

MODULE 1

1. INTRODUCTION

1.1 HYDROLOGY

1.2 SCOPE OF HYDROLOGY

1.3 IMPORTANCE OF HYDROLOGY

1.4 HYDROLOGIC CYCLE (HORTON'S)

1.5 WATER BUDGET EQUATION

1.6 PRECIPITATION

1.7 DEFINITIONS

1.8 FORMS OF PRECIPITATION

1.9 FORMATION OF PRECIPITATION

1.10 TYPES OF PRECIPITATION

1.11 MEASUREMENT OF RAIN FALL

1.11.1 NON RECORDING RAINGAUGE

1.11.2 RECORDING RAIN GAUGES

1.12 COMPUTATION OF MEAN RAINFALL

1.13 ESTIMATION OF MISSING DATA

1.14 RAINGAUGE DENSITY

1.15 OPTIMUM NUMBER OF RAIN GAUGE STATIONS

1.16 CONSISTENCY OF RAINFALL DATA (DOUBLE MASS CURVE METHOD)

1.17 PRESENTATION OF PRECIPITATION DATA

1. INTRODUCTION

The world's total water resources are estimated to be around 1.36×10^{14} ha-m. 92.7% of this water is salty and is stored in oceans and seas. Only 2.8% of total available water is fresh water. Out of this 2.8% fresh water, 2.2% is available as surface water and 0.6% as ground water. Out Of the 2.2% surface water, 2.15% is stored in glaciers and ice caps, 0.01% in lakes and streams and the rest is in circulation among the different components of the Earth's atmosphere.

Out of the 0.6% ground water only about 0.25% can be economically extracted. It can be summarized that less than 0.26% of fresh water is available for use by humans and hence water has become a very important resource. Water is never stagnant (except in deep aquifers), it moves from one component to other component of the earth through various process of precipitation, run off, infiltration, evaporation etc. For a civil engineer, it is important to know the occurrence, flow, distribution etc. it important to design and construct many structures in contact with water.

1.1 HYDROLOGY

Hydrology may be defined as applied science concerned with water of the Earth in all its states, their occurrences, distribution and circulation through the unending hydrologic cycle of precipitation, consequent runoff, stream flow, infiltration and storage, eventual evaporation and re-precipitation. Hydrology is a highly inter-disciplinary science. It draws many principles from other branches of science like:-

- Meteorology and Climatology
- Physical Geography
- Agronomy and Forestry
- Geology and Soil science
- Oceanography
- Hydraulics
- Probability and Statistics
- Ecology

Hydrology concerns itself with three forms of water:-

- Above land as atmospheric water or precipitation.
- On land or surface as stored water or runoff
- Below the land surface as ground water or percolation

1.2 SCOPE OF HYDROLOGY

The study of hydrology helps us to know:

1. The maximum probable flood that may occur at given sit and its frequency; this is required for the safe design of drains, bridges & culverts, dams & reservoirs, channels and other flood control system.
2. The water yield from a basin –its occurrence, quantity and frequency etc; this is necessary for the design of dams, municipal water supply, water power, river navigation etc.
3. The ground water development for which a knowledge of Hydro geology of the area i.e. formation of the soils, recharge facilities like streams and reservoirs, rainfall pattern, climate; cropping pattern etc are required.
4. The maximum intensity of storm & its frequency for the design of drainage project in the area.

1.3 IMPORTANCE OF HYDROLOGY

- Design of Hydraulic Structures: Structures such as bridges, causeways, dams, spillways etc. are in contact with water. Accurate hydrological predictions are necessary for their proper functioning. Due to a storm, the flow below a bridge has to be properly predicted. Improper prediction may cause failure of the structure. Similarly the spillway in case of a dam which is meant for disposing excess water in a dam should also be designed properly otherwise flooding water may overtop the dam.
- Municipal and Industrial Water supply: Growth of towns and cities and also industries around them is often dependent on fresh water availability in their vicinity. Water should be drawn from rivers, streams, ground water. Proper estimation of water resources in a place will help planning and implementation of facilities for municipal (domestic) and industrial water supply.
- Irrigation: Dams are constructed to store water for multiple uses. For estimating maximum storage capacity seepage, evaporation and other losses should be properly estimated. These can be done with proper understanding of hydrology of a given river basin and thus making the irrigation project a successful one. Artificial recharge will also increase ground water storage. It has been estimated that ground water potential of gangetic basin is 40 times more than its surface flow.

- Hydroelectric Power Generation: A hydroelectric power plant need continuous water supply without much variations in the stream flow. Variations will affect the functioning of turbines in the electric plant. Hence proper estimation of river flow and also flood occurrences will help to construct efficient balancing reservoirs and these will supply water to turbines at a constant rate.
- Flood control in rivers: Controlling floods in a river is a complicated task. The flow occurring due to a storm can be predicted if the catchment characteristics are properly known. In many cases damages due to floods are high. Joint work of hydrologist and meteorologists in threatening areas may reduce damage due to floods. Flood plain zones maybe demarked to avoid losses.
- Navigation: Big canals in an irrigation scheme can be used for inland navigation. The depth of water should be maintained at a constant level. This can be achieved by lock gates provided and proper draft to be maintained. If the river water contains sediments, they will settle in the channel and cause problems for navigation. Hence the catchment characteristics should be considered and sediment entry into the canals should be done.
- Erosion & sediment control: Excessive erosion in the catchment feeds the sediment into the runoff. The reservoir may lose their capacity at a faster rate reducing their economic span drastically. Tones of fertile top soil will be lost every year resulting in crop yields. Hydrology of the catchment along with the knowledge of the existing water shed management practices will help in finding out the effective erosion. These measures includes the fixing crop pattern & cropping procedures, formation of contour bunds, aforestation etc. effective erosion control measures not only decreases the sediment load in the stream but also reduces peak flood discharges because of increased infiltration opportunities in the catchment.
- Pollution control: It is an easy way to dispose sewage generated in a city or town into streams and rivers. If large stream flow is available compared to the sewage discharge, pollution problems do not arise as sewage gets diluted and flowing water also has self-purifying capacity. The problem arises when each of the flows are not properly estimated. In case sewage flow is high it should be treated before disposal into a river or stream.

1.4 HYDROLOGICAL CYCLE

Water exists on the earth in gaseous form (water vapor), liquid and solid (ice) forms and is circulated among the different components of the Earth mainly by solar energy and planetary forces. Sunlight evaporates sea water and this evaporated form is kept in circulation by gravitational forces of Earth and wind action. The different paths through which water in nature circulates and is transformed is called hydrological cycle. Hydrological cycle is defined as the circulation of water from the sea to the land through the atmosphere back to the sea often with delays through process like precipitation, interception, runoff, infiltration, percolation, ground water storage, evaporation and transpiration also water that returns to the atmosphere without reaching the sea.

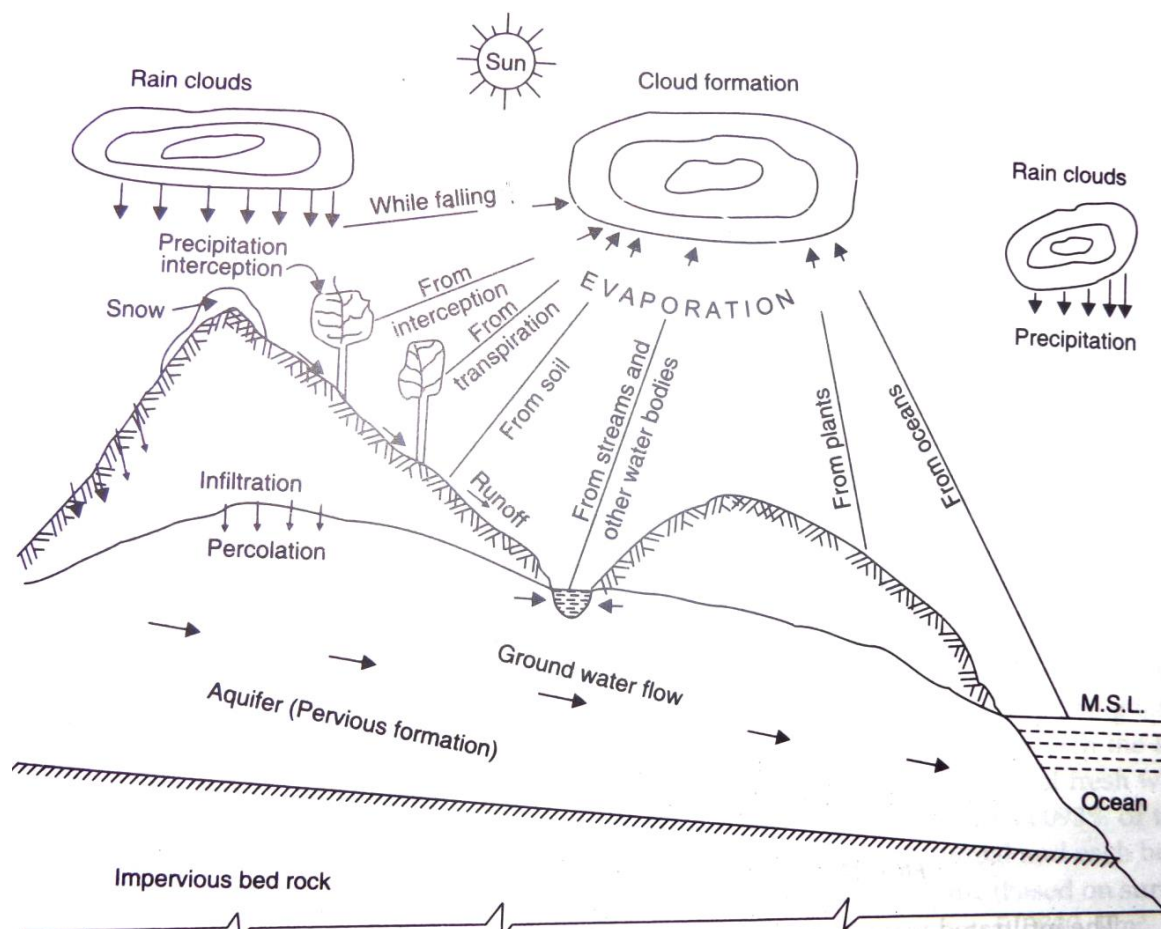


FIG 1: Descriptive representation of hydrological cycle

The hydrological cycle has 3 important phases:

1. Evaporation & Evapotranspiration
2. Precipitation
3. Run off

Evaporation takes place from the surface of ponds, lakes, reservoirs and ocean surfaces. Transpiration takes place from surface vegetation i.e. from plant leaves of cropped land forest

etc. These vapours rise to sky and are condensed at higher altitude and form the clouds. The clouds melt and sometime burst resulting in precipitation of different forms like rain, snow, hail, mist and frosts. A part of this precipitation flows over the land as runoff and a part infiltrate into the soil which build up ground water table. The surface run-off joins the stream and thus water stored in the reservoir. A portion of the surface runoff and ground water flows back to ocean. Again evaporation starts from surfaces of lakes, reservoirs and ocean & thus the cycle repeats.

The hydrological cycle can also be represented in many different ways in diagrammatic forms as

1. Horton's Qualitative representation
2. Horton's Engineering representation

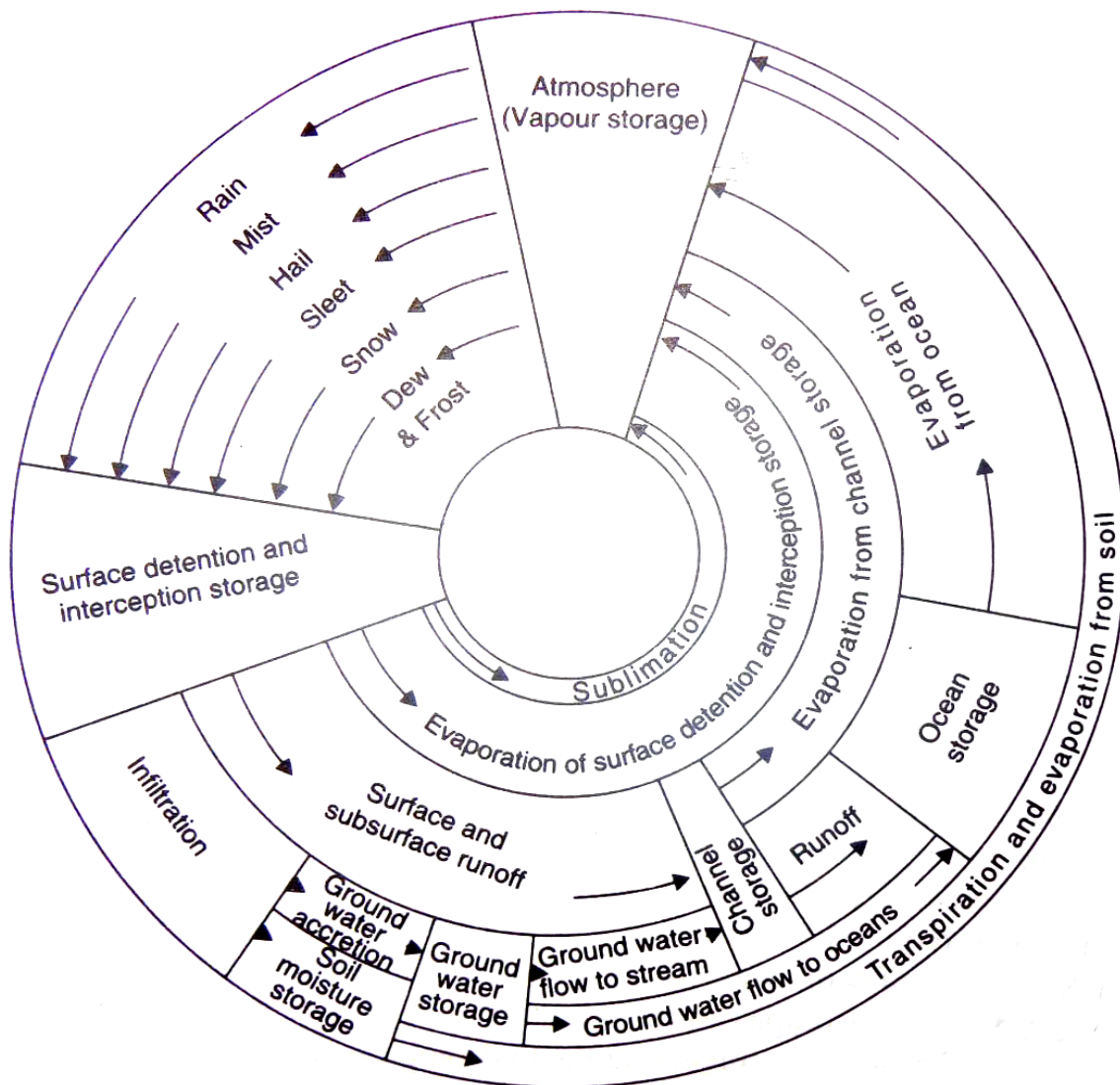


FIG 1.2: Qualitative representation of Horton's hydrological Cycle

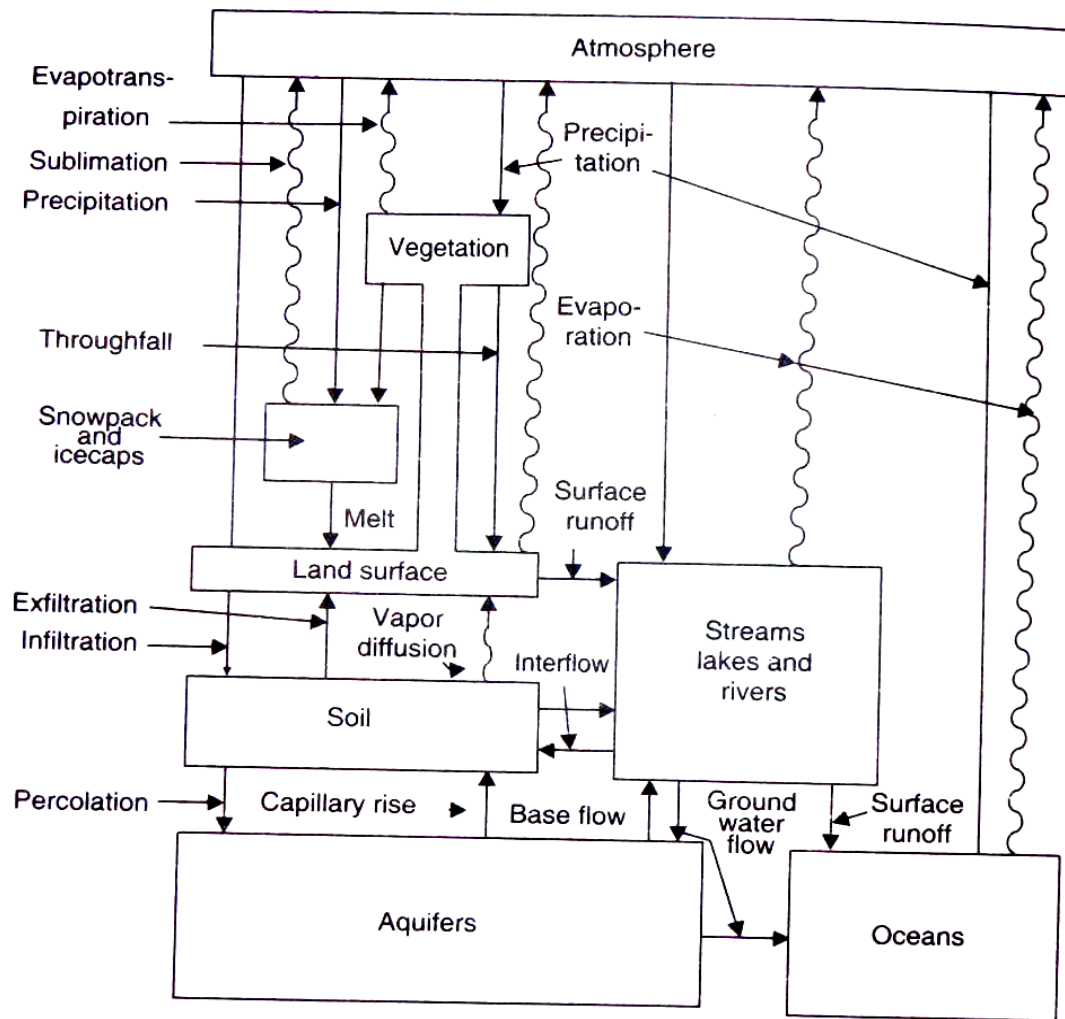
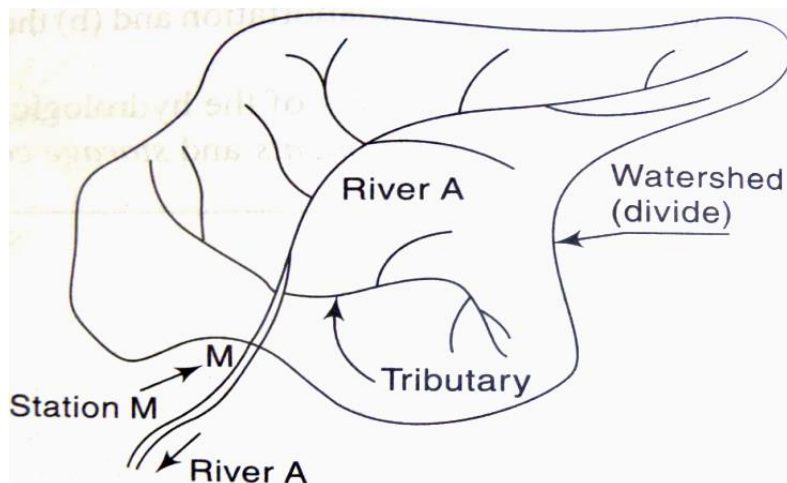


FIG 1.3: Engineering representation of Horton's hydrological Cycle

1.5 WATER BUDGET EQUATION FOR A CATCHMENT

The area of land draining into a stream at a given location is known as catchment area or drainage area or drainage basin or water shed.



For a given catchment area in any interval of time, the continuity equation for water balance is given as: (Change in mass storage) = (mass in flow) - (mass outflow)

$$\Delta s = V_i - V_o$$

The water budget equation for a catchment considering all process for a time interval Δt is written as: $\Delta s = P - R - G - E - T$

Where, Δs represent change in storage

P- Precipitation, G- Net ground water flowing outside the catchment, R- Surface runoff

E- Evaporation, T- Transpiration

Storage of water in a catchment occurs in 3 different forms and it can be written as:

$$S = S_s + S_m + S_g$$

Where, S- storage, S_s - Surface water storage, S_m - soil moisture storage,

S_g - ground water storage

Hence change in storage maybe expressed as:

$$\Delta S = \Delta S_s + \Delta S_m + \Delta S_g$$

The rainfall runoff relationship can be written as: $R = P - L$

R- Surface runoff, P- Precipitation, L- Losses

i.e. water not available to runoff due to infiltration, evaporation, transpiration and surface storage.

1.6 PRECIPITATION

It is defined as the return of atmospheric moisture to the ground in the form of solids or liquids. Precipitation is the fall of water in various forms on the earth from the cloud. The usual form of precipitation is rain and snow. In India snowfall occurs only in Himalayan region during winter. Most of the precipitation occur in India is the form of rain.

The following are the main characteristics of rainfall:

a. Amount or quantity: The amount of rainfall is usually given as a depth over a specified area, assuming that all the rainfall accumulates over the surface and the unit for measuring amount of rainfall is cm. The volume of rainfall = Area x Depth of Rainfall (m^3)

The amount of rainfall occurring is measured with the help of rain gauges.

b. Intensity: This is usually average of rainfall rate of rainfall during the special periods of a storm and is usually expressed as cm/ hour.

c. Duration of Storm: In the case of a complex storm, we can divide it into a series of storms of different durations, during which the intensity is more or less uniform.

d. Aerial distribution: During a storm, the rainfall intensity or depth etc. will not be uniform over the entire area. Hence we must consider the variation over the area i.e. the aerial distribution of rainfall over which rainfall is uniform.

1.7 DEFINITIONS

Infiltration: Infiltration is the passage of water across the soil surface. The vertical downward movement of water within the soil is known as percolation. The infiltration capacity is the maximum rate of infiltration for the given condition of the soil. Obviously the infiltration capacity decreases with time during/ after a storm.

Overland Flow: This is the part of precipitation which is flowing over the ground surface and is yet to reach a well-defined stream.

Surface runoff: When the overland flow enters a well-defined stream it is known as surface runoff (SRO).

Interflow for Sub surface flow: A part of the precipitation which has in-filtered the ground surface may flow within the soil but close to the surface. This is known as interflow. When the interflow enters a well-defined stream, then and only it is called run off.

Ground water flow: This is the flow of water in the soil occurring below the ground water table. The ground water table is at the top level of the saturated zone within the soil and it is at atmospheric pressure. Hence it is also called phreatic surface. A portion of water may enter a well-defined stream. Only then it is known as runoff or base flow. Hence we say that runoff is the portion of precipitation which enters a well-defined stream and has three components; namely- surface runoff, interflow runoff and ground water runoff or base flow.

Evaporation: This is the process by which state of substance (water) is changed from liquid state to vapor form. Evaporation occurs constantly from water bodies, soil surface and even from vegetation. In short evaporation occurs when water is exposed to atmosphere (during sunlight). The rate of evaporation depends on the temperature and humidity.

Transpiration: This is the process by which the water extracted by the roots of the plants is lost to the atmosphere through the surface of leaves and branches by evaporation. Hence it is also known as evapotranspiration.

1.8 FORMS OF PRECIPITATION

1. Drizzle – This is a form of precipitation consisting of water droplets of diameter less than 0.05 cm with intensity less than 0.01cm/ hour. In this drops are so small that they appear to flow in the air.
2. Rainfall – This is a form of precipitation of water drops larger than 0.05cm diameter up to 0.6cm diameter. Water drops of size greater than 0.6 cm diameter tend to break up as they fall through the atmosphere. Intensity varies from 0.25 cm/ hour to 0.75cm/ hour.
Light Rain – Traced to 0.25cm/hr
Moderate rain – 0.25cm/hr to 0.75cm/hr
Heavy rain – greater than 0.75cm/hr
3. Snow – This is precipitation in the form of ice crystals. These crystals usually carry a thin coating of liquid water and form large flakes when they collide with each other.
4. Hail – The precipitation in the form of balls are irregular of ice of diameter 5mm or more is called Hail.
5. Glaze (Freezing Rain) – This is the ice coating formed when a drizzle or rainfall comes in contact with very old objects on the ground. It occurs when there is cold layer of air with temperature below 0°C
6. Sleet – Sleet is the precipitation in the form of melting snow. It is a mixture of snow and rain. It is in the form of pellet of diameter 1mm-4mm. Sleet is also known as small hail.
7. Frost – Frost is a form of precipitation which occurs in the form of scales, needles, feathers or fans.
8. Dew – Dew is a form of precipitation which doesn't occur because of condensation in higher layer of atmosphere but it is formed by condensation directly on the ground. Dew occurs in the night when the ground surface is cooled by outgoing radiation.

1.9 FORMATION OF PRECIPITATION

Precipitation occurs when the following four conditions are satisfied:

- Cooling of air masses
- Formation of clouds into ice crystals due to condensation
- Growth of water droplets
- Accumulation of moisture

Cooling of air masses

Cooling occurs when air ascends from earth surface to upper level in the atmosphere. The decrease in temperature of undisturbed atmospheric air with an increase in altitude is called lapse rate ($6.5^{\circ}\text{C}/\text{km}$). The precipitation depends on the lapse rate and amount of cooling.

Formation of clouds due to condensation

Condensation occurs when the water vapour in the atmosphere is converted into liquid droplet or into ice crystals when temperature is quite low. Clouds are formed due to condensation. The water vapour converted into water droplets due to the presence of small solid particles called condensation nuclei or Hygroscopic nuclei of sizes 0.001 micron to 10 micron. The rate of condensation increases as the number of nuclei increases.

Growth of water droplets

The size of water droplets in a cloud is usually very small of about 0.02mm. However this cannot reach the ground unless there is growth in water droplet. This can be achieved by means of coalescence. Coalescence of droplets occurs to form larger drops and is due to difference of velocity of larger droplets and smaller droplets and due to co-existence of ice crystals and water droplets in clouds.

Accumulation of moisture

The air must contain sufficient amount of moisture so that appreciable precipitation can occur after meeting the evaporation losses between the clouds and ground. Accumulation of moisture in atmosphere occurs due to evaporation of lands, vegetation and water surfaces.

1.10 TYPES OF PRECIPITATION

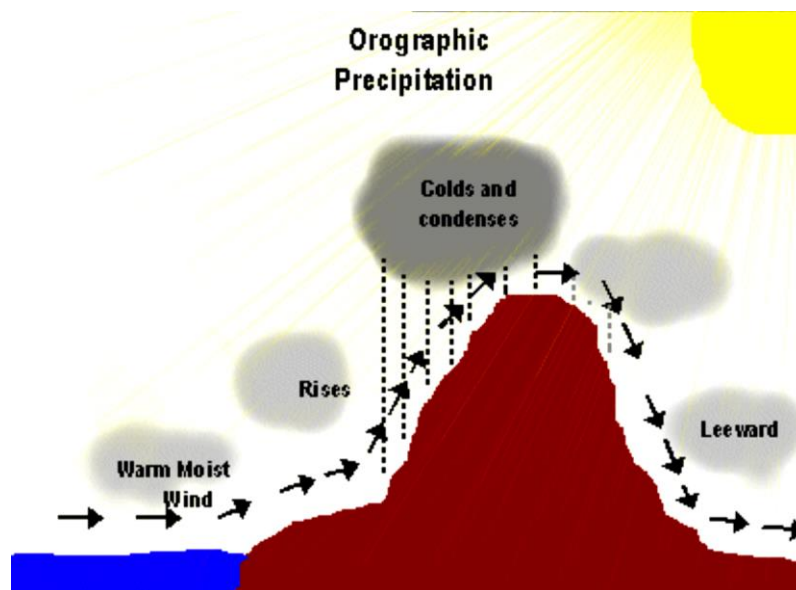
One of the essential requirements for precipitation to occur is the cooling of large masses of moist air. Lifting of air masses to higher altitudes is the only large scale process of cooling. Hence the types of precipitation based on the mechanism which causes lifting of air masses are as follows:

1. Convective precipitation: This is due to the lifting of warm air which is lighter than the surroundings. Generally this type of precipitation occurs in the tropics where on a hot day, the ground surface gets heated unequally causing the warmer air to lift up and precipitation occurs in the form of high intensity and short duration. This usually occurs in the form of a local whirling thunder storm and for very short duration, it is called

‘tornado’, when accompanied by very high velocity destructive winds. Convective precipitation covers small area and rainfall intensity may be very high (10cm/hr).

2. Orographic Precipitation: It is the most important precipitation and is responsible for most of heavy rains in India. Orographic precipitation is caused by air masses which strike some natural topographic barriers like mountains and cannot move forward and hence the rising amount of precipitation. The greatest amount of precipitation falls on the windward side and leeward side has very little precipitation.

Ex: Cherrapunji, Agumbe in Western Ghats of southern India gets heavy Orographic precipitation.



3. Cyclonic Precipitation: This is the precipitation associated with cyclones or moving masses of air and involves the presence of low pressures. A cyclone is a large zone of low pressure which is surrounded by a circular wind motion. This type of precipitation occurs due to pressure differences created by the unequal heating of earth's surface. Air tends to move into low pressure zone from surrounding areas and displaces low pressure air upwards. The wind blows spirally inward counter clockwise in the northern hemisphere and clockwise in the southern hemisphere.

This is further sub divided into 2 categories

- a. Non Frontal cyclonic precipitation: In this, a low pressure area develops. (Low-pressure area is a region where the atmospheric pressure is lower than that of surrounding locations). The air from surroundings converges laterally towards the low pressure area. This results in lifting of air and hence cooling. It may result in precipitation.

- b. Frontal cyclonic precipitation: FRONT is a barrier region between two air masses having different temperature, densities, moisture, content etc. If a warm and moist air mass moves upwards over a mass of cold and heavier air mass, the warm air gets lifted, cooled and may result in precipitation. Such a precipitation is known as warm front precipitation.

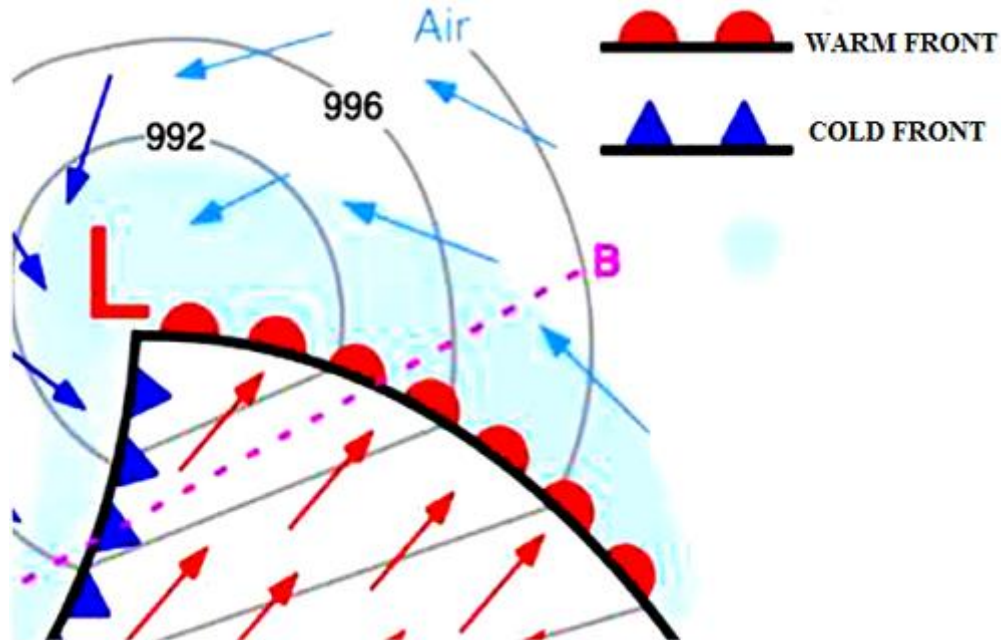


FIG: Cyclonic precipitation

4. Turbulent Precipitation: This precipitation is usually due to a combination of the several of the above cooling mechanisms. The change in frictional resistance as warm and moist air moves from the ocean onto the land surface may cause lifting of air masses and hence precipitation due to cooling. This precipitation results in heavy rainfall. The winter rainfall in Tamilnadu is mainly due to this type of turbulent ascent.

1.11 MEASUREMENT OF RAINFALL

Rainfall is measured on the basis of the vertical depth of water accumulated on a level surface during an interval of time, if all the rainfall remained where it fell. It is measured in mm. The instrument used for measurement of rainfall is called "Rain gauge". These are classified as:

- Non recording type Raingauge
- Recording type Raingauge

1.11.1 Non recording type Raingauges

These rain gauges which do not record the depth of rainfall, but only collect rainfall. Symon's rain gauge is the usual non recording type of rain gauge. It gives the total rainfall that has

occurred at a particular period. It essentially consists of a circular collecting area 127 mm in diameter connected to a funnel. The funnel discharges the rainfall into a receiving vessel. The funnel and the receiving vessel are housed in a metallic container. The components of this rain gauge are shown in fig below.

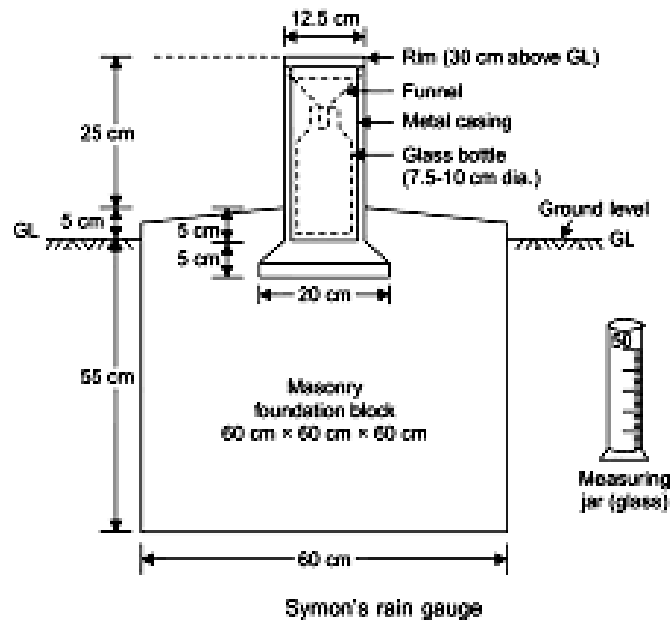


FIG 1.4: Symons Raingauge

The water collected in the receiving bottle is measured by a graduated measuring jar with an accuracy of 0.1 ml. the rainfall is measured every day at 8:30 am IST and hence this Raingauge gives only depth of rainfall for previous 24 hours. During heavy rains, measurement is done 3 to 4 times a day.

Thus Symons Raingauge gives only the total depth of rainfall for previous 24 hours and doesn't provide intensity and rainfall duration of the rainfall during different time interval of the day.

1.11.2 Recording type Raingauges

These are rain gauges which can give a permanent, automatic rainfall record (without any bottle recording) in the form of a pen mounted on a clock driven chart. From the chart intensity or rate of rainfall in cm per hour or 6 hrs, 12 hrs..... besides the total amount of rainfall can be obtained.

Advantages of recording rain gauges:

1. Necessity of an attendant does not arise
2. Intensity of rainfall at anytime as well as total rainfall is obtained, where as non recording gauge gives only total rainfall.

3. Data from in accessible places (hilly regions) can be continuously obtained.
4. Human errors are eliminated.
5. Capacity of gauges is large.
6. Time intervals are also recorded.

Disadvantages of recording rain gauges:

1. High initial investment cost.
2. Recording is not reliable when faults in gauge arise (mechanical or electrical) till faults are corrected.

1.11.2.1 TYPES OF RECORDING RAINGAUGE

1. Tipping bucket rain gauge:

This is the most common type of automatic rain gauge adopted by U S Meteorological Department.

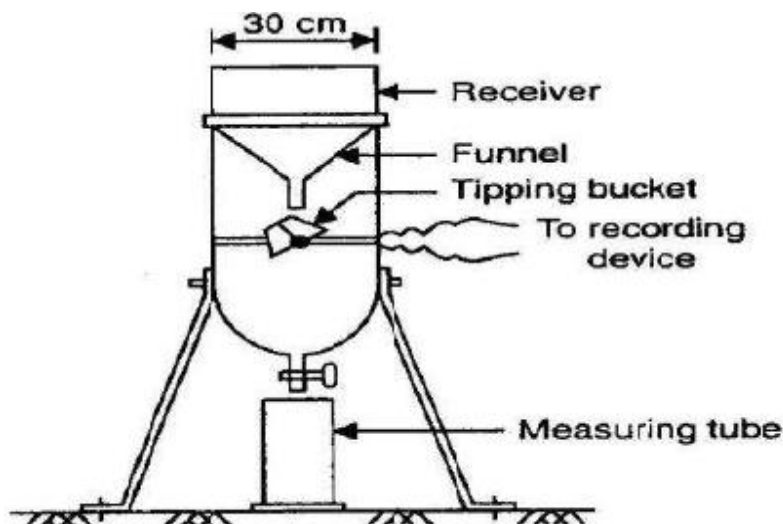


FIG 1.5: Tipping Bucket Raingauge

This consists of receiver draining into a funnel of 30 cm diameter. The catch (rainfall) from funnel falls into one of the pair of small buckets (tipping buckets). These buckets are so balanced that when 0.25 mm of rainfall collects in one bucket, it tips and brings the other bucket into position.

Tipping of bucket completes an electric circuit causing the movement of pen to mark on clock driven receiving drum which carries a recorded sheet. These electric pulses generated are recorded at the control room far away from the rain gauge station. This instrument is further suited for digitalizing the output signal.

The tipping bucket Raingauge is quiet durable, simple to operate and convenient but it has following disadvantage:

- It doesn't give accurate result in case of intense rainfall, because some of rain which falls during the tipping of bucket is not measured.
- Because of discontinuous nature of the record, the instrument is not satisfactory for using light drizzle or very light rain.
- The time of beginning and ending of rainfall cannot be determined accurately.
- This gauge is not suitable for measuring snow without heating the collector.

2. Weighing bucket rain gauge:

This is the most common type of recording or automatic rain gauge adopted by Indian Meteorological Department. The construction of this rain gauge is shown in figure below.

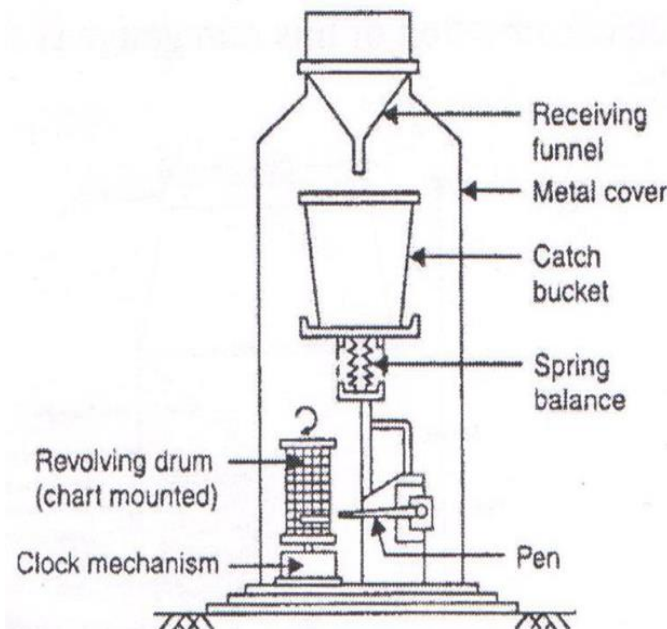
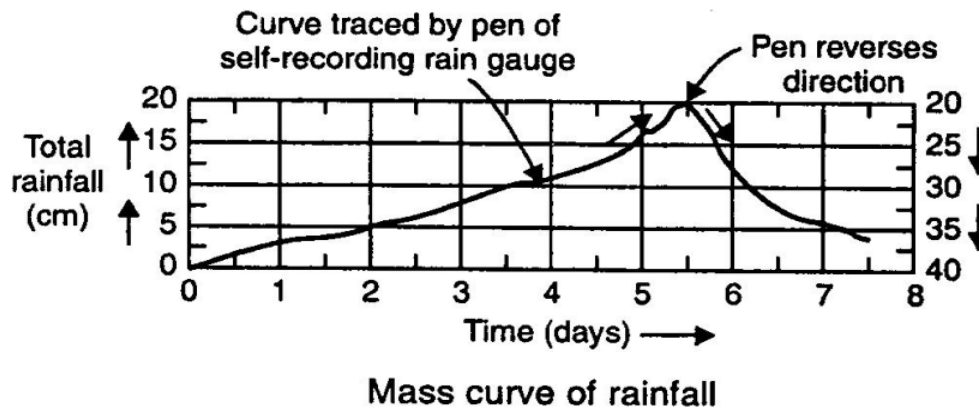


FIG 1.6: Weighing Bucket Raingauge

It consists of a receiving bucket supported by a spring or lever. The receiving bucket is pushed down due to the increase in weight (due to accumulating rain fall). The pen attached to the arm continuously records the weight on a clock driven chart. The chart obtained from this rain gauge is a mass curve of rain fall.



From the mass curve the average intensity of rainfall (cm/hr) can be obtained by calculating the slope of the curve at any instant of time. The patterns as well as total depth of rain fall at different instants can also be obtained.

The advantages of this raingauge are that it can record snow, hail and mixture of rain and snow.

The disadvantages are:

- The effect of temperature and friction on weighing mechanism may introduce error.
- Failure of reverse mechanism results in loss of record.
- Because of wind action on bucket, erotic traces may be recorded on the chart.

3. Siphon or float type rain gauge

This is also called integrating rain gauge as it depicts an integrated graph of rain fall with respect to time. The construction of this rain gauge is shown in figure below.

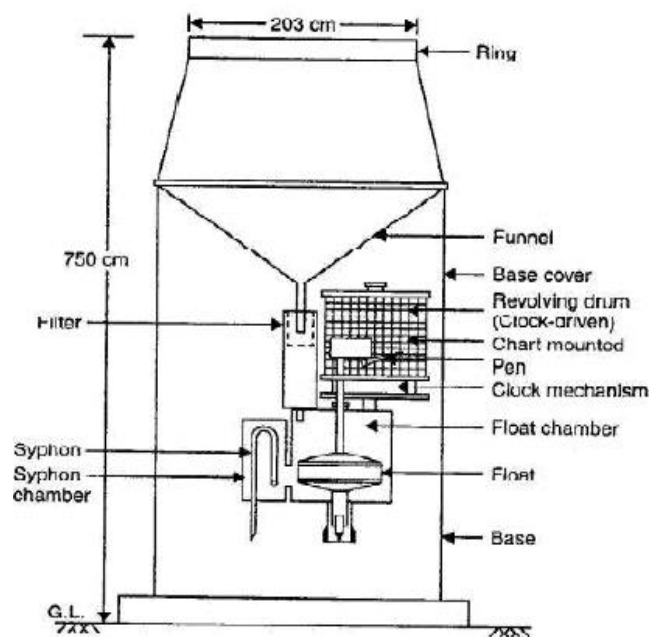
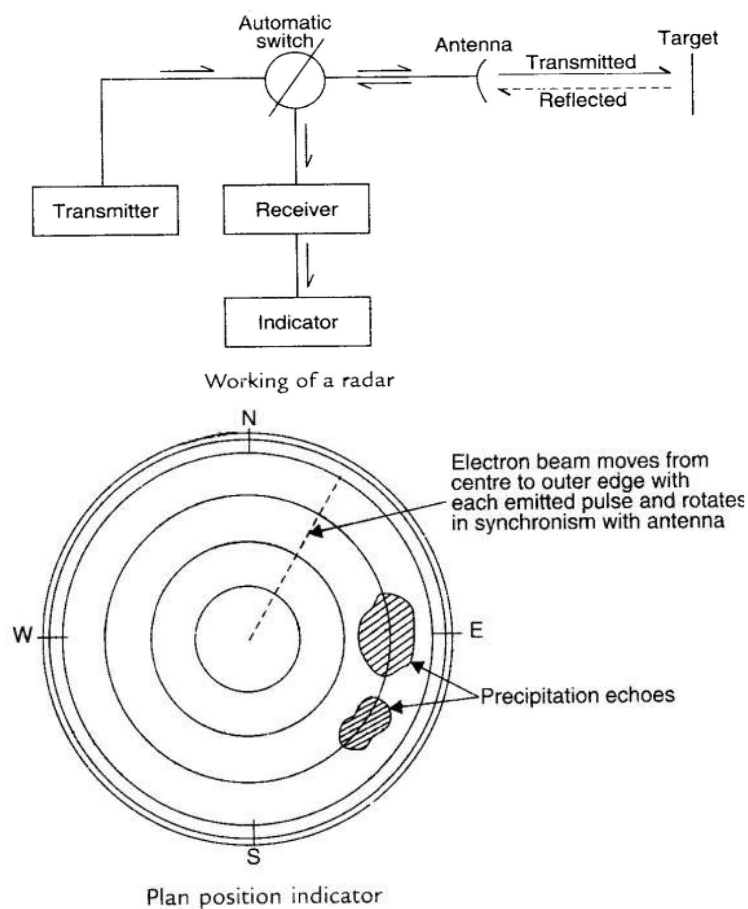


FIG 1.7: SIPHON RAINGAUGE

A receiver and funnel arrangement drain the rainfall into a container, in which a float mechanism at the bottom is provided. As water accumulates, the float rises. A pen arm attached to the float mechanism continuously records the rainfall on a clock driven chart and also produces a mass curve of rain fall. When the water level rises above the crest of the siphon, the accumulated water in the container will be drained off by siphonic action. The rain gauge is ready to receive the new rainfall.

4. Radar measurement of rainfall

The principle involves RADAR as shown in figure below. Electromagnetic waves known as pulses are produced by a transmitter and are radiated by a narrow beam antenna. The reflections of these waves from the targets (echoes) are again intercepted by the same antenna. A receiver detects these echoes, amplifies and transforms them into video form on an indicator called Plan Position indicator. The screen of indicator is illuminated dimly where there is no target (rainfall) and a bright spot occurs where there is a target and a bright patch where there is an extended object such as rain shower.



FACTORS GOVERNING SELECTION OF SITE FOR RAIN GAUGE STATIONS:

- The site for rain gauge station should be an open space without the presence of trees or any covering.
- The rain gauge should be properly secured by fencing.
- The site for rain gauge station should be a true representation of the area which is supposed to give rainfall data.
- The distance of any object or fence from the rain gauge should not be less than twice the height of the object or fence and in no case less than 30 m.
- The rain gauge should not be set upon the peak or sides of a hill, but on a nearby fairly level ground.
- The rain gauge should be protected from high winds.
- The rain gauge should be easily accessible to the observers at all times.

1.12 DETERMINATION OF AVERAGE PRECIPITATION OVER AN AREA

The rainfall measured by a rain gauge is called point precipitation because it represents the rainfall pattern over a small area surrounding the rain gauge station. However in nature rain fall pattern varies widely. The average precipitation over an area can be obtained only if several rain gauges are evenly distributed over the area. But there is always limitation to establish several rain gauges. However this draw back can be overcome by adopting certain methods as mentioned below, which give fair results.

Arithmetic mean method: In this method to determine the average precipitation over an area the rainfall data of all available stations are added and divided by the number of stations to give an arithmetic mean for the area. That is if P_1 , P_2 and P_3 are the precipitations recorded at three stations A, B and C respectively, then average precipitation over the area covered by the rain gauges is given by

$$P_{av} = \frac{P_1 + P_2 + P_3}{3}$$

This method can be used if the area is reasonably flat and individual gauge readings do not deviate from the mean (average). This method does not consider aerial variation of rainfall, non-even distribution of gauges, Orographic influences (presence of hills), etc. This method can also be used to determine the missing rain fall reading from any station also in the given area.

Thiessen Polygon method: This is also known as weighted mean method. This method is very accurate for catchments having areas from 500 to 5000 km². In this method rainfall recorded at each station is given a weight age on the basis of the area enclosing the area. The procedure adopted is as follows.

The rain gauge station positions are marked on the catchment plan.

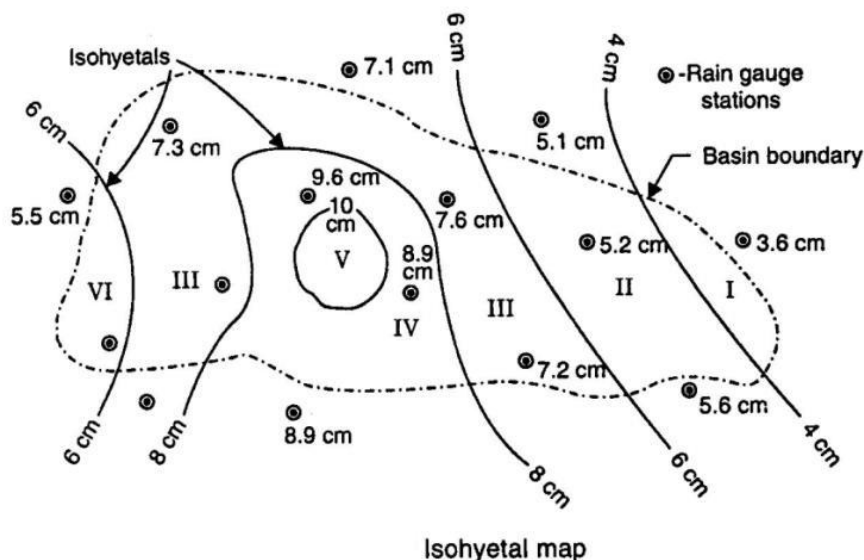
- Each of these station positions are joined by straight lines.
- Perpendicular bisectors to the previous lines are drawn and extended up to the boundary of the catchment to form a polygon around each station.
- Using a planimeter, the area enclosed by each polygon is measured.
- The average precipitation over an area is given as

$$(P_{av} = P_1A_1 + P_2A_2 + P_3A_3 + \dots + P_nA_n / A_1 + A_2 + A_3 + \dots + A_n)$$

Where $P_1, P_2, P_3, \dots, P_n$ are rainfall amounts obtained from 1 to n rain gauge stations respectively are areas of polygons surrounding each station.

$A_1, A_2, A_3, \dots, A_n$ are areas of polygons surrounding each station.

Isohyetal Method: Isohyets are imaginary line joining points of equal precipitation in a given area similar to contours in a given area.



In Isohyetal Method for determining the average precipitation over an area, Isohyets of different values are sketched in a manner similar to contours in surveying in a given area. The mean (average) of two adjacent Isohyetal values is assumed to be the precipitation over the

area lying between the two isohyets. To get the average precipitation over an area the procedure to be followed is

- Each area between the isohyets is multiplied with the corresponding mean Isohyetal value (precipitation).
- All such products are summed up.
- The sum obtained from above is divided by the total area of the catchment (gauging area).
- The quotient obtained from above represents average precipitation over gauging area.

1.13 ESTIMATION OF MISSING PRECIPITATION RECORD

A sufficiently long precipitation record is required for frequency analysis of rainfall data. But a particular rain gauge may not be operative for sometime due to many reasons it becomes necessary to estimate missing record & fill the gap rather than to leave it empty. This is done by the following method.

1. Interpolation from Isohyetal map

In an Isohyetal map of the area the position of the station (rain gauge) where record is missing is marked by interpolation techniques the missing record is worked out the factors like storm factor, topography nearness to sea are considered for proper estimation.

2. Station Year method

In this method the records of 2 or more stations are combined into one long record provided station records are independent and areas in which stations located are climatologically the same. The missing record at any station in a particular year may be found by ratio of averages or by graphical comparison.

3. Arithmetic average method

Here number of other rain gauge station record surrounding station in question (missing record) is required. The missing rainfall record at the station is taken as average of all available data surrounding station in question. $P_1, P_2, P_3, \dots, P_n$ are rainfall record from n station surrounding a non operative station 'x' the rainfall data for station 'x' is given as

$$P_x = (P_1 + P_2 + P_3 + \dots + P_n) / n$$

This method is applicable when normal annual rainfall at station 'x' does not differ by more than 10% with the surrounding station.

4. Normal ratio method

This method is applicable when normal annual rainfall at required station differ more than 10% of annual rainfall at surrounding station.

Let $P_1, P_2, P_3, \dots, P_n$ be rainfall record at 'n' station during a particular storm surrounding station 'x' (with missing record). Let $N_1, N_2, \dots, N_n$ be annual normal rainfall for 'n' station. N_x be annual rainfall for station 'x'. Then the rainfall at station 'x' during a given storm is calculated as

$$P_x = 1/n (N_x/N_1 P_1 + N_x/N_2 P_2 + \dots + N_x/N_n P_n)$$

1.14 RAIN GAUGE DENSITY

The catchment area of a rain gauge is very small compared to the areal extent of a storm. It becomes obvious that to get a representative picture of a storm over a catchment, the number of rain gauges should be as many as possible. On the other hand topographic conditions and accessibility restrict the number of rain gauges to be set up. Hence one aims at optimum number of rain gauges from which accurate information can be obtained. From practical considerations IMD as per IS 4987 has recommended the following rain gauge densities depending upon the type of area.

- Plain areas – 1 station per 520 km²
- Areas with 1000 m average elevation - 1 station per 260 to 350 km²
- Predominantly hilly areas with heavy rainfall - 1 station per 130 km²

1.15 OPTIMUM NUMBER OF RAIN GAUGE STATIONS

If there are already some raingauge stations in a catchment, the optimal number of stations that should exist to have an assigned percentage of error in the estimation of mean rainfall is obtained by statistical analysis as

$$N = (C_v/E)^2$$

Where, N= optimal number of stations

E = allowable degree of error in the estimate of mean rainfall

If there are n stations in the catchment each recording rainfall values $P_1, P_2, \dots, P_n$ in a known time, the coefficient of variation

$$C_v = 100\sigma/P$$

$$\sigma = \sqrt{\frac{n}{n-1} * [P^2 - \bar{P}^2]}$$

$$P = (P_1 + P_2 + P_3 + \dots + P_n) / n$$

$$P^1 = (P_1^2 + P_2^2 + P_3^2 + \dots + P_n^2) / 3$$

1.16 TESTS FOR CONSISTENCY OF RAINFALL

If the conditions relevant to the recording of a raingauge station have undergone significant change during the period of record, inconsistency could arise in the rainfall data of that record. Some of the common causes for inconsistency of record are:

1. Shifting the raingauge station to new location.
2. The neighborhood oh the station undergoing a marked change.
3. Change in the ecosystem due to calamities such as forest fires, land slide etc.
4. Occurrence of observational error from certain data.

Checking for inconsistency of a record is done by “double mass curve technique”. This technique is based on the principle that “when each recorded data comes from the same parent population they are consistent.

A group of 5 to 10 base stations in the neighborhood of the problematic station ‘X’ is selected. The data of annual (monthly) mean rainfall of the station X and also the average rainfall of the group of the base stations covering a long period is arranged in reverse chronological order. The accumulated precipitation of station X and the accumulated precipitation values of the average of the group of base station are calculated starting from the latest record. Values of $\sum P_x$ are plotted against $\sum P_{avg}$ for various consecutive time periods. A decided break in the slope of the resulting plot indicate a change in precipitation regime of station ‘X’ beyond the period of change of regime is corrected by using the relation:

$$P_{c_x} = P_{x*} \frac{M_c}{M_a}$$

Where, P_{c_x} = Corrected precipitation at any time period T_1 at station X

P_x = Original recorded precipitation at time period T_1 at station X

M_c = Corrected slope of the double mass curve

M_a = Original slope of the double mass curve

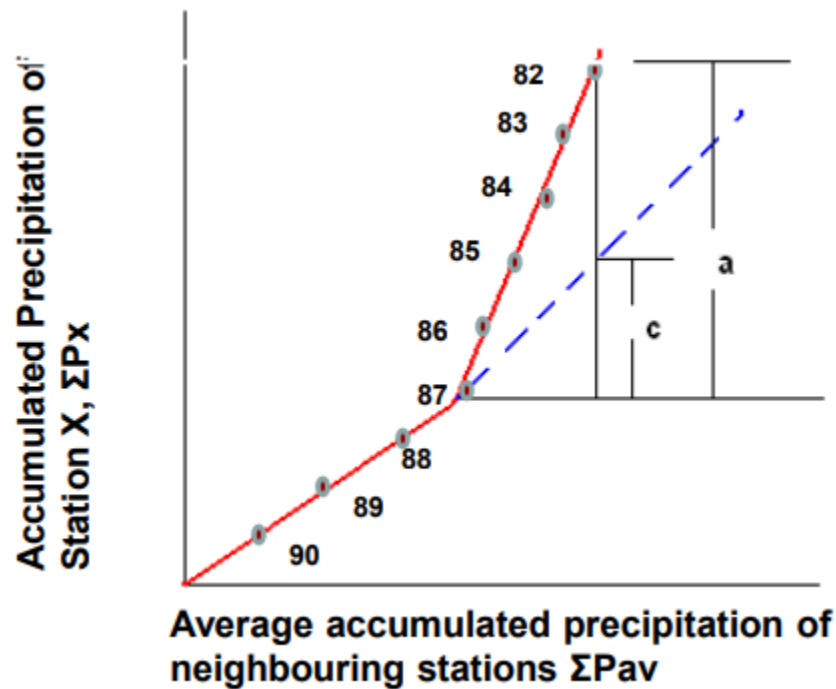


FIG: Double mass curve

1.17 PRESENTATION OF RAINFALL DATA

1. The Mass Curve of Rainfall

The mass curve of rainfall is a plot of the accumulated precipitation against time, plotted in chronological order. Records of float type and weighing bucket type gauges are of this form. A typical mass curve of rainfall at a station during a storm is shown in figure below. Mass curve of rainfall are very useful in extracting the information on the duration and magnitude of a storm. Also, intensities at various time intervals in a storm can be obtained by the slope of the curve. For non recording rain gauges, mass curves are prepared from knowledge of the approximate beginning and end of a storm and by using the mass curve of adjacent recording gauge stations as a guide.

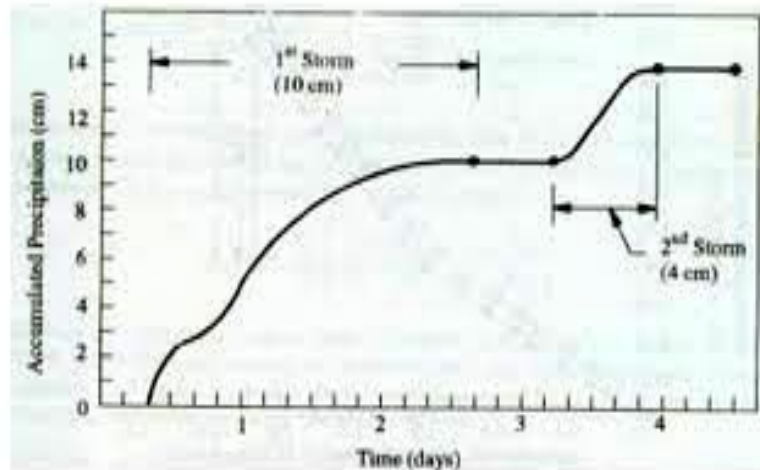


FIG: Mass Curve of Rainfall

2. Hyetograph

A hyetograph is a plot of the intensity of rainfall against the time interval. The hyetograph is derived from the mass curve and is usually represented as a bar chart. It is very convenient way of representing the characteristics of a storm and is particularly important in the development of design storms to predict extreme floods. The area under a hyetograph represents the total precipitation received in the period. The time interval used depends on the purpose, in urban drainage problems small durations are used while flood flow computations in larger catchments the intervals are about 6h.

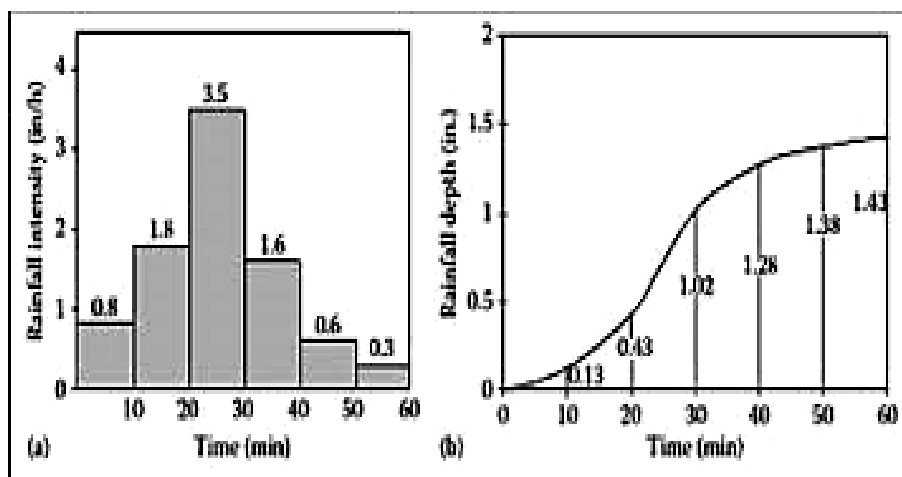


FIG: Hyetograph of a storm

3. Point rainfall

It is the total liquid form of precipitation or condensation from the atmosphere as received and measured in a rain gauge. It is expressed as so many 'mm' of depth of water.

4. Ordinate graph

The ordinate graph represents the rainfall in any year as an ordinate line drawn to some scale at the corresponding year.

5. Moving Average Curve

The graphical representation of rainfall in any of the above methods may not show any trend or cyclic pattern present in the data. The moving average curve smoothens out the extreme variations and indicate the trend or cyclic pattern if any more clearly. It is also known as the moving mean curve.

The procedure to construct the moving average curve is as follows:

The moving average curve is constructed with a moving period (m) year, where m is generally taken to be 3 to 5 years. Let $X_1, X_2, X_3, \dots, X_n$ be the sequence of given annual rainfall in the chronological order. Let Y_i denote the ordinate of the moving average curve for the i^{th} year. Then $m = 3$, Y_i is computed from

$$Y_2 = X_1 + X_2 + X_3 / 3$$

$$Y_3 = X_2 + X_3 + X_4 / 3$$

$$Y_i = X_{(i-1)} + X_i + X_{(i+1)} / 3$$

$$Y_{(n-1)} = X_{(n-2)} + X_{(n-1)} + X_n / 3$$

From the above equations the computed value of 'i' correspond in time, the middle value of 'x' being average and therefore it is convenient to use odd values of "m".

1.18 IMPORTANT QUESTIONS

1. Explain Horton's qualitative Hydrologic cycle?
2. Explain with a neat sketch Siphon's rain gauge?
3. Define precipitation. Explain various forms of precipitation?

1.19 OUTCOMES

- Understand the importance of hydrology and its components.
- Measure precipitation and analyze the data and analyze the losses in precipitation.

1.20 FURTHER READING

- nptel.ac.in/downloads/105105110/