MODULE 1

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1. INTRODUCTION

The world's total water resources are estimated to be around 1.36X 1014 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.

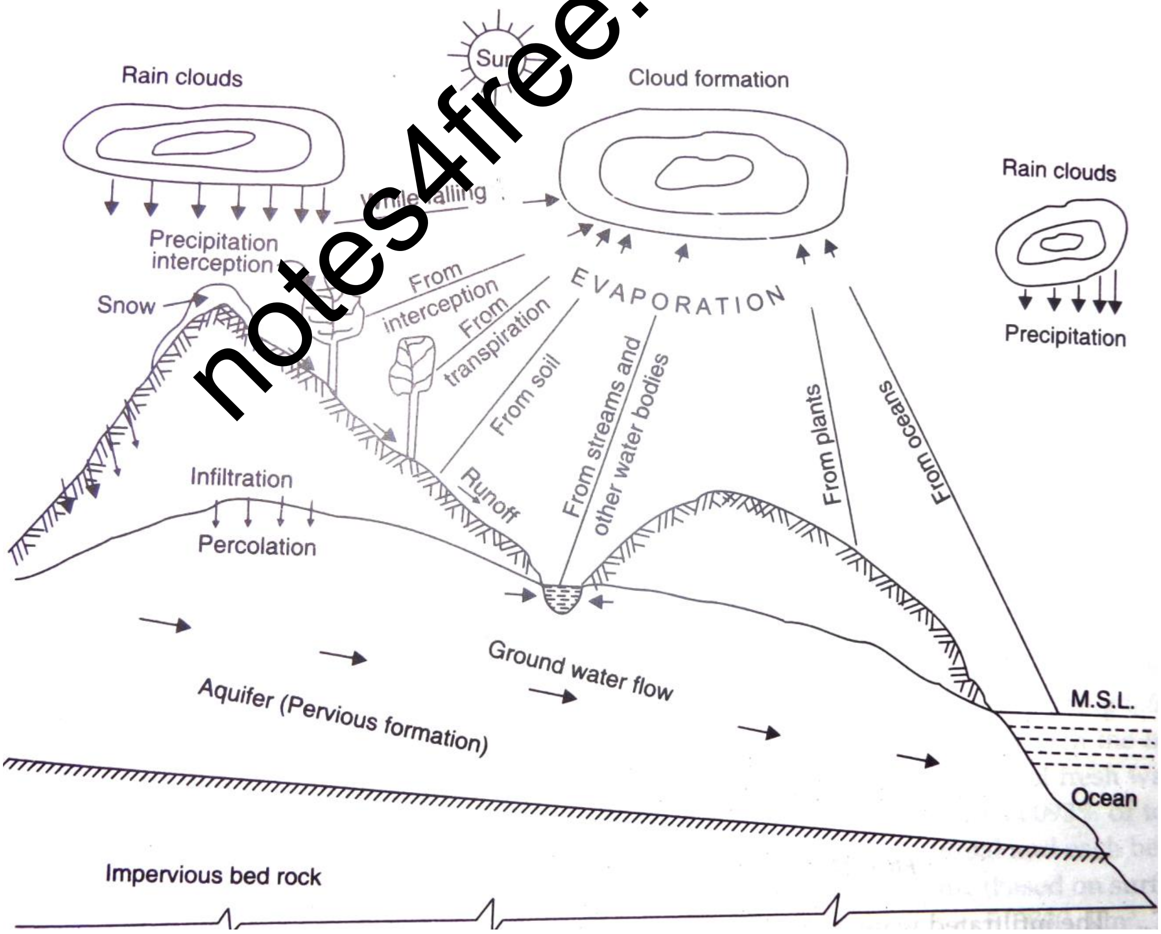


FIG 1: Descriptive representation of hydrological cycle

The hydrological cycle has 3 important phases:

1. Evaporation & Evapotranspiratrion
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

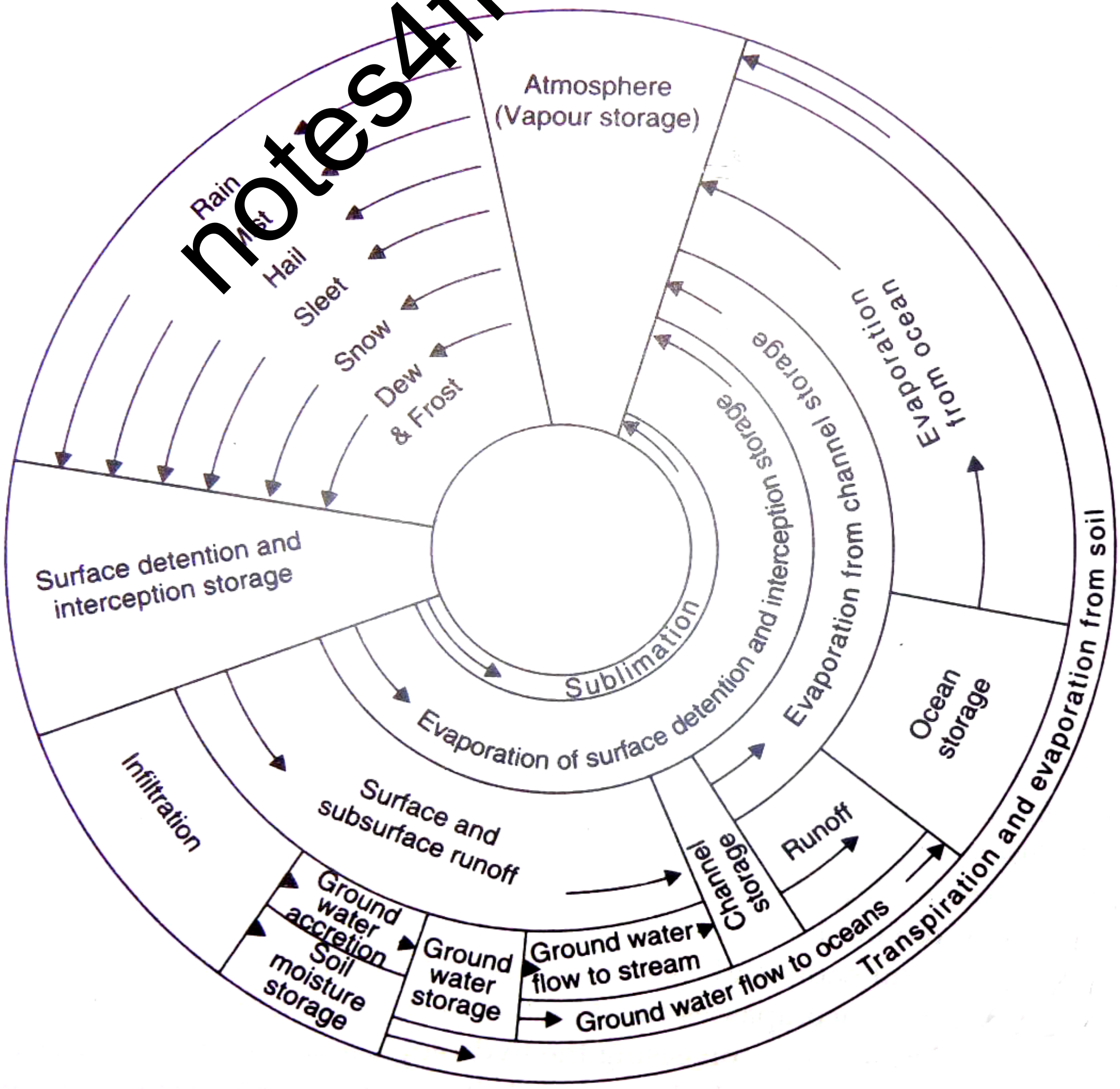


FIG 1.2: Qualitative representation of Horton's hydrological Cycle

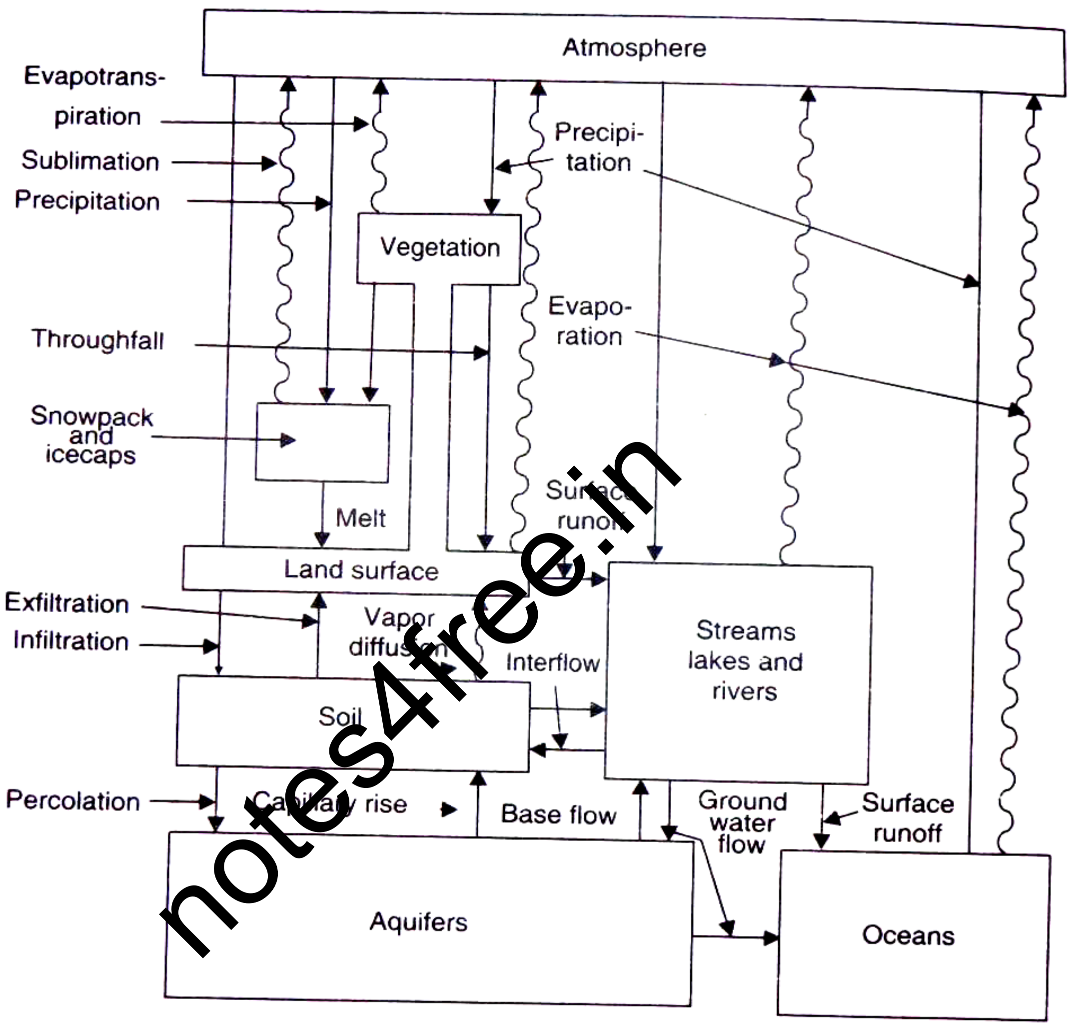
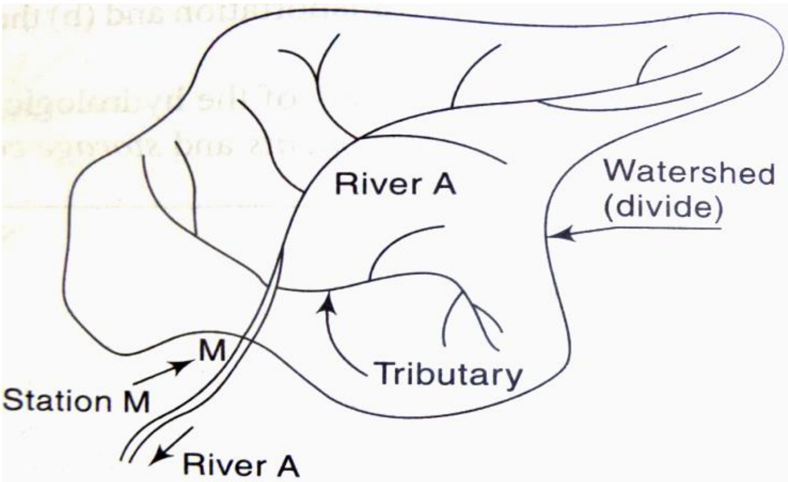


FIG 1.3: Engineering representation of Horton's hydrological Cycle

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, Ss - Surface water storage, S_m - soil moisture storage,

Sg - 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 water. 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 cold objects on the ground. It occurs when there is cold layer of air with temperature below 0^0C
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 ascents 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 (6.5^0C/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 quiet 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 Hydroscopic 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 loses 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

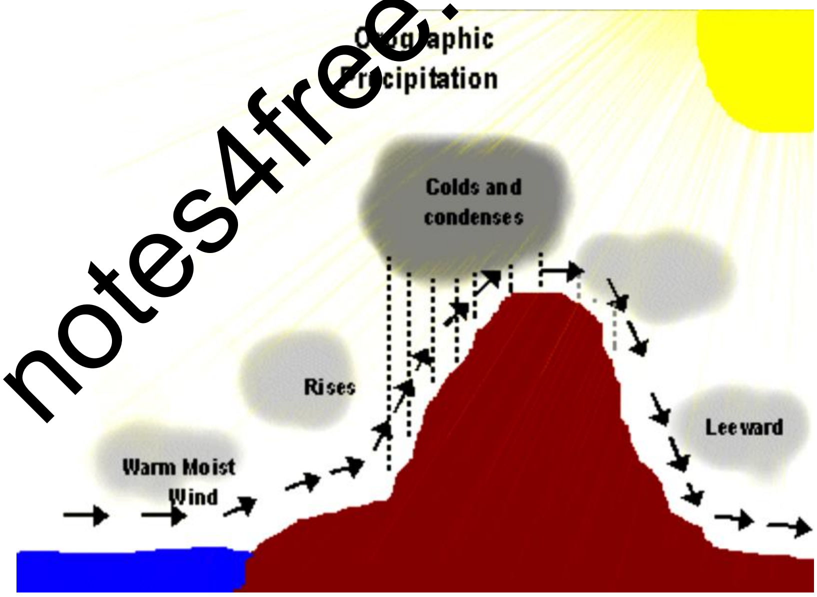
One of the essential requirements for precipitation to occur is the cooling of large masses of moist air. Lifting of air masses to higher altitudes is the only large scale process of cooling. Hence the types of precipitation based on the mechanism which causes lifting of air masses are as follows:

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 occur dye 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.

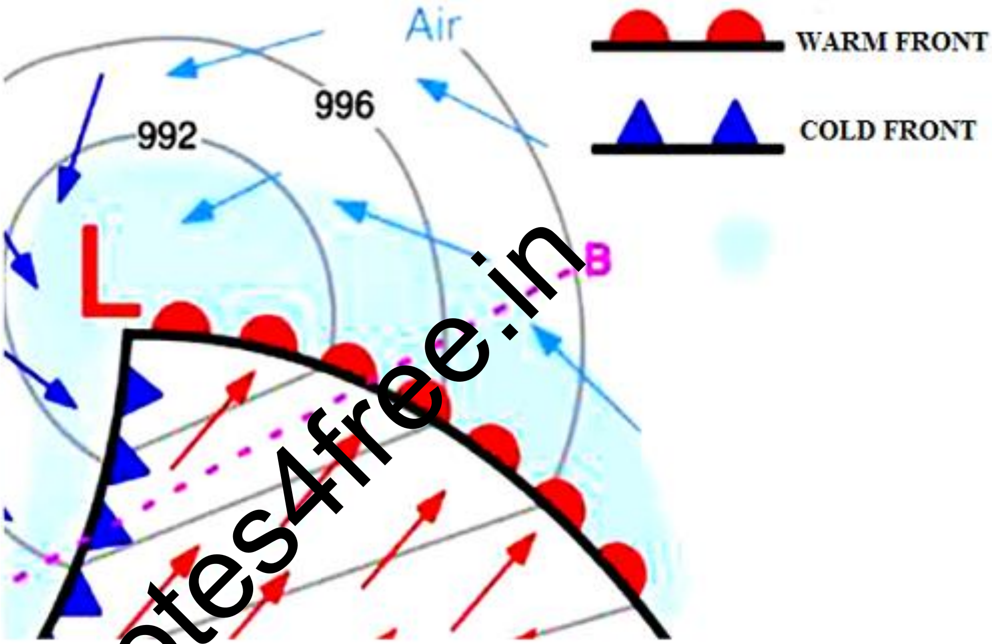


FIG: Cyclonic precipitation

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 a shown in fig below.

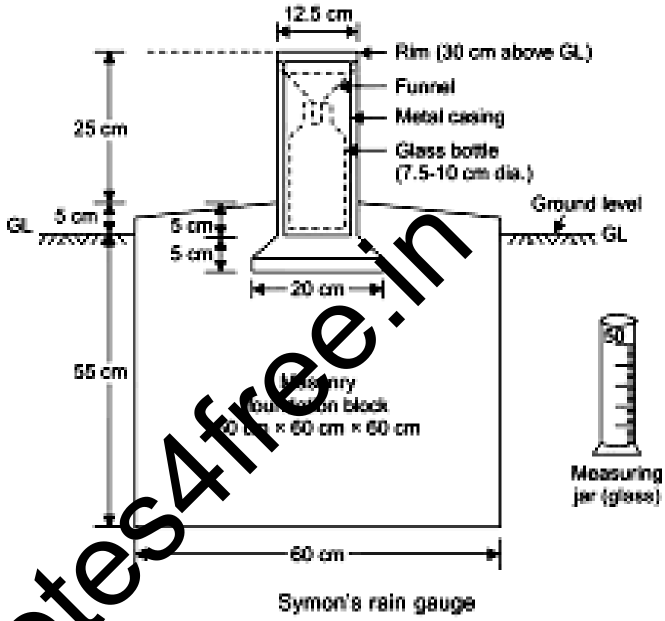


FIG 1.4: Symons Raingauge

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.

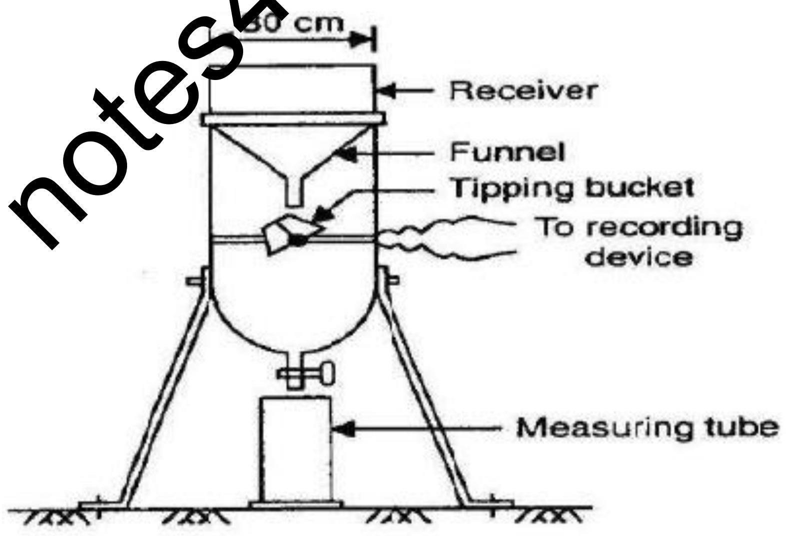


FIG 1.5: Tipping Bucket Raingauge

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.

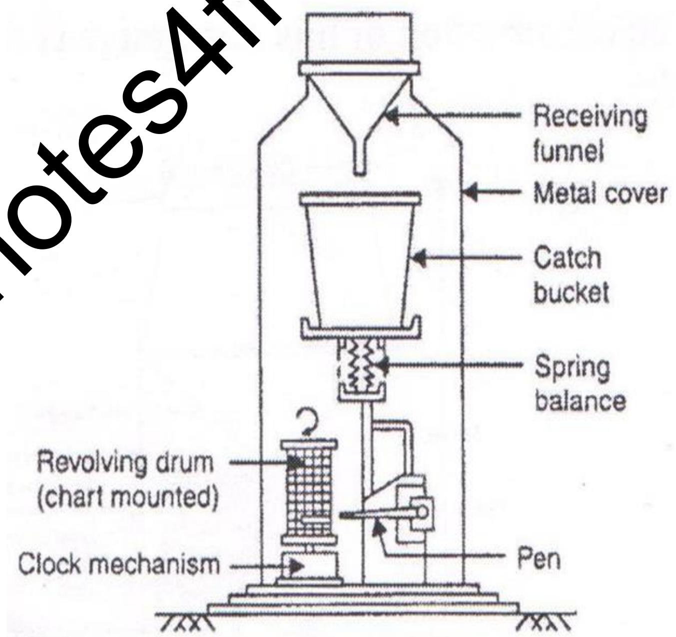
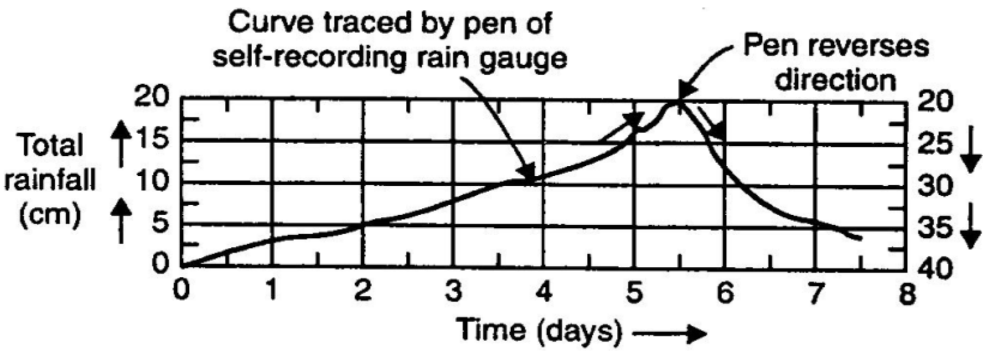


FIG 1.6: Weighing Bucket Raingauge

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.



Mass curve of rainfall

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.

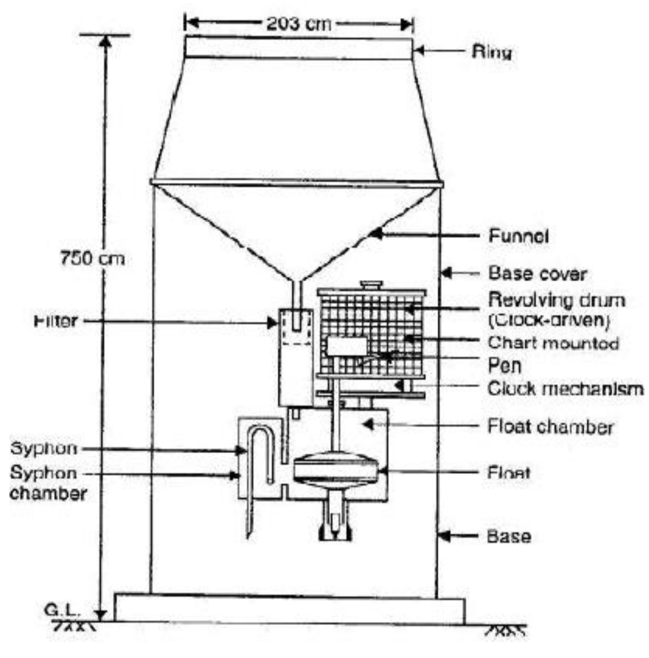
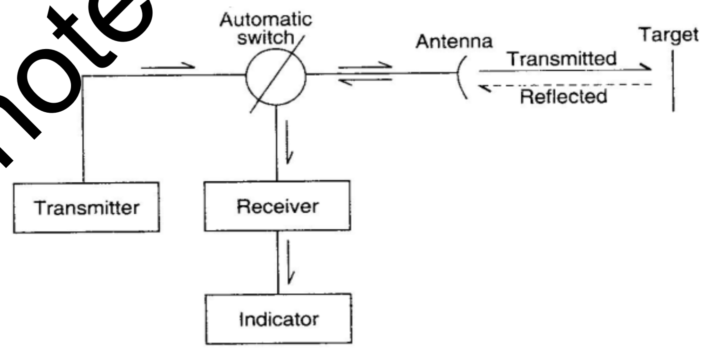


FIG 1.7: SIPHON RAINGAUGE

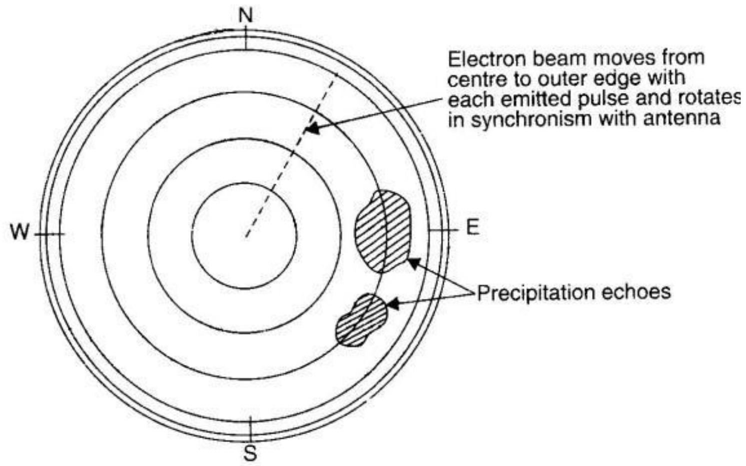
A receiver and funnel arrangement drain the rainfall into a container, in which a float mechanism at the bottom is provided. As water accumulates, the float rises. A pen arm attached to the float mechanism continuously records the rainfall on a clock driven chart and also produces a mass curve of rain 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.



Working of a radar



Plan position indicator

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 P1, P2 and P3 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

$$P_{av} = P_1+P_2+P_3/3$$

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.

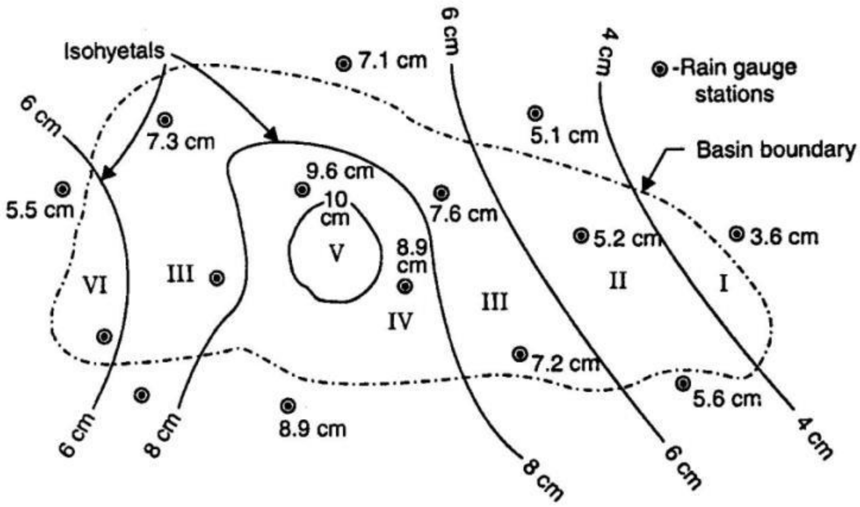
- Each of these station positions are joined by straight lines.
- Perpendicular bisectors to the previous lines are drawn and extended up to the boundary of the catchment to form a polygon around each station.
- Using a planimeter, the area enclosed by each polygon is measured.
- The average precipitation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

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

Where P_1, P2, P3………… 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……… 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.



Isohyetal map

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 passion 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 o fall available data surrounding station in question. P1, P2, P3-------- etc Pn are rainfall record from —n‖ station surrounding a non operative station ‘x’ the rainfall data for station ‘x’ is given as

$$P_x = (P_1 + P_2 + P_3 \text{------} + P_n) / 3$$

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-------- Pn be rainfall record at ‘n’ station during a particular storm surrounding station ‘x’ (with missing record). Let N_1, N_2 -------- 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

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

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 km^2
- Areas with 1000 m average elevation - 1 station per 260 to 350 km^2
- Predominantly hilly areas with heavy rainfall - 1 station per 130 km^2

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……... Pn in a known time, the coefficient of variation

$$C_v = 100\sigma/P$$

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

$$P = (P_1 + P_2 + P_3 ------ + P_n) / 3$$

$$P^1 = (P_1^2 + P_2^2 + P_3^2 \text{------} + P_n^2) / 3$$

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

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

Mc = Corrected slope of the double mass curve

Ma = Original slope of the double mass curve

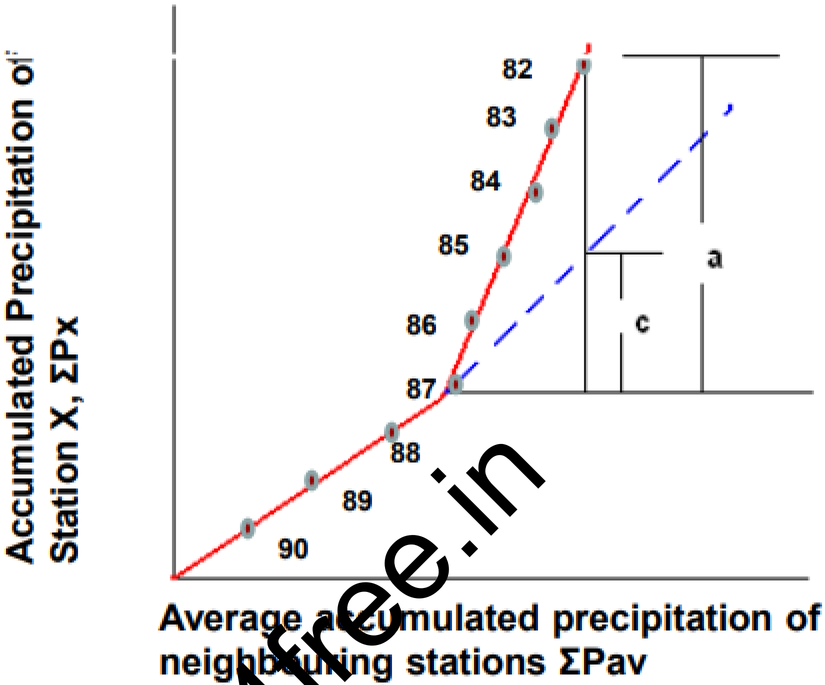


FIG: Double mass curve

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 interval s 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.

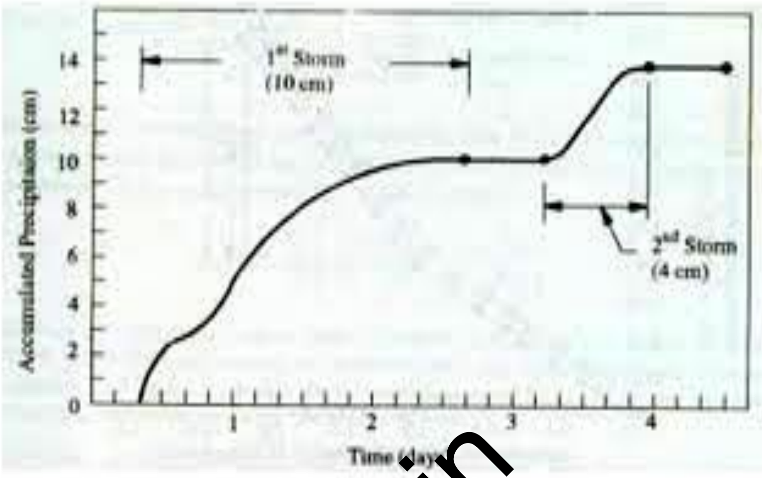


FIG: Mass Curve of Rainfall

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.

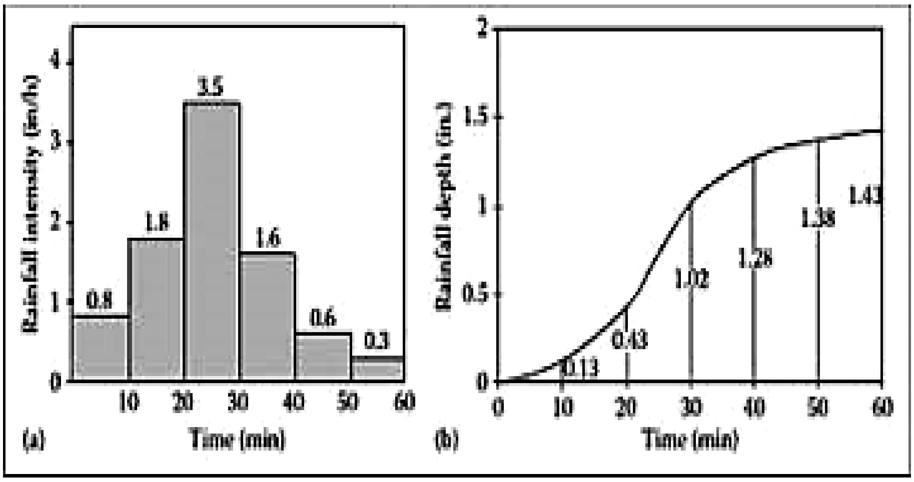


FIG: Hyetograph of a storm

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…………… Xn be the sequence of given annual rainfall in the chronological order. Let Yi denote the ordinate of the moving average curve for the i^{th} year. Then m = 3, Yi 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/

MODULE 2

2.1 EVAPORATION

2.1.1 INTRODUCTION

2.1.2 PROCESS

2.1.3 FACTORS AFFECTING EVAPORATION

2.1.4 DALTONS LAW OF EVAPORATION

2.1.5 MEASUREMENT OF EVAPORATION

2.1.6 ESTIMATION USING EMPERICAL FORMULAE

2.1.7 RESERVOIR EVAPORATION & CONTROL

2.2 EVAPOTRANSPIRATION

2.2.1 FACTORS AFFECTING EVAPOTRANSPIRATION

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2.3 INFILTRATION

2.3.1 INTRODUCTION

2.3.2 FACTORS AFFECTING INFILTRATION CAPACITY

2.3.3 MEASUREMENT BY DOUBLE RING INFILTROMETER

2.3.4 HORTON'S INFILTRATION EQUATION

2.3.5 INFILTRATION INDICES

LOSSES FROM PRECIPITATION

The hydrological equation states that _Runoff = Rainfall – Losses‘. Hence the runoff from a watershed resulting due to a storm is dependent on the losses. Losses may occur due to the following reasons

1. Evaporation
2. Evapotranspiration
3. Infiltration
4. Interception
5. Watershed leakage

The first three contribute to the major amount of losses.

2.1 EVAPORATION

2.1.1 INTRODUCTION

It is the process by which a liquid changes to gaseous state at the free surface through transfer of heat energy. In an exposed water body like lakes or ponds, water molecules are in continuous motion with a range of velocities (faster at the top and slower at the bottom). Additional heat on water body increases the velocities. When some water molecules posses' sufficient kinetic energy they may cross over the water surface. Simultaneously the water molecules in atmosphere surrounding the water body may penetrate the water body due to condensation. If the number of molecules leaving the water body is greater than the number of molecules arriving or returning, difference in vapour pressure occurs, leading to evaporation.

2.1.2 EVAPORATION PROCESS

When the external thermal energy supplied to surface of water body, the kinetic energy of water molecules will be increased. When the molecules near the free surface attain enough kinetic energy, they escape from the water body they eject themselves in to the atmosphere. Out of total atmospheric pressure on the free surface there will be some contribution from the vapour molecules present in the free surface. This partial pressure exerted by the vapour is called vapour pressure. Continued supply of heat energy causes accumulation of more and more vapour molecules and thus gaseous medium can no longer accommodate and reject vapour molecules in the form of condensation at the same rate as vaporization. At this stage the air is said to be saturated. At saturation the partial pressure exerted by water vapour is called the saturation vapour pressure and denoted by (e_s) which increase with temperature.

Thus if vapour pressure of air above free surface of water is already equal to the saturation vapour pressure (e_s) neither evaporation no condensation takes place and then it is called as equilibrium state.

From the above explanation for evaporation to occur it is necessary to have:

(1) A supply of water
(2) A source of heat
(3) Vapour pressure deficit, i.e difference b/w saturated vapour pressure of water correspond to water temperature.

2.1.3 FACTORS AFFECTING EVAPORATION

1. <u>Vapour pressure difference:</u> The number of molecules leaving or entering a water body depends on the vapour pressure of water body at the surface and also the vapour pressure of air. Higher water temperature leads to high vapour pressure at surface and tends to increase the rate of evaporation. High humidity in air tends to increase vapour pressure in air and in turn reduces rate of evaporation.

2. <u>Temperature of air and water:</u> The rate of emission of molecules from a water body is a function of its temperature. At higher temperature molecules of water have greater energy to escape. Hence maximum evaporation from water bodies takes place in summer. It has been estimated that for every 1o C rise in atmospheric temperature increases 5 cm of evaporation annually.

3. <u>Wind Velocity:</u> When wind velocity is more the saturated air (humid air) is drifted away and dry air comes in contact with water surface which is ready to absorb moisture. Hence rate of evaporation is dependent on wind velocity. It has been estimated that 10% increase in wind velocity increases 2 – 3% of evaporation.

4. <u>Quality of water:</u> The rate of evaporation of fresh water is greater than saline water. (Specific gravity of saline water is greater than that of fresh water. It is established that saline water has lesser vapour pressure and it is observed that evaporation from fresh water is 3 – 4% more than sea water.

5. <u>Atmospheric pressure and Altitude:</u> Evaporation decreases with increase in atmospheric pressure as the rate of diffusion from water body into the air is suppressed. At higher altitude the atmospheric pressure is usually lesser and there by evaporation rate is higher.

6. <u>Depth of water body:</u> Evaporation shallow water bodies is greater when compared to deep water bodies as the water at lower levels in deep water bodies is not heated much and vapour pressure at lower levels is also reduced.

7. Humidity: If the humidity of the atmosphere is more the evaporation will be less because during the process of evaporation, water vapour, moving from the point of higher moisture content to lower moisture content and rate of this movement is grounded by this difference of their moisture content or moisture gradient existing in air.

8. Radiation: Since the evaporation requires continuous supply of energy which is derived mainly from solar radiation. The radiation will be a factor of considerable importance. Evaporation increase and the radiation increases and vice versa.

2.1.4 DALTONS LAW OF EVAPORATION

The rate of evaporation is function of the difference in vapour pressure at the water surface and the atmosphere. Dalton‘s law of evaporation states that ―Evaporation is proportional to the difference in vapour pressures of water and air.

i.e. $E \alpha (e_w - e_a)$ or $E = k (e_w - e_a)$

Where, E = daily evaporation

e_w = saturated vapour pressure of water at a given temperature

e_a = vapour pressure of air

k = proportionality constant

Considering the effect of wind Dalton‘s Law is expressed as $E = k^l (e_w - e_a) (a+b*V)$

Where, V = wind velocity in km/hour k^l, a & b are constants for a given area.

2.1.5 MEASUREMENT OF EVAPORATION

In order to ensure proper planning and operation of reservoirs and irrigation systems estimation of evaporation is necessary. However exact measurement of evaporation is not possible. But the following methods are adopted as they give reliable results.

- Pan measurement methods
- Use of empirical formulae
- Storage equation method
- Energy budget method

PAN MEASUREMENT METHOD

Any galvanized iron cylindrical vessel of 1.2 m to 1.8 m diameter, 300 mm depth with opening at the top can be used as an evapometer or evaporation pan. During any interval of time evaporation is measured as the drop in water level in the pan. Rainfall data, atmospheric pressure data, temperature, etc should also be recorded. It has been correlated that evaporation from a pan is not exactly the same as that taking place from a water body. Hence while using a pan measurement data for measuring evaporation from a lake or a water body, a correction factor has to be applied or multiplied by a pan co-efficient.

Pan co-efficient = (actual evaporation from reservoir / measured evaporation from pan)

The evaporation pans adopted in practice have a pan coefficient of 0.7 to 0.8.

The popularly used evaporation pans are:

1. ISI standard pan or Class A pan
2. US Class A pan
3. Colorado sunken pan
4. US Geological Survey floating pan

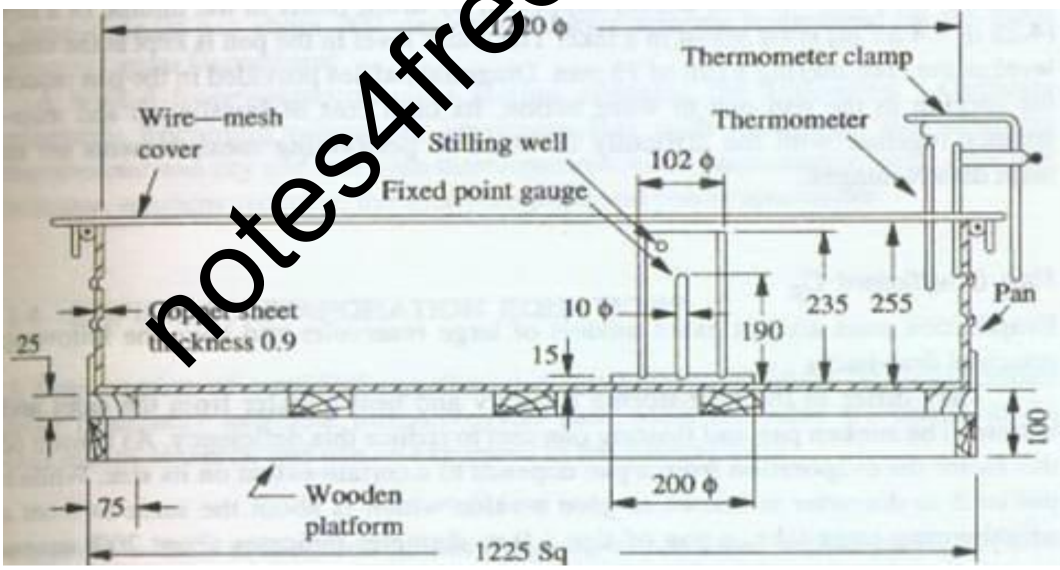


Fig: ISI standard pan or Class A pan

This evaporation pan should confirm to IS – 5973:1976 and is also called Class A pan. It consists of a circular copper vessel of 1220 mm effective diameter, 255 mm effective depth and a wall thickness of 0.9 mm. A thermometer is assembled to record the variation in temperature. A wire mesh cover with hexagonal openings is provided at the top to prevent entry of foreign matter. A fixed gauge housed in a stilling well as shown in figure is provided. During evaporation measurement a constant water level is maintained at the top level of fixed gauge. For this purpose water has to be added or removed periodically. The water level measurements are done using micrometer hook gauge. The entire assembly is mounted on a level wooden platform.

PAN CO-EFFICCIENT

Evaporation pans are not exact models of large reservoirs or lakes, because of the exposure conditions which are not identical in both the cases. Specially the heat storing capacity and the heat transformed from the side & bottom of pan are quite different from those of large lake are reservoir, also the height of the rim above the water surface in the pan effects the wind action over the surface and creates a shadow of variable magnitude over water surface which effects radiation incident to the water surface. In view of the above evaporation measured from the pans has to be corrected to get the evaporation from the lake under a similar climatic exposure condition. Thus a co-efficient called pan co-efficient is introduced and is given by:

Pan Co-efficient (Cp) = (Actual evaporation from the lakes or reservoirs/ Measured evaporation from the pan)

The pan co-efficient for different types of pans are tabulated below:-

Type of Pan	Range of Cp	Average Cp
ISI Pan	0.65-1.0	0.80
Class A load pan	0.60-0.80	0.70
Colorado Sunken pan	0.75-0.86	0.78
Floating Pan	0.70-0.80	0.80

2.1.6 USE OF EMPIRICAL FORMULAE

Based on Dalton's law of evaporation, various formulae have been suggested to estimate evaporation.

1. Meyer's formula:

$$E = C*(e_s - e_a)*(1+0.06215V)$$

Where, E = evaporation from water body (mm/month)

e_s= saturation vapour pressure at water surface (mm of mercury) corresponding to mean monthly temperature of water

e_a= actual vapour pressure of air based on mean monthly temperature & relative humidity

v = monthly mean wind velocity in Km/hr, 10m above the ground

c = 50 (small shallow ponds)

= 11 (for large or deep water bodies)

2. Rohwer's formula:

$$\mathbf{E = 0.771(1.465 - 0.000732Pa)*(0.44+0.7334v)*(e_s - e_a)}$$

Where, E = evaporation in mm/day

Pa = Mean Barometric Reading in mm mercury

e_s= saturation vapour pressure at water surface (mm of mercury) corresponding to mean monthly temperature of water

e_a= actual vapour pressure of air based on mean monthly temperature & relative humidity

v = monthly mean wind velocity in Km/hr, 10m above the ground

2.1.7 METHODS TO CONTROL EVAPORATION FROM LAKES

Following are some recommended measures to reduce evaporation from water surfaces.

1) Storage reservoirs should have more depth and less surface area. The site for construction of a dam should be so chosen that a deep reservoir with minimum surface area exposed to atmosphere is formed.

2) Tall trees on the wind ward side of the reservoir should be planted so that they act as wind breakers.

3) By spraying a chemical such as Acetyl Alcohol on water surface, a film of 0.15 microns thickness is produced on the surface. This film allows precipitation in but does not allow evaporation. This is suitable when wind velocities are less and for small and medium sized reservoirs.

4) In case of ponds and lakes entire water body can be covered by thin polythene sheets as mechanical covering.

5) In reservoirs outlet arrangements should be so done to let out warmer water at top than cold water from bottom.

6) De-weeding the reservoirs should be done such that water consumed by weeds is reduced.

7) The streams and channels to be straightened so that length and in turn exposed area to atmosphere are reduced.

2.2 EVAPOTRANSPIRATION

- **Evapotranspiration:** In agricultural fields apart from transpiration, water is also lost due to evaporation from adjacent soil. The sum of these two losses is often termed as evapotranspiration (Et) or consumptive use (Cu).
- **Potential evapotranspiration**: When sufficient moisture is freely available to completely meet the needs of the vegetation fully covering an area, the resulting evapotranspiration is called potential evapotranspiration.
- **Actual evapotranspiration**: The real evapotranspiration occurring in a specific situation in the field is called actual evapotranspiration. The knowledge of evapotranspiration, potential evapotranspiration and actual evapotranspiration are very much useful in designing irrigation systems (in deciding the amount of water to be supplied for raising crops).

2.2.1 FACTORS AFFECTING EVAPOTRANSPIRATION

Potential evapotranspiration is controlled by meteorological facts but actual evapotranspiration is affected by plant and soil factors. In total the factors affecting evapotranspiration are:

1. Temperature
2. Humidity
3. Percentage sunshine hours
4. Wind speed
5. Type of crop
6. Season
7. Moisture holding capacity of soil
8. Irrigation Methods
9. Cropping patterns

2.2.2 DETERMINATION OF EVAPOTRANSPIRATION (ET) OR CONSUMPTIVE USE OF WATER

The time interval for supplying water to agricultural crops, is a factor dependent on water requirement of crops, soil properties and as well as consumptive use. Hence accurate determination of consumptive use or evapotranspiration is very much essential. The methods of determining consumptive use are:-

i) Direct measurement method

ii) By use of empirical formulae

- **Direct measurement methods**

The different methods of direct measurement are

a. Soil moisture studies on plots

b. Tank and lysimeter method

c. Field experimental plots

d. Integration method

e. Inflow and outflow studies for large areas

a) Soil moisture studies on plots

Soil moisture measurements are done before and after supplying water. The quantity of water extracted per day from the soil is computed for each required period. A curve is drawn by plotting the rate of water consumed against time. This curve is useful for determining the average consumption daily or on monthly basis.

b) Tank and lysimeter method

Tanks are watertight cylindrical containers which are open at one end. They have a diameter of 1-3 m and depth of 2-3 m. They are set in ground with the rim in flush with the ground surface. The quantity of water to keep a constant moisture content (for optimum growth) is determined, which itself represents consumptive use. A lysimeter is a container similar to tank but has pervious bottom free drainage through the bottom is collected in a pan which is kept below. The consumptive use of water in this case therefore the difference between the water applied and drainage collected in the pan.

c) Field experimental plots

In this method water is applied to selected field plots in such a way that there is neither runoff nor deep percolation. Yield obtained from different plots is plotted against total water used. It can be observed that increase in yield occurs with increase in water applied up to a certain point. Further increase in water content reduces yield. This break point in water application is taken as consumptive use.

d) Integration method

In this method the consumptive use of water for large areas is determined as the sum of the following products.

I) Consumptive use of each crop and its area

II) Consumptive use of natural vegetation and its area

III) Evaporation from water surfaces and their area

IV) Evaporation from open lands and their area

e) Inflow and outflow studies for large areas

In this method consumptive use of water for large areas is given by the equation:

$$Cu = I + P + (Gs - Ge) - O$$

Where, I= Total inflow into the area during a year

P = Total precipitation in the area during a year

Gs = Ground water storage at the beginning of the year

Ge = Ground water storage at the end of the year

O = Outflow from the area during the year

- **By Use of Empirical formulae**

Following are some of the empirical methods or relations suggested for calculating consumptive use

a) Blaney Criddle method

b) Penman method

c) Lowry and Johnson method

d) Hargreaves pan method

2.2.3 BLANEY CRIDDLE EQUATION

Blaney and Criddle developed a simple equation for estimating evapotranspiration. It is assumed that the evapotranspiration is closely correlated with the mean monthly temperatures and daylight hours. The monthly consumptive use factor 'f' is defined as:

$$f = (p * Tm / 100)$$

Where Tm is the monthly mean temperature in ^{0}F, p is the monthly daylight hours expressed as percent of the daylight hours of the year and f is in inches.

In other words p is obtained from the expression p = (possible sunshine hours for the particular month/ possible sunshine hours for the whole year) * 100

p = (possible sunshine hours for the particular month/ 365*12) * 100

The value of p depends on the latitude of the place and the month of the year.

The monthly consumptive use is then obtained as:

u = k*f

Where k is an empirical crop co-efficient. The monthly consumptive use u are added for all the months of the crop to yield the seasonal consumptive use or the total evapotranspiration in inches. The value of k depends on the month and the place.

The Blaney – Criddle equation gives reasonably accurate estimates of evapotranspiration provided a locally developed crop co-efficient is used. However it takes only temperature and daylight hours into account and the other important factors like humidity and wind are ignored.

2.3 INFILTRATION

2.3.1 INTRODUCTION

The water entering the soil at the ground surface after overcoming resistance to flow is called infiltration. The process is also termed as infiltration. Infiltration fills the voids in the soil. Excess water moves down by gravity and it is known as percolation. Percolation takes place till water reaches ground water table. For continuous infiltration to occur it is essential that percolation should also be continuous, which is also dependent of ground water movement. Infiltration process: Infiltration plays an important role in the runoff process and it can be easily understood by a simple analogy as shown below. The soil medium where infiltration is to be observed may be considered as a small container covered with a wire gauge mesh. If water is poured over the gauge, part of it enters the soil and some part over flows. Further the runoff and infiltration depend on the condition of soil. When soil reaches saturated condition infiltration stops and all input becomes runoff. Usually at the beginning of a storm infiltration is more and runoff is less and when storm continues infiltration becomes lesser and runoff become constant. The volume of rainfall that will result in runoff is called _Rainfall excess'.

- **Infiltration rate** (f): It is actually the prevailing rate at which the water is entering the given soil at any given instant of time. It is expressed in cm/hr (i.e. depth of water entering soil per unit time).
- **Infiltration Capacity** (fp): It is the maximum rate at which a soil in any given condition is capable of absorbing water.

2.3.2 FACTORS AFFECTING INFILTRATION CAPACITY

The variations in the infiltration capacity are large. The infiltration capacity is influenced by many factors. Some factors contribute to long term variation, but some cause temporary variations.

a. Depth of surface retention and thickness of saturated layer of soil:

Infiltration takes place due to combined influence of gravity and capillary force. Due to this a layer of soil near the surface becomes saturated. If the thickness of saturated soil at any given time and at any given section is 'L' the water will flow through a series of tiny tubes of length 'L'. Therefore infiltration capacity should decrease with time in a continuous rain and become a constant ultimately.

b. Soil Moisture:

The soil moisture affects the infiltration capacity in 2 ways:

(i) If the soil is quiet dry at the beginning of the rain, there is a strong capillary attraction for moisture in subsurface layers that acts in the same direction as gravity and given high initial value of infiltration. As water percolates down the surface layer becomes semi saturated & capillary forces diminish hence f also reduces.

(ii) When the soil is subjected to wetting very fine soil particles called colloids will swell slightly and reduce the size of the voids. This leads to reduce of 'f' with time.

c. Compactness of soil:

(i) Due to rain – The clay surfaced soils are compacted even by the impact of rain drops which reduce 'f'. This compaction not only reduces the porosity but also pore sizes. This effect is negligible in sandy soil. Protection by vegetative cover or practically eliminate this effect even in fine textured soils.

(ii) Due to man & animals – where heavy pedestrian or vehicular traffic moves on the soil, the surface is rendered relatively impervious and this reduces 'f'.

d. In wash of fines:

When the soil becomes very dry, the surface often contains many fine particles. When rain falls and infiltration begins, these fines are carried into the soils and are deposited in the voids, thus reduce the infiltration capacity.

e. Vegetative covers:

The natural surface cover has also an important influence on infiltration. The presence of dense cover on vegetation on the surface increase 'f'. The vegetative covers retard the movement of overland flow and causes high depth of detention. Vegetative cover also reduces the raindrop compaction and provides a layer of decaying organic matter which promotes the activity of borrowing insects and animals which in turn produces permeable soil structures. Transpiration by vegetation tends to keep the soil moisture at low levels. Also these factors tend to increase the infiltration capacity 'f'. Surfaces covered with snow paved urban area will obviously have very low or zero infiltration capacity.

f. Temperature:

The effect of temperature on infiltration capacity is explained through viscosity. The flow through soil pores is almost laminar for which the resistance is directly proportional to the viscosity. At high temperature viscosity of water is low high filtration capacity is expected. During winter season the temperature is less and thus infiltration capacity becomes less. This is one of the factors responsible for seasonable variation in 'f'.

2.3.3 MEASUREMENT OF INFILTRATION

Infiltration rates are required in many hydrological problems such as runoff estimation, soil moisture studies in agriculture, etc. The different methods of determination of infiltration are

1. Use of Infiltro-meters
2. Hydrograph analysis method

The infiltrometer always gives the infiltration capacity at a particular site and infiltration from this at various locations in the basin may give fairly satisfactory estimate average infiltration capacity for the entire basin. In the hydrograph analysis method the actual infiltration rate curve is obtained, provided the accurate measurement of rainfall and runoff from the basin made.

Infiltro-meters are of two types.

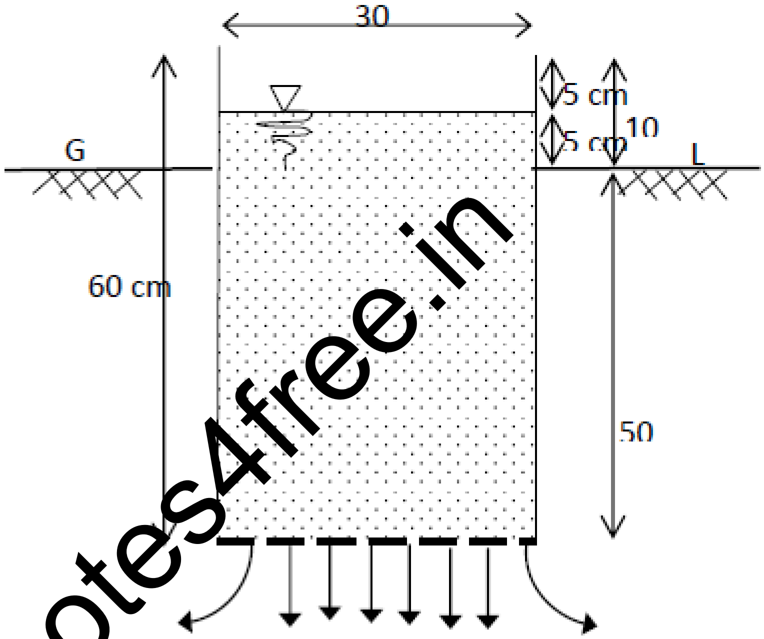
a) Flooding type Infiltro-meters

b) Rainfall simulators

In flooding type Infiltro-meters water is applied in form of a sheet, with constant depth of flooding. The depletion of water depth is observed with respect to time. In case of rainfall simulators water is applied by sprinkling at a constant rate in excess of infiltration capacity and the runoff occurring is also recorded. Infiltro-meters adopted in practice are,

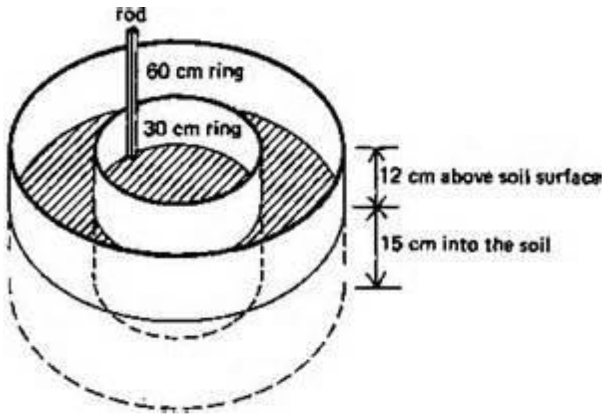
1. Simple (Tube Type) Infiltro-meters
2. Double ring Infiltro-meters

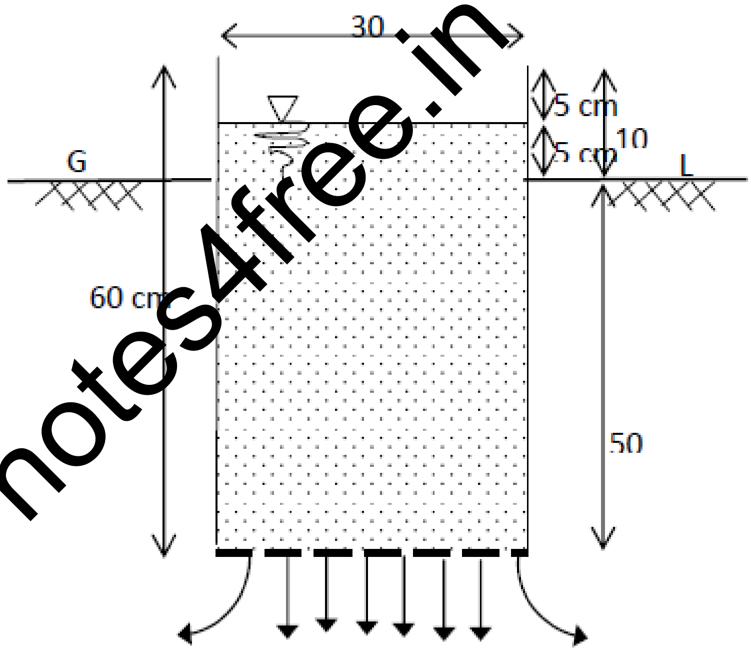
- **Simple (Tube Type) Infiltro-meters** It is essentially a metal cylinder with openings at both ends. It has a diameter of 30 cm and length of 60 cm. This is driven into the ground as shown and water is poured from the top till the pointer level as shown. As infiltration continues the depleted volume of water is made up by adding water from a burette or measuring jar to maintain constant water level. Knowing the volume of water added during different time intervals the infiltration capacity curve is plotted. The experiment is continued till a uniform rate of infiltration is obtained, which may take 2 to 3 hours.



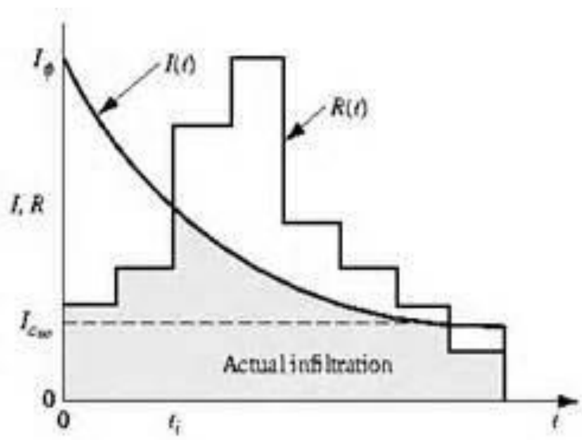
- **Double ring Infiltro-meters**

A tube infiltrometer has a drawback that infiltration in it does not represent or simulate the actual field conditions because the water tends to disperse laterally after coming out at the bottom. To overcome this draw back a Double ring Infiltro-meter is widely used. It consists of two consecutive rings driven into the ground as shown in the figure below. The inner ring has a diameter of 30 cm and outer ring has a diameter of 60 cm. They are concentrically driven into the ground as shown in figure. A constant water depth of 5 cm is maintained in both the rings. The outer ring provides a water jacket to the water infiltrating from the inner ring and thus simulates the natural conditions. The water depths in both the rings are maintained constant during the observation period. The measurement of water volume added into the inner ring is only noted. The experiment is carried out till constant infiltration arte is obtained. To prevent any disturbance or accidental fall of foreign matter the top of the infiltrometer is covered with a perforated disc.





Infiltration capacity curve: It is the graphical representation of variation of infiltration capacity with time, during and a little after rain many factors affect infiltration capacity of a given soil. Typical infiltration capacity curves for a soil are as follows.



2.3.4 INFILTRATION EQUATIONS

The data from Infiltro-meters can be used to plot an infiltration capacity curve. Infiltration capacity curve is a decaying curve which shows high infiltration capacity rate at beginning and decreases exponentially and attains minimum or constant value over time. Many mathematical equations have been proposed to describe the shape of the curve. The most commonly used equation is ―Horton‘s Equation‖.

The infiltration rate (f) at any time 't' is given by Horton's equation

$$\mathbf{Fp = Fc + (Fo - Fc)\, e^{-Kt}}$$

F_o= initial rate of infiltration capacity

F_c= final constant rate of infiltration at saturation

K= a constant depending primarily upon soil and vegetation

e= base of Napier an logarithm

t= time from beginning of storm

Fc= shaded area obtained as shown from the graph also known as field capacity is the amount of rainfall which can be absorbed by soil.

This equation when conjunctively used with rain fall data (hyetograph) can be used to calculate surface runoff volumes occurring during a storm.

2.3.5 INFILTRATION INDICES

The infiltration capacity curves which are developed either from infiltrometer tests or the hydrograph analyses methods can be used to estimate the runoff from a given storm. The infiltration rate curve appropriate to the soil, vegetation and antecedent moisture conditions existing at the time of occurrence of storm is superimposed on the rainfall hyetograph with base lines coincident as shown in figure below.

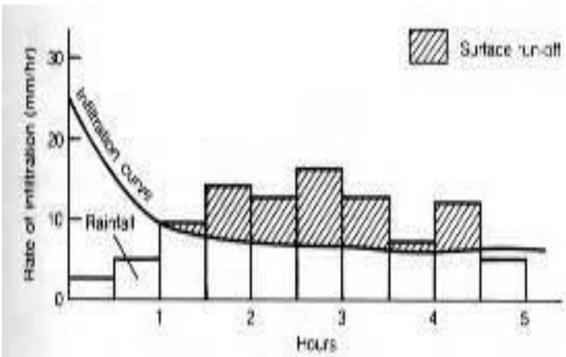


FIG 4 Changes in infiltration through a rainstorm for sandy loam soils

The area of the rainfall hyetograph above the infiltration curve would then represents the runoff volume whose time distribution may be obtained through the application of unit hydrograph principle. The rainfall volume below the infiltration curve represents the total depth of infiltration during the storm. Though this approach appears to be simple there are some difficulties. If the rainfall intensity is always more than the infiltration capacity the results are satisfactory. If the rainfall intensity fluctuates above & below the infiltration capacity rate curve the problem is complicated. The above difficulties led to the use of infiltration indices. These indices in general express the infiltration as an average rate throughout the storm. Since the infiltration capacity actually decrease with prolonged rainfall the use of an average value assumes too little infiltration during the first part of the storm and too much near the end of it.

1. Φ - Index

The Φ - Index is an average rainfall intensity above which the rainfall volume equals the runoff volume. The rainfall hyetograph is plotted on a time based and a horizontal line is drawn such that the shaded area above the line exactly equals the measured runoff. Since the unshaded area below the line is also measured rainfall but did not appear, as runoff it represents all the losses including depression storage, evaporation, interception as well as infiltration. However, infiltration is the largest loss compared to the other losses. The Φ - Index can be determined for each flood event for which the runoff measurements are available.

2. W – Index

The W – Index is refined version of Φ - Index. It excludes the depression storage and interpolation from the total losses. It is the average infiltration rate during the time rainfall intensity exceeds the capacity rate.

That is, $W = F/t = (P-Q-S)/t$

Where F is the total infiltration, t is the time during which rainfall intensity exceeds infiltration capacity, P is the total precipitation corresponding to t, Q is the total storm runoff and S is the volume of depression, storage and interception. Thus W- index is essentially equal to Φ - Index minus the depression and interception storage.

3. W_{min} – Index

This is the lowest value of W – Index which is observed under very wet initial conditions. Under these conditions since the retention rate is very low W - Index and Φ - Index tend to be equal. This index is principally used in studies of maximum flood potential.

2.4 IMPORTANT QUESTIONS

- Explain the factors affecting evaporation?
- Define evaporation. With a neat sketch explain measurement of evaporation using "IS class A pan"?
- Explain estimation of evaporation by Meyer's and Rohwer's empirical formulae?
- What are the measures taken to reduce evaporation?
- Enlist the factors affecting evapotranspiration?
- Explain Blaney Criddle equation for estimating evapotranspiration?
- What are the different methods of estimating evapotranspiration? Explain any two methods.
- Explain the factors affecting infiltration capacity.
- Describe the method of determining infiltration capacity using double ring infiltrometer.
- Differentiate between:
- W-index & ϕ index (b) AET & PET (c) Infiltrometer & Lysimeter.
- With a neat sketch explain Double mass technique.

2.5 OUTCOMES

- Understand different types of loses in precipitation and factors affecting it.

2.6 FURTHER READING

- https://nptel.ac.in/courses/105101002/3

MODULE 3

3.1 RUNOFF

3.1.1 DEFINITION

3.1.2 CONCEPT OF CATCHMENT

3.1.3 FACTORS AFFECTING RUNOFF

3.1.4 RAINFALL – RUNOFF: RELATIONSHIP USING REGRESSION ANALYSIS.

3.2 HYDROGRAPHS

3.2.1 DEFINITION

3.2.2 COMPONENTS OF HYDROGRAPH

3.2.3 BASE FLOW SEPARATION

3.2.4 UNIT HYDROGRAPH: ASSUMPTION, APPLICATION AND LIMITATIONS,

3.2.5 DERIVATION FROM SIMPLE STORM HYDROGRAPHS

3.2.6 S CURVE AND ITS COMPUTATIONS

3.1 RUN OFF

3.1.1 INTRODUCTION

When precipitation occurs on land, a part of it is intercepted by vegetation and some part of it is stored as depression storage. A part of precipitation infiltrates into the ground. The rate of infiltration depends on the nature of the soil, moisture content in soil, topography, etc. If the rate of precipitation is greater than the rate of infiltration, then the rainfall in excess of infiltration will start flowing over the ground surface and is also known as over land flow. When overland flow is occurring infiltration and evaporation may also occur. When over land flow reaches a well-defined stream it is known as surface run off. A portion of infiltrating water will satisfy soil-moisture deficiency. A portion may move in soil but very close to the surface. If this also reaches a well-defined stream it is known as inter flow or subsurface flow. Another portion of infiltration may percolate deeper into the soil to reach ground water table. Under favorable conditions some of the ground water may reach the streams and this portion is known as Base flow or ground water flow. A part of precipitation may occur directly on stream surface and this is known as channel Precipitation.

Hence, Total runoff = Surface run off + Inter flow + Base flow + Channel precipitation.

It is also evident that evaporation always occurs along with transpiration.

Hence, Precipitation = Run off + Evaporation

OR

Precipitation = (Surface run off + Inter flow + Base flow + Channel precipitation) + Evaporation

3.1.2 DEFINITIONS

1. Total Run off: This is the part of precipitation which appears in streams. It consists of Surface run off, Inter flow, Base flow, and Channel precipitation.

2. Surface run off (SRO): This is the part of overland flow which reaches the streams.

3. Direct run off (DRO): It consists of Surface run off, Inter flow, and Channel precipitation, but does not include Base flow. Since channel precipitation is small and inter flow is uncertain, it is usual to include these two run offs in surface run off. Hence there is no difference between direct run off and surface run off. Hence Total run off = Surface run off + Base flow Since the base flow occurs in the stream after a longer time compared to surface run off, it is necessary to separate the base flow and surface run off in preparing hydrographs.

4. Hydrograph: A hydrograph is a plot of the run off or discharge in a stream versus time. Hydrographs may be developed for isolated or complex storms using stream gauging data. The area under the hydrograph gives the total volume of runoff and each ordinate gives the discharge at the instant considered. It also indicates the peak discharge and the time base of the flood in the stream.

5. Rainfall excess: This is the portion of rainfall appearing in the stream as surface run off.

6. Effective rainfall: This is the portion of rainfall which appears in the stream as the sum of Surface run off, Inter flow, and Channel precipitation. Since channel precipitation is small and inter flow is uncertain, it is usual to include these two run offs in surface run off. Thus rainfall excess and effective rainfall may be considered to be the same.

Note: Surface run off = Precipitation – (interception + depression storage + evaporation + infiltration)

7. Channel storage: As runoff occurs in the stream, the water level will rise along the length of the stream. Thus a large volume of water is temporarily stored in the channel. This is known as channel storage. It reduces or moderates flood peaks. The channel storage therefore causes delay in the appearance of discharge at any section of the stream.

3.1.3 METHODS OF ESTIMATING RUN OFF FROM BASINS

The basin area contributing to the flow in a stream goes on increasing as we go down along a stream. Hence the section at which the flow is measured should be specified. The various methods for estimating run off from basins are

a. Empirical formulae and charts

b. By estimating losses (evaporation, transpiration, etc.)

c. By infiltration

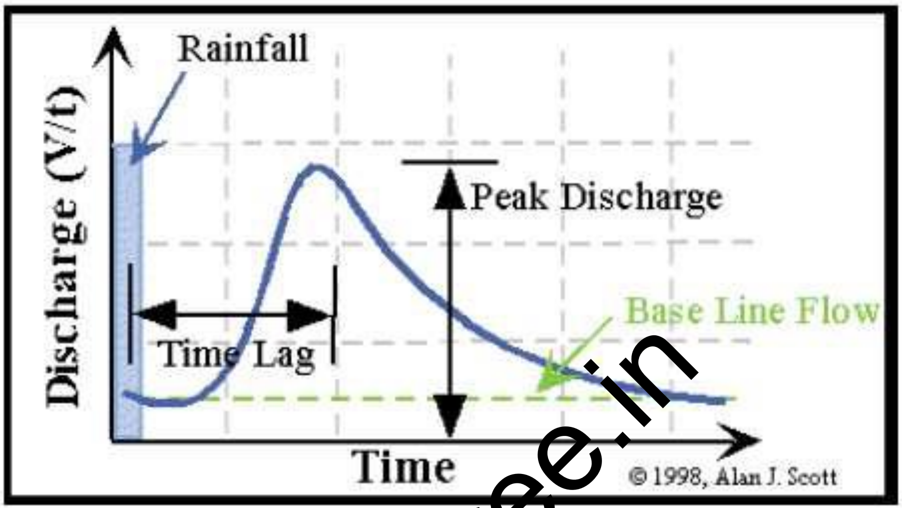
d. Unit Hydrograph method

e. Synthetic Unit Hydrograph method (Synder‘s method)

It is difficult to obtain even a fairly approximate estimate of run off because the various processes such as overland flow, base flow, infiltration, evaporation, etc are highly irregular and complex. Thus none of the above methods can be considered as accurate. However the Unit Hydrograph method is easier and is considered as the best among the methods mentioned.

3.2 HYDROGRAPH

A Hydrograph is a graph showing the variation of discharge versus time.



At the beginning there is only base flow (i.e., the ground water contribution to the stream) gradually deflecting in a conical form. After the storm commences, the initial losses like interception and infiltration are met and then the surface flow begins. They hydrograph gradually rises and reaches its peak value after a time tp (log time or basin log) measured from the centroid of the hydrograph of the net rain. Thereafter it declines and there is a change of slope at the inflection point i.e., there has been inflow of the rain up to this point and after this there is gradual withdrawal of catchment storage. There after the GDT declines and the hydrograph again goes on depleting in the exponential form called the ground water depletion curve or the recession curve.

3.2.1 HYDROGRAPH WITH MULTIPLE PEAKS

Basic definitions (Hydrograph features):

a) Rising limb: It is the curve or line joining the starting point 'A' of the raising curve and the point of reflection. The shape of the raising line is influenced by the rainfall characteristics.

b) Peak or Crest: It represents the highest point/position of the hydrograph. Its duration also depends on the intensity and duration of the rainfall.

c) Falling limb or depletion curve: It is the descending portion or the hydrograph. The shape of the falling limb it mainly a function of the physical features of the channel alone and is independent of storm characteristics (it depends on basin characters).

d) Time to peak (tp): It is the time to peak from the starting point of hydrograph

e) Lag time: The time interval from the centre of mass of rainfall to the centre of mass hydrograph is the lag-time.

f) It is the total duration or time elapsed between the starting and ending of the hydrograph.

3.2.2 FACTORS AFFECTING THE SHAPE OF THE FLOOD HYDROGRAPH

a) Climatic factors

b) Physical factors

- Climatic factors include

1) Storm characteristics, intensity, duration, magnitude and movement of storm

2) Initial loss due to interception etc.

3) Evapotranspiration

- Physical factors include

1) Basic characteristics, shape, size, slope, nature of the valley, elevation, drainage density

2) Infiltration characteristics, land use and cover, soil type, geological conditions etc.

3) Channel characteristics, cross section, roughness and storage capacity

(For a given duration, the peak and volume of surface runoff are essentially proportional to the rainfall intensity. Duration of rainfall of given intensity directly effects the volume of runoff. If the storm moves in the downstream direction flow will be quicker at the basin. Smaller catchments yield a more rapid and intense flood per unit area. Vegetation and forests increase infiltration and also the storage capacity of the soils; vegetal cover reduces the peak flow.

3.2.3 UNIT HYDROGRAPH

A unit hydrograph is defined as the hydrograph of direct runoff resulting from one cm depth excess rainfall occurring uniformly over the basin and at a uniform rate for a specified duration.

Assumptions:

1. The effective rainfall is uniformly distributed within the specified period of time or within its duration

2. The time or base duration of the hydrograph of direct runoff due to an effective rainfall of unit duration shall be constant.

3. The effective rainfall is uniformly distributed throughout the area of drainage basin.

4. The direct runoff of common base line are proportional to the total amount of direct runoff.

5. The hydrograph of runoff due to a given period of rainfall for a drainage area shows all the combined physical characteristics.

Limitations of Unit hydrograph theory:

1. Unit hydrograph is based on the assumption that effective rainfall is uniform over the entire basin. However it is seldom true particularly in the case of large base. As such unit hydrograph theory is limited to the basins of size nor exceeding 6000 km2 . Thus large basins should be subdivided & unit hydrograph should be separately developed for each basin.

2. This theory is not applicable when approachable quantity of precipitation occurs in the form of snow.

Derivation:

1. Few unit periods of intense rainfall duration corresponding to an isolated storm uniformly distributed over the area are collected from the past rainfall records.

2. From the collected past records of the drainage for the forms prepare the storm hydrograph for some days after and before the rainfall of that unit duration.

3. Draw the line reporting the ground water flow and direct runoff by any of the standard base flow separation procedures.

4. From the ordinate of the total runoff hydrograph deduct the corresponding ordinates of base flow to obtain the ordinates of direct runoff.

5. Divide the volume of direct runoff by the area of the drainage basin to obtain the net precipitation depth(x) over the basin.

6. Divide each of the ordinates of direct runoff by net precipitation depth to obtain the ordinates of the unit hydrograph. i.e., ordinate of unit hydrograph (UHG) = Ordinate of direct runoff

(FHG)/Depth of net precipitation(x) i.e, UHG=FHG/x

7. Plot the ordinates of the unit hydrograph against time since the beginning of direct runoff, which is the unit hydrograph for the basin for the duration of the storm.

3.2.4 HYDROGRAPH SEPARATION/BASE FLOW SEPARATION:

In figure: By simply drawing a line ‘AC’ tangential to both the limbs at their lower portion. This method is very simple but is approximate and can be used only for preliminary estimates.

2. Extending the recession curve existing prior to the occurrence of the storm upto the point ‘D’ directly under the peak of the hydrograph and then drawing a straight line DE. Where E is a point hydrograph ‘N’ days after the peak & N 9in days) is given by N= 0.8f

3 Where A is the area of drainage basin (km) & the size of the areas of the drainage basin as a

guide to the values of 'N' are given below: Area of drainage basin, km Time after peak N (days) Simply by drawing a straight line AE, from the point of rise to the point E on the hydrograph, 'N' days after the peak. By producing a point on the recession curve backwards up to a point 'F' directly below the inflection point and the joining a straight line AF.

3.3 IMPORTANT QUESTIONS

- Explain factors affecting Runoff?
- Explain relation between rainfall & runoff using regression analysis.
- With a neat sketch explain the fan and fern leaf catchment.
- List out various methods for estimation of design flood. Explain rational method of flood estimation.
- Explain typical single peaked hydrograph components with a neat sketch.
- Define unit hydrograph. List the assumptions made in deriving unit hydrograph and its limitations.
- Explain the procedure for drawing master depletion curve.
- Explain the procedure for deriving a unit hydrograph from an isolated storm.
- With a neat sketch explain S Hydrograph or summation hydrograph.

3.4 OUTCOMES

- Understand the concept of hydrograph and runoff

3.5 FURTHER READING

https://nptel.ac.in/courses/105101002/9

https://nptel.ac.in/courses/105101002/7

MODULE 4

4.1 IRRIGATION:

4.1.1 DEFINITION.

4.1.2 BENEFITS AND ILL EFFECTS OF IRRIGATION.

4.1.3 SYSTEM OF IRRIGATION:

4.3.1.1 SURFACE AND GROUND WATER,

4.3.1.2 FLOW IRRIGATION,

4.3.1.3 LIFT IRRIGATION,

4.3.1.4 BANDHARA IRRIGATION.

4.2 WATER REQUIREMENTS OF CROPS:

4.2.1 DUTY, DELTA AND BASE PERIOD,

4.2.2 RELATIONSHIP BETWEEN THEM,

4.2.3 FACTORS AFFECTING DUTY OF WATER CROPS AND CROP SEASONS IN INDIA,

4.2.4 IRRIGATION EFFICIENCY,

4.2.5 FREQUENCY OF IRRIGATION.

4.1.1 INTRODUCTION

Irrigation may be defined as the process of artificially supplying water to the soil for raising crops. It is a science of planning and designing an efficient low cost irrigation system to suite the natural conditions. It is the engineering of controlling and harnessing the various natural sources of water by the construction of dams and reservoirs, canals and head works finally distributing the water to the agricultural fields. Irrigation engineering includes the study and design of works connected with river control, drainage of water logged areas and generations of hydroelectric power.

- **Necessity or Importance of Irrigation**

India is basically an agricultural country and its resources on depend on the agricultural output. Prosperity of our country depends mainly upon proper development of agriculture. Even after 60 years of Independence, we have not succeeded in solving our food problems. The main reason for this miserable state of affair is that we still continue to remain at the mercy of rain and practice age old methods of cultivation. Plants usually derive water from nature through rainfall. However, the total rainfall in a particular area may be either insufficient or ill timed. In order to get the maximum yield, it is necessary to have a systematic irrigation system for supplying optimum quantity of water at correct timing.

- **Importance of irrigation can be summarized under the following four aspects:**

1. Area of less rainfall: Artificial supply of water is necessary when the total rainfall is less than the water requirement of crops in such cases, irrigation works may be constructed at a place where more water is available and conveyed to water deficit areas.

Eg: The Rajasthan canal supplies water from the river Yamuna to the arid regions of Rajasthan where annual rainfall is less than 100 to 200 mm.

2. Non-Uniform rainfall: The rainfall in a particular area may not be uniform over the entire crop period. Rainfall may be there during the early period of crops and may become scanty or unavailable at the end resulting in lesser yield or total loss of the crop. Collection of water during periods of excess rainfall and supplying the stored water during periods of scarcity may prove beneficial to the farmers. Most irrigation projects in India are based on this aspect.

3. Commercial crops with additional water: The rainfall in a particular area may be sufficient to raise the usual crops but insufficient for raising commercial and cash crops such as sugarcane and cotton. In such situations, utilizing stored water by irrigation facilities is advantageous.

4. Controlled Water Supply: Dams are normally meant for storing water during excess flow periods. But in situations of heavy rainfall, flooding can be controlled by arresting the flow in the river and excess water can be released during low flow conditions.

4.1.2 Benefits of Irrigation:

There are many direct and indirect benefits or advantages of irrigation which can be listed as follows.

1. Increase in food production: Crops need optimum quantity of water at required intervals assured and timely supply of water helps in achieving good yield and also superior crops can be grown and thus, the value of the crops increases.

2. Protection from famine: Irrigation works can be constructed during famine (drought). This helps in employment generation and people also get protection from famine. After completion of such works, continuous water supply may be available for crops and people.

3. Cultivation of Cash crops: With the availability of continuous water supply, cash crops such as sugarcane, indigo, tobacco, cotton etc. can be grown.

4. Increase in prosperity of people: Due to assured water supply people can get good yield and returned for their crops. Land value increases and this raises the standard of living of the people and hence prosperity takes place.

5. Generation of hydroelectric power: Major river valley projects are designed to provide power generation facilities also apart from irrigation needs.

6. Domestic and Industrial water supply: Water stored in reservoirs can also be used to serve other purposes like domestic water supply to towns and cities and also for industrial use. Canals can also be effectively used to serve these purposes.

7. Inland Navigation: In some cases, the canals are very large enough to be used as channels for inland navigation as water ways are the cheapest means of transportation.

8. Improvement in communication: Main canals in large irrigation projects are provided with inspection roads all along the sides. These roads can be asphalted and used as a means of communication.

9. Canal plantation: Due to continuous flow of water adjoining areas of a canal are always saturated with water. In such places, trees can be planted which increases the timber wealth of the country.

10. Improvement in ground water storage: Due to constant percolation and seepage of irrigation water, ground water table rises. The ground water may percolate and may be beneficial to other areas.

11. Aid in civilization: Due to introduction of river valley projects, tribal people can adopt agriculture as their profession which helps in improving the standards of living.

12. General development of a country: By assured water supply, farmers can expect good yield. By exporting surplus goods, Government can get revenue. The government can then come forward to improve communications facilities such as roads and railways and also social development by providing schools, hospitals etc.,

ILL-EFFECTS OF IRRIGATION

If water is used in a controlled and careful manner, there would be no ill effects of irrigation. Excess and unscientific use of irrigation of water, givers raise to the following ill effects.

1. Water logging: Excess water applied to the fields allows water to percolate below and ground water table rise. The ground water table may rise saturating the root zone of the crop and cutting of air supply to the roots of the crops. Such a phenomenon is called water logging. Under such conditions fertility of land reduced and also reduction of crop yield.

2. Breeding placed for mosquitoes: Excess application of water for irrigation leads to water logging and formation of stagnant water fools, which become breeding places for mosquitoes, thus helping spreading of malaria.

3. Unhealthy Climate: Due to intense irrigation the climate becomes damp during summer due to humidity, the climate is sultry and in winter it becomes excessively cold. The resistance of the body to diseases is reduced. In addition to the above, careless use of water leads to wastage of useful irrigation water for which any government will have incurred huge amounts.

4.1.3 TYPES OR SYSTEMS OF IRRIGATION

4.1.3.1 Lift Irrigation: It is that system of irrigation in which irrigation water is available at a level lower than that of the land to be irrigated and hence water is lifted by pumps or other mechanism (Hydraulic ram and siphon action) and then conveyed to agriculture fields by gravity flow. Irrigation through wells is an example of lift irrigation. Water from canals or any other source can also be lifted when the level of water is lower than that of the area to be irrigated.

4.1.3.2 Inundation Irrigation: It is that system of irrigation in which large quantity of water flowing in a river is allowed to flood or inundate the fields to be cultivated. The land becomes thoroughly saturated. Excess water is drained off and the land is prepared for cultivation. Moisture stored in the soil is sufficient to bring the crop to maturity. Inundation irrigation is commonly practiced in delta region of rivers. Canals may be also employed to inundate the fields when water is available in plenty.

4.1.3.3 Perennial Irrigation: It is that system of irrigation in which irrigation water is supplied as per the crop requirements at regular intervals throughout the crop period. The source of irrigation water may be a perennial river, stored water in reservoirs or ground water drawn from open wells or bore wells. This is the most commonly adopted irrigation system.

4.1.3.4 Direct Irrigation: It is a type of flow irrigation in which water from rivers and streams are conveyed directly to agricultural fields through a network of canals, without making any attempt to store water this is practiced in areas where the rivers and streams are perennial. Small diversion dams or barrages may be constructed areas the rivers to raise the water level and then divert the water into canals.

4.1.3.5 Storage Irrigation: Dams are constructed across rivers which are non- perennial. The discharge in such rivers may be very high during rainy season and may become less during dry stream. By constructing dams across such rivers water can be stored as reservoir during excess flow and can be utilized or diverted to agriculture fields through canals as and when required. Such a system is known as storage irrigation.

4.1.4 BANDHARA IRRIGATION

It is a special irrigation scheme adopted across small perennial rivers. This system lies somewhere between inundation type and permanent type of irrigation. A Bandhara is a low masonry weir (obstruction) of height 1.2m to 4.5m constructed across the stream to divert water into a small canal. The canal usually takes off from one side and the flow into the canal is controlled by a head regulator.

The length of the main canal is usually restricted to about 8km. A series of Bandharas may be constructed one below the other on the same stream so that water spilling over from one Bandhara is checked by another Bandhara. The irrigation capacity of each Bandhara is may be about 400 hectares. Bandharas are adopted across small streams having isolated catchments which are considered to be non feasible or uneconomical to be included under a large irrigation scheme.

This method of irrigation is followed in Central Maharashtra and is commonly known there as the ‘Phad’ system.

Advantages of Bandharas:

1. Small quantity of flow in streams can be fully utilized or otherwise might have gone as a waste.

2. As the length of the canal is short, seepage and evaporation losses are less.

3. Intensive irrigation with high duty may be achieved and the area to be irrigated is close to the source

4. The initial investment and maintenance cost of the system is low.

Disadvantages of Bandharas:

1. The supply of water is unreliable when the flow in streams becomes lesser.

2. Excess water available cannot be utilized as area for cultivation below each Bandhara is fixed.

3. In dry seasons, people living on the downstream side of Bandharas may be deprived of water for domestic made also.

4.2 WATER REQUIREMENT OF A CROP

It is the total quantity of water required by the crop from the time it is sown to the time it is harvested. Different crops require different quantities of water. Since the growing crops use water continuously, it is essential to maintain the quantity of readily available moisture in the soil by irrigation. As such the total quantity of water required by a crop is so distributed that a part of it is applied each time at a more or less fixed interval throughout the period of growth. The quantity of water applied at each irrigation should be such that water sufficient to meet the needs of the crop for a period between two successive irrigations is stored in the soil. Therefore in addition to the total quantity of water required by a crop, it is also essential to determine the frequency of irrigation as well as the quantitv ofwater required to be applied during each application.

4.2.1 DEFINITIONS

Duty of Water:

Duty represents the irrigating capacity of a unit of water.

It is usually defined as the area of land in hectares which can be irrigated to grow a crop of the cumec of water is continuously supplied for the entire period of the crop.

Delta:

It is the total depth of water required by a crop during the entire crop period and is denoted as 'Δ'

4.3 IMPORTANT QUESTIONS

- Define irrigation? What is the necessity of irrigation?
- Discuss in brief the benefit and ill effects of irrigation.
- With a neat sketch explain Bhandhara irrigation scheme.
- Explain irrigation efficiencies.
- Define duty? What are the factors affecting duty of water? Explain.
- Explain consumptive use of water. List the factors affecting consumptive use of water.
- Explain irrigation requirements of crops.
- Explain the following:

  (a) Base period (b) crop period (c) Time factor

  (d) Gross command area (e) Culturable command area
- The base period, Intensity of Irrigation and duty of water for various crops under a canal system are given the table below. Determine the reservoir capacity if the culturable commanded area is 40,000 hectares, canal loses are 20% and reservoir loses are 10%.

Crop	Base period (in days)	Duty of water at the field (hectares/cumec)	Intensity of Irrigation (%)
Wheat	120	1800	20
Sugarcane	360	1700	20
Cotton	180	1400	10
Rice	120	800	15
Vegetables	120	700	15

- A water course has a culturable command area of 1200 hectares. The intensity of irrigation for crop A is 40 % and for B is 35%, both the crops being rabi crops. Crop A has a kor period of 20 days and crop B has kor period is 15 days. Calculate the discharge of the water course if the kor depth for crop A is 10cm and for it is 16cm.
- The gross commanded area for a distributory is 20000 hectares, 75% of which can be irrigated. The intensity of irrigation for Rabi season is 40% that for Kharif season is 10%. If kor period is 4 weeks for rabi and 2.5 weeks for Kharif, determine the outlet discharge. Outlet factors for rabi and Kharif may be assumed as 1800 hectares/ cumec and 775 hectares/ cumec. Also calculate delta for each crop.

4.4 OUTCOMES

- Understand the concept of hydrograph and runoff

4.5 FURTHER READING

https://nptel.ac.in/courses/105101002/9

https://nptel.ac.in/courses/105101002/7

MODULE 5

5.1 CANALS

5.1.1 TYPES OF CANALS

5.1.2 ALIGNMENT OF CANALS

5.1.3 DRAWBACKS KENNEDY'S METHOD

5.1.4 DRAWBACKS IN LACEY'S

5.2 RESERVOIRS

5.2.1 INVESTIGATION FOR RESERVOIR SITE

5.2.2 SELECTION OF SITE FOR RESERVOIR

5.2.3 STORAGE ZONES

5.2.4 DETERMINATION OF STORAGE CAPACITY USING MASS CURVES

5.1 CANALS

A canal is an artificial channel, generally trapezoidal in shape, constructed on the ground to carry water to the fields either from a river or tank or reservoir.

If the full supply level (FSL) of a canal is below the natural ground surface, an open cut or excavation is necessary to construct a canal. If the FSL of the canal is above the existing ground level, the canal is constructed by providing earthen banks on both sides. In the first case the channel is called a canal in cutting and in the second case it is called a canal in filling. Sometimes a canal can be of the intermediate type and the channel is called a canal in partial cutting and Partial filling.

5.1.1 CLASSIFICATION OF CANALS:

The irrigation canals can be classified in different ways based on the following considerations.

1. Classification based on the nature of source of supply:

a) Permanent canals

b) Inundation canals

- A permanent canal is one which draws water from a permanent source of supply. The canal in such cases is made as a regular graded canal (fixed slope). It is provided with permanent regulation and distribution works. A permanent canal may also be perennial canal or nonperennial canal depending on whether the source supplying water is a perennial one or a nonperennial.
- An inundation canal is one which draws water from a river when the water level in the river is high or the river is in floods. These canals are not provided with any regulatory works, but an open cut is made in the banks of the canal to divert water.

2. Classification based on the function of the canal:

a) Feeder canals

b) Carrier canals

c) Navigation canals

d) Power canals

- A feeder canal is constructed for the purpose of supplying water to two or more canals only but not directly irrigating the fields.
- A carrier canal carries water for irrigating the fields and also feeds other canals for their needs.

- A canal serving the purpose of in-land navigation is called a navigation canal.
- A power canal supplies water to a hydro electric power generation plant for generation of electrical power.

3. Classification based on the discharge and its relative importance in a given network of canals:

a) Main canal

b) Branch canal

c) Major distributory

d) Minor distributory

e) Water course or Field channel

- A main canal is the principal canal in a network of irrigation canals. It directly takes off from a river, reservoir or a feeder canal. It has large capacity and supplies water to branch canals and even to major distributaries.
- Branch canals take off from a main canal on either side at regular intervals. They carry a discharge of about 5 cumec and are not usually used to directly irrigate the fields.
- A major distributory takes off a branch canal or a main canal. It has a discharge capacity of 0.25 to 5 cumec. They are used for direct irrigation and also to feed minor distributaries.
- Minor distributaries are canals taking off from the branch canals and major distributaries. They carry a discharge less than 0.25 cumec. These canals supply water to field channels.
- A water course or field channel takes off from either a major or minor distributory or a branch canal also. These are constructed and maintained by the cultivators/farmers. The other canals are constructed and maintained by the government or the Command Area Development Authority.

4. Classification based on Canal alignment:

a) Ridge canal or watershed canal

b) Contour canal

c) Side slope canal

- A Ridge canal or watershed canal is one which runs along the ridge or watershed line. It can irrigate the fields on both sides. In case of ridge canals the necessity of cross drainage works does not arise as the canal is not intercepted by natural streams or drains.

- A contour canal is one which is aligned nearly parallel to the contours of the country/area. These canals can irrigate the lands on only one side. The ground level on one side is higher and hence bank on the higher side may not be necessary.
- A contour canal may be intercepted by natural streams/drains and hence cross drainage works may be essential.
- A Side slope canal is one which is aligned at right angles to the contour of the country/area. It is a canal running between a ridge and a valley. This canal is not intercepted by streams and hence no cross drainage works may be essential. This canal has steep bed slope since the ground has steep slope in a direction perpendicular to the contours of the country/area.

5. Classification based on the financial output:

a) Productive canals

b) Protective canals

- A productive canal is one which is fully developed and earns enough revenue for its running and maintenance and also recovers the cost of its initial investment. It is essential the cost of its initial investment is recovered within 16 years of construction.
- Protective canals are those constructed at times of famine to provide relief and employment to the people of the area. The revenue from such a canal may not be sufficient for its maintenance. The investment may also not be recovered within the stipulated time.

6. Classification based on the soil through which they are constructed:

a) Alluvial canals

b) Non-alluvial canals.

- Canals constructed in alluvial soils are known as alluvial canals. Alluvial soils are found in the Indo-Gangetic plains of North India. The alluvial soils can be easily scoured and deposited by water.
- Canals constructed through hard soils or disintegrated rocks are called non-alluvial canals. Such soils are usually found in Central and South India.

7. Classification based on lining being provided or not:

a) Unlined canals

b) Lined canals

- An unlined canal is one which the bed and banks of the canal are made up of natural soil through which it is constructed. A protective lining of impervious material is not provided. The velocity of flow is kept low such that bed and banks are not scoured.
- A lined canal is one which is provide with a lining of impervious material on its banks and beds, to prevent the seepage of water and also scouring of banks and bed. Higher velocity for water can be permitted in lined canals and hence cross sectional area can be reduced.

5.1.2 CANAL ALIGNMENT

In aligning an irrigation canal, the following points must be considered.

1. An irrigation canal should be aligned in such a way that maximum area is irrigated with least length of canal.
2. Cross drainage works should be avoided as far as possible, such that the cost is reduced.
3. The off taking point of the canal from the source should be on a ridge, such that the canal must run as a ridge canal and irrigate lands on both sides.
4. Sharp curves in canals must be avoided.
5. In hilly areas, when it is not possible to construct ridge canals, the canal must be made to run as a contour canal.
6. The canal should be aligned such that the idle length of the canal is minimum.
7. The alignment should be such that heavy cutting or heavy filling are avoided. If possible balanced depth of cutting and filling is achieved.
8. It should not be aligned in rocky and cracked strata.
9. The alignment should avoid villages, roads, places of worship and other obligatory points.

5.1.3 DRAW BACKS IN KENNEDY'S THEORY:

1. Kutters equation is used for determining the mean velocity of flow and hence the limitations of kutter's equation are incorporated in Kennedy's theory.
2. The significance of B/D ratio is not considered in the theory
3. No equation for the bed slope has been given which may lead to varied designs of the channel with slight variation in the bed slope.

4. Silt charge and silt grade are not considered. The complex phenomenon of silt transportation is incorporated in a single factor are called critical velocity ratio.
5. The value of m is decided arbitrarily since there is no method given for determining its value.
6. This theory is aimed to design only an average regime channel.
7. The design of channel by the method based on this theory involves trial and error which is quite cumbersome.

5.1.4 DRAW BACKS IN LACEY'S THEORY:

1. The theory does not give a clear description of physical aspects of the problem.
2. It does not define what actually governs the characteristics of an alluvial channel.
3. The derivation of various formulae depends upon a single factor f and dependence on single factor f is not adequate.
4. There are different phases of flow on bed and sides and hence different values of silt factor for bed and side should have been used.
5. Lacey's equations do not include a concentration of silt as variable.
6. Lacey did not take into account the silt left in channel by water that is lost in absorption which is as much as 12 to 15% of the total discharge of channel.
7. The effect of silt accumulation was also ignored. The silt size does actually go on decreasing by the process attrition among the rolling silt particles dragged along the bed.
8. Lacey did not properly define the silt grade and silt charge.
9. Lacey introduced semi ellipse as ideal shape of a regime channel which is not correct.

5.2 RESERVOIR

5.2.1 INVESTIGATIONS FOR RESERVOIR:

Following are the investigations that are usually conducted for reservoir planning.

1. Engineering Investigations / Surveys
2. Geological Investigations
3. Hydrologic Investigations

Engineering investigations / surveys:

- Generally Engineering Surveys are conducted for the dam, the reservoir and their associated works. During this investigation topographic survey of the area is carried out and the contour plan is prepared. The horizontal control is usually provided by triangulation survey and vertical control by precise leveling.
- At the dam site, very accurate triangulation survey is conducted and a contour plan to a scale of 1:250 or 1:500 is generally prepared with contour intervals in the range of 1 to 2 m. Such a survey should cover an area at hart upto 200 m upstream 400 m downstream and for adequate width beyond the two abutments.
- For the reservoir, the contour plan is generally prepared to a scale of 1:15,000 with contour intervals between 2 to 3 m. The area elevation and storage elevation curves are prepared for different elevations upto an elevation of 3 to 5 m higher than the anticipated maximum water level.

Geological investigations:

Following are the reasons for carrying out the Geological investigations at a reservoir site:

- Suitability of foundation for the dam.
- Water tightness of the reservoir basis.
- Location of quarry sites for the construction.

Hydrological investigations:

Following purposes demand the hydrological investigations:

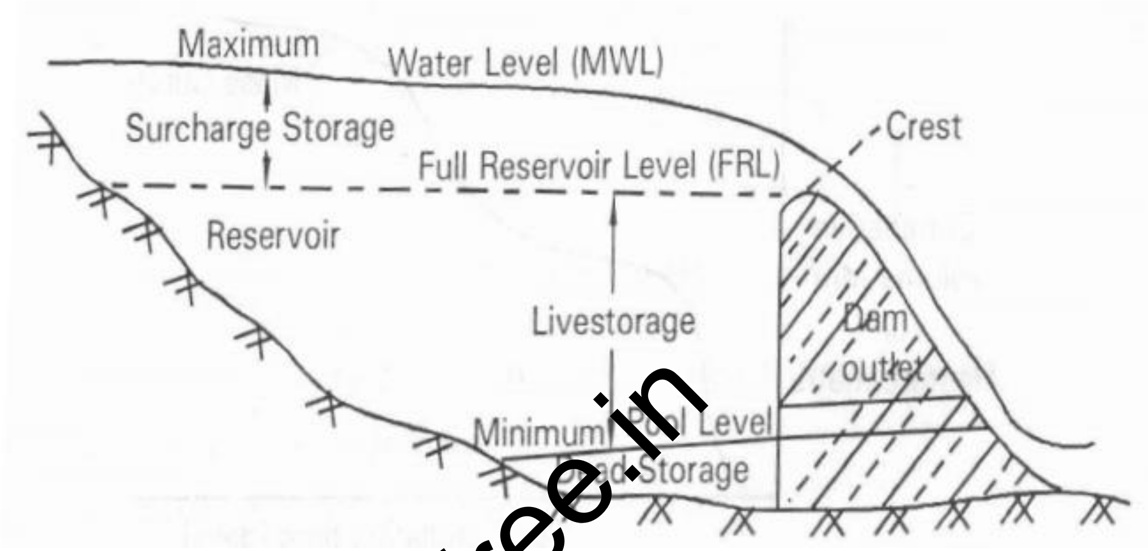
- To study the runoff pattern and to estimate yield.
- To determine the maximum discharge at the site.

5.2.2 SELECTION OF SITE FOR A RESERVOIR

A good site for a reservoir should have the following characteristics:

- Large storage capacity: The topography of the proposed site should be such that the reservoir has a large capacity for storing the water.
- Suitable site for the dam: A suitable site for the proposed dam should be available on the downstream side of the reservoir, with very good foundation; narrow opening in the valley to provide minimum length of the dam and also the cost of construction should be minimum.
- Water tightness of the reservoir: Geology at the proposed reservoir site should be such that the entire reservoir basin is water tight. They should have Granite, Gneiss, Schists, Slates, or Shales etc.
- Good hydrological conditions: The hydrological conditions of the river at the reservoir should give high yield. Evaporation, transpiration, and percolation losses should be minimum.
- Deep reservoir: The proposed site should be such that a deep reservoir is formed after the dam construction. The reason being evaporation losses would be minimum; in addition to low cost of land acquisition and less weed growth.
- Small Submerged area: At the proposed site, the submerged area should be minimum and should not affect the ecology of the area. Important places, monuments, roads, railway lines should not sub merge.
- Minimum silt inflow: The life of reservoir is defined by the quantity of silt inflow, which means that, if the silt inflow is large, the life would be less. Hence, it is necessary to select the reservoir site at such a place, where the silt inflow is minimum.
- No objectionable minerals: The proposed site should be free from soluble and objectionable salts, which may pollute the reservoir.
- Minimum acquisition and construction cost: The overall cost of the project should be minimum in terms of dam construction, land acquisition for reservoir, buildings, roads, railways etc.

5.2.3 STORAGE ZONES OF A RESERVOIR:



1. Live Storage or useful storage: Is that amount of water available or stored between the minimum pool level (LWL) and the full reservoir level (FRL). Minimum pool level or low water level is fixed after considering the minimum working head required for the efficient working of turbines.
2. Surcharge Storage: Is the volume of water stored above the full reservoir level (FRL) up to the maximum water level (MWL) In case of a multipurpose reservoir, useful storage or live storage is divided into A. Conservation storage B. Flood control storage
3. Dead storage: Is the volume of water held below the minimum pool level. This storage is not useful and hence cannot be used for any purpose under ordinary operating conditions.
4. Bank storage: Water stored in the banks of a river is known as bank storage. In most of the reservoirs the bank storage is small since the banks are generally impervious.
5. Valley storage: Is the volume of water held by the natural river channel in its valley upto the top of its banks before the construction of the reservoir. The valley storage depends upon the cross section of the river, the length of the river and its water level.

5.2.4 DETERMINATION OF STORAGE CAPACITY USING MASS CURVES

Mass Curve is a graphical representation of cumulative volume of water in the reservoir Vs cumulative time. It will be a continuously raising curve.

Fixing Capacity of a reservoir Capacity of a reservoir depends on the inflow and demand. It is a fact that if the available inflow is more than the demand, there is no necessity of any storage. On the other hand, if the inflow is less and demand is high a large reservoir capacity is required. Capacity for a reservoir can be determined by the following methods

(i) Mass curve or graphical method

(ii) Analytical method

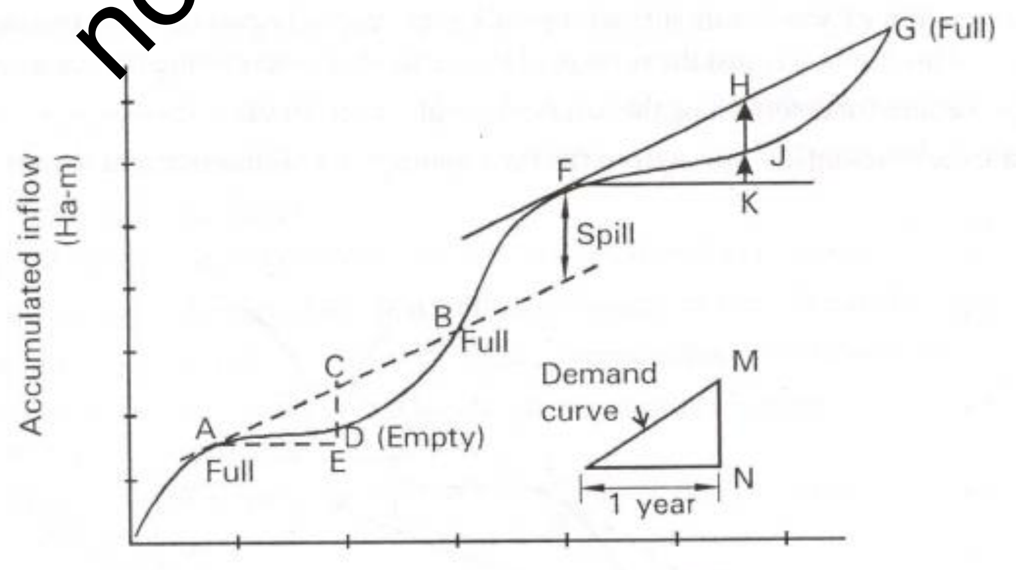
(iii) Flow duration curve method

Mass curve method or Graphical method

Storage required for uniform demand: In the case of uniform demand, the mass curve will be a straight line.

The procedure adopted will be as follows:

1. Prepare the mass inflow curve for the flow hydrograph of the site for a number of consecutive years including the most critical years (or the driest years) when the discharge is low, Fig shows the mass inflow curve.
2. Prepare the mass demand curve corresponding to the given rate of demand. If the rate of demand is constant, the mass demand curve is a straight line as shown in fig. 1.3. The scale selected for plotting of the mass inflow and mass demand curve should be the same.



3. Draw the lines AB, FG etc. such that they are parallel to the mass demand curve, and they are tangential to the peak points or crests at A, F etc. of the mass inflow curve points A, F, etc. indicate the beginning of dry periods marked by the depressions.
4. Determine the vertical intercepts CD, HJ etc. between the tangential lines and the mass inflow curve. These intercepts indicate the volumes by which the inflow volumes fall short of demand, which can be explained as follows:

- Assuming that the reservoir is full at point A, the inflow volume during the period AE is equal to ordinate DE and the demand is equal to ordinate CE. Thus the storage required is equal to the volume intercepted by the intercept CD.

5. Determine the largest of the vertical intercept determined in step (4). The largest vertical intercept represents the storage capacity required. Following import points have to be noted:

- The capacity obtained in the net storage capacity which must be available to meet the demand. The gross capacity of the reservoir will be more than the net storage capacity. It is obtained by adding the evaporation and seepage losses to the net storage capacity.
- The tangential lines AB, FG etc. when extended forward must interest the inflow curve. This is necessary for the reservoir to get filled again. If these lines do not intersect the mass curve, the reservoir would not fill again. Many times very large reservoirs may not get refilled every year.
- The vertical distance such as EL between the successive tangents represents the volume of water flowing over the spillway.

5.3 IMPORTANT QUESTIONS

- What are the considerations made during alignment of canals?
- Write a note on canal classification?
- Write a short note on:

  (a) Critical velocity ratio (b) Regime Channel
- Design and sketch a trapezoidal canal by Kennedy's theory for a discharge of 5 cumec. The channel is to be laid on a slope of 0.2m per kilometer. Assume: N = 0.025 and m=1.
- Determine the dimensions of the irrigation canal for the following data B/D ratio = 3.7, N = 0.0225, m = 1.0 and S = 1/4000 side slopes of the channel are 0.5H: 1V. Also determine the discharge which will be flowing in the channel.
- Design a irrigation channel in alluvial soil according to Lacey's silt theory for the following data:

  Full supply discharge = 10 cumec

  Lacey's silt factor = 0.9

  Side slopes of channel = 0.5H: 1V
- The slope of the channel in alluvium is 1/4000. Lacey's silt factor is 0.9 and side slopes are 0.5H: 1V. Find the channel section and maximum discharge which can be allowed to flow in it.

- Explain with neat sketch storage zones of reservoir.
- Explain the different investigations conducted before selecting a reservoir site.
- Explain the determination of storage capacity of reservoir by mass curves.

5.4 OUTCOMES

- Understand the concept of designing a canal and reservoir

5.5 FURTHER READING

- https://nptel.ac.in/courses/105105110
- https://nptel.ac.in/courses/105105110/29