upper size of water drop is generally 6.25mm, as drops greater than this tend to break up as they fall through the air.

Glaze :-

when the drizzle (or) rain freezes as it comes in con with cold objects, it is known as glaze.

sleet :-

It is frozen rain drops cooled to the ice stage while falling through air at sub-freezing temperature.

Snow :-

Precipitation in the form of ice crystals resulting from sublimations i.e water vapour changed directly to ice.

Snow flakes :-

Number of ice crystals fused together form snow flakes.

Hail :-

Hail is lumps (or) bulbs of ice over 5mm diameter formed by alternate freezing (or) melting as they are carried up down in highly turbulent air currents.

Types of precipitation :-

Precipitation is often classified according to the factor responsible for lifting. They are classified into 4 types.

1. cyclonic precipitation.
2. convective precipitation.
3. orographic precipitation.
4. precipitation due to turbulent ascent.

cyclonic precipitation :-

This precipitation results from lifting of air masses converging in to low pressure area of cyclone. This is again classified into two types.

a. frontal precipitation :-

A boarder region b/n two adjacent air masses having different characterstics such as temperature & humidity is called a front.

The lifted warm air mass cools down at high altitudes causing precipitation. A front may be cold (or) warm front depending upon whether there is active (or) passive ascent of warm air mass over cold air mass.

b) Non frontal precipitation :-

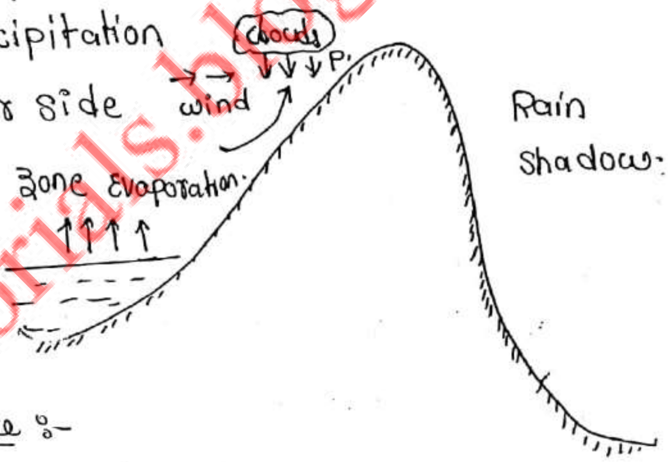
In this case, the moist warm air mass is stationary & the moving cold air mass meets it. Thus, due to lightness of the warm air there is passive ascent of warm air over cold air owing to the active under cutting. when the lifted warm air cools down at higher altitude precipitation occures.

Convective precipitation :-

This is due to natural rising of warmer lighter air in colder, denser surrounding. The difference in temperature may result from unequal heating at the surface, unequal cooling at the top of the air layer. This precipitation is spotty & its intensity may vary from light showers to cloud bursts.

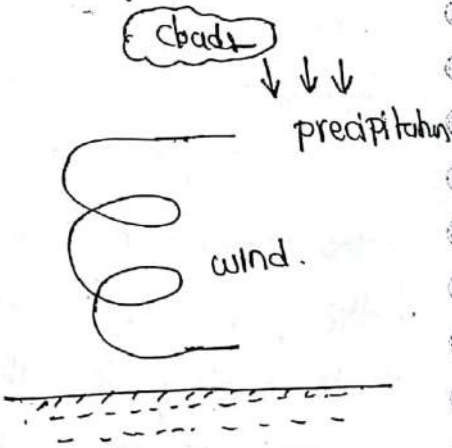
Orographic precipitation :-

Orographic precipitation is due to the lifting of warm moisture laden air masses due to topographic barriers i.e mountains. As it reaches higher elevation, it comes in contact with cold air & precipitation occurs. The zone to the other side of the mountain will be the zone of rain shadow area, where rain fall not occurs.



Precipitation due to turbulence :-

Air mass is forced to rise up due to greater friction of earth surface after its travel over ocean. The air mass rises up because of increased turbulence & friction, when ultimately occurs condenses & precipitation occurs. winter rain fall in Madras state is mainly due to this process.



Rainguages :-

Rainguages are used to measure the rain fall intensity. It is expressed as the depth in cm (or) inches.

Rainguages are classified in to two types

1. Non-automatic rain guages.
2. Automatic Rainguages.

Non-automatic Rainguages :-

This is also known as non-recording Rainguage. Symon's Rainguage is most common type of non-recording rainguage & it used by Indian Meteorology Department.

Symon's Rainguage :-

1. It consists of cylindrical vessel 127mm in diameter with a base Enlarged to 210mm diameter.
2. The top of section is a funnel provided with circular brass rim excatly 127mm Internal diameter.
3. The funnel shank is inserted in the neck of a receiving bottle which is 75 to 100mm diameter.
4. A receiving bottle of rainguage has a capacity of about 75 to 100mm of rainfall.
5. During A heavy rain fall, this quantity is frequently exceeded, the rain should be measured 3 (or) 4 times in a day
6. A cylindrical graduated measuring glass is furnished with each instrument, which reads 0.2mm.
7. The rainguage is set up in a concrete block of 60cm x 60cm x 60cm.

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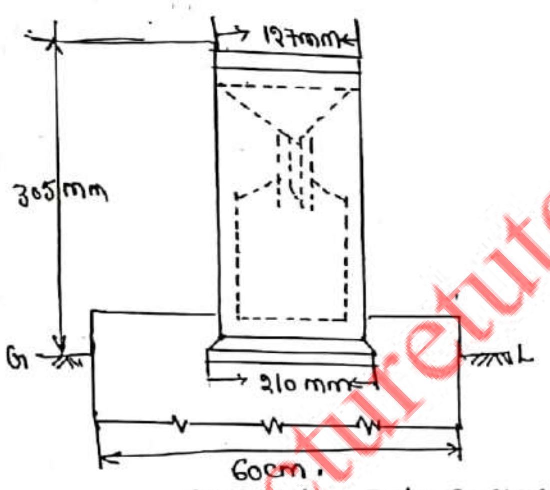
Automatic rainguages :-

These are integrating type recording rainguages & are in three types.

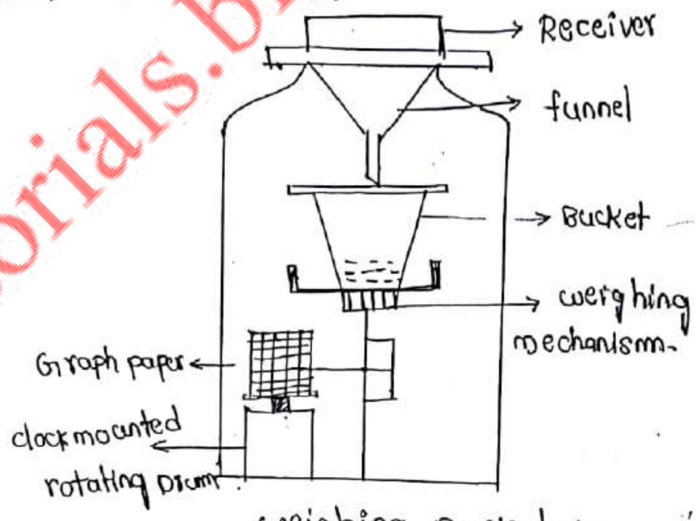
1. weighing Bucket type Rainguage :-

Self Recording gauges are used to determine rates of rainfall over short periods of time.

The weighing bucket rainguage essentially consists of a receiver bucket supported by a spring (or) lever balance (or) any other weighing mechanism. The movement of the bucket due to increasing weight is transmitted to a pen which traces the record on a clock driven chart.



Symon's Rain Gauge



weighing Bucket type

2. Tripping Bucket type Rainguage :-

1. A tripping Bucket type rainguage consists of 300mm diameter sharp edge receiver. At the end of receiver is provided a funnel.

2. A pair of buckets are provided under the funnel in such a way that when one bucket receives 0.25mm of precipitation it tips, discharging its contents into a

container bringing the other bucket under the funnel.

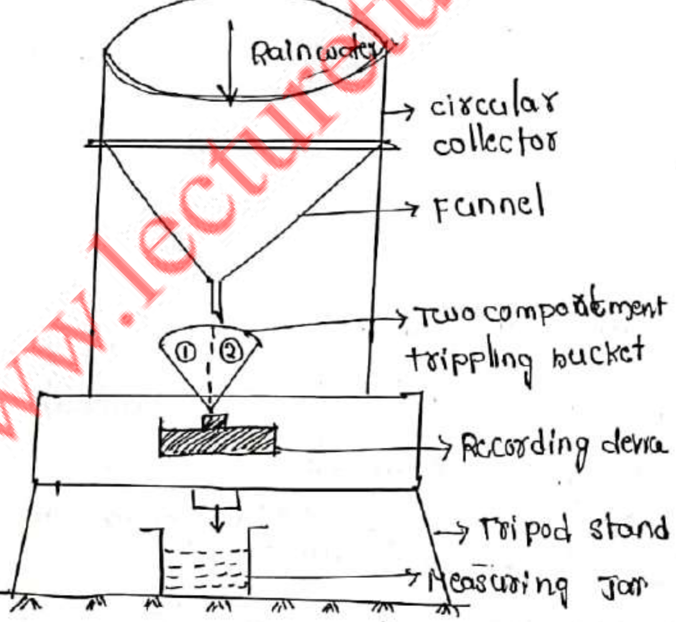
Trippling bucket completes an electric circuit causing the movement of pen to mark on clock driven revolving drum which carries a record sheet.

Float (or) syphon Rainguage:-

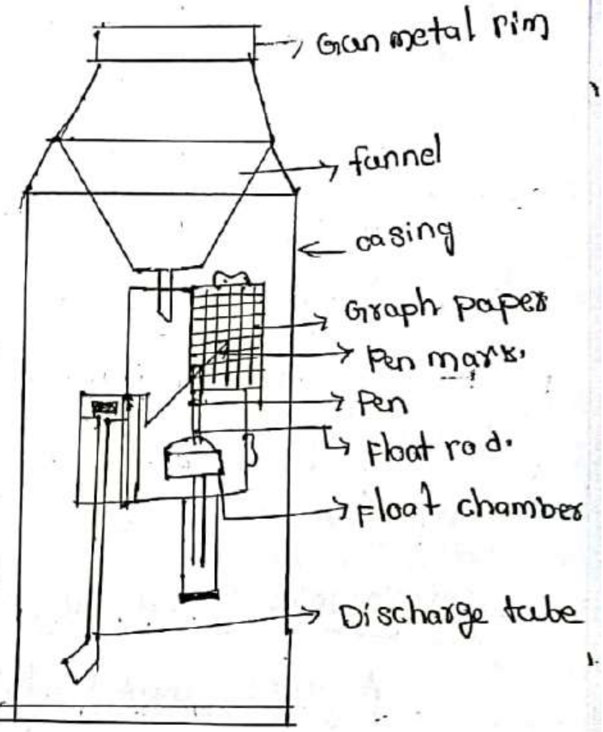
It's working is similar to the weighing bucket type guage. A funnel receives the rain water which is collected in a rectangular container.

A float is provided at the bottom of the container. The float is raised as the water level rises in the container, it's movement being recorded by a pen moving on a record drum actuated by a clock work.

When the water level in the container rises so that the float touches the top, the siphon comes into operation, & releases the water. Then the water is drained out.



Tripping Bucket type.



Float type / syphon Rainguage

selecting the site for a rainguage station:-

1. The site of rainguage station should be open place
2. The distance b/n the rainguage & nearest object should be atleast twice the hight of the object. i.e 30 meters.
3. The rainguage should never be situated on the side (or) top of a hill.
4. A fence, if erected to protect the guage from cattle etc, should be so located that distance of the fence is not less than twice its height.

Advantages of recording Rainguages:-

1. The rainfall is recorded automatically & therefore, there is no necessity of any attendant.
2. The recording rain guage also gives the intensity of rainfall at any time while the non recording guage gives the total rainfall in any particular interval.
3. As no attendant is required such rainguage can be installed in far off places also
4. Possibility of human error is obviated.

Disadvantages:-

1. It is costly in comparison with non-recording guage.
2. Faulty may be develop in electrical /mechanical mechanism (or) recording the rainfall.

Microwave Radar for Measurement of rainfall:

A microwave Radar can be used to obtain, roughly, information on rainfall distribution within its ~~[illegible]~~

scanning area. The image on the radar screen can be inter-preted as an approximate indication of rainfall intensity. Since the amount of deflected energy is dependent on the raindrop size & the distance from transmitter & the drop size is roughly correleated with rain intensity.

Totaliser :-

A totaliser, used mainly for measuring rainfall for hydrolog purposes, consists of a large container with a funnel like opening which can hold rain catch of large quantity.

It is mostly used to measure rainfall at a remote plac at large interval of time.

To record snow as precipitation at remote location, a storage guage is used. It is generally 305mm in diamet with enough height, with anti freeze chemical to melt the sn

Rainguage Network :-

The rainguage density (or) network density is define as the ratio of total area of catchment to the total numb of guages in the catchments.

IS- code recommendations :-

IS- code has recommended the following densities.

1. one guage per 520 Km^2 in plain areas.
2. one guage per 260 Km^2 to 290 km^2 in regions with elevation of 1000m above mean sea level.
3. one rainguage per 130 km^2 in Hilly regions.

Adequacy of Raingauge stations :-

optimum no. of rainguage stations (N) as per ISI is

$$N = \left[\frac{C_v}{P}\right]^2$$

where, C_v = coefficient of variation of the rainfall values of existing stations.

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

S_x = standard deviation.

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

P = desired degree of error in estimating rainfall.

⇒ Generally 'P' values will be taken as 10%.

If $N < m$ ⇒ Rainguages are sufficient in number

$N > m$ ⇒ Rainguage are deficient in number

∴ extra Rainguages required = $N - m$

where, m = no. of existing stations.

Estimation of missing Rainfall Data :-

The following methods are used for estimation of missing Rainfall Data.

1. Arithmetic mean method.
2. Normal Ratio method.
3. Inverse distance method.

Arithmetic mean method :-

A/c to this method, the missing rainfall P_x of the station x is computed by simple arithmetic average of the rainfall at the near by stations,

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

$$\boxed{P_x = \frac{1}{n}(P_1 + P_2 + \cdots + P_n)}$$

n = number of known stations.

conditions :-

1. The normal annual rainfall of the missing station is within 10% of the normal annual rainfall of the index stations.
2. Data atleast three index stations should be available.
3. The index stations should be evenly spaced & closed.

Normal ratio method :-

In this method, the rainfall of the surrounding index stations are weighed by the ratio of normal annual rainfalls by using following equation

$$\boxed{P_x = \frac{N_x}{n}\left[\frac{P_1}{N_1} + \frac{P_2}{N_2} + \cdots + \frac{P_n}{N_n}\right]}$$

where, $N_1, N_2 \ldots N_n$ = normal annual rainfall of index stations

N_x = normal annual rainfall of missing station

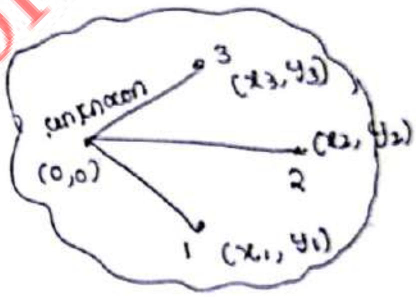
n = number of index stations.

⇒ The above method is used when the normal annual precipitation of the index stations differ more than 10% of missing station.

3. Inverse distance method :-

In this method a set of rectangular co-ordinate axes are passed through the missing raingauge station taken as origin (0, 0). The co-ordinates (x_i, y_i) of each index station, surrounding the missing station are found.

The missing rainfall data of the station x is computed from the following



$$\boxed{P_x = \frac{\Sigma P_i \omega_i}{\Sigma \omega_i}}$$

where, ω_i = weightage of each index station

$$\boxed{\omega_i = \frac{1}{x_i^2 + y_i^2}}$$

Computation of Avg. Rainfall over a Basin :-

The avg. Rainfall over a Basin is calculated by using

1. Arithmatic average method.
2. Thiessen polygon method.
3. Isohyetal method.
4. Grid point method.

Arithmetic Average Method :-

This is the simplest method of Estimating avg. rain fall is to compute the arithmatic avg. of the recorded rain fall values at various stations.

If $P_1, P_2, P_3 --- P_n$ are the precipation or rainfall values measured at 'n' guage stations.

$$\boxed{P_{avg} = \frac{1}{n} \Sigma P_i}$$

Thiessen polygon method :-

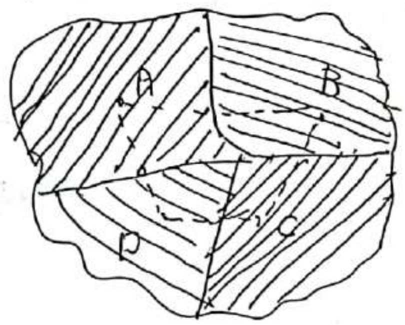
This method is more common method of weighing the rain-guage observations. Thiessen polygon method is also called weighted mean method & more accurate.

Procedure :-

1. Join the adjacent rain guage stations A, B, C, D etc; by straight lines.
2. construct the perpendicular bisectors of each of these line
3. The polygon formed by the ⊥lar bisectors around a station encloses an area. Find the area of each of these polygo shown by hatched area.
4. Multiply the area of each Thiessen polygon by the rain guage value of enclosed station.

$$\text{Avg. precipitation}, \; P_{av} = \frac{A_1P_1 + A_2P_2 + --- + A_nP_n}{A_1 + A_2 + --- + A_n}$$

$$\boxed{P_{av} = \frac{\Sigma (A \times P)}{\Sigma A}}$$



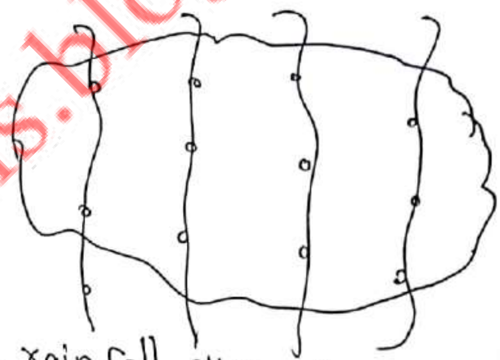
Defects :-

1. A new thiessen diagram is required, if there is an addition / detetion of rain guage station for the basin.
2. No account is taken of the orographic features of the catchment
3. The method does not consider topographic features & other barriers.

Isohyetal Method :-

An isohyet is a line, on a rainfall map of the basin, Joining places of equal rainfall readings. An isohyetal map showing contours of equal rainfall presents more accurate picture of the rainfall distribution over the basin

Procedure :-



1. From the rainfall values recorded at various rain-guage stations, prepare the isohyetal map for the storm causing the rainfall over the area.
2. Measure the areas enclosed b/n successive isohyets with the help of planimeter.
3. Multiply each of these areas by the avg. rainfall b/n the isohyets.
4. The avg. rainfall is then computed from the expression

$$\boxed{P_{av} = \frac{\Sigma\left[A\left[\frac{P_1+P_2}{2}\right]\right]}{\Sigma A}}$$

* This is the accurate method, than the remaining.

D. Grid point method :-

In this method, all the grid stations are marked on the map of the basin, along with the depth of precipitation.

On this map, drawn to a suitable scale, a uniform rectangular grid at some suitable spacing is super-impose. The avg. precipation of the four grid corners is the multi-plied by the area of grid, to give the avg. precipitation volume of grid.

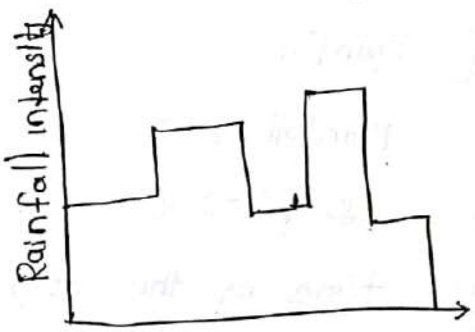
The sum of all such products divided by the total are of the basin will give avg. precipitation for the basin.

Presentation of Rainfall Data :-

There are three methods of presentation of rainfall data. They are.
1. Hyetograph method.
2. Mass curve of rain fall method.
3. Point rain fall method.

Hyetograph method :-

A hyetograph is a bar graph showing the intensity of rainfall with time. The hyetograph can be prepared either from the mass curve of rain fall; or directly from the data obtained from automatic rainguages.

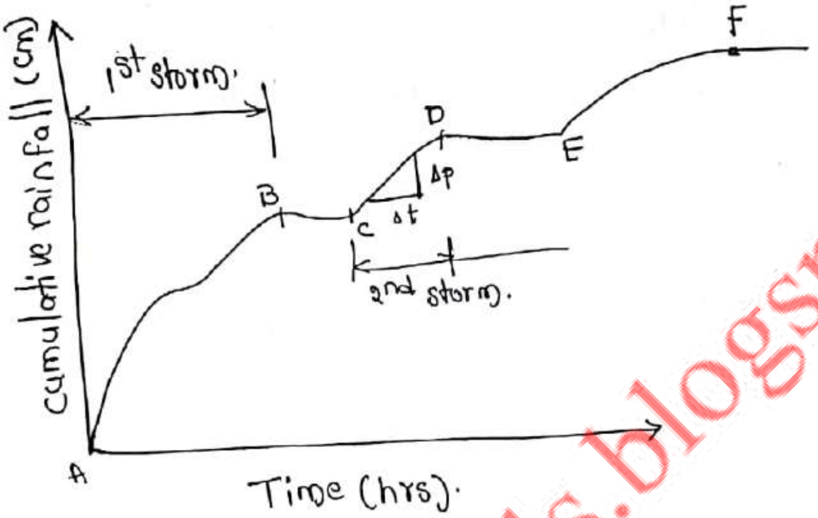


Mass curve of Rainfall :-

A mass curve of rainfall is a plot of cumulative depth of rainfall against time.

* Mass curves of rainfall are very useful in extracting the information on the duration & magnitude of a storm.

The steepness of curve indicates the intensity of rainfall. A horizontal portion of the curve indicates that there was no rainfall during the period.

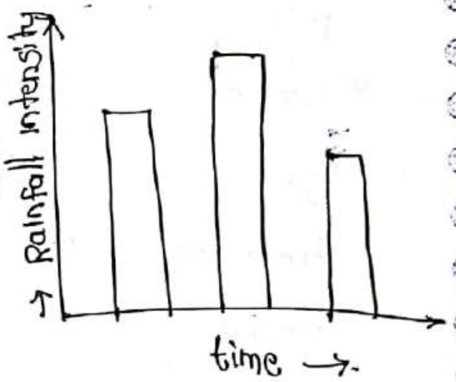


The intensity of rainfall during any period is

$$\boxed{i = \frac{\Delta P}{\Delta t}}$$

Point Rainfall method :-

The Rainfall data of a station is known as point rainfall or station rainfall. The point rainfall data is presented graphically as plots of magnitude vs chronological time in the form of a bar diagram.



Point precipitation data are used to estimate the areal variability of rainfall.

D. Intensity of Rainfall :-

It is defined as the rate at which rainfall occurs, & it expressed as cm/h (or) mm/hr.

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

The intensity of rainfall is classified in to the following type

1. Light Intensity rainfall – 2.5mm/hr
ii. Moderate intensity rainfall – 2.5 – 7.5 mm/hr
iii) Heavy intensity – > 7.5 mm/hr.

Frequency of Rainfall :-

The frequency of a rainfall is the number of time that a given magnitude of rainfall may occur in a given period. The study of the probability of occurence of a particular Extreme rain fall is importance to determination of Design floo

The reccurrence interval is the interval in years for occurrence of the event of same magnitude.

$$\text{Return period / Recurrence interval}, \; T = \frac{1}{Pro.}$$

The formulae for probability are

i) california formula : $Pro = \frac{m}{N}$

ii) Hazen formula : $Pro = \frac{2m-1}{2N}$

iii) weibull formula : $Pro = \frac{m}{N+1}$.

Probability ; $= nC_r \, p^r q^{n-r}$.

where, n = no of yrs taken

P = same events occured

q = Same events not occured

r = no. of times repeated.

Reliability :- It is the frequency of flood not come in the future. ∴ r = 0, $P = {}^nC_0\, P^0 q^n$

$$\boxed{R = (1-P)^n}$$

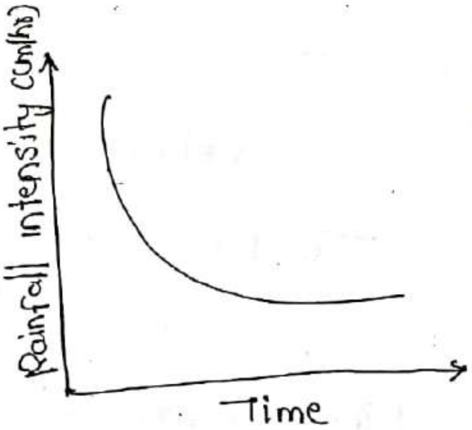
Risk :-
It is the frequency of flood Atleast ~~one~~/more times are come ∴ $\boxed{Risk = 1 - q^n}$

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

$$\therefore f = 100\,Pro = \frac{1}{T} \times 100.$$

Intensity Duration Analysis :- (IDF curves)

It has generally observed that greater the intensity of rainfall, shorter is the length of time it continues. As the duration of ~~maximum~~ ~~intensity of~~ storm increases, the maximum intensity of storm decreases.



* Sherman gave the following relation

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

i = intensity of rainfall (cm/hr)

t = time in min.

a, b, n = constants to be determined for the area.

* The world's greatest recorded rainfall lie on (or) just under a straight line whose equation is

$R = 16.6\,D$ ...

R = Rainfall (inch) D = Duration (hrs).

highest intensities → 200 mm in 20 min
40 mm in a min
26 m in a year.

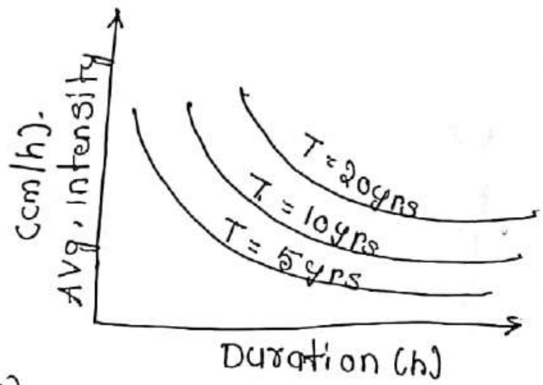
intensity Duration frequency relationship :-

It is observed that a storm of any given duration will have larger intensity. If it's return period is large. This means for storm of given duration, storms of higher intensity in that duration are rarer than storms of smal Intensity.

The relation between intensity, duration & return period can be expressed as

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

where, x, b & n = constants for the catchments
T = Return period (yrs).



→ constants values are based on studies conducted by central soil & water conservation research & training institute, Dehradun.

Areas	K	b	n	x
Bellary	6.16	0.5	0.694	0.972
Rajpur	4.62	0.15	0.139	0.928
Bhopal	6.93	0.5	0.189	0.878

Depth Area relationships :- (Graph curves)

The Areal distribution characteristics of a storm of given duration is reflected in the depth area relation -ships & depth area curves.

Precipitation rarely occurs uniformly over the whole area. For a rainfall of a given duration, the avg depth of rainfall decreases from maximum value as the area increases.

The relation ship is expresed as

$$\bar{P} = P_n e^{-kA^n}$$

where, $\bar{P}$ = Avg. depth in cm, over an Area.

P_n = highest amount of Rainfall observed at that area

A = Area in km^2

K, n = constants.

K & n values for different duration area.

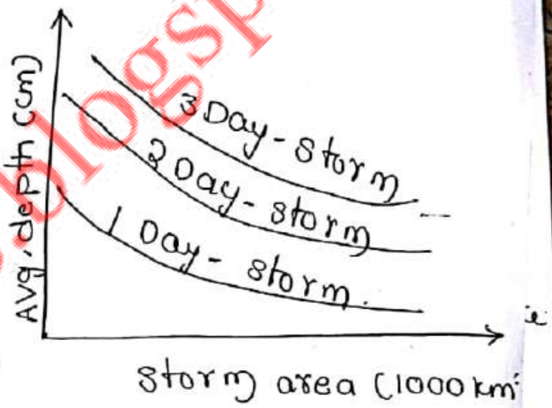
Duration of storm	K	n
1 day	9.256×10^{-4}	0.6614
2 day	9.877×10^{-4}	0.6306
3 day	1.745×10^{-4}	0.5961.

Depth - Area - Duration curves :-

Rain fall rarely occurs uniformly over the whole of the catchment. Variations in total depth of rainfall & intensity occur from centre to the peripheries of storm.

The knowledge of maximum depth of rainfall occurin on areas of various sizes for storms of different durations is of great important in hydrological design problems. The development of releation b/w maximum depth, area & duration for a region is known as DAD Analysis.

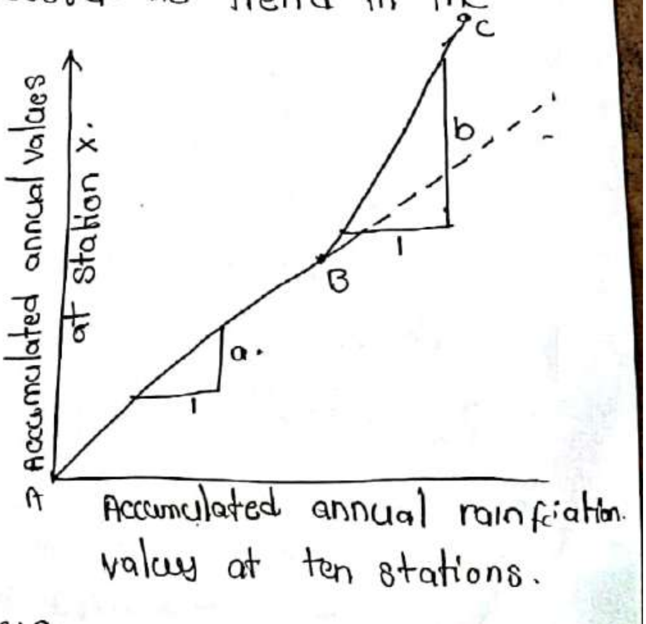
These curves are used to determine the maximum amounts of precipation of various Durations over areas of various sizes.



<u>Consistency of Rainfall Data (or).</u>

<u>Double mass curve of rainfall :-</u>

This curve of rain fall is a technique used for checking the consistency of a record. The trend in the rainfall records at a station may slightly change after some years due to change in the Environment of a station, (or) tampering of the instrument (or) shift in the observation pratices.



A Double mass curve is a graph plotted b/n the Accumulated annual rainfall at a given station 'x' versus accumulated annual values of the avg. of group of base stations, for various consecutive time periods as shown in fig.

A break in the slope of the resulting plot indicates a change in the precipitation regime of station x. The precipitation values at the station x, beyond the period of break are corrected by the following relationship :-

$$P_{xc} = P_x \cdot \frac{a}{b}.$$

P_{xc} = corrected precipitation at the test station x, at any time 't'

P_x = recorded precipitation at the test station x, at time 't'.

Probable maximum precipitation :- (PMP)

PMP is defined as that rainfall over a basin which would produce the flood flow with virtually no risk of being exceeded.

⇒ PMP, for a region is the precipitation resulting from the most critical meteorological combinations that are considered probable of occurrence.

→ The PMP can be estimated by maximising different parameters like humidity, temperature, wind velocity & other connected meterological factors of an observed severe storm over the basin. it can be determined by two methods.

i) Meteorological approach :-

world's greatest observed point rain fall is a st. line. whose equation is $\boxed{R = 16.6\, D^{0.475}}$

ii) statistical approach :-

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

$\bar{P}$ = mean of annual maximum rainfall series.

σ = standard deviation of the series.

K = frequency factor.