

# HYDROLOGY, PERCIPITATION

## 1.1 INTRODUCTION:

Hydrology is the science that treats the waters of the earth, their occurrence, circulation and distribution, their chemical and physical properties and their reaction with the environment, including the relation to living things. The domain of hydrology embraces the full life history of water on the earth.

## 1.2 DEFINITIONS:

**1.2.1 Hydrology:** Hydrology is defined as science dealing with the occurrence, circulation, distribution and properties of the waters of the earth and its atmosphere.

(Or)

Hydrology is defined as Hydro (Water) + Logus (Science).

**1.2.2** Hydrology is further divided into:

**1.2.2.1 Scientific Hydrology:** deals with academic aspects.

**1.2.2.2 Engineering Hydrology:** deals with engineering applications as estimation of water resources, study of precipitation, runoff, evaporation and transpiration, study of problems such as floods and droughts.

**1.2.2.3 Climatology:** deals with the study of climate over given area within a specified period of time.

**1.2.2.4 Meteorology:** is branch of science dealing with the atmospheric phenomena.

## 1.3 IMPORTANCE OF HYDROLOGY:

### 1.3.1 Structural and Hydraulic Design:

- For any type of reservoir a **spillway** of sufficient capacity is most essential.
- The capacity of the spillway, its height, downstream protection works etc. depend on the correct assessment of flood flow and routing.

**Note:** Spillway means a channel that carries excess water over or around a dam or other obstruction.

### **1.3.2 Municipal and Industrial Water Supply:**

- Due to constant increase in the urban and industrial water demands greater efforts are being made by hydrologists to meet the demands.

### **1.3.3 Irrigation:**

- Irrigation demands are similar to municipal and industrial water supply but on a larger scale.
- Hydrology plays an important role, to evaluate new projects in areas where the margin of safety is already low or to discover new source of water and its applications.

### **1.3.4 Power:**

- Hydrological studies are most essential for the operation of an Hydel project.
- For the storage plant, low seasonal flows rather than low daily flows are important and the reservoir draw down studies is must to determine the relative economics of various heights of the dam and power generating capacities.

### **1.3.5 Flood Control:**

- Flood control project range from small improvements like channel straightening to large project involving huge budget.
- Hence, for the large projects statistical and probabilistic flood frequency analysis are necessary.
- These studies would yield fruitful results in proper flood controlling methods.

### **1.3.6 Navigation:**

- When the stream is running through non – alluvial soils hydrological studies are relatively simple as the analysis involves hydraulic computation.
- However streams carrying sediment pose much more complex problems.

### **1.3.7 Erosion Control:**

- Proper hydrological investigations are necessary in the operation and maintenance of a reservoir increasing the life of the reservoir by reducing the silt entering it.

### **1.3.8 Pollution Control:**

- With the increase in population, large scale industrialization, the streams and rivers are getting polluted and are posing more and more danger to the public health, water life etc.

- Hence a complete stream pollution control study including an investigation of stream, particularly the magnitude and duration of low flows are found to be more useful.

## 1.4 GLOBAL WATER DISTRIBUTION:

- The total water available on the earth is about  $140 \times 10^{16}$  meter<sup>3</sup>.
- Out of this 97% is contained in the oceans and sea as salt water, the remaining 3% is fresh water.
- Table from World Water Balance and Water Resources of the Earth, UNESCO, 1978.

Item	Area (10 <sup>6</sup> km <sup>2</sup> )	Volume (km <sup>3</sup> )	Percent of Total Water	Percent of Fresh Water
Oceans	361.3	1,338,000,000	96.5	-
Ground Water				
Fresh	134.8	10,530,000	0.76	30.1
Saline	134.8	12,870,000	0.93	-
Soil Moisture	82.0	16,500	0.0012	0.05
Polar Ice	16.0	24,023,500	1.7	68.6
Other Ice and Snow	0.3	340,600	0.025	1.0
Lakes				
Fresh	1.2	91,000	0.007	0.26
Saline	0.8	85,400	0.006	-
Marshes	2.7	11,470	0.0008	0.03
Rivers	148.8	2,120	0.0002	0.006
Biological Water	510.0	1,120	0.0001	0.003
Atmospheric Water	510.0	12,900	0.001	0.04
Total Water	510.0	1,385,984,610	100	-
Fresh Water	148.8	35,029,210	2.5	100

## 1.5 WATER RESOURCES OF INDIA:

- It is a fact that Asia's Water Supply is the lowest with an average annual runoff of only 17 cm.
- However India is well placed with  $16.83 \times 10^{11}$  meter<sup>3</sup> running off a total area of 369 million hectares, yielding an overall runoff 457 mm, almost same as the richest continent which gets 450 mm.
- But, the water supply in India is not well distributed as can be seen from table.
- Table shows the Surface water potential of India.
- Table gives the run off data of the Indian Rivers.

No.	River Basins	Water Potential million Cubic meters
1	West Flowing Rivers (Rivers of Kerala, Tamil Nadu, Tapi Basin and Narmada Basin and the basins above Narmada)	305471.3
2	East Flowing Rivers (Kaveri Basin, Mahanadi Ganga, Godavari, Krishna, Pennar and between Kaveri and Pennar)	355599.9
3	Indus Basin	79473.1
4	Ganga Basin (Chambal, Yamuna, Ramganga, Gomti, Ghagra and Main Ganga Basins)	550082.7
5	Brahmaputra and Barak Basins	590713.6
Total		1881340.6

No.	Region	Catchment area 1000 km <sup>2</sup>	Annual Runoff cm
1	Rivers falling into Arabian Sea (except the Indus system)	481	63
2	Indus Basin in India	354	22
3	Rivers falling into Bay of Bengal (except Ganga and Brahmaputra)	1210	34
4	Ganga System	978	50
5	Brahmaputra System	506	75

It may be interesting to note that out of the  $16.83 \times 10^{11}$  meter<sup>3</sup> of water, only 20% is utilised at present, giving considerable scope for further development of water resources.

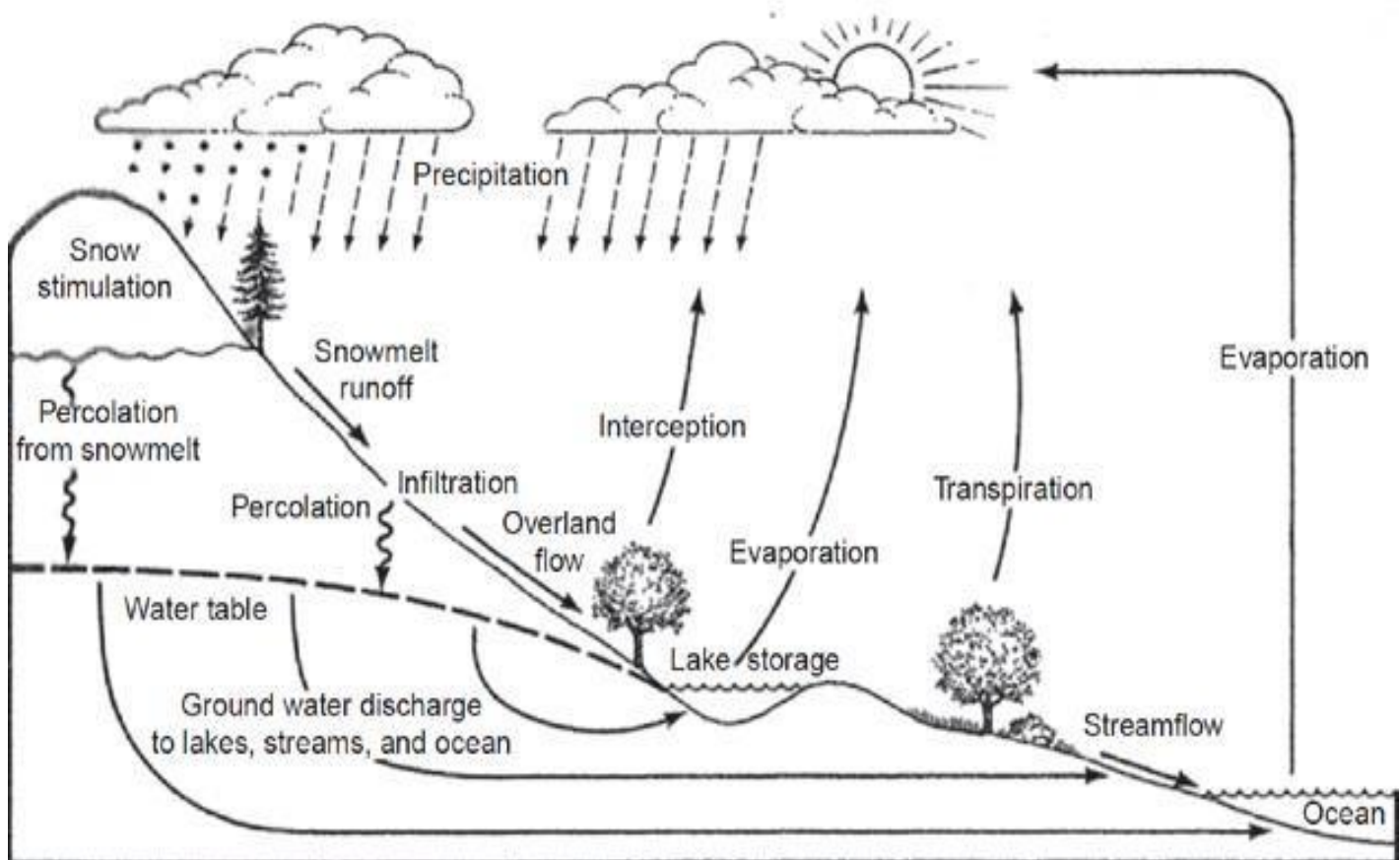
## 1.6 WATER RESOURCES OF INDIA:

Success of any water resources development project depends on timely and sufficient availability of water. Hence proper assessment of this natural resource assumes great importance. Therefore, Hydrological investigation from the first step in any water resources development scheme involving design construction and operation of hydraulic structures is of importance. An engineer is supposed to have an idea of the practical applications of Hydrology. The applications of hydrology are:

- Hydrology is used to estimate the probable maximum flood at a proposed site of dam, bridge etc.

- The variation of water production from a catchment can be calculated and described by hydrology.
- Engineering hydrology helps in determining the relation between a catchment surface water and ground water resources.
- The expected flood flows over a spillway at a highway culvert, or in an urban storm drainage system can be known through hydrology.
- Hydrology helps us to know the required reservoir capacity in order to assure adequate water for irrigation or municipal water supply in drought conditions.
- Hydrology helps in the design of river training works.
- Dependable yields from the stream for generation of hydroelectric power can be calculated.
- Water supply to township and sewerage schemes can be properly designed.
- Water resources account of a river basin can be prepared.
- Operation of reservoirs can be done in an efficient manner.

## 1.7 HYDROLOGIC CYCLE:



- The natural sequence through which water passes into the atmosphere as water vapour, precipitates to earth in liquid or solid form and ultimately return to the atmosphere through evaporation.

(Or)

- The sequence of condition through which water passes from vapor in the atmosphere through precipitation upon land or water surfaces and ultimately back into the atmosphere as a result of evaporation and transpiration.

The hydrologic cycle consists of following processes:

**1.7.1 Evaporation and Transpiration:** due to Sun's radiation the water from the surface of Seas, Oceans, Rivers and Lakes get evaporated. Whereas the **transpiration** is the process of water getting lost from the plants/vegetation.

**1.7.2 Precipitation:** it can be defined as the fall of moisture from the atmosphere to the earth's surface in any form either liquid or solid.

**1.7.3 Runoff:** it is the portion of precipitation which makes way towards the sea or ocean either as surface or subsurface water. Surface runoff is the water flowing over land.

**1.7.4 Interflow or Sub-surface Runoff:** is the portion of precipitation in filtering into the surface soil and depending upon the geology of the place runs as sub-surface runoff and hence joins the streams and rivers.

**1.7.5 Ground Water Flow or Base Flow:** is the portion of precipitation which after infiltration, percolates down and joins the ground water reservoir that ultimately connects the sea or ocean. Hence, the hydrologic cycle can be mathematically expressed as:

$$P = R + E + S$$

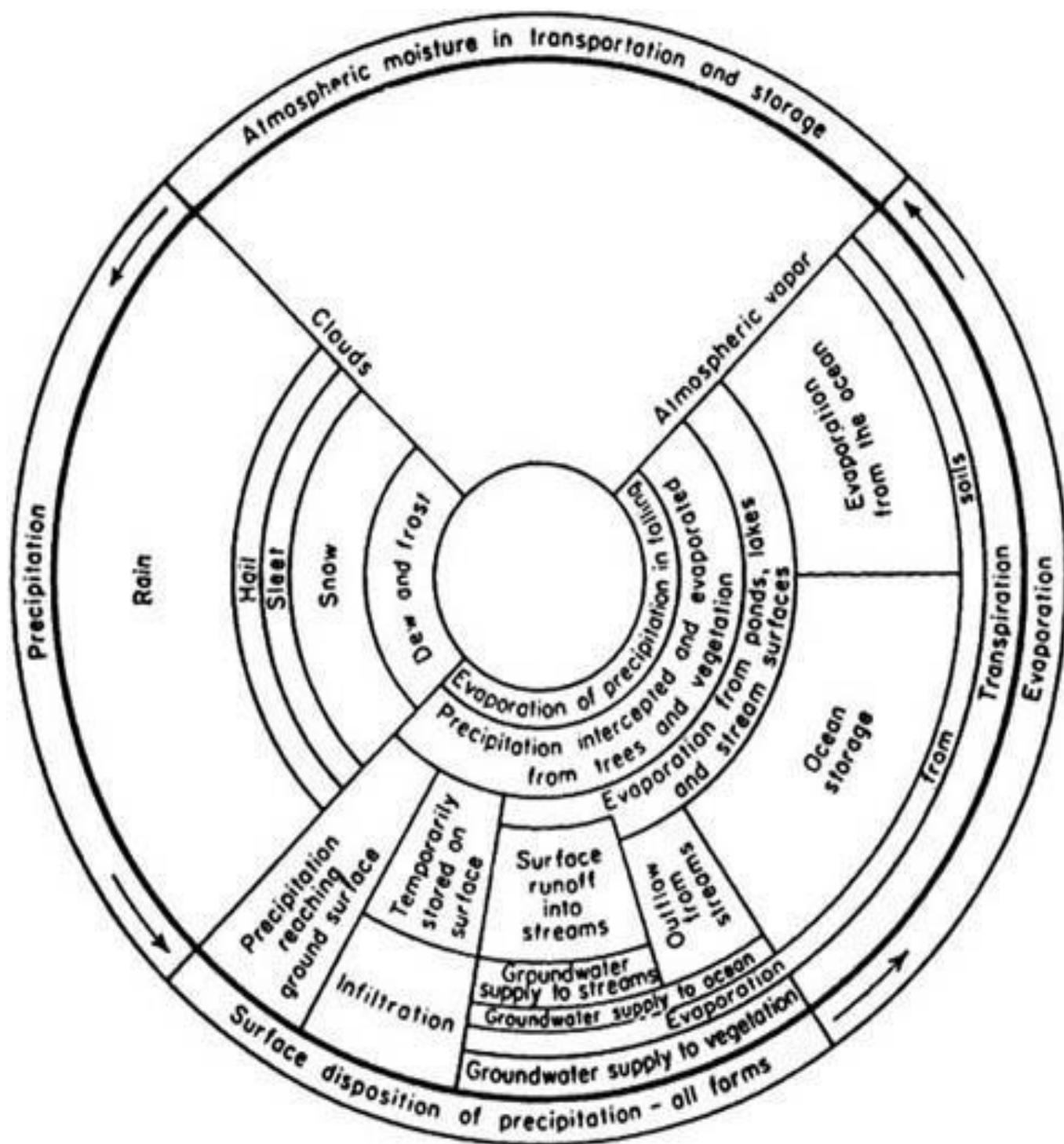
Where,

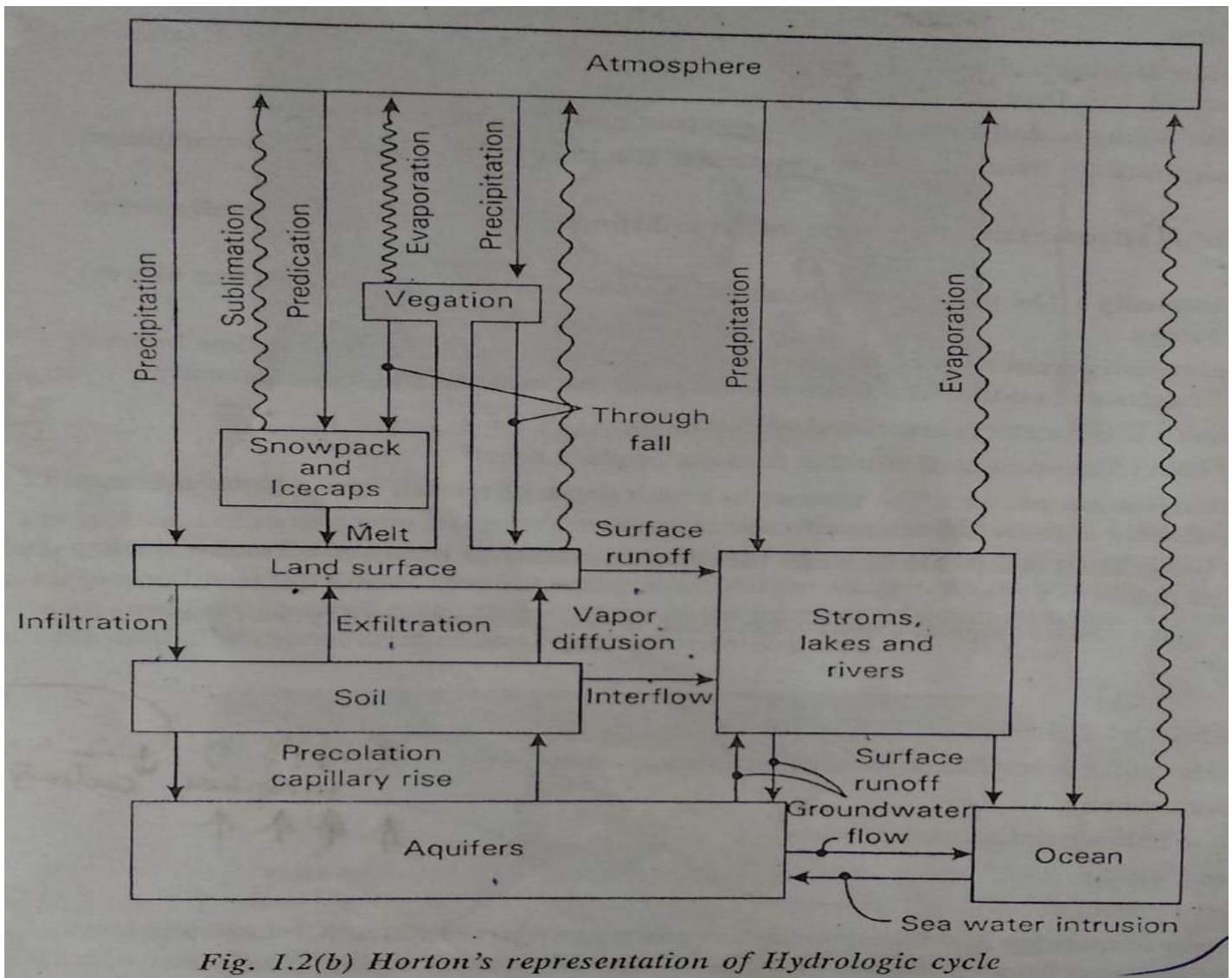
P = Precipitation

R = Surface and Sub-surface runoff

E = Total evaporation

S = Surface and Subsurface storage of water





*Fig. 1.2(b) Horton's representation of Hydrologic cycle*

## 1.8 PRECIPITATION:

### 1.8.1 Introduction:

Precipitation is any form of solid or liquid water that falls from the atmosphere to the earth's surface. In India, **rain** is the most common of precipitation. Formation of precipitation requires lifting of air mass so that it cools and condenses.

### 1.8.2 Definitions:

**1.8.2.1 Precipitation:** it denotes all forms of water that reach the earth from the atmosphere. Examples are rainfall, snow fall, frost and dew.

**1.8.2.2 Rain:** water falling in drops condensed from vapor in the atmosphere is rain.



**1.8.2.3 Point Precipitation:** precipitation at a particular site in contrast to the mean precipitation over the area.

**1.8.2.4 Point Rainfall:** it is the rainfall at single station to distinguish it from average rainfall over an area.

**1.8.2.5 Rainfall Intensity:** the rate at which rainfall occurs expressed in depths units per unit time.

**1.8.2.6 Rainfall Intensity Frequency or Rainfall Recurrence Interval:** the average time interval between the occurrence of rainfall of a given intensity and that an equal or greater intensity.

**1.8.2.7 Rain Storm:** it is the storm associated with rainfall.

**1.8.2.8 Priming Rain:** the amount of rain that does not produce runoff.

**1.8.2.9 Storm Distribution Patter:** the manner in which depth of rainfall varies from station to station throughout the area for a given storm.

**1.8.2.10 Snow:** precipitation composed of white ice crystals, chiefly in hexagonal forms and often becoming snowflakes.

**1.8.2.11 Storm:** it is a meteorological disturbance which is either unusual or of greater magnitude, rate or intensity.

## **1.9 FORMATION OF PRECIPITATION:**

The condition for precipitation to take place may be follows:

- Supply of moisture
- Cooling to below point of condensation
- Condensation
- Growth of particles

The supply of moisture is obtained through evaporation from wet surfaces, transpiration from vegetation or transport from elsewhere. The cooling of moist air may be through contact with a cold earth surface causing dew, mist or fog and loss of heat through long wave radiation. However, much more important is the lifting of air masses under adiabatic conditions causing a fall of temperature to near its dew point.

## 1.10 FORMS OF PRECIPITATION:

The various forms of precipitation are:

**1.10.1 Drizzle:** these are water drops which are less than 0.5 mm in diameter and the intensity less than 1 mm per hour.

**1.10.2 Rain:** these are water drops which are more than 0.5 mm and less than 6 mm in diameter.

Light rain – up to 2.5mm/h.

Moderate rain – 2.5 to 7.5mm/h.

Heavy rain – more than 7.5mm/h.

**1.10.3 Glaze:** it is the ice coating formed when drizzle or rain freezes as it comes in contact with cold objects on the ground.

**1.10.4 Sleet:** it is the frozen rain drop cooled to the ice stage while falling through the air at subfreezing temperature.

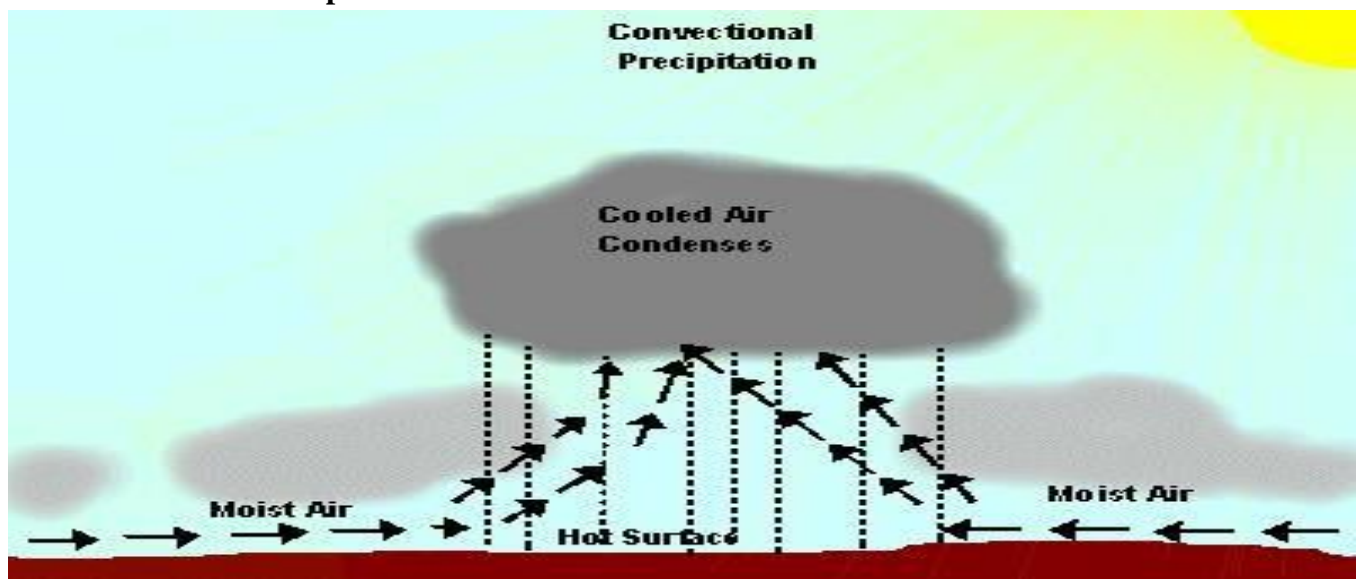
**1.10.5 Snow:** it is the precipitation in the form of ice crystals, when the water vapor directly becomes ice.

**1.10.6 Snow Flake:** ice crystals fused together represent snow flake.

**1.10.7 Hail:** it is the precipitation in the form of ice balls or lumps of ice whose diameter is more than 5mm. These are formed by alternate freezing and melting process.

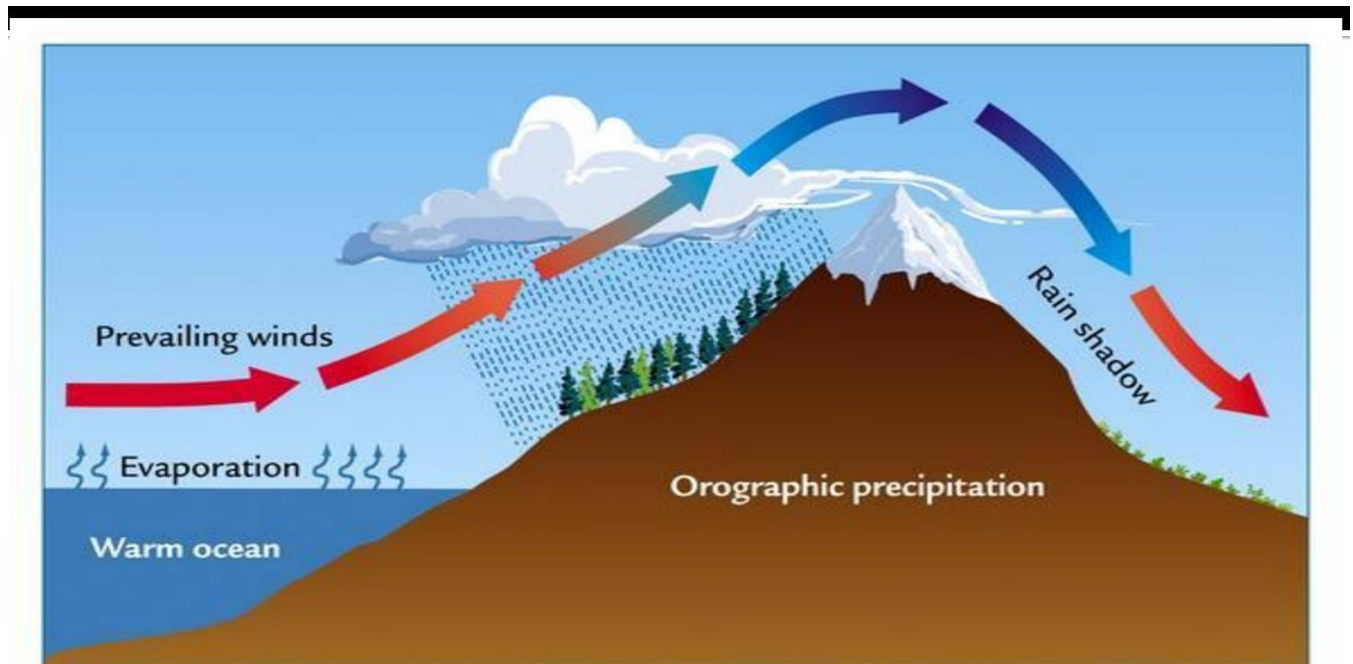
## 1.11 TYPES OF PRECIPITATION:

### 1.11.1 Convective Precipitation:



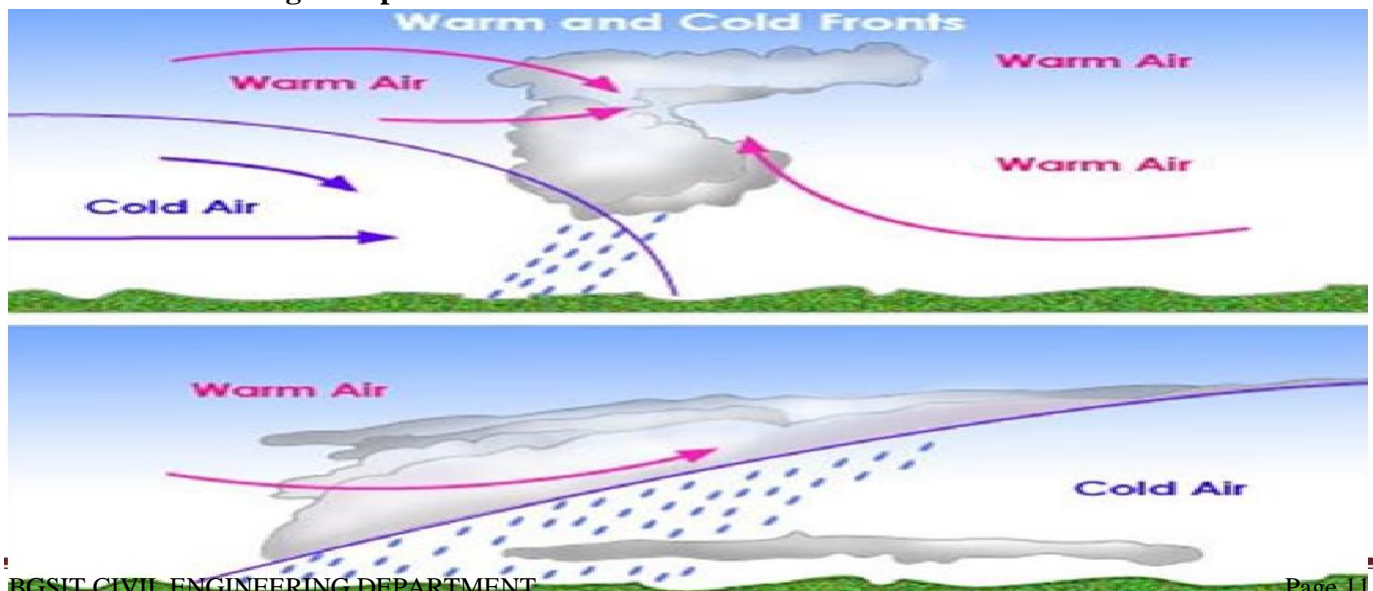
- This is caused by the rising of warmer, lighter air in colder denser surroundings.
- The difference in temperature results in unequal heating cooling at the top of the air layer or mechanical lifting when the air is forced to pass over denser, colder air mass or over mountain barrier.

### 1.11.2 Orographic Precipitation:



- The moist air masses get lifted to higher altitudes and hence undergo cooling condensation and finally precipitation occurs.
- Thus in mountain range, the windward slopes tend to have heavy precipitation when compared to the backward slopes.

### 1.11.3 Frontal Lifting Precipitation:



- The existence of an area with low pressure causes surrounding air to move into the depression, displacing low pressure air upwards, which may then be cooled to dew point.
- If cold is replaced by warm air the frontal zone is usually large and the rainfall of low intensity and long duration.
- A cold front shows a much steeper slope of the interface of warm and cold air usually resulting in rainfall of shorter duration and higher intensity.

#### **1.11.4 Cyclonic Precipitation:**

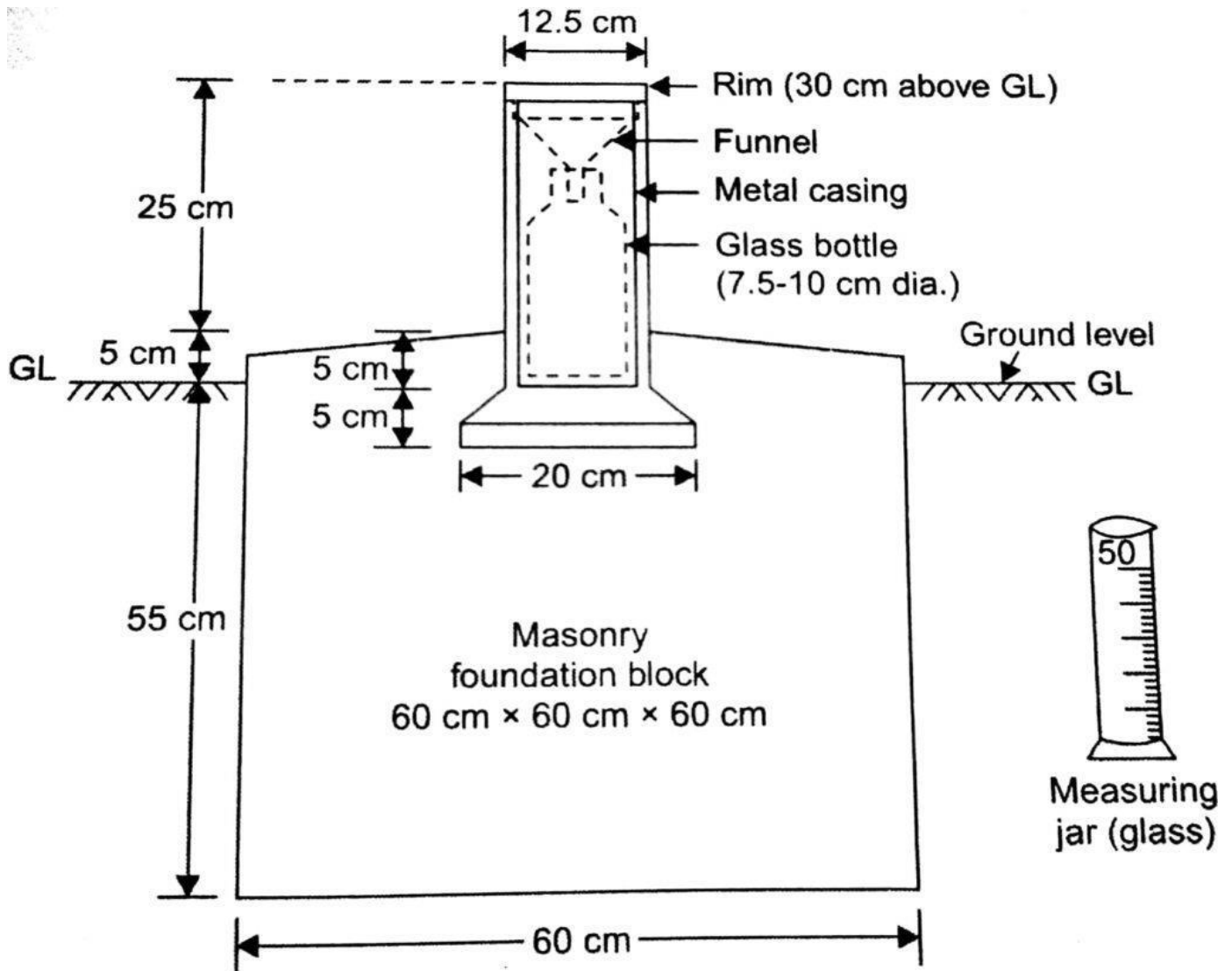
- These are active depression, which gain energy while moving over warm ocean water and which dissipate energy while moving over land or cold water.
- They may cause rains and heavy storms.
- Typical characteristics of these tropical depression are high intensity rainfall of long duration (several days).
- Notorious tropical depression occur in the Caribbean.
- The Bay of Bengal (monsoon depression), The Far East (Typhoons), Southern Africa (Cyclones) and an island of the pacific (cyclones, willi – willies).
- This group of depressions is quite different in character from other lifting mechanism.
- Data on extreme rainfall originating from cyclones should be treated separately from other rainfall data, as they belong to a different statistical population.

#### **1.11.5 Convergence:**

- The Inter – Tropical Convergence Zone (ITCZ) is the tropical region where the air masses originating from the Tropics of Cancer and Capricorn converge and left.
- In the tropics, the position of the ITCZ governs the occurrence of wet and dry seasons.
- This convergence zone moves with seasons.
- In July, the ITCZ lies to the North of the equator and in January it lies to the South.
- In the tropics the position of the ITCZ determines the main rain bringing mechanism which is also called monsoon.
- Hence, the ITCZ is also called as the monsoon Trough, particularly in Asia.
- In certain places near to the equator, such as on the coast of Nigeria, the ITCZ passes two times per year, causing two wet seasons near the tropics of Capricorn and Cancer, however, there is generally only one dry season and one wet season.

## 1.12 MEASUREMENT OF PRECIPITATION:

### 1.12.1 Non-Recording Type of Raingauge:



- The non-recording raingauge that is extensively used in India is the SYMON's raingauge.
- It is essentially consists of a receiving funnel 127 mm in diameter, this funnel discharges the rainfall into a collecting vessel.
- The funnel and the receiver are housed in a metallic container as shown in figure.
- The so collected rainfall is accurately measured with the help of a carefully calibrated measuring jar.
- Generally, the rainfall is measured every day at 8.30 hours.
- However during heavy rains, it must be measured daily thrice or four times.
- Symons raingauge gives the total rainfall but not the intensity.

- It is very much essential to protect the gauge from being damaged by cattle or human beings and hence a fence is erected around it.

Following points are too satisfied while selecting the raingauge station.

- The site is true representative of the area for which the station is to give rainfall.
- The site is an open place.
- The site is a level ground.
- In hilly areas, the site should be selected that the gauge is protected from strong winds.
- The site is free from obstructions such as tall buildings, trees, if unavoidable the distance between the site and obstruction must be minimum twice the height of obstruction.

### 1.12.2 Recording Gauges:

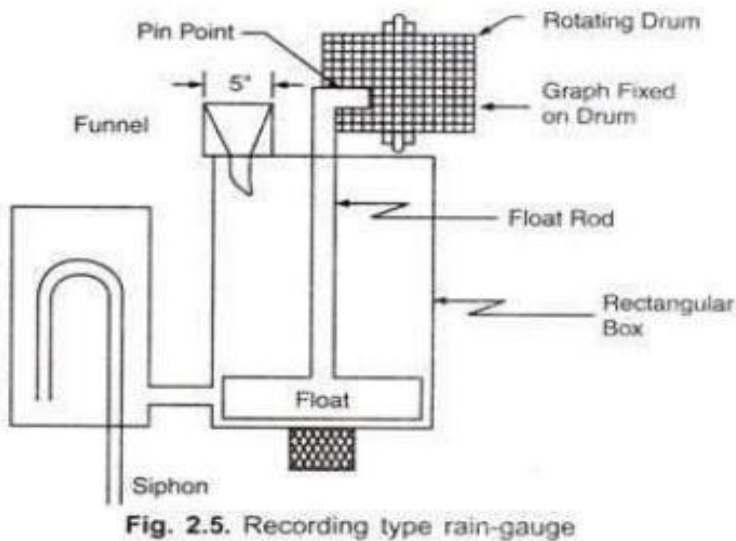


Fig. 2.5. Recording type rain-gauge



- Are devices or instruments used for measuring the rainfall at a place.
- Such type of gauges can give continuous record of rainfall with respect to time and hence provide valuable data of intensity and duration of the rainfall for hydrological analysis of storms.

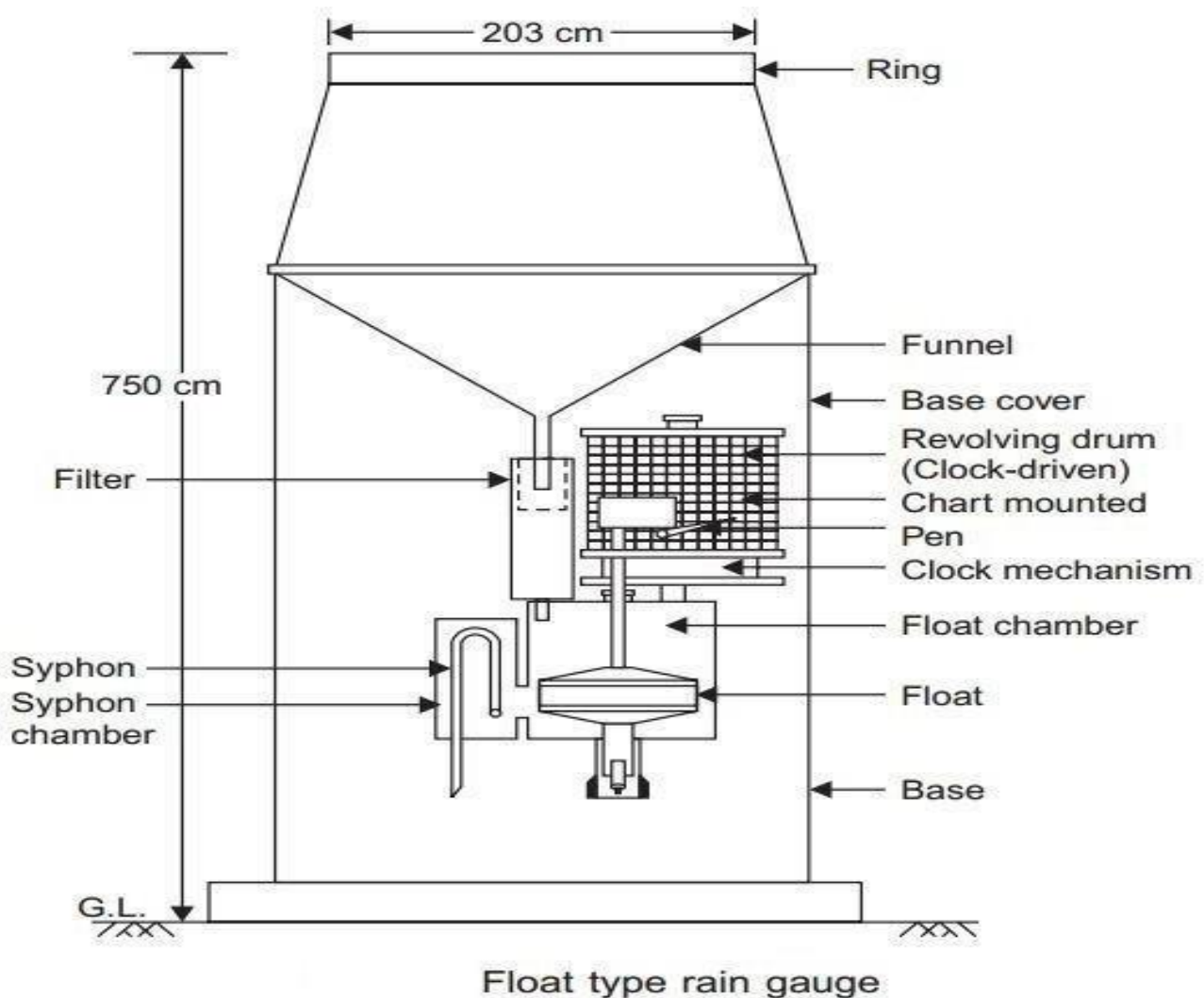
### 1.12.2.1 Advantages:

- No attendant is required to operate the recording gauge.
- Such a raingauge can be installed in remote and hilly areas.
- Human error can be eliminated by adopting such a gauge.
- Capacity of such a gauge is generally more than the non-recording gauge.
- It can be operated for longer durations without much attention.

### 1.12.2.2 Disadvantages:

- Initial cost is high compared to the non-recording gauge.
- Since the number of moving components are more, the recording process may be disturbed due to mechanical faults or any other mechanism.

### 1.12.3 Syphon Type Raingauge:



- It is also known as a float type of raingauge.
- It consists of a 127mm dia funnel, provided on one side of the top of rectangular float chamber, as shown in figure.
- As the water level rises in the chamber, the float also rises.
- The movement is thus transmitted on a pen arm moving on a revolving chart held on a clock driven drum.
- The pen arm plots the mass curve of the rainfall.
- As soon as the chamber fills, syphon comes into picture bringing back the float to its original lowest position.

### **1.13 RAINGAUGE DENSITY:**

- Means the number of raingauges that are to be installed in a given area, so that better and accurate results are possible.
- In India, on an average one raingauge is installed for every 500km<sup>2</sup> where as one station is installed for every 100km<sup>2</sup> in other developed countries.

The optimum number of raingauge stations that are necessary to gauge the average rainfall within a reasonable limit of error can be determined as follows:

- Calculate the total rainfall (R) over the given area as  $R = P_1 + P_2 + \dots + P_n$  where, n is the number of stations, P is the rainfall recorded at each station.
- Calculate the average rainfall (x) as,  $x = (R / n)$ .
- Calculate the standard deviation  $S_x^2 = \{\Sigma (x_i - x)^2 / (n - 1)\}$ .
- Calculate  $C_v = (S_x / x) * 100$ .
- Calculate N for the given P,  $N = (C_v / P)^2$ .
- Number of additional gauges = (N – m).

### **1.14 AVERAGE RAINFALL OVER A CATCHMENT:**

- Raingauges represent only point sampling of the areal distribution of a storm, but hydrological analysis requires a knowledge of the rainfall over the catchment area.
- Hence the point rainfall values are converted into an average value or an equivalent uniform depths of the following methods.



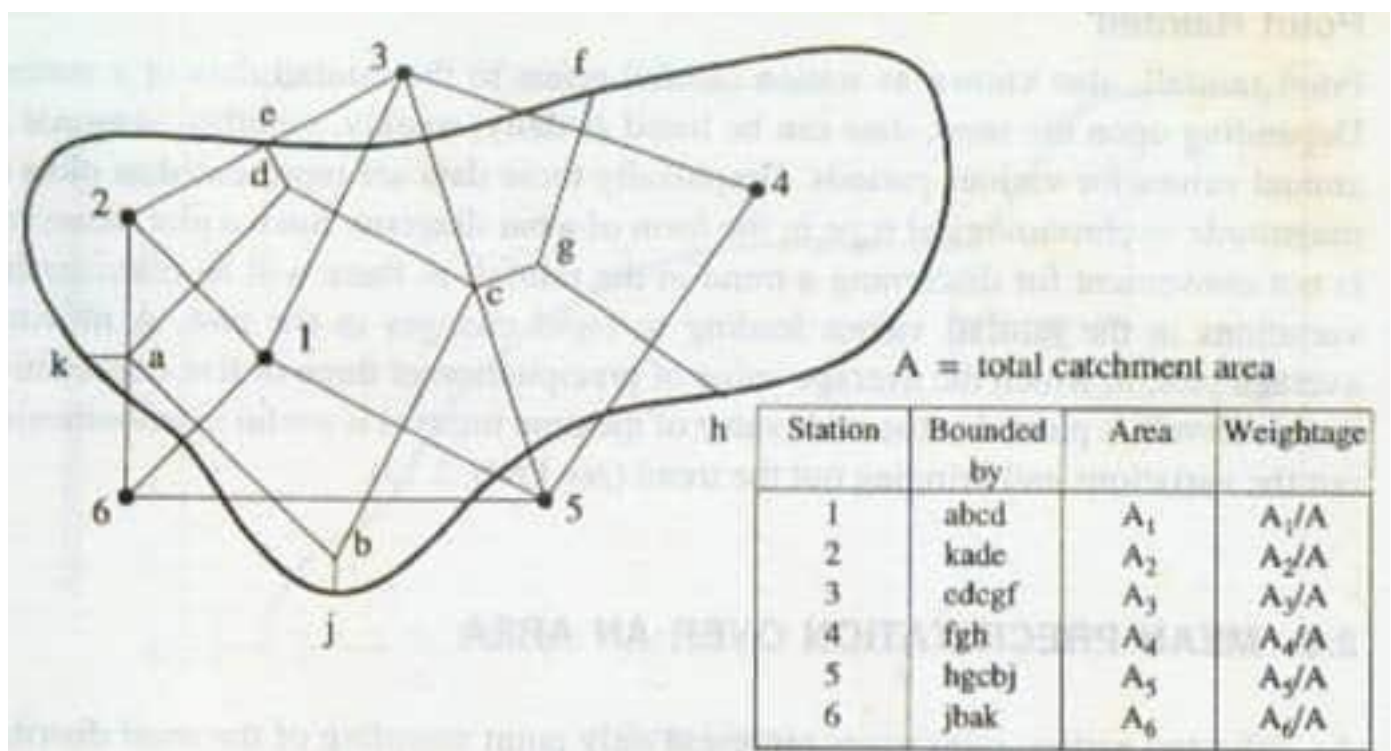
### 1.14.1 Arithmetic Average Method:

- Let  $P_1, P_2, \dots, P_n$  be the point rainfalls recorded during a particular storm by the  $n$  gauges.
- The average precipitation over the area can be calculated as:

$$P_{av} = \{\Sigma P / n\}$$

- This method is adopted to flat terrains where the gauges are uniformly distributed and the rainfall at different stations do not vary widely from the average value.
- In practice, this is not commonly used.

### 1.14.2 Thiessen's Polygon Method:



- It is also known as the weighted mean method.
- Here the rainfall recorded at each station is given a weightage on the basis of an area closet to the station.

The procedure is as follows:

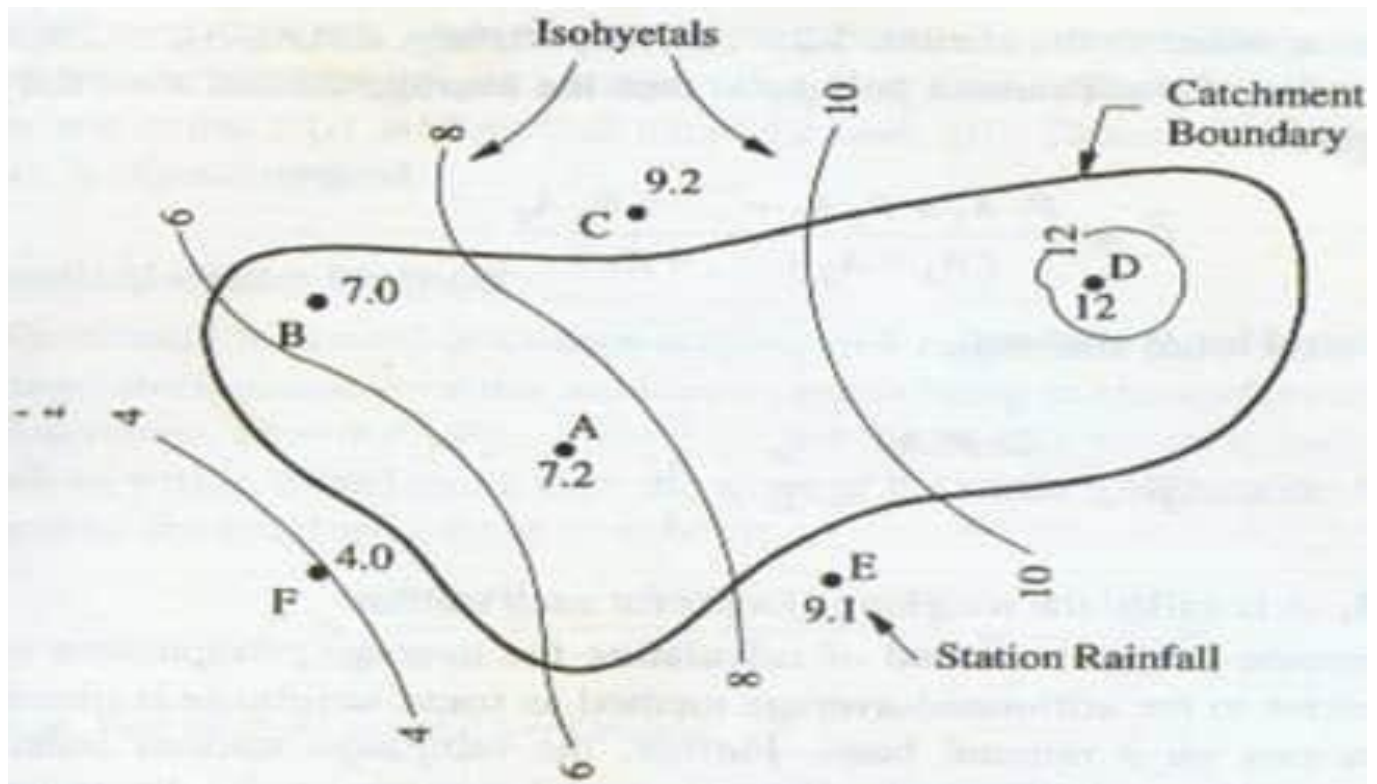
- Locate the positions of the rain gauge stations A, B, C, D and E on the catchment map as shown.
- Join each adjacent station by a straight line as shown in figure.
- To each of these lines drop perpendicular bisector so that they form polygons representing areas  $A_1, A_2, \dots$  involving each of the stations A, B,  $\dots$  as shown in figure.
- Let  $P_1, P_2, \dots$  be the point rainfall at stations A, B,  $\dots$

- The average rainfall over the catchment is given by the equation.

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

- This is a better method when compared with the arithmetic average method.
- It is suitable for areas which are plain and of intermediate size of the order of 750 to 3000km<sup>2</sup> and also where the number of raingauge stations are few compared to the size.

### 1.14.3 Isohyetal Method:



- An isohyetal is a line joining of equal rainfall.
- It is better when compared to the previous two methods.
- This method permits the use and interpolation of other nearby gauges and makes corrections accordingly.

The procedure as follows:

- The catchment area is drawn to a scale and the rain gauge stations marked on it.
- The lines of equal rainfall (isohytes) are drawn on the map, considering the orographic effect on the rainfall.
- The area between the two adjacent isohytes is measured using a planimeter.
- In case, the isohytes go out of the catchment boundary line is used as the boundary line.
- The average rainfall over the catchment is calculated from the relation.

$$P_{av} = [ \{ A_1 * (P_1 + P_2)/2 + \dots\dots A_{n-1} * (P_{n-1} + P_n)/2 \} / A_1 + A_2 + \dots\dots\dots + A_n ]$$

## 1.15 ADJUSTMENT OF MISSING RAINFALL:

### 1.15.1 Normal Ratio Method:

- This method is applicable if the normal annual rainfall at the missing station X is within 10% of the adjoining three stations A, B and C.
- In this method the rainfall values at three stations are weighted by the ratio of the normal annual rainfall value N.

$$P_x = 1/3 * \{(N_x/N_A)P_A + (N_x/N_B)P_B + (N_x/N_C)P_C\}$$

- In case there are M number of reference stations, then

$$P_x = (N_x/M) * \{(P_A/N_A) + (P_B/N_B) + \dots + (P_m/N_m)\}$$

### 1.15.2 Adjustment of Rainfall Data by Double Mass Curve Method:

- A double mass curve is a graphical representation of the accumulated annual rainfall at a given station X, (plotted on Y-axis) whose consistency has to be checked, versus the average of the accumulated annual rainfall of a number of reference stations (plotted on X-axis).
- This technique is based on the fact that when each recorded data comes from the same parent population, they are consistent.
- Generally a graph of 5 to 10 base stations surrounding the station whose data is to be checked are taken as reference.
- The data of the annual or mean monthly rainfall of the station X and also the average rainfall of the number of reference stations is arranged in the reverse chronological order.
- The accumulated precipitation of the station X (i.e.  $\Sigma P_x$ ) and the accumulated values of the average group of the base stations (i.e.  $\Sigma P_v$ ) are calculated starting from the latest record.
- The values of  $\Sigma P_x$  are plotted on Y-axis along with the corresponding values of  $\Sigma P_v$  on X-axis as shown in figure.
- A discontinuity in the slope of the straight line indicates the deviation of data at station X.
- The so deviated values at the station X can be calculated from the relation.

$$P_{cx} = P_x * (S_c / S_a)$$

Where

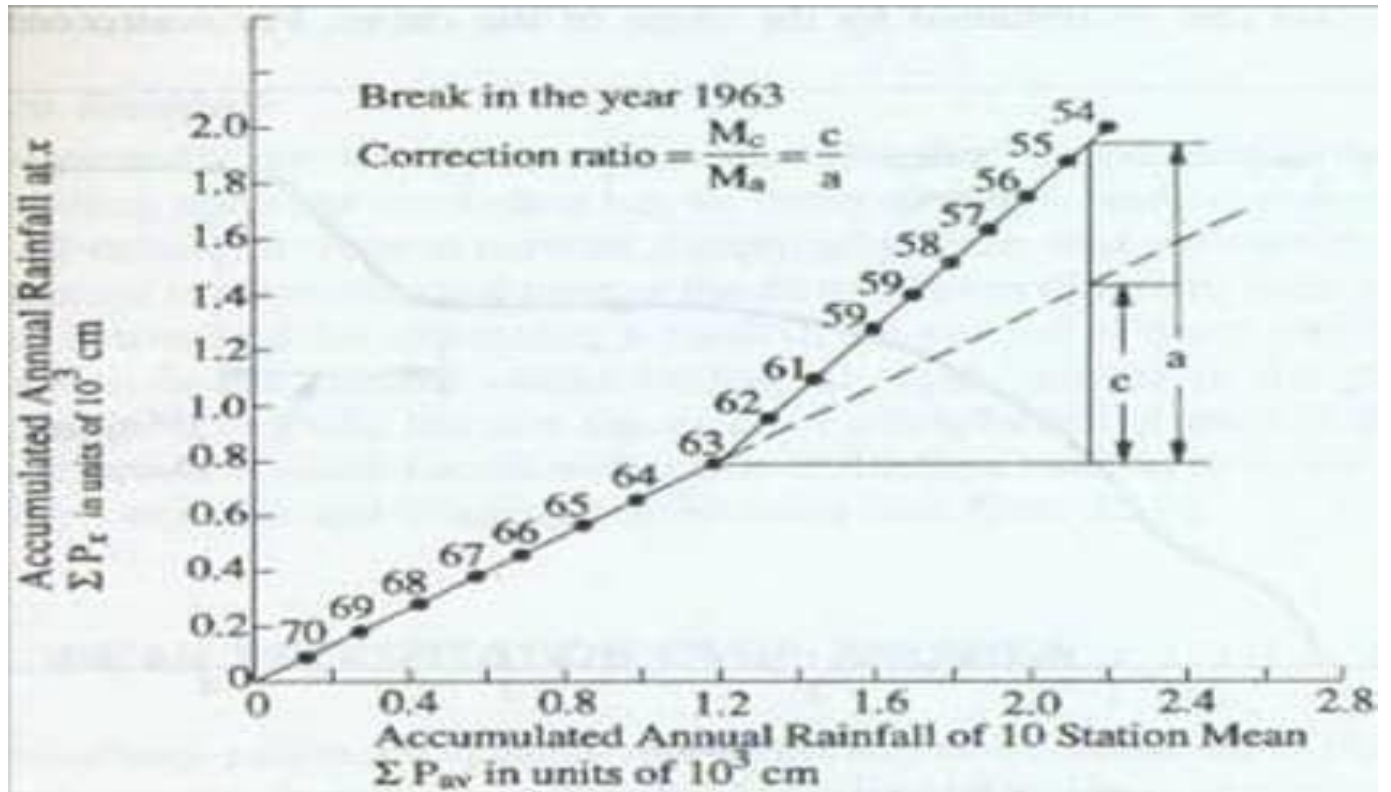
$P_{cx}$  = corrected precipitation at any period  $t_1$  at station X.

$P_x$  = original recorded precipitation at time  $t_1$  at station X.

$S_c$  = corrected slope of the double mass curve.

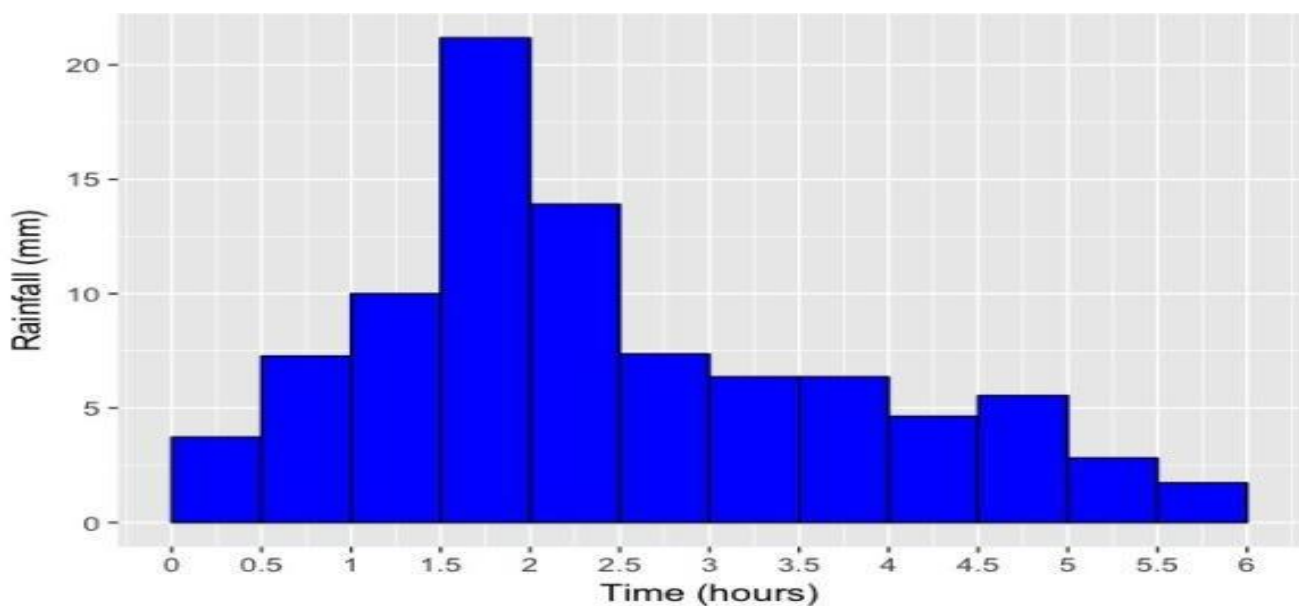
$S_a$  = original slope of the mass curve.

The double mass curve is also helpful in checking arithmetical errors in transferring the rainfall data from one record to another.



## 1.16 PRESENTATION OF PRECIPITATION DATA:

### 1.16.1 Hyetograph:



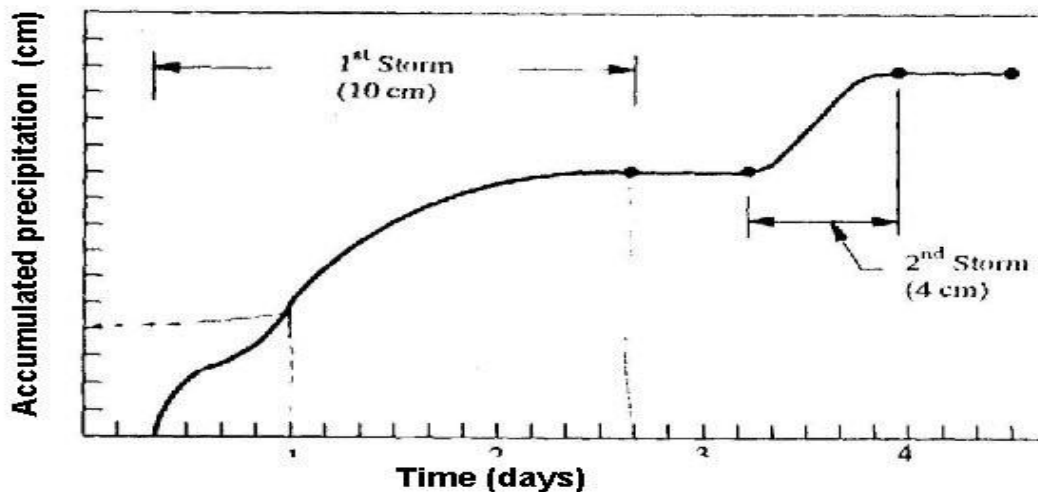
- An hyetograph is a graphical representation in the form of a bar chart of the intensity of rain with respect to time as shown in figure.
- It is the most convenient of representing the characteristics of a storm and is particularly important in the calculation of extreme floods.
- The area under the hyetograph gives the total precipitation during a particular period of time.

#### 1.16.2 Mass Curve:

- Mass curve is a graph showing the cumulative depth of rainfall against time.
- An automatic or recording raingauge records the rainfall in the form of a mass curve.
- Figure represents a typical mass curve of rainfall.
- The instantaneous slope of the mass curve gives the rainfall intensity.
- It is obvious that if the slope of mass curve is zero, the intensity of rainfall is zero.

## PRESENTATION OF RAINFALL DATA

### Mass Curve of Rainfall



### 1.16.3 Moving Average Curve:

- The moving average curve smoothens out the extreme variations and indicate the trend or cyclic pattern, if any more clearly and is known as moving mean curve the moving average curve is constructed with a moving period of  $m$  year where  $m$  is considered as 3 or 5 years.
- Let  $X_1, X_2, \dots, X_n$  be the sequence of given rainfall in the chronological order.
- Let  $Y_i$  denote the ordinate of the moving average for the  $i$  year.
- Then for  $m=3$ ,  $Y_i$  is computed as:

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

$$Y_3 = (X_2 + X_4 + X_5 / 3)$$

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

- It is clear that the calculated value of  $Y$  corresponds in time to the middle value of  $X$  values being average and therefore is convenient to use odd values of  $m$ .
- A moving average of  $m$  applied to a sequence of  $n$  values yields a sequence of  $(n - 2K)$  values, where  $k = (m - 1) / 2$  for any general  $m$ , the  $Y$  terms can be expressed as

$$Y_i = (1/m) \{ \sum_{j=i-k}^{i+k} X_j \} \text{ for } i = k + 1, k + 2, \dots, (n - k)$$

- Although it is possible to use moving average with any  $m$ , it is necessary that  $m$  be small compared to  $n$ .
- Generally no persistent regular cycles can be expected in the annual rainfall data.

# **LOSSES: EVAPORATION, EVAPO – TRANSPIRATION, INFILTRATION**

## **2.1 EVAPORATION:**

### **2.1.1 Introduction:**

**Evaporation** is the process by which surface water transfer into vapor state, which diffuses into the atmosphere. The water molecules both in the air and in the water are in rapid motion. Evaporation occurs when the number of moving molecules that break from the water surface escape into the air as vapor. Evaporation, which may occur from water surfaces, wet leaf surfaces or from water on the soil particles, is important in water management and conservation. Evaporation of water from reservoirs, rivers and agricultural fields results in major losses of critical water resources, especially in arid reasons. In arid regions, evaporation can account for as much as 25 to 30% of the total consumptive use of surface water.

### **2.1.2 Evaporation Process:**

- When external thermal energy is supplied to the water surface, the kinetic energy of the water molecules increases.
- When the water molecules at the surface reach sufficient kinetic energy they escape from the water body overcoming the intermolecular forces and eject themselves into the atmosphere.
- When external thermal energy is not made available, heat energy is removed from the water body during the process of evaporation and hence lowering the water temperature.
- Therefore, evaporation is indirectly a process of cooling.
- The partial pressure or vapor pressure is the differential value of atmosphere pressure and the vapor molecule pressure.
- Continued supply of heat energy causes accumulation of more and more vapor molecules and a stage may come when the gaseous medium can no longer accommodate any more and rejects the vapor molecules in the form of condensation at the same rate of vaporization, this represents the saturation of air.
- At saturation, the partial pressure exerted by the water vapor is termed as saturation vapor pressure  $e_s$ .
- As saturation vapor pressure increases with increase in temperature.

- Equilibrium is said to occur when the vapor pressure of air above the surface of water is already equal to the saturation vapor pressure  $e_s$ .
- Hence it is clear that for evaporation to occur it is necessary to have:
- Supply of water
- Source of heat energy
- Vapor pressure depict a difference between the saturated vapor pressure of water  $e_s$  and the actual vapor pressure of air above the free surface  $e_a$ .
- According to Dalton vapor pressure  $E$  can be expressed as

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

$C$  = a coefficient which accounts for other factors which effect evaporation.

**2.1.3 Definition:** it is the process under which a portion of water near its surface is changed from liquid state to a gaseous state below the boiling point through the transfer of heat energy.

## **2.2 FACTORS AFFECTING EVAPORATION:**

**2.2.1 Vapor Pressure Difference:** evaporation depends upon the difference between saturated vapor pressure of the air at the temperature of water and of dew point.

**2.2.2 Temperature of Air and Water:** the rate of evaporation increases with the increase in temperature of water.

**2.2.3 Relative Humidity:** evaporation is inversely proportional to humidity.

**2.2.4 Atmospheric Pressure and Altitude:** evaporation decreases with increase in atmosphere pressure. At higher altitudes the atmosphere pressure decreases thereby increasing the rate of evaporation.

**2.2.5 Wind Velocity:** when the wind velocity is more, the rate of evaporation will be more.

**2.2.6 Water Depth:** has nothing to do with the surface evaporation, however evaporation will be more from shallow water depths.

**2.2.7 Water Surface Area:** rate of evaporation is directly proportional to water surface area, longer the area more is the evaporation and vice versa.

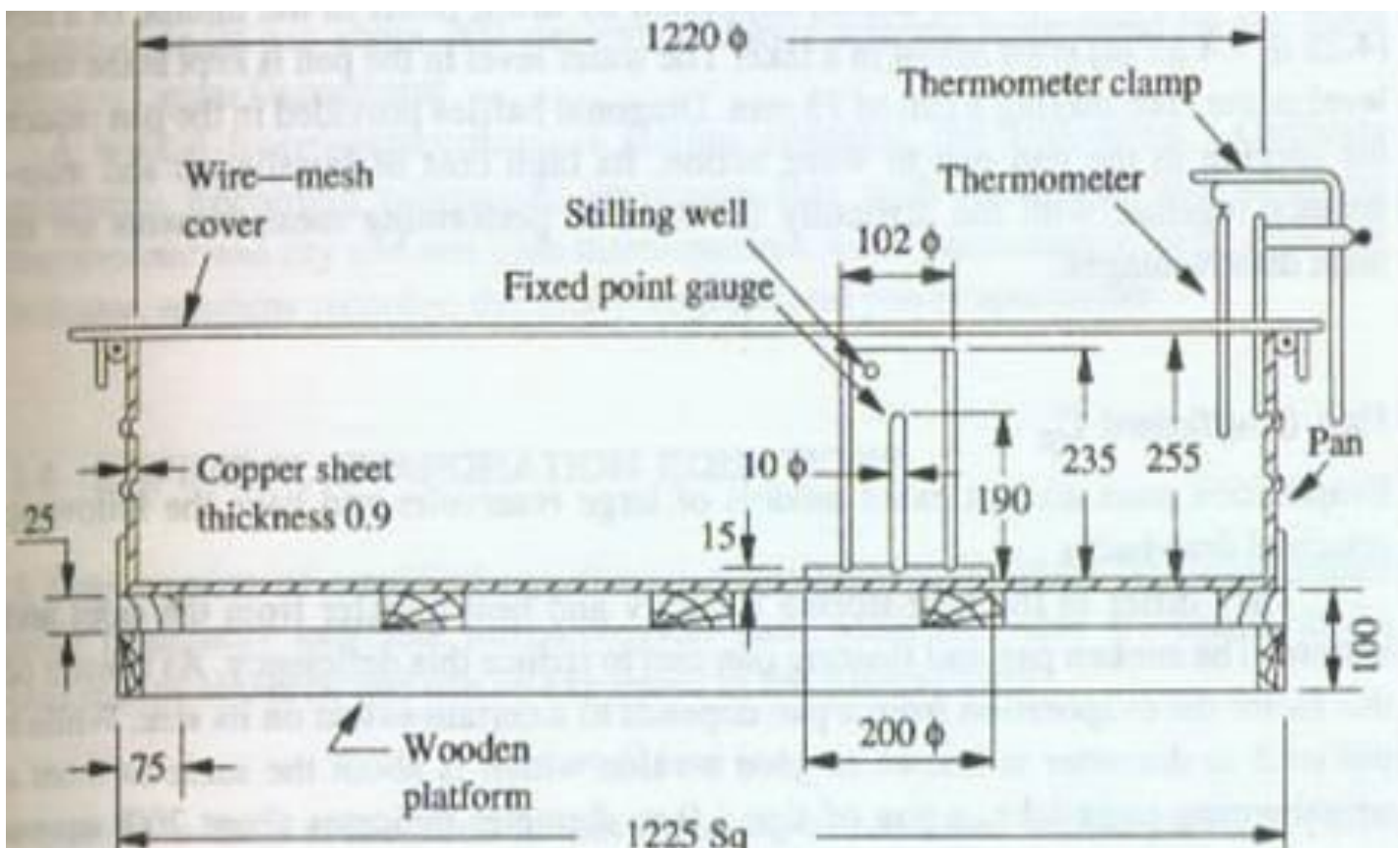
**2.2.8 Water Quality:** turbidity of water decreases the rate of evaporation.



**2.2.9 Meteorological Factors:** the rate of evaporation is influenced by solar radiation, latitude, season, time of the day and sky conditions.

### 2.3 MEASUREMENT OF EVAPORATION:

- The class A pan as suggested by IS 5973 – 1970, 1220mm diameter and 255mm in depth.
- This pan is made of 0.9mm thick copper sheet, tinned inside and painted white outside as shown in figure.
- A point gauge is used to measure the depths of water.
- A calibrated cylindrical measuring jar is used to add or remove water maintaining the level in the pan to a fixed mark.
- The top of the pan is covered with a galvanized iron net to protect the water from birds and animals and also this mesh makes the water temperature more uniform during day and night.
- The evaporation from this pan is found to be about 14% less, compared to that from the unscreened pan.
- The entire pan is mounted on a square wooden platform of 225mm width and 100mm height to enable circulation of air underneath the pan.





## **2.4 ESTIMATION OF LAKE EVAPORATION:**

Evaporation from water surfaces can be estimated using the following methods:

### **2.4.1 Storage Equation or Water Budget Method:**

$$I - O = \Delta S$$

(or)

$$I - O = (dS / dt)$$

Where

I = Inflow

O = Outflow

$\Delta S$  = Change in storage

#### **2.4.2 Energy Budget Method:**

- It involves the application of the law of conservation of energy.
- The energy available for evaporation is determined knowing the incoming energy, outgoing energy and energy stored in the water body over a known interval of time.
- Value of E, the evaporation in cm can be calculated from the equation:

$$E = \frac{Q_s - Q_r - Q_b + Q_v - Q_\Phi}{\rho H_v (1+R)}$$

Where

$\rho$  = density of water

$H_v$  = latent heat of evaporation

R = bowen ratio = {heat lost by conduction / heat lost by evaporation}

$Q_s$  = sun and sky radiation incident at the water surface

$Q_r$  = reflected radiation

$Q_b$  = net energy lost by the water body through exchange of long wave radiation

$Q_v$  = net energy advected into the water body

$Q_\Phi$  = increase in the energy stored in the water body

#### **2.4.3 Mass Transfer Method:**

- This method is based on the theories of turbulent mass transfer in boundary layer to calculate the mass water vapour transfer from the surface to the surrounding atmosphere.

#### 2.4.4 Meyer's Equation:

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

Where

E = evaporation in mm/month

$e_s$  = saturation vapour pressure in mm of mercury corresponding to mean monthly temperature of air

$e_a$  = actual vapour pressure in air based on mean monthly temperature and relative humidity

V = monthly mean wind velocity in km/hr at 10m above ground

C = 15 small shallow ponds

#### 2.4.5 Rohwer's Equation:

$$E = 0.771 (1.465 - 0.000732 P_a) (0.44 + 0.07334 V) (e_s - e_a)$$

Where

E = evaporation in mm/day

$P_a$  = mean barometric reading in mm of mercury and  $e_s$ ,  $e_a$  and V have the same meaning as mentioned in Meyer's Equation

### 2.5 REDUCTION OF EVAPORATION:

Following are some of the recommended measures to reduce evaporation from water surfaces:

- The reservoir should be of larger depth and lesser surface area.
- By growing tall trees on the windward side of the reservoir, wind velocity can be reduced and hence the evaporation loss can be reduced.
- By allowing flow of water, temperature can be reduced and in turn evaporation can be reduced.
- By removing the water loving weeds and plants from the periphery of the reservoir, evaporation can be reduced.
- By spreading certain chemicals a film is formed on the water surface and thereby it is suited for small and medium reservoirs, also when the velocity is small.
- By straightening the streams, channels, the exposed area of the water surface is reduced and hence evaporation can be reduced.

- By covering the reservoir surface with polythene sheets, evaporation can be reduced. But this method is suited for small reservoir.
- By developing underground reservoir, evaporation can be reduced.

## **2.6 RESERVOIR EVAPORATION:**

- Very large quantities of water is generally lost from a storage reservoir due to evaporation and such a loss depends upon various factors like: water surface area, water depth, humidity, wind velocity, temperature, atmospheric pressure and quality of water.
- The evaporation loss from a reservoir can be effectively estimated by measuring the standard pan evaporation and multiplying it by the pan coefficient.
- The evaporation losses become very significant particularly in a hot and humid country like India.
- Therefore, realistic estimation of this loss is very essential.
- Evaporation loss can vary from place to place and season to season.
- On the basis of review conducted on 130 reservoir the central water commission (CWC) in 1990 has estimated the average annual evaporation loss around 225 cm.

## **2.7 EVAPO – TRANSPIRATION:**

**2.7.1 Definition:** is a combination of the words evaporation and transpiration. It refers to the process of water (moisture) moving from the soil and the plant and entering the earth's atmosphere.

## **2.8 FACTORS AFFECTING EVAPO – TRANSPIRATION:**

- Usually the factors which govern the evaporation and transpiration are found to govern evapo – transpiration process.
- But it is important to note the difference between potential evapo – transpiration (PET) and actual evapo – transpiration (AET).
- PET is essentially controlled by the meteorological factors, whereas AET is considerably affected by plant and soil.

In general:

- PET tends to increase as the temperature, sunshine and wind speed increases and decreases in humidity.
- There is a close relationship between solar radiation and evapo – transpiration.
- Type of plant will influence the evapo – transpiration i.e., a light coloured plant would reflect away more radiation than a dark coloured surface.

- Orientation of row crops would also influence the evapo – transpiration for the reason that interception of solar energy is a function of orientation.
- Presence or absence of crops in the surrounding lands may also influence evapo – transpiration.
- Evapo – transpiration tends to be more when air masses pass over a cooler cropped and irrigated field when compared to that coming from a bare ground.
- AET is influenced by the soil and plant factors also.
- AET is found to be a function of density of vegetation cover.
- Evapo – transpiration reduces with reduction in density of vegetation cover.
- AET varies with stages of plant growth or development.

## **2.9 MEASUREMENT OF EVAPO – TRANSPIRATION:**

- Usually evapo – transpiration is measured with the help of LYSIMETER or Evapo – transpirometer.
- It is usually a circular tank of about 60 to 90 cm in diameter and 180 cm deep.
- It required larger diameters up to 3m and depth 3m are being used.
- The lysimeter is filled with soil with the crop under study in it.
- The entire meter is buried with its top in flush with the surrounding ground surface.
- The sides of the meter would be impervious but the bottom being pervious.
- The upper surface is watered of known volume and the water passing out of the tank bottom is measured by volumetric or gravimetric method.
- The soil moisture is measured by moisture sampling.
- Evapo – transpiration is then determined from the measurement of amount of water added outflow at the tank bottom and changes in the soil moisture.
- It is advisable that the meter is guarded at least by four hectares around it.

### **2.9.1 Limitation of Lysimeter:**

- Differences may exist between the lysimeter and natural conditions of soil profiles, soil moisture region, plane rooting characteristics, methods of water application, water table, temperature and the net energy exchange.

## 2.10 ESTIMATION OF EVAPO – TRANSPIRATION:

### 2.10.1 Penman's Method:

- It is an equation obtained with a strong theoretical back ground involving the combination of energy – balance and mass transfer approach.
- The daily potential evapo – transpiration in mm/day (PET) is given by the equation.

$$PET = \frac{AH_n + E_a \gamma}{A + \gamma}$$

Where

A = slope of the saturation vapor pressure versus temperature curve at the mean air temperature in mm of mercury per degree centigrade

H<sub>n</sub> = net radiation in mm of evaporable water per day

E<sub>a</sub> = parameter including wind velocity and saturation deficit

γ = psychrometric constant = 0.49 mm of mercury/°C

### 2.10.2 Blaney Criddle Method:

- This is very common method adopted for the estimation of the consumptive use, it is given by

$$C_u = \frac{K_p}{40} (1.8t + 32) \text{ in MKS system}$$

Where

C<sub>u</sub> = monthly consumptive use in cm

K = crop factor, determined by experiments for each crop

t = mean monthly temperature

P = monthly percent of annual day light hours that occur during the period

- The above formula involves the use of crop factor K, the value of which is to be determined for each crop and different places.
- At present, this information is not available in India.

- Also, this formula does not consider many important factor such as humidity, wind velocity, elevation etc. on which consumptive use is dependent.

## **2.11 METHODS OF REDUCING THE EVAPO – TRANSPIRATION:**

Evapo – transpiration can be reduced in the following ways:

- Soil surface should be laid with protective mulches.
- Weeds must be removed from the cropped lands.
- Shallow rooted plants should be grown on deep soil instead of deep rooted plants.

## **2.12 INFILTRATION:**

**2.12.1 Introduction:** We have observed from hydrologic cycle, infiltration is one of the ways through which the rainwater reaching the earth's surface is disposed of. Infiltration is the only source for groundwater replenishment and thus forms an important part of the hydrological cycle.

**2.12.2 Definition:** is defined as the process by which water enters the soil through pores or interstices or in other words it is the movement of water through the soil surface.

## **2.13 FACTORS AFFECTING INFILTRATION:**

**2.13.1 Soil Porosity:** infiltration increases with increase in porosity.

**2.13.2 Freezing of Soil:** when the soil is frozen infiltration reduces.

**2.13.3 In wash of Fine Material:** fine material forms a relatively impervious layer, thereby infiltration reduces.

**2.13.4 Initial Moisture Content:** initially when the soil is dry, infiltration will be high, but reduces as the water content in the soil increases.

**2.13.5 Microstructure of the Soil:** when the soil has more openings due to various reasons, infiltration would be more.

**2.13.6 Compaction due to Men and Animals:** higher the compaction, lesser will be infiltration.

**2.13.7 Vegetal Cover:** vegetation greatly promotes infiltration.

**2.13.8 Compaction due to Rain:** when soil compacted due to rain, infiltration reduces.



**2.13.9 Drop Size and Rainfall Intensity:** when soil is compacted due to rain, infiltration reduces.

**2.13.10 Temperature:** high temperature and less viscosity results in higher infiltration capacity.

**2.13.11 Season:** seasonal variation in infiltration is influenced by temperature, evaporation, vegetation etc.

**2.13.12 Land Slope:** Land slope is observed to have little effect on infiltration rate.

## **2.14 MEASUREMENT OF INFILTRATION:**

The various methods for determining infiltration are:

- Infiltrometer
- Observation in pits and ponds
- Placing a catch basin below a laboratory sample
- Artificial rain simulators
- Hydrograph analysis

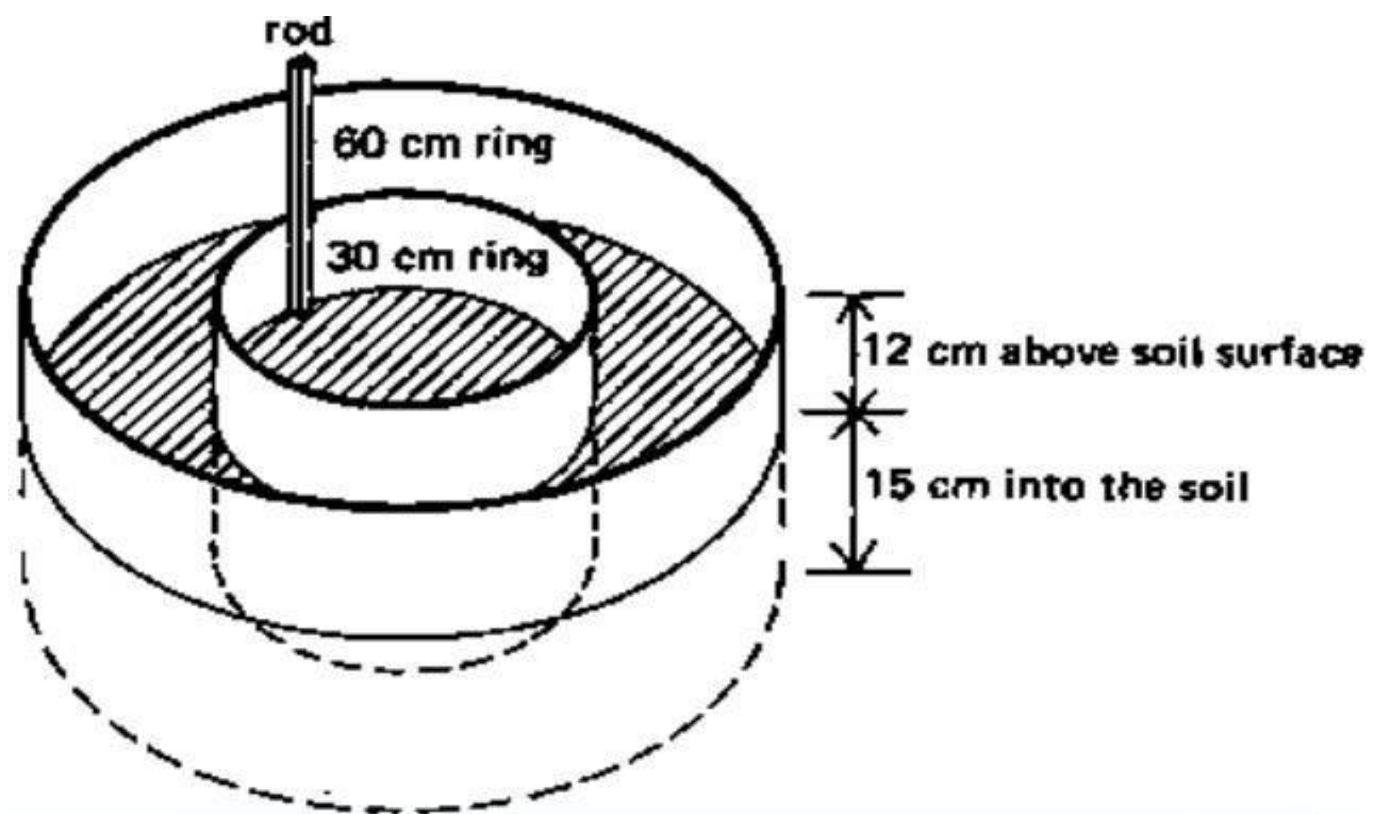
In general

- Infiltrometer are of two types; Double ring infiltrometer and Tube infiltrometer.
- In the second method, infiltration can be determined by noting the water levels in the pits and ponds and deducting the loss due to evaporation.
- In the third method, a catch basin (Lysimeter) is placed under a laboratory sample or at some depth below the land surface, the infiltration water can be measured.
- In the fourth method, on a small area of 0.1 to 50 square meter water is applied by artificial shower at a uniform rate. The resulting surface measured, from which the infiltration capacity of the soil can be determined.
- In the hydrograph analysis method, by knowing accurately the varying intensities of rainfall during a storm and the continuous record of the resulting runoff, the infiltration capacity can be determined.

### **2.14.1 Double Ring Infiltrometer:**

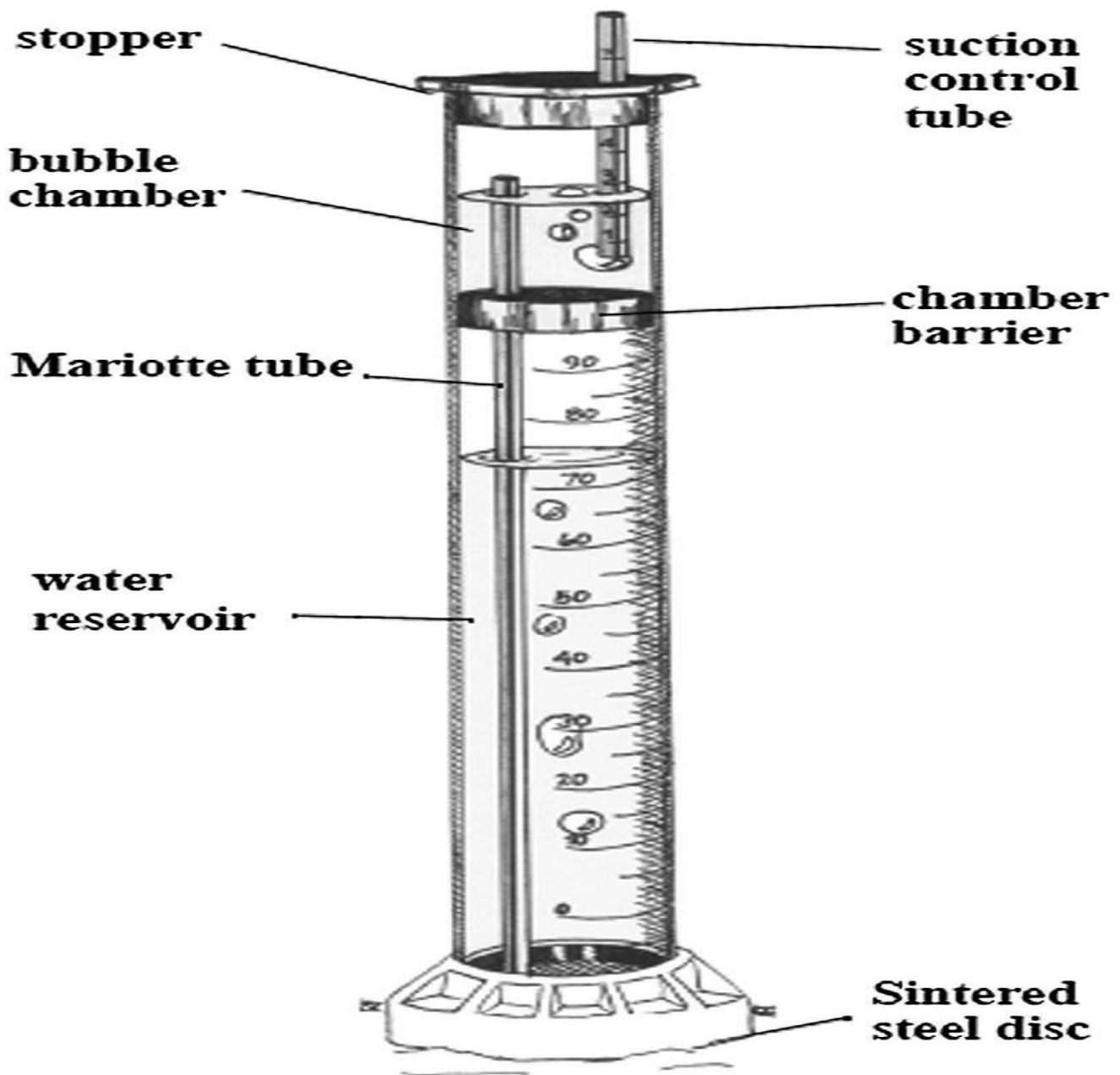
- A double ring infiltrometer will be shown in figure.
- It essentially consists of two hollow concentric metallic rings, driven into the soil uniformly to a depth of about 15cm.
- Once it is driven, soil adjacent to it is tamped.

- Point gauges for recording the water levels are fixed in the center of the rings and in the annular space between the two rings.
- Water is poured into the rings to maintain the desired depth and the level maintained constant by adding water at regular intervals of time.
- A graph of infiltration rate cm/hour versus time is plotted so as to facilitate the determination of the infiltration rate.
- The outer ring to some extent eliminates the edge effect of the surrounding drier soil and to prevent the water within the inner space from spreading over a larger area after penetrating below the bottom of the ring.



#### 2.14.2 Tube Infiltrometer:

- It consists of a single tube of about 25cm in diameter and 45 to 60cm long as shown in figure.
- It is driven into the ground at least to a depth up to which the water percolates during the experiment and thus no lateral spreading can occur.
- The rate at which water is required to be added to maintain constant water depth in the tube determines the infiltration capacity.



## 2.15 INFILTRATION INDICES:

**2.15.1 Supra – Rain:** the rainfall in excess of a particular value of  $\Phi$  index for the entire pattern of storm rainfall is known as supra – rain.

**2.15.2  $\Phi$  Index:** is the average rainfall above which the rainfall volume is equal to the runoff volume.

$$\Phi \text{ Index} = (\text{Basin recharge} / \text{Duration of rainfall})$$

**2.15.3 W Index:** it is defined as the difference of  $\Phi$  index with the initial losses.

$$W \text{ Index} = (\Phi \text{ Index} - \text{Losses})$$

$$\text{W Index} = \frac{P - R - I}{t}$$

Where

P = total precipitation in cm

R = total runoff in cm

I = initial losses

t = duration of rainfall excess (hours) i.e., the time in which the rainfall intensity is greater than initial capacity

W Index = average rate of infiltration cm/hour

## 2.16 HORTON'S EQUATION FOR FINDING THE INFILTRATION RATE:

- Figure shows the typical variation of the infiltration capacity for a soil.
- It is clear from the figure that the infiltration capacity for a particular soil decreases with increases in time, from the start of the rainfall; it decreases with the degree of saturation and depends upon the type of soil.
- Horton expressed the decay of the infiltration capacity with time as:

$$f = f_c + (f_o - f_c) e^{-Kt}$$

Where

$f_o$  = initial rate of infiltration capacity,

$f_c$  = final constant rate of infiltration at saturation,

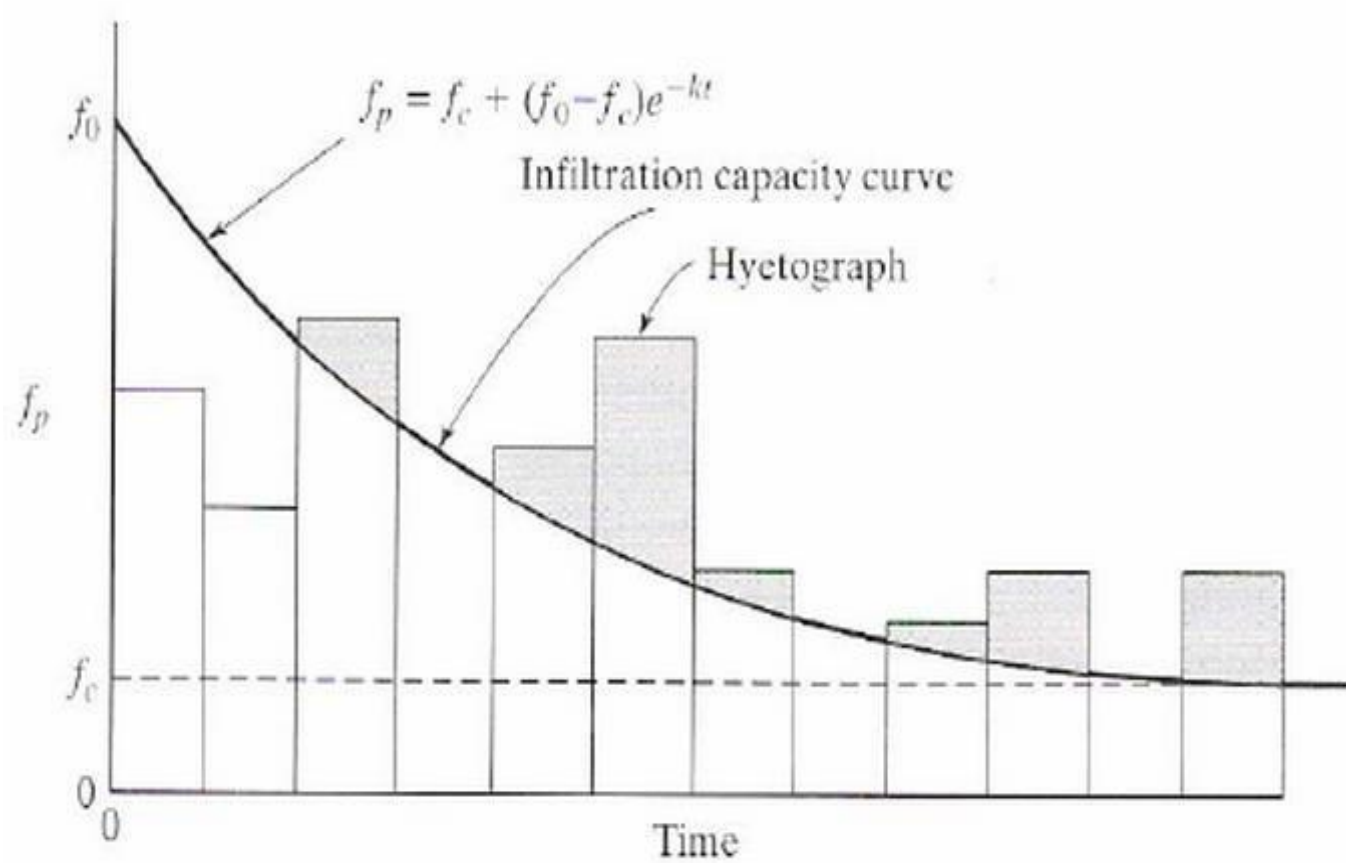
K = constant depending primarily upon soil and vegetation,

e = base of the Napierian logarithm,

$F_c$  = shaded area in figure,

t = time from the beginning of the storm.

- The infiltration takes place only when  $f = f_p$  and when  $i \geq f_p$  but when  $i < f_p$ ,  $f < f_p$  actual infiltration rates are approx equal to the rainfall rate.



# **RUNOFF, HYDROGRAPHS**

## **3.1 RUNOFF:**

### **3.1.1 Introduction:**

Runoff is the portion of rainfall which flows through the rivers, streams etc. or runoff is the portion of the precipitation making its way towards stream channels, lakes or oceans as surface flow. Basically there are three types of runoff:

#### **3.1.1.1 Surface Runoff:**

- It is that portion of rainfall (after all the losses such as interception, infiltration, depression, storage, etc. are met) that enters streams immediately after the rainfall.
- After a lapse of time, overload flow joins streams.
- Sometime known as prompt runoff.

#### **3.1.1.2 Subsurface Runoff:**

- Certain amount of rain water enters the soil and hence flows laterally towards the stream without joining water table.
- Also takes little time to reach the stream.

#### **3.1.1.3 Base Flow:**

- It is also known as delayed flow.
- This water meets the ground water table and joins the stream or ocean.
- The movement of this flow is very slow and may take months or years to reach the stream.

## **3.2 RUNOFF PROCESS IN RURAL AREAS:**

- In arid and semi-arid with scarce vegetation and those distributed by human's infiltration capacity is a limiting factor and Horton overland flow is a dominant process.
- This also happen when the top soil is frozen.
- In most humid region, subsurface storm flow and saturation overland flow are dominant process.

- Where the soils are well drained, deep and very permeable, the water table deep and the saturation zone is confined to the valley floor.
- Saturation overland flow is less important than subsurface storm flow in this situation.
- Where the soils are thin and only moderately permeable and slope is gentle and concave shaped, the water table is shallow and the saturated zone expands readily, saturation overland flow dominates in this situation.

### **3.3 RUNOFF PROCESS IN URBAN AREAS:**

- Modification of the land surface during urbanisation changes the type and magnitude of runoff processes.
- Covering parts of the catchment with impervious roofs and concrete lots increases the volume and rate of Horton overland flow.
- Planners have to design detention ponds to accommodate increase runoff.
- Gutters and storm sewers convey runoff rapidly to stream channels, the channels are straightened and lined with concrete to increase the efficiency, so that they transmit the flood downstream more quickly.
- The capacity of culverts and bridges are overtaxed and residential areas become flooded during large storm.

### **3.4 FACTORS AFFECTING RUNOFF:**

Following are the factors affecting runoff:

#### **3.4.1 Climate Factors**

**3.4.1.1 Type of Precipitation:** rainfall and snowfall.

**3.4.1.2 Rainfall Intensity:** high intensity rainfall causes more rainfall.

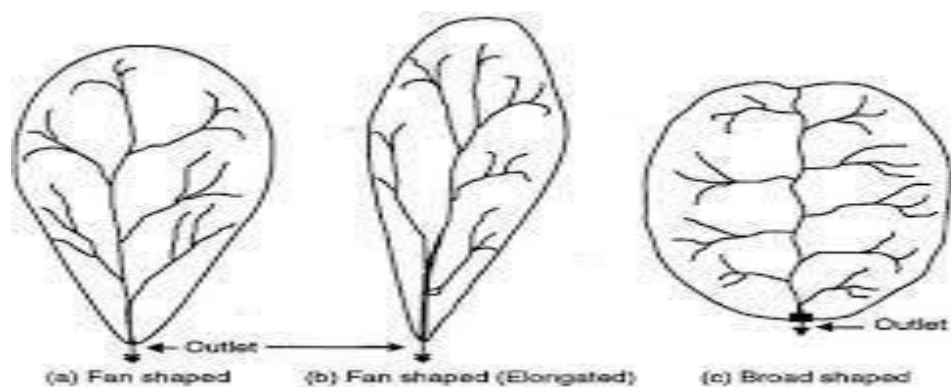
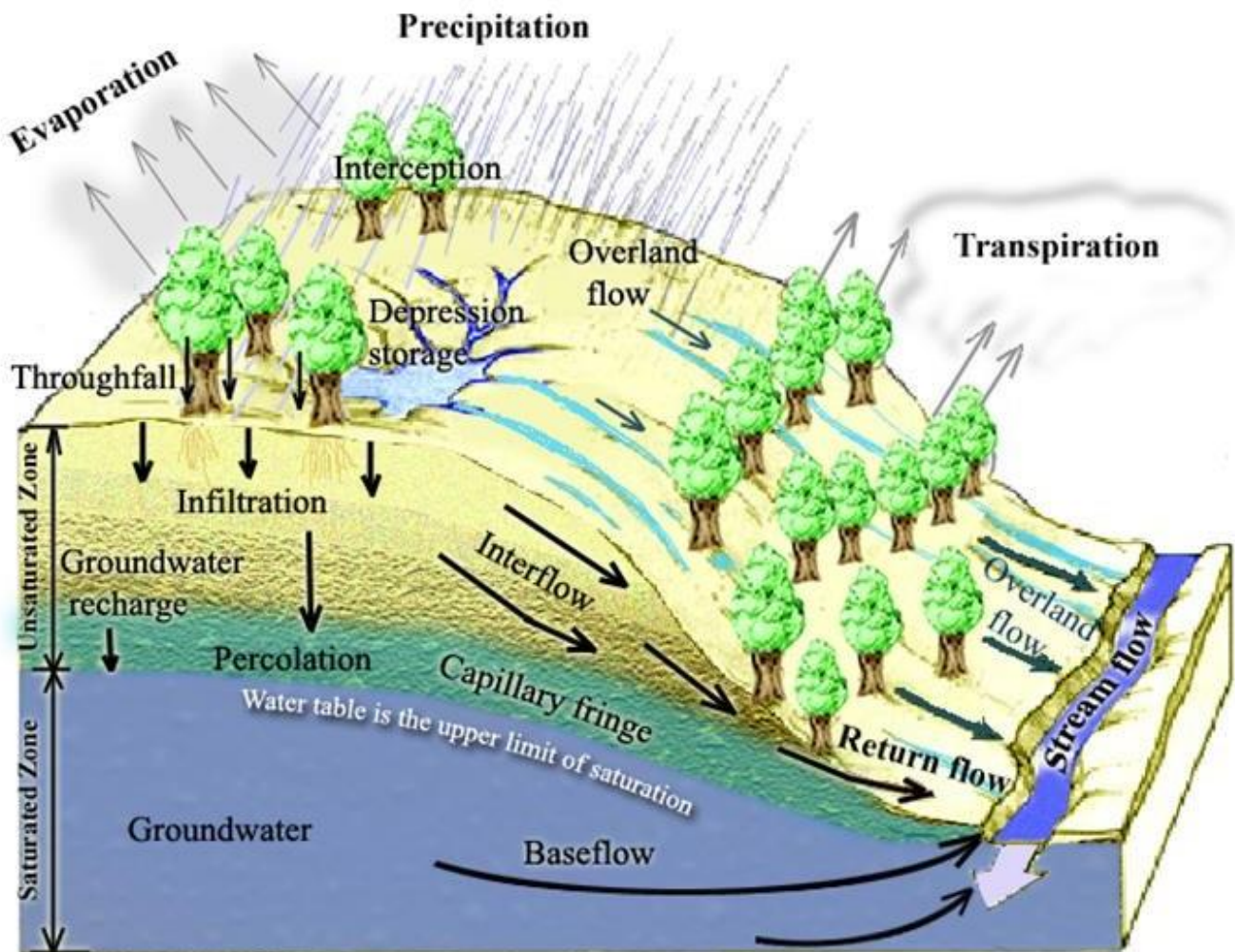
**3.4.1.3 Duration of Rainfall:** when duration increases, infiltration capacity decreases resulting in more runoff.

**3.4.1.4 Rainfall Distribution:** rainfall distribution in a catchment varies and hence runoff also varies. In case of more rainfall close to the outlet, peak flow occurs quickly.

**3.4.1.5 Direction of Prevailing Wind:** if the wind direction is towards the flow direction, peak flow occurs quickly.

**3.4.1.6 Other Climatic Factors:** temperature, wind velocity, relative humidity, annual rainfall affect the initial loss of precipitation and thereby affecting runoff.

**3.4.1.7 Physiographic Factors:** size of watershed, large the watershed, more time is required to deliver the runoff to the outlet point, small watersheds dominated by overland flow and larger watersheds by runoff, shape of watershed.





### 3.5 RAINFALL – RUNOFF RELATIONSHIPS USING REGRESSION ANALYSIS:

- Regression analysis is a method of developing a relationship between parameters.
- In practice linear regression analysis is carried out using the principle of Least Squares developed by Snedecor and Cochran in 1967.
- Considering the two variables X and Y, the linear regression equation would be of the form.

$$Y = a + b X$$

Where

a = Y intercept

b = slope coefficient

- Usually Runoff (R) would be the Y variable and Rainfall (P) X variable.
- The total number of observations (n) is known as length of the record.
- The normal equations for solving are.

$$\Sigma Y = na + b \Sigma X$$

$$\Sigma'XY = a \Sigma'X + b \Sigma'X^2$$

- The sums  $\Sigma'X$ ,  $\Sigma'Y$ ,  $\Sigma'X^2$  and  $\Sigma'Y^2$  are considered over the length of the record (n).
- It is fact that the analytical method gives more reliable values of the constants a and b than the graphical procedure.
- In spite of the fact that the procedure of solving normal equations is simple another method by name performance testing is found to be more useful.
- In performance testing method, the arithmetic mean of the two series (X' and Y') is first estimated.
- In next step, the series of deviations X and Y represented as x and y where  $x = (X' - \bar{X})$  and  $y = (Y' - \bar{Y})$  are obtained. Hence,

$$b = \Sigma(xy) / \Sigma x^2$$

a =  $\bar{Y} - b\bar{x}$  are determined.

### 3.6 HYDROGRAPHS:

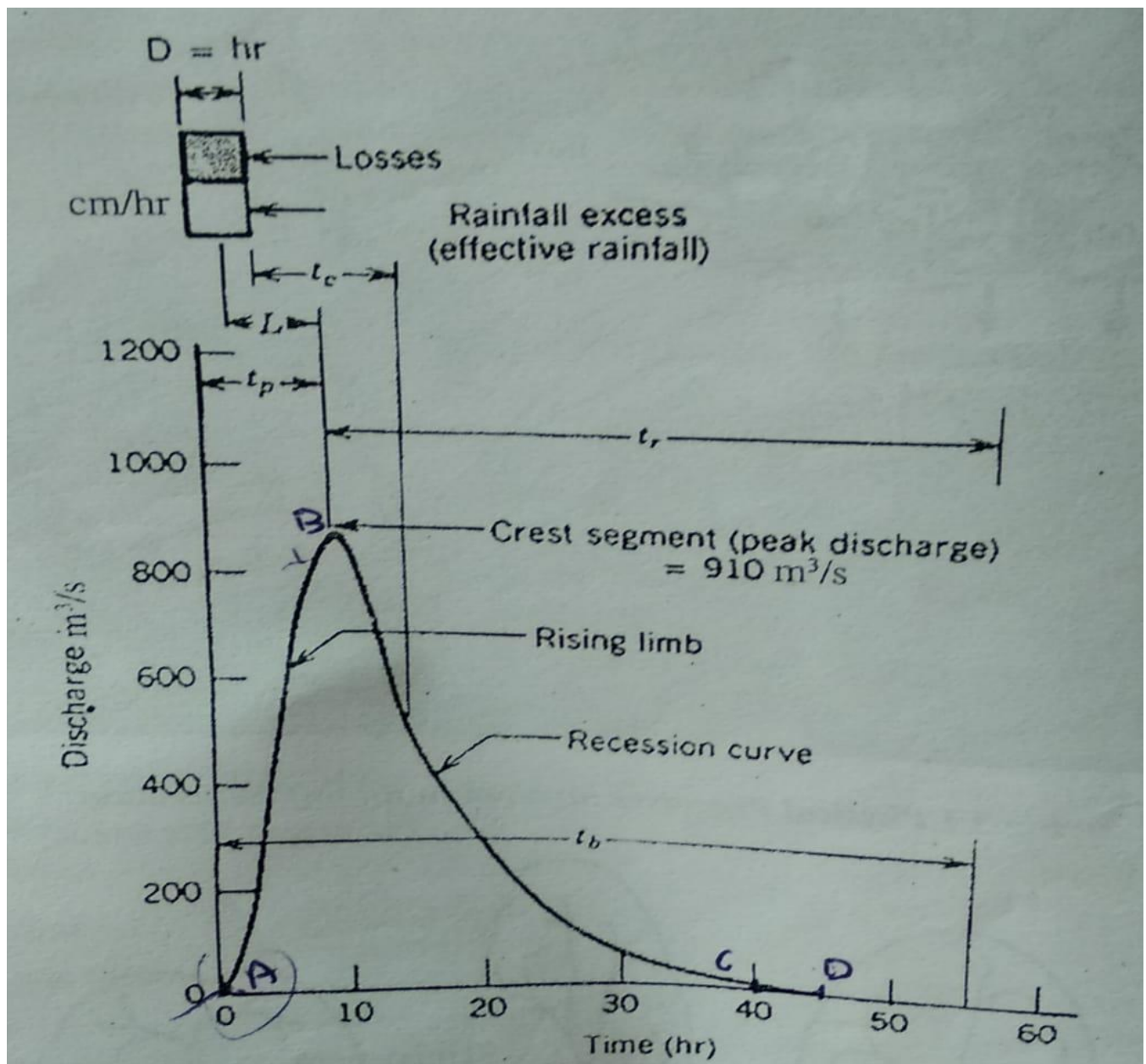
#### 3.6.1 Introduction:

A hydrograph can be due to contributions of surface runoff, interflow and ground water runoff and the hydrograph can be regarded as an integral expression of the physiographic and climatic characteristics governing the relations between rainfall and runoff. A hydrograph shows the time distribution of runoff at

the outlet of the catchment or basin along with the complexities of the characteristics of the catchment, by a single empirical curve. Hence the hydrograph forms a basis to relate rainfall and the time distribution of runoff produced by it. A detailed analysis of a hydrograph has an important role in flood control and flood forecasting or in establishing design flows as far as hydraulic structures that are required to pass off the flood water.

**3.6.2 Definition:** a hydrograph is a graphical representation of any hydrological parameter (like discharge, stage etc.) on Y axis with time on X axis.

### 3.7 COMPONENTS OF HYDROGRAPH:



A flood hydrograph is a graph of discharge v/s time. Figure shows the components of such a hydrograph they are:

**3.7.1 Rising Limb or Concentration Curve (AB):** it is the curve or line joining the starting point A of the rising curve and the point of inflection B. the shape of the rising limb is influenced mainly by the storm or rainfall characteristics.

**3.7.2 Peak or Crest (BC):** it represents the highest portion of the hydrograph. Its duration also depends on the intensity and duration of the rainfall.

**3.7.3 Falling Limb or Depletion Curve (CD):** it is the descending portion of the hydrograph beyond the point of contraflexure. The point of inflexion represents the time at which the surface inflow into the channel ceases. The shape of the falling limb is mainly a function of the physical features of the channel alone and is independent of the storm characteristics. The shape of the curve CD depends entirely on the basin characters.

**3.7.4 The Time to Peak ( $t_{pk}$ ):** it is the time to peak (P) from the starting point of the hydrograph (A).

**3.7.5 Lag Time ( $T_L$ ):** the time interval from the centre of mass of rainfall to the centre of mass hydrograph is the lag time.

**3.7.6 Time Base ( $T_B$ ):** it is the total duration or time elapsed between the starting and ending of the hydrograph i.e. the time between A and D.

### **3.8 FACTORS AFFECTING THE SHAPE OF THE FLOOD HYDROGRAPH:**

The factors affecting the shape of the flood hydrograph can mainly due to:

#### **3.8.1 Climatic Factors**

#### **3.8.2 Physical Factors**

- For a given duration, the peak and volume of the surface runoff are essentially proportional to the rainfall intensity.
- Duration of the rainfall of given intensity directly effects the volume of rainfall.
- If the storm moves in the downstream direction, flow will be quicker at the basin.
- Shape of a catchment has great influence on the shape of the hydrograph with regards to the period of concentration, maximum flood intensity and curves of rising and falling flood.

- Smaller catchment yields a more rapid and intense flood per unit area. It gives a high and narrow hydrograph which becomes lower as the catchment area increases.
- The slope of the main stream controls the velocity of flow in the channel. The basin slope is important in small catchments where the overland flow is relatively more important. In such cases steeper slope of the catchment results in larger peak discharges.
- A large drainage density creates situation conducive for quick disposal of runoff down the channel.
- Vegetation and forests increases the infiltration and storage capacities of the soils, vegetal cover reduces the peak flow.

Climatic Factors	Physical Factors
Storm characteristics, Intensity, Duration, Magnitude and Movement of storm.	Basin characteristics, Shape, Size, Slope, Natural of the valley, Elevation, Drainage density.
Initial loss	Infiltration characteristics: Land use and cover, Soil type and Geological conditions, Lakes etc.
Evapo – Transpiration	Channel characteristics: Cross section, Roughness and Storage capacity.

### 3.9 UNIT HYDROGRAPH:

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

#### 3.9.1 Assumptions made in deriving the unit hydrograph are:

- The effective rainfall is uniformly distributed within the specified period of time or within its duration.
- The time or base duration of the hydrograph of direct runoff due to an effective rainfall of unit duration shall be constant.
- The effective rainfall is uniformly distributed throughout the area of the drainage basin.
- The direct runoff or ordinates of common base line are proportional to the total amount of direct runoff represented by each hydrograph.
- The hydrograph of runoff due to a given period of rainfall for a drainage area, shows all the combined physical characteristics.

### 3.9.2 Practical Problems:

- The choice of the unit period.
- Determination of the base length and base flow.
- The effect of non-uniformity of rainfall over the catchment and intensity variation within the unit period.
- The effect of storm movement and the applicability of the unit hydrograph theory to large basins.
- Unit hydrograph is well suited for areas between 200 Hectares to 5000 km<sup>2</sup>.

### 3.9.3 Derivation of Unit Hydrograph:

- Few unit periods of intense rainfall duration corresponding to an isolated storm uniformly distributed over the area are collected from the past rainfall records. (the unit storm is a storm of such duration that the period of surface runoff is not much less for any other storm of shorter duration).
- From the collected past records of the drainage (rivers) discharge for the storms prepare the storm hydrograph for some days after and before the rainfall of that unit duration (i.e. select a flood hydrograph which has resulted from a unit storm as specified in step 1).
- Draw the line separating the ground water flow (base flow) and direct runoff by any of the standard base flow separation procedures.
- From the ordinates of the total runoff hydrograph (at regular time intervals) deduct the corresponding ordinates of base flow to obtain the ordinates of direct runoff.
- Divide the volume of direct runoff by the area of the drainage basin to obtain the net precipitation depth (X) over the basin.
- Divide each of the ordinate of direct runoff by the net precipitation depth to obtain the ordinates of the unit hydrograph.

$$\text{Ordinate of Unit Hydrograph (UHG)} = \{ \text{Ordinate of direct runoff (FHG)} / \text{Depth of net precipitation(X)} \}$$

$$\text{UHG} = \{ \text{FHG} / \text{X} \} \times 1$$

$$\text{FHG} = \text{UGH} \times \text{X}$$

- 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 (producing the flood hydrograph).

### 3.9.4 Limitations of Unit Hydrograph Theory:

- It is a fact that similar rainfall distribution from storm to storm over a large area is quite rare. Hence this theory is limited to catchments not exceeding 5000 km<sup>2</sup>.
- The rainfall distribution over an odd shaped catchment, especially very long and having narrow width would be uneven. Therefore unit hydrograph for such a catchment may not be suitable.
- In mountainous catchments, where orographic precipitation is common, aerial distribution is more or less uneven, but the pattern tends to remain the same from storm to storm and hence unit hydrograph theory may not be successful.
- When the precipitation is mostly of snowfall, the unit hydrograph theory would not yield accurate results.
- The linear relationship fails when the catchment has large storage reservoirs, lakes and low areas. Thereby, unit hydrograph theory fails.
- Unit hydrograph theory is not acceptable when the base period and peak flow vary more than  $\pm 20\%$  and  $\pm 10\%$  respectively.

### 3.9.5 Applications of Unit Hydrograph Theory:

- Unit hydrograph theory can be used for flood forecasting and warning.
- It is a fact that the unit hydrograph is a linear model of the catchment, the theory can be adopted for determining the runoff hydrograph of the catchment even for extreme magnitude to determine peak flow for design of hydraulic structures.
- Unit hydrographs prove to be more helpful for the extension of flood records, along with the help of rainfall data.

## 3.10 BASE FLOW SEPARATION:

Following are the different methods of the base flow separation:

### 3.10.1 I – Method:

- Generally the method of base flow separation should be such that time base of the direct runoff remains relatively constant, from storm to storm.
- This is usually achieved by terminating the direct runoff at the fixed time after the peak of the hydrograph.
- As the thumb rule the value of N can be obtained from the relation.

$$N = \{A^{0.2} / 1.21\}$$

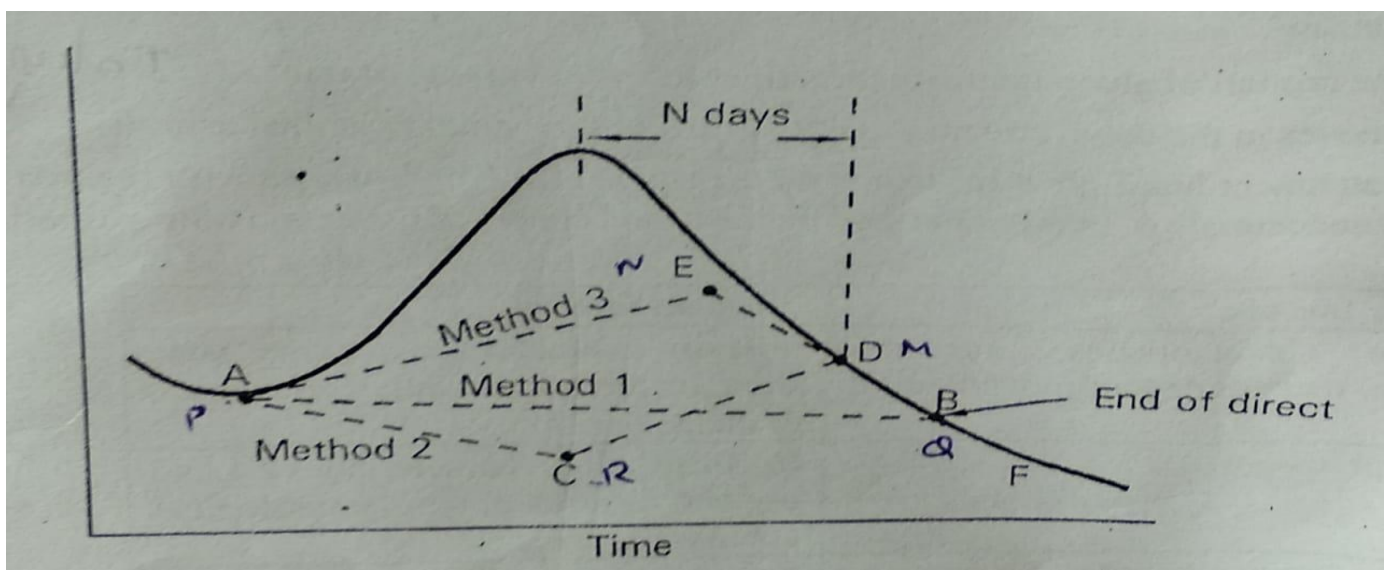
- Where  $A$  = drainage or catchment area in  $\text{km}^2$
- But, the value of  $N$  can also be determined by inspection of a number of hydrographs, keeping in mind that the total base should not be excessively long and the rise of the ground water should not be too large.
- In figure portion of the curve above  $PQ$  is direct (surface) runoff and that below is the base flow (sub-surface flow).

### 3.10.2 II – Method:

- In this method the base flow curve (i.e. falling limb of the hydrograph after the point of inflexion existing prior to the commencement) of the surface runoff is extended till it intersect the ordinate drawn at the peak point ( $R$ ) as shown in figure.
- This point is joined to point  $Q$  by a straight line segments  $PR$  and  $RQ$  demarcate the base flow and surface runoff.
- This is probably the most widely used base flow separation procedure.

### 3.10.3 III – Method:

- In this method the base flow separation is achieved by projecting backwards the recession curve, (after the depletion of the flood water) till it intersects the ordinate at the point of inflection as shown by line  $MN$  in figure.
- Points  $P$  and  $N$  are joined by an arbitrary smooth curve.
- This method may give better results where the ground water contribution are significant and reach the stream quickly.



### 3.11 S – HYDROGRAPH:

- S – Curve or a summation curve is a hydrograph of direct surface discharge that would result from a continuous effective rainfall at a constant rate for an infinite period.
- It is the curve obtained by summation of t – hour's unit hydrographs spaced t – hours apart.
- Figure shows a series of t – hour's unit hydrographs arranged with their starting points t – hours apart.
- At any given time the ordinates of the various curves occurring at that time coordinate are summed up to obtain ordinate of the S – curve.
- A smooth curve drawn through these ordinates will be the S – curve.
- This S – curve is due to t – hour's unit hydrograph.
- It has an initial steep portion and reaches a maximum equilibrium discharge at a time equal to the time base of the first unit hydrograph.
- The average intensity of excess rainfall producing the S – curve is  $1/t$  cm/hour and the equilibrium discharge is

$$Q_e = \{(A/t) \times 10^4\} \text{ meter}^3 / \text{sec}$$

Where

A = catchment area in km<sup>2</sup>

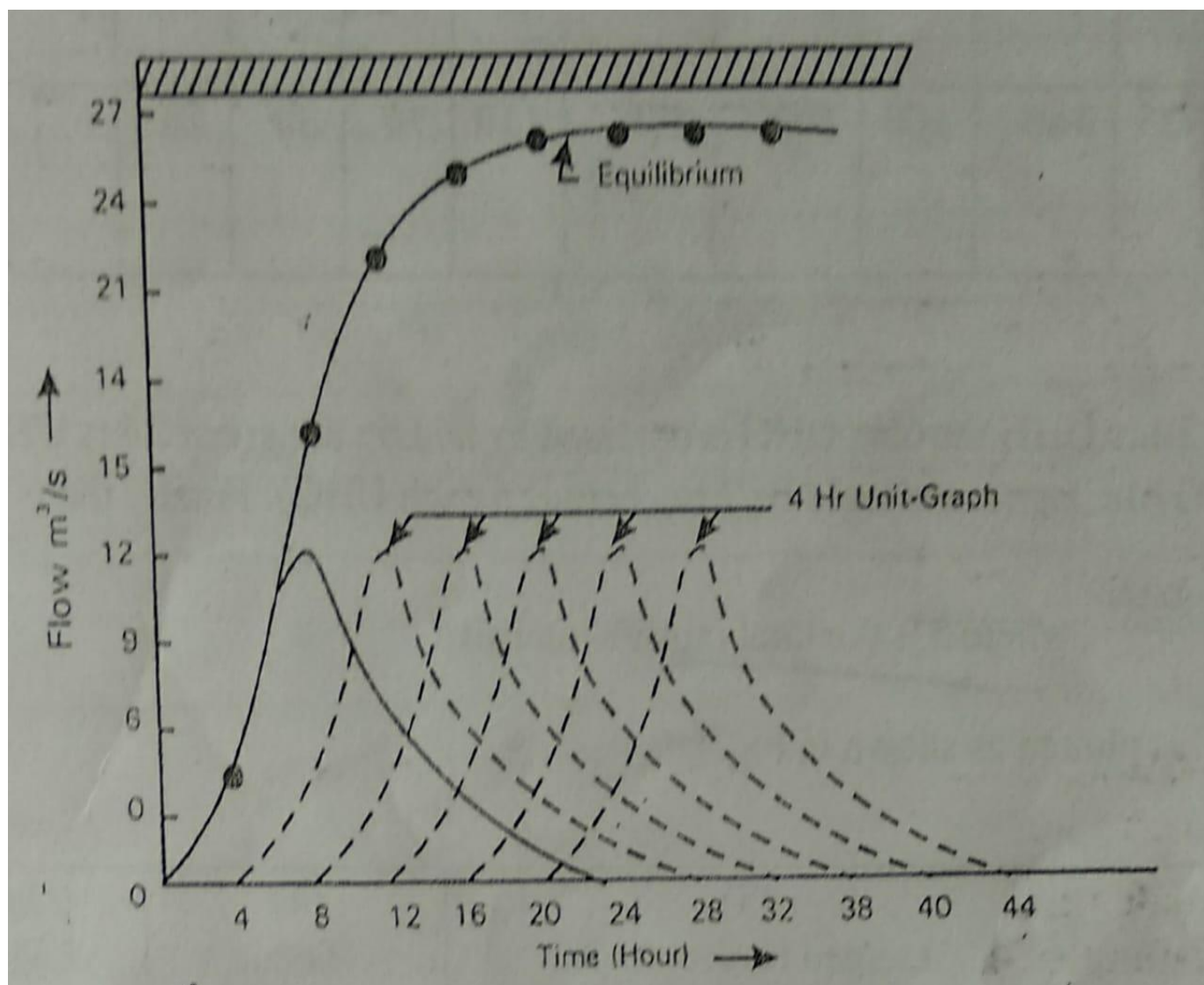
t = duration in hours of excess rainfall of the unit hydrograph used in deriving the curve

- Alternatively

$$Q_e = 2.778 \times \{A/t\} \text{ m}^3 / \text{sec}$$

- The S – hydrograph technique is very much useful in deriving a unit hydrograph of one duration knowing an unit hydrograph of other duration.





# **IRRIGATION, WATER REQUIREMENT OF CROPS**

## **4.1 IRRIGATION:**

### **4.1.1 Definition of Irrigation:**

Irrigation is defined as the systematic process of artificially supplying water to land for raising crops. It is the profession, science of planning and designing an efficient, economic system to fit natural conditions.

## **4.2 NECESSITY OF IRRIGATION IN INDIA:**

India being an agricultural country, as such all the resources depends on the agricultural output. The yield of an agricultural land depends on number of factors, however moist vital need is adequate quantities of water at various stages of the growth of the plants, but such conditions are rarely satisfied by natural rains. Hence the necessity of irrigation are as follows:

### **4.2.1 Less Rainfall:**

- When the rainfall is less than 100cm i.e. less than needed for the crop, artificial supply is necessary.
- Hence irrigation work may be constructed at places where adequate quantities of water is available and convey the same to places of necessity.

### **4.2.2 Non – Uniformity of Rainfall:**

- The rainfall over a particular area may be sufficient but not uniform over the crop period.
- In other words more water is supplied during the monsoon months, there is acute requirement of irrigation in other periods.

### **4.2.3 Commercial Crops with addition Water:**

- The rainfall in a particular area may be sufficient to raise the regular crops, but large quantities of water may be necessary for raising commercial and cash crops like sugar cane etc.

### **4.2.4 Controlled Water Supply:**

- By constructing a proper distribution system, crop yield can be substantially increased.

### **4.3 BENEFITS AND ILL EFFECT OF IRRIGATION:**

Irrigation project are designed in such a way that, they give both direct and indirect benefits.

#### **4.3.1 Direct Benefits or Advantages:**

**4.3.1.1 Increase in Food Production:** this is achieved by controlled and timely supply of optimum quantity of water to the crop.

**4.3.1.2 Protection from Famine:** irrigation projects can save the places of famine in two ways: during construction employment opportunities are provided to the local people and after construction continuous supply is assured even during drought period.

**4.3.1.3 Cultivation of Cash Crops:** due to irrigation, it is possible to grow cash crops such as sugarcane, tobacco, cotton etc.

**4.3.1.4 Addition to the Wealth of the Country:** irrigation projects are so designed that they bring some revenue to the country in the form of tax, bumper crops and hence saves importing of food crops from other countries.

**4.3.1.5 Increase in Prosperity of People:** as continuous water supply is assured from an irrigation project, two or more superior crops can be grown, plus the value of the agricultural lands increases, thereby increasing the prosperity of people.

**4.3.1.6 Hydro – Electric Power Generation:** major project are designed in such a way that power generation can be done together with irrigation.

**4.3.1.7 Domestic and Industrial Water Supply:** water from irrigation canals can be used for domestic and industrial water supply.

**4.3.1.8 Improvements of Communication:** as all the canals are provided with inspection roads, which can be metalled and hence can be used as means of communication.

**4.3.1.9 Canal Plantation:** the area along the canal is always damp and hence canal plantation is possible, which in turn increases the wealth of the country and also minimizes soil erosion.

**4.3.1.10 Improvement in the Ground Water Storage:** due to constant percolation and seepage of water, the ground water table raises, which is beneficial for better growth of the crop.

**4.3.1.11 Aid in Civilization:** due to the improvement of irrigation projects there will be increase in the yield, the standard of living of the farmer gets improved and becomes more civilized.

#### **4.3.2 Indirect Benefits or Disadvantages:**

- Climate becomes damp and cold, giving rise to malaria.
- Excess irrigation with poor drainage may result in water logging and causes salt efflorescence, resulting in drastic reduction of crop yield.
- Land revenue decreases in places where irrigation is extended as a protective measure.
- Excessive seepage from unlined canals would lead to water logging of adjacent lands.

#### **4.4 ENVIRONMENTAL IMPACTS OF IRRIGATION:**

- Introduction to irrigation results in extensive changes in vegetation, flora and fauna, thereby altering the ecology of the command area of the project.
- These improvements have a chain of advantages for a more prosperous life for the people.
- Barren, unfertile lands are turned into green pastures, good forests and change of human environment too.
- However on the contrary the development of irrigation to meet the constantly increasing food demand has detrimental environmental hazards in the form of water logging and salinity.
- Proper care must be taken to drain the command areas in order to decrease the adverse environmental effects of irrigation.

#### **4.5 SYSTEM OF IRRIGATION:**

Various systems of irrigation are broadly classified as follows:

- **Flow Irrigation or Gravity Irrigation:** the water is supplied to the fields by gravity only, through a network of canals. This system is further subdivided into perennial irrigation and flood or inundation irrigation.
- **Lift Irrigation or Pumped Irrigation:** water is lifted with the help of pumps and discharged into lift canal. The source of supply can be from a river or canal and from ground surface.

##### **4.5.1 Flow Irrigation:**

Flow irrigation is that type of irrigation in which the irrigation water is supplied to a field by gravity.

Flow irrigation is divided into two classes:

**4.5.1.1 Perennial Irrigation System:** the water necessary for irrigation is supplied in accordance with the crop requirements throughout the crop period. Hence, for such a system some storage works such as dams, weirs or barrages are necessary to store excess water during floods and release it to the crops at the time of necessity.

**4.5.1.2 Inundation or Flood Irrigation System:** water is flooded, till the land gets thoroughly saturated. Irrigation is carried out after draining the water.

#### **4.5.2 Direct Irrigation and Storage Irrigation:**

##### **4.5.2.1 Direct Irrigation:**

- A weir or barrage is constructed across a river, so that the water can be diverted into the canal, such a system is also known as river canal irrigation.
- In this method water is not stored.
- Hence water level in the canal varies according to the water level in the river.
- Sarda canal system and Ganga canal system of UP are examples of this system of irrigation.

##### **4.5.2.2 Storage Irrigation:**

- In this system water is impounded in the form of a reservoir by the construction of a dam or a weir and this water is used for irrigation through a network of canals.
- Generally in order to achieve economy the project may be multipurpose, meaning the water can be used for number of purposes.
- This system is used when the monsoon are heavy during part of the year, but for most of the months in the year the discharge is not sufficient to meet the demand of the canals.

#### **4.5.3 Bandhara Irrigation System:**

- Bandhara irrigation is a special type of irrigation and is essentially a diversion irrigation scheme on non – perennial streams.
- This system is practiced in some parts of Maharashtra and Karnataka.
- The bandhara system was developed by late Sir M Visvesvaraya.
- A bandhara is a masonry diversion weir of small height of about 1.2m to 4.5m, constructed across the stream and the water from the upstream side of such a structure being diverted into small canals.
- It is the cheapest and most economical type of irrigation.

- Bandharas can be constructed in series and irrigation can be carried out on both the sides of the canals.
- The capacity of each bandhara can vary from few hectares to few hundred of hectares, depending on the volume of water available.
- Generally the length of a bandhara canal should not be more than 8km.

#### **4.5.3.1 Location of Bandharas:**

- The rivers should preferably be perennial in nature.
- Good foundation should be available for constructing the bandhara.
- The section at the site should be straight, narrow and well defined.
- The command of the canal should be fairly good and fertile.
- The natural banks on both sides of the site should be high so that no land is wasted on the upstream side.
- The cost of construction should be less or economical.

#### **4.5.3.2 Advantages:**

- The system of irrigation has a low initial cost.
- Losses in the canal are less, therefore duty of water is more.
- Small quantities of water which would have otherwise gone water is utilized to maximum in this system.
- As the lengths of the main canal and the distribution system being small, seepage and evaporation losses are very less.

#### **4.5.3.3 Disadvantages:**

- When excess water is available, it goes waste, since the area to be irrigated is small and fixed.
- Water supply in the canal depends on the nature of the river.
- As the water resources upstream of the bandhara depends on the nature of the stream, water may not be available for domestic purposes during dry seasons.

#### **4.5.4 Tank Irrigation:**

- Tank irrigation is a storage on the upstream which utilizes the water stored on the upstream side of a smaller (less than 12m height) earth dam or a bund.
- The reservoir or storage so formed upstream of such a bund is known as a tank.

- Tank irrigation method is very much popular in South India.
- Generally tank bunds are provided with sluices or outlets for discharging water from the tank for the tank for the purpose of irrigation.
- Excess water can be discharged from a surplus escape weir provided in the body or at one end of the tank bund.
- When a tank neither receives water from an upper tank nor discharges its own surplus into a lower tank, it is called an isolated tank.
- When a number of tanks are connected in series, such that any tank either receives the surplus water into the lower tank or do both, they are known as tanks in series or group of tanks.
- The storage capacity of a tank can be computed by using the contour plan of the area of the water spread, the total capacity will be sum of the capacities between successive contours.
- When the contour plan is not available and if only the area of the tank at full tank level FTL multiplied by one third of the vertical distance between the FTL and the deepest bed level of the tank or the level of the silt of the lowest sluice whichever is higher of the two.

#### **4.5.4.1 Failure of Tank Bunds:**

A tank bund may fail due to any of the following reasons:

**4.5.4.1.1 Hydraulic Failures:** may be due to overtopping, erosion of the upstream face, cracking due to fast action, erosion of downstream face by gully formation, erosion of the downstream toe.

**4.5.4.1.2 Seepage Failures:** may be due to piping through the foundations, piping through the body of the dam, sloughing of downstream toe.

**4.5.4.1.3 Structural Failures:** may be due to foundation slide, slide in embankments.

#### **4.5.5 Lift Irrigation:**

This system is also known as the pumped irrigation, which can be further classified into:

**4.5.5.1 Lift Irrigation from Surface Source:** the water is lifted with the help of pump and discharged into lift canals. The water source may be river or gravity canal. The water so lifted flows to the fields through a network of gravity canals.

**4.5.5.2 Lift Irrigation from Ground Source:** the water is lifted by means of tube wells or open wells. The water from such wells are pumped into the network of canals, leading to the place of necessity.

#### **4.5.6 Methods of Lifting Water from Shallow Wells:**

Following methods are generally used for lifting water from open wells for the purpose of irrigation.

##### **4.5.6.1 Persian Wheel:**

- This method is used for lifting water from wells which are 10 to 20 m deep.
- This is very common in western UP and Punjab.
- It consists of a big framed wooden wheel fixed in a vertical position above the top of the well.
- At the end of the axle of this wheel, another vertical wooden wheel of smaller diameter is fitted, this smaller wheel is rotated by a gear mechanism, which in turn is driven by a pair of bullock.
- As the bullocks move round all the wheels rotate and the metallic buckets filled with water start coming to the upstream end of the field canal, through which water flows to the land.

##### **4.5.6.2 Doon:**

- This method is used to lift waters up to 1.2m closed at upstream end and open on the downstream side.
- This chute is supported at its centre on a horizontal rod on which it rocks.
- The closed upstream end of the chute is connected by a rope on one side and a counter weight mechanism to the other side.
- A wooden platform is fixed in the channel near its berm such that the top of platform is above the water level in the channel.
- The farmer stands on the platform who can operate the chute to lift the irrigation water from the channel to the irrigation fields.

##### **4.5.6.3 Wind Lasso:**

- This method is employed for lifting small quantity of water for irrigation or for drinking.
- In this method two wheels each having four or six projecting arms are joined together to form a cylindrical wooden frame.
- This cylinder is rested on top of the well.
- The bucket is tied to one of the rope while the other end of it is fixed to the axle of the frame.
- For lifting the water the wooden cylinder is rotated in one direction so that the bucket is lowered into the well and when it is full the cylinder is rotated in the opposite direction till the bucket rises to the top of the well so that the water can be discharged into the canal.
- This process is repeated as per requirements.



#### **4.5.6.4 Advantages of Well:**

- Water is under the sole control of the farmer hence it can be used according to the necessity in the field.
- Isolated areas, not served by any other irrigation scheme can be irrigated by wells.
- Pumping or lifting of water from well depresses the water table, this reduces the chances of water logging.
- The maintenance cost is low.
- Due to minimum conveyance losses, duty of water will be quite high.
- Overall cost of the project is small.
- In tube well irrigation, water can be supplied to the irrigator on volumetric basis, thus there is more scope for economic use of water.

#### **4.5.6.5 Disadvantages of Well:**

- Any defect in the lifting mechanism, leads to interruption in the water supply.
- Since the well water is free from silt contents, it has minimum manure value.
- The cost of irrigation with well is high.
- The quantity of well water and its yield depends on the ground water storage, if it is less, the irrigation capacity will also be less.

#### **4.5.7 Comparison of Lift Irrigation and Canal Irrigation:**

- In lift irrigation, pumping device are essential, while in the canal irrigation no such devices are required.
- In the case of lift irrigation, the farmer can irrigate his fields as per his requirements, while in the canal irrigation he has to wait for his turn.
- In lift irrigation pumping of water reduces the possibility of water logging, but in the case of canal irrigation water logging is possible.
- In the case of lift irrigation, water supply gets disrupted due to repair or due to power failure.
- Lift irrigation can be implemented anywhere and everywhere, but canal irrigation is possible in places where water can flow by gravity only.
- Due to the absence of silt in well water, its manorial value will be low, but in case of canal water, silt content is more meaning relatively high manorial value. This is an added advantage of canal irrigation.

- The area under irrigation in the case of lift irrigation will be relatively small compared to the canal irrigation.
- Lift irrigation water is used economically when compared to the canal irrigation.
- Lift irrigation is possible at all times even in draughts, but irrigation becomes more difficult when the rains fail.
- Staff requirement for lift irrigation is small compared to the canal irrigation.

#### **4.5.8 Tube Well Irrigation:**

- The maximum discharge from ordinary open well vary between 4 to 5 liters/sec, hence their usage is limited to small locality or dwellings, also it may not be economical to install pumps in such wells.
- In order to get more yield, tube wells are commonly used.
- These wells consist of blind pipes and strainer pipes driven into water bearing strata.
- The maximum yield of such a well will be about 200 lps and the depth may vary from 50 to 500m.

Following types of tube wells are usually constructed:

- Strainer type tube wells.
- Cavity type tube wells.
- Slotted type tube wells.
- Perforated type tube wells.

### **4.6 DEFINITIONS:**

**4.6.1 Delta ( $\Delta$ ):** it may be defined as the total volume of water delivered by the area over which it has been spread.

or

It is the total depth of water in centimetres required by a crop to come to its maturity.

**4.6.2 Duty:** it denotes the irrigating capacity of a unit water. It is usually defined as the area of land in hectares which can be irrigated for growing any crop if one cumec or  $1 \text{ m}^3/\text{sec}$  of water is continuously supplied to the land for the entire base period of the crop.

**4.6.3 Gross Duty:** it is the duty of water measured at the source of diversion of irrigation supplies.

**4.6.4 Nominal Duty:** it is the duty sanctioned as per schedule of the irrigation department.

**4.6.5 Economic Water Duty:** it is the duty of water which results in the maximum yield.

**4.6.6 Designed Duty:** it is the duty of water assumed in an irrigation project for designing the capacity of a channel.

**4.6.7 Farm Duty or Net Duty:** it is the duty measured in the farm.

**4.6.8 Flow Duty:** it is the duty determined at the head of a channel.

**4.6.9 Quantity Duty:** it is the duty expressed in terms of the volume of water stored, and is expressed as hectares/million cubic meters of water available.

**4.6.10 High Duty:** when small amounts of water matures comparatively small area under crop the duty is said to be high.

**4.6.11 Low Duty:** when large amounts of water matures comparatively small areas under a crop the duty is said to be low.

**4.6.12 Base of Duty of Water:** it is defined as the period to which the stated duty of water has reference. When the duty of water is expressed for the entire base period and if the base is not mentioned it is evident that the duty refers to the entire base period.

**4.6.13 Base Period:** it is the period from the first to the last watering of the crop just before its maturity. It is expressed in number of days.

**4.6.14 Outlet Factor:** the duty of water at the outlet or at the head of a field channel is known as the outlet factor.

**4.6.15 Cumec Day:** the total quantity of water flowing continuously for one day at the rate of one cumec is known as cumec day.

1 cumec day =  $1 \times 24 \times 60 \times 60 = 8.64 \times 10^4 \text{ m}^3 = 8.64 \text{ Hectare – meters}$ .

**4.6.16 Consumptive Use of Evapo Transpiration:** it is defined as the total quantity of water used by the vegetative growth of a given area in transpiration and buildings of plant tissue and that evaporated from the adjacent soil in the area in any specified time.

**4.6.17 Effective Rainfall:** it is that part of the precipitation falling during the growing period of a crop that is available to meet the evapo transpiration needs of the crop.

**4.6.18 Water Conveyance Efficiency [ $\eta_a$ ]:** it is defined as the ratio of the quantity of water delivered to the field to the quantity of water diverted into the canal system from the storage.

**4.6.19 Water Application Efficiency [ $\eta_u$ ]:** it is defined as the ratio of the quantity of water stored in the root zone of the plant to the quantity of water delivered to the field.

**4.6.20 Water Use Efficiency [ $\eta_s$ ]:** it is defined as the quantity of water beneficially used including the water required for leaching to the quantity of water delivered.

**4.6.21 Water Storage Efficiency [ $\eta_c$ ]:** it is defined as the ratio of the quantity of water stored in the irrigation to the quantity of water needed to bring the moisture content of the soil to the field capacity.

**4.6.22 Consumptive Use Efficiency [ $\eta_{cu}$ ]:** it is defined as the ratio of the normal consumptive use of water to the net amount of water depleted from the root zone.

**4.6.23 Consumptive Irrigation Requirement [CIR]:** it is defined as the amount of irrigation water that is required to meet the evapo transpiration needs of a crop during its full growth.

$$\text{Consumptive Irrigation Requirement} = \text{Consumptive Use} - \text{Effective Rainfall}$$

**4.6.24 Net Irrigation Requirement [NIR]:** it is defined as the amount of irrigation water required to be delivered at the field to meet the evapo transpiration needs of a crop as well as other needs such as leaching etc.

$$\text{Net Irrigation Requirement} = \text{Consumptive Use} - \text{Effective Rainfall} + \text{Amount of Water required for Leaching}$$

**4.6.25 Field Irrigation Requirement [FIR]:** it is defined as the amount of water required to meet the net irrigation plus the amount of water lost as surface runoff and through deep percolation.

**4.6.26 Gross Irrigation Requirement [GIR]:** it is defined as the amount of water required to meet the field irrigation requirements plus the amount of irrigation water lost in conveyance through the canal system.

**4.6.27 Paleo:** it is first watering before sowing the crop. Paleo watering is done to provide sufficient quantities of water to the unsaturated zone of the soil.

**4.6.28 Full Supply Coefficient:** it is defined as the area estimated to be irrigated during the base period divided by the design full supply discharge of the channel at its head during maximum demand.

## 4.7 RELATION BETWEEN DUTY, DELTA AND BASE PERIOD:

Let

$D$  = Duty of water in hectares/cumec

$B$  = Base period of the crop in days

$\Delta$  = Delta of water in meters

Volume of water applied to  $D$  Hectares of the field corresponding to a depth of  $\Delta$  meters in  $B$  days

$$= D \times \Delta \text{ Hectares} - \text{meter}$$

$$= D \times \Delta \times 10^4 \text{ meter}^3 - [1]$$

Volume of one cubic meter of water flowing for  $B$  days =  $1 \times 24 \times 60 \times 60 \times B$

$$= 8.64 \times 10^4 \times B \text{ meter}^3 - [2]$$

Equating 1 and 2 equations

$$D \times \Delta \times 10^4 = 8.64 \times 10^4 \times B$$

$$D = 8.64 \{B / \Delta\} - [3]$$

In equation 3

$D$  = hectares / cumec

$B$  = days

$\Delta$  = meters

Values of Duty, Delta and Base periods for some of the common Rabi and Kharif Crops:

No. Crop	Base Period (B) Days	Delta ( $\Delta$ ) meters	Average Duty D (Hectares/cumec)
<b>RABI CROPS</b>			
Wheat	150 to 180	0.3 to 0.35	1800
Potato	135 to 165	0.6 to 0.80	1600
Gram	150 to 195	0.15	2000

Peas	150 to 195	0.55	1500
Barley	150 to 180	0.3 to 0.35	1800
<b>KHARIF CROPS</b>			
Rice	90 to 135	0.8 to 1.40	900
Bajra	120 to 150	0.30	2000
Maize	120 to 135	0.35 to 0.45	1800
Dals	120 to 150	0.30	2000

#### **4.8 FACTORS AFFECTING CROP WATER REQUIREMENTS:**

The water requirements of crop are affected by the following parameters:

- Depth of the ground water table.
- Slope of the ground surface.
- Climatic conditions of the region.
- Intensity of irrigation.
- Texture and structure of soil.
- Moisture storage capacity of the soil.
- Type and quantity of manure applied to the fields.
- System of irrigation used.

#### **4.9 OPTIMUM USE OF IRRIGATION WATER:**

- Optimum requirements of water is defined as the quantity of water supplied to a crop, giving maximum yield of the crop.
- This requirement can be satisfied by irrigation water as well as by rainwater.
- Hence it is essential to know the optimum water requirement for a particular crop.
- Supply of less water may result in the plant to spend extra energy to get moisture from the soil which otherwise would have been used in its growth.
- Supply of excess water will expel the air from the soil pores and will prevent free circulation of fresh air, essential for food preparation of the plant.

## 4.10 IMPORTANCE OF DUTY:

Knowledge of duty of water for crops serves the following purposes:

- It helps in the design of irrigation channel in an irrigation project.
- Also knowing the amount of water available in the head of the main canal and overall duty, we can get an idea regarding the extent of area that can be irrigated from the available water.
- It helps to check the efficiency of the working of a canal system.
- From the area actually matured by canals in existence, it is possible to know whether the area actually matured is as proposed in the project or not.

## 4.11 FACTORS AFFECTING DUTY OF IRRIGATION WATER:

The duty of irrigation water depends upon the following factors:

**4.11.1 Soil Characteristics:** the duty of water directly depends on the soil characteristics, if the soil is pervious and coarse grained, losses are more, thereby there will be reduction in duty.

**4.11.2 Sub – Soil Conditions:** seepage losses depends on the sub – soil condition. If the water table is close to the normal supply level, seepage losses will be minimum and the duty of water will be high.

**4.11.3 Climate Conditions:** evaporation of water will be high when the temperature is high and the humidity is less this results in severe reduction of the duty of water.

**4.11.4 Rainfall:** if the irrigated area receives sufficient rainfall at the right time, then the quantity of irrigation supplied reduces, thereby the duty will be more.

**4.11.5 Type of Crop:** it is a fact that different crops require different amounts of water and hence the duties would be different for different crops. This means that a crop requiring more water would have less duty and vice versa.

**4.11.6 Crop Period:** the crop period/base period varies from crop to crop. This means that a crop with longer base period has lesser duty and vice versa.

**4.11.7 Unevenness of the Irrigation Fields:** even fields have better duty compared to uneven fields as more water is lost in the latter case.

**4.11.8 Preparation of Fields:** properly deep ploughed fields require overall less quantity of water, hence the duty will be more.

**4.11.9 Longitudinal Slope of Fields:** fields having little longitudinal downward slope towards the further end, requires less water and hence duty of water will be high.

**4.11.10 Field Position in Relation to Canal:** duty of water depends on the distance of the field from the canal outlet, which means if the distance of the field is more than the water losses will be more, or the duty will be less.

**4.11.11 Use of Irrigation Water:** when the irrigation water is assessed volumetrically, water will be more economically used, meaning that the duty will be more.

**4.11.12 Skill of the Farmer:** skilled farmer will make proper use of water, thereby the duty of water will be high at such places.

**4.11.13 Chemical Composition of Water:** when the water quality is good, lesser quantities are required for irrigation, compared with water having chemicals. Hence duty for good quality water will be high.

**4.11.14 Method of Irrigation:** duty of water is more in case of perennial irrigation.

**4.11.15 Mode of Applying Water:** the flood irrigation system has lesser duty than the furrow system.

**4.11.16 Time and Frequency of Cultivation:** frequent cultivation reduces the loss of moisture through weeds. Also when the soil is in good tilth, evaporation losses are less, hence better duty.

**4.11.17 Canal Conditions:** lined canals have higher duties compared to unlined canals as losses are minimum in the former case.

## **4.12 METHODS OF IMPROVING DUTY:**

Following are the various methods of improving duty:

- By adopting suitable methods of applying water, conveyance losses can be minimized thereby duty of water can be increased.
- By properly ploughing and levelling off the field before sowing the crop and also giving good tilth, duty can be improved.
- By frequent cultivation of the land moisture loss is reduced, thereby duty can be increased.
- By lining the network of canals, percolation and evaporation losses are reduced and hence duty can be increased.
- By reducing the idle length of the canal, duty can be increased.
- By practicing the rotation of crops, duty can be increased.



- By adopting the volumetric method of assessing the irrigation water, duty can be increased.
- By selecting the source, yielding good quality water, duty can be increased.
- By avoiding the canal route through sandy or porous reaches, losses can be minimized, thereby duty can be increased.
- By properly training farmers, to use water economically, duty can be increased.
- By establishing research stations the study of soil and conservation of moisture, duty can be increased.

#### **4.13 CROP ROTATION:**

- Crop rotation means that nature of the crop sown in a particular field is changed year after year.
- It is a fact that all crops require similar type of nutrient salts, but quantities may vary.
- Hence if different crops are grown there would be more balanced feeding and the soil deficient in one particular type of nutrient is allowed to build up.
- Insects and crop diseases will multiply if the same crop is grown continuously.
- Rotation will check the disease.
- There could be deep rooted and shallow rooted crops in rotation and if they are allowed to draw their food from different depths, the soil will be better utilized.

For examples of crop rotation are:

- Groundnut rotation with cotton.
- Bajra rotation with cotton.
- Cotton after gram.
- Wheat after sugarcane.
- Rice gram.

#### **4.14 FREQUENCY OF IRRIGATION:**

- Irrigation frequency refers to the number of days between irrigation during periods without rainfall.
- It depends on consumptive use of rate of a crop and on the amount of available moisture in the crop root zone.
- It is function of crop, soil and climate.
- Sandy soils must be irrigated more often the fine texture deep soils.

- A moisture use ratio varies with the kind of crop and climate conditions and increases as crop grows larger and days become longer and hotter.
- In general, irrigation should start when about 50 percent and not over 60 percent of the available moisture has been used from the root zone in which most of the roots are concentrated.
- The stage of crop growth with reference to critical periods of growth is also kept in view while designing irrigation frequency.
- The interval that can be safely allowed between two successive irrigation is known as frequency of irrigation.
- $\text{Irrigation Interval} = \{ \text{Allowable soil moisture depletion} / \text{Daily water use} \}$

#### **4.14.1 Factors Affecting Frequency of Irrigation:**

##### **4.14.1.1 Humidity:**

- In rainy season, the humidity is high and rains may be received just when the crop is in need of water.
- In such case, some irrigation turns could be stopped and frequency may be extended to 20 days.
- During winter season, also the frequency will be longer than in summer because of less evapo transpiration, dew fall, night time humidity and less sunshine.
- The frequency may therefore be 15 to 20 days in winter and 6 to 8 days in summer.
- In summer irrigation, water is given more frequently and hence more frequency of irrigation in summer, medium in winter and less in rainy season.

##### **4.14.1.2 Stage of Growth of Crops:**

- During certain stages particularly at flowering and fruit formation stages of crop requires much larger quantities of water than earlier stages.
- In earlier stages, even if a little less water than estimated daily use is provided, the crop will stand without any harm, perhaps a slight moisture stress may encourage better root growth.

##### **4.14.1.3 Type of Crop:**

- The frequency of irrigation will also depend up on the crop.
- A succulent leaf vegetable will require irrigation more often than cereal crop like Jowar.
- Crops which are doses of fertilizers need more water than those with little or no fertilizers.

#### 4.14.1.4 Soil Type:

- Light soil requires more frequent irrigation than the loamy soils.
- Sandy loam soil need to be irrigated every fifth day while clay loam may be irrigated every tenth day.
- Time required to irrigate an area.
- The time required to irrigate an area depends up on magnitude of discharge, quantity of water applied, irrigation efficiency and area.
- The time required to irrigate an area is calculated by the formula.

$$IQT = Ad$$

Where

I = irrigation efficiency

Q = discharge in cusec

T = time in hours

A = area in acres

d = moisture deficit in soil

# CANALS, RESERVOIRS

## 5.1 CANALS:

### 5.1.1 Introduction:

Canals are as old as irrigation and they date back to many centuries, particularly in India and Egypt. However, during these periods irrigation was restricted to smaller areas and these areas were fed by **Inundation Canals** of short length from a river. During 19<sup>th</sup> century canal design more scientific with the use of Chezy, Kutter and Bazin formulae and in India Kennedy and Lacey's equation more popular. Presently advanced equations and methods are being used in designing both unlined and lined canals. It is a fact that net error of canals play a vital role in any irrigation factor. Therefore, proper design of canals is of great importance. Usually canals suffer from silting and scouring problems in addition to weed growth, heavy seepage losses leading to extensive water logging on its sides, throughout the length. The velocity of water in a canal shall neither be too high nor too low. Also it is most essential to select a most economical section of the canal.

### 5.1.2 Definition of Canal:

A canal is a passage for the flow of water, mainly under gravitational force. It is generally trapezoidal in shape constructed on the ground to carry water to the fields from a storage system like a tank or reservoir.

## 5.2 TYPES OF CANALS:

### 5.2.1 Alluvial and Non – Alluvial Canals:

- **Alluvial canals** are those constructed through alluvial soils, their bed and banks comprise of the same material that is being transported by the canal.
- Such a canal can be readily silted or scoured.
- These canals are designed using the Lacey's Regime Theory.
- Alluvial canals generally take off from a barrage or a weir.
- Such soils are available in Indo – Gangetic plains of North India.
- **Non – alluvial canals** are those constructed through hard soils or fresh rocks.
- These types of canals are stable, usually designed for higher velocities and can withstand erosion.
- They are designed using Manning's, Chezy's and Kutter's equations.

- Non – alluvial canals take off from reservoirs. Such canals are usually found in central and South India.

#### 5.2.2 Permanent and Inundation Canals:

- **Permanent canals** are the canals fed by a permanent source of supply.
- They are also known as perennial canals.
- They are well graded channels and are provided with permanent regulation and distribution works.
- **Inundation canals** are the canals which usually draw their supplies during monsoon.
- These canals are not provided with any head works for diverting the water but are provided with canal head regulators.
- Inundation canals are non – perennial in nature.

#### 5.2.3 Lined and Unlined Canals:

- A **lined canal** is one which is provided with a protective covering on the bed and sides, in order to prevent seepage of water and also to minimize the erosion.
- An **unlined canal** is one which has its bed and sides made up of soil through which it is constructed and no protective covering is provided.
- The velocity in such a canal is maintained low to overcome the risk of erosion.

#### 5.2.4 Productive and Protective Canals:

- A **productive canal** is one which when completed fully yields enough revenue for its running and maintenance.
- A **protective canal** is constructed as a relief work against famine to provide employment to the people of that area.
- The revenue from such a canal does not cover its running charges and also does not repay its initial capital expenditure.

### 5.3 CLASSIFICATION OF CANALS BASED ON DISCHARGE:

The irrigation canals can be classified on the basis of their discharge carrying capacity and relative importance in the network into the following categories:

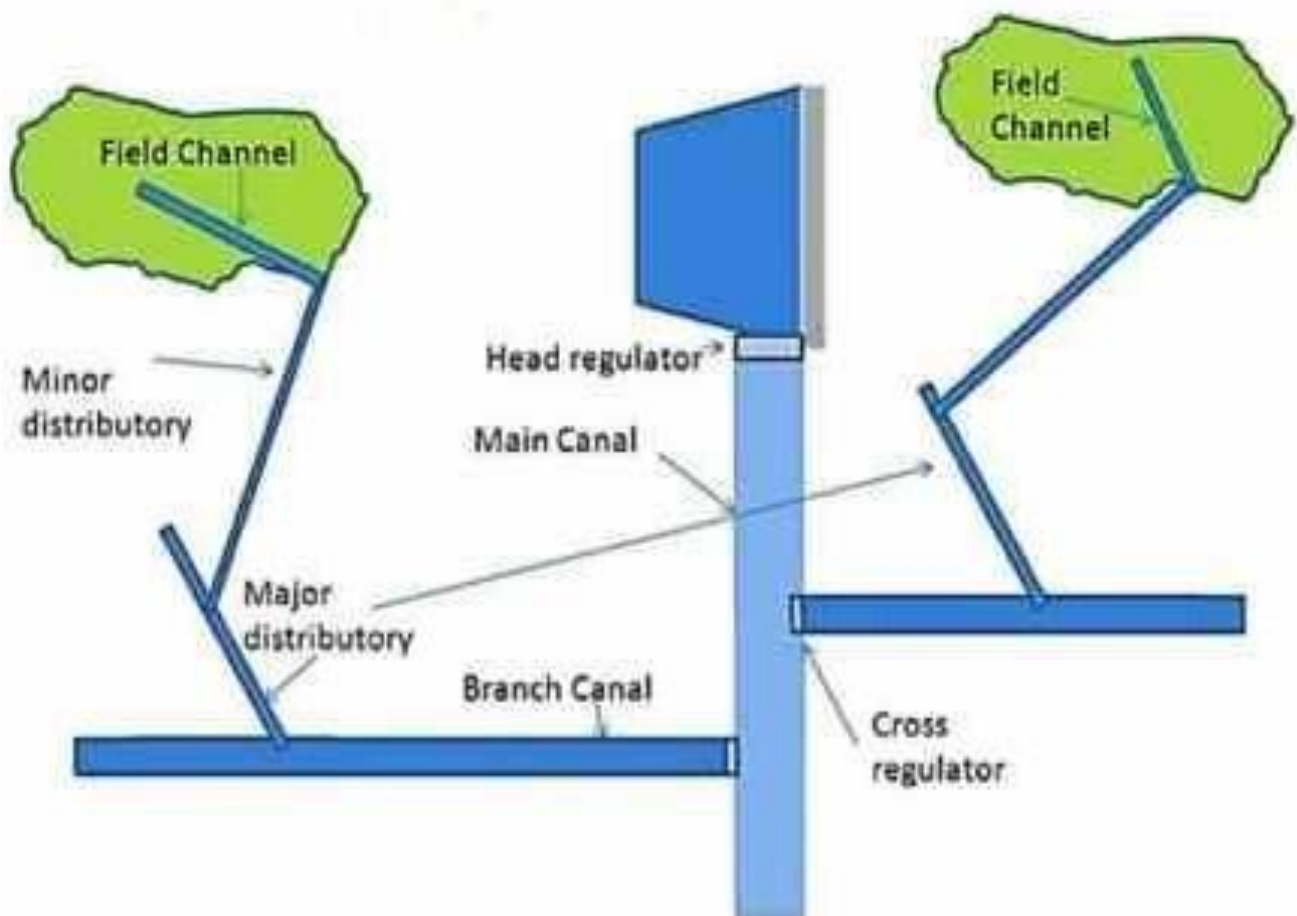
**5.3.1 Main Canal:** it is the principal canal of the network, it generally takes off from the reservoir. Such a canal carries heavy discharge and is not used for direct irrigation. Main canal is intended to supply water to the branch canal and major distributary.

**5.3.2 Branch Canal:** these are canals branching off from the main canal in either direction taking off at regular intervals. The discharge in such canals will be more than 5 cumecs. The main function of a branch canal is to supply water to the major and minor distributaries.

**5.3.3 Major Distributary:** takes off from branch canal. It supplies water for irrigation to the fields through the outlets provided along its length. The discharge in such a canal varies from 0.25 to 5 cumecs.

**5.3.4 Minor Distributary:** it is a canal taking off from the major distributary or a branch canal. The discharge carrying capacity of such a channel will be less than 0.25 cumec.

**5.3.5 Field Channel or Minor:** it is a canal supplying water to the fields directly. It takes off from a major or a minor distributary. These canals even though constructed by the irrigation department, have to be maintained and regulated by the farmer. The discharge in this canal will be less than 0.1 cumec.

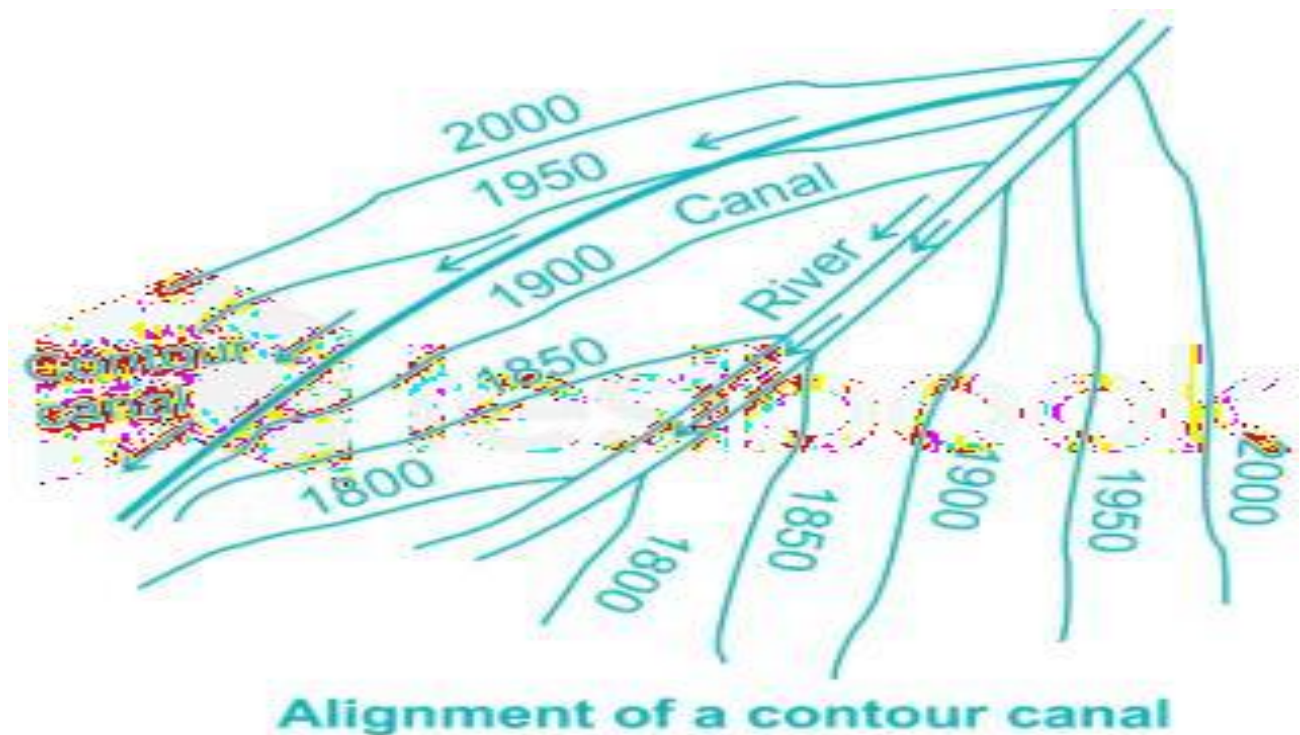


## 5.4 CLASSIFICATION OF CANALS BASED ON THEIR ALIGNMENT:

Based on alignment canals can be classified as:

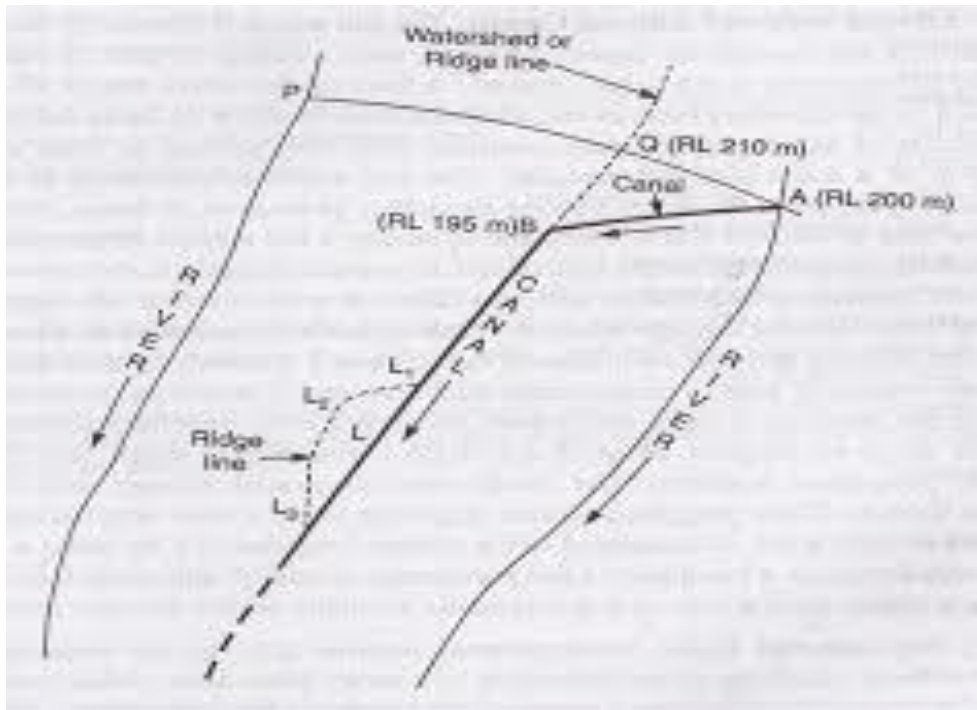
### 5.4.1 Contour Canal:

- It is a canal aligned nearly parallel to the contours of the country as shown in figure.
- It is also known as a single bank canal.
- A contour canal can irrigate only on one side.
- The contour canal does not follow the same contour all along its length due to the fact that some bed slope is necessary for the flow of water under gravity.
- A contour canal has to cross drainage and hence needs canal cross drainage works.



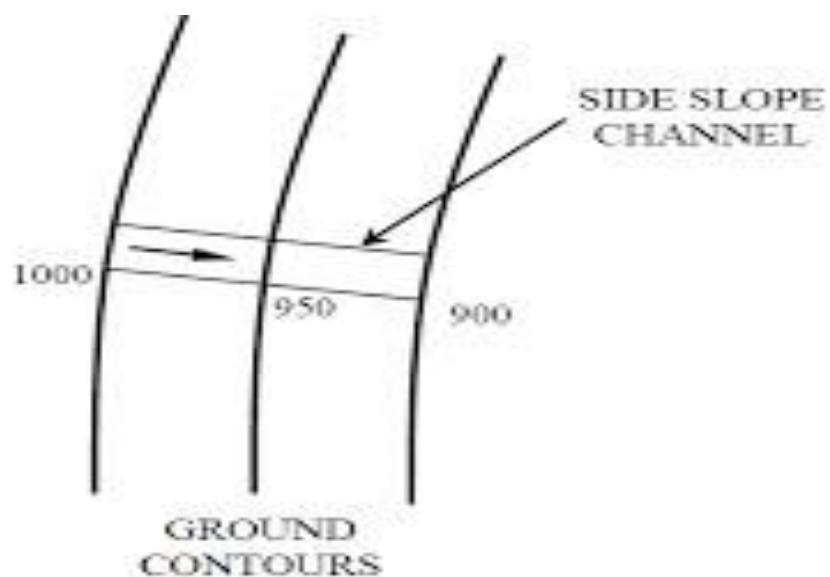
### 5.4.2 Water Shed Canal or Ridge Canal:

- It is a canal which is aligned along the ridge or the natural water shed line as shown in figure.
- Such a canal does not need any cross drainage works.
- Cost analysis reveals that the ridge canals are most economical.
- Sometimes it may be necessary to abandon the ridge line in order to bypass habitations such as villages, towns etc. situated on the water shed.



#### 5.4.3 Side Slope Canal:

- This type of a canal is aligned roughly at right angles to the contours of the country.
- Hence it runs approximately parallel to the natural drainage, thereby cross drainage works are avoided.
- The main disadvantages of such a canal is that it has very steep bed slope of the ground is at right angles to the contours of the country.
- Figure shows a side slope canal.



**Fig: Alignment of a side slope canal**



#### **5.4.4 Detour Canal:**

- A contour canal may have to cross number of C D works.
- A detour canal envisages adoption of a lengthy alignment so that the cost of construction of the canal and its related hydraulic structures are a minimum.
- However, the lengthy alignment of a detour canal may result in loss of command and increased number of C D works.

### **5.5 CONSIDERATION FOR ALIGNMENT OF A CANAL:**

Following are the various consideration for the alignment of a canal.

- The alignment should be such that it ensures the most economical way of distributing water to the land, has the maximum commanded area and minimum number of drainage work.
- The alignment on a watershed being the most economical is preferred.
- The length of the main canal from the point, where it takes off from river to a point where it mounts on a watershed should be minimum.
- The contour alignment should be changed in order to reduce the number of cross drainage works.
- The alignment should avoid villages, roads, places of worship etc.
- The alignment should pass through the balanced depth of cut.
- The number of kinks and acute curve must be minimum.
- Idle length of the canal should be minimum.
- The alignment of the canal should be avoided in rocky, brackish or cracked strata.

### **5.6 DEFINITIONS:**

**5.6.1 Water Requirement of a Crop:** it can be defined as the quantity of water required by a crop in a given period of time for normal growth under field conditions.

**5.6.2 Total Water Requirement:** it can be defined as the quantity of water needed for potential production per unit of land for sustained production and is then sum of consumptive use, application conveyance losses and other special needs.

**5.6.3 Unit Water Requirement:** it is defined as the weight of water actually used by the plants or crops in producing unit weight of dry matter.

**5.6.4 Optimum Moisture Percentage:** it is that moisture corresponding to which optimum growth of plant takes place.

**5.6.5 Readily available Moisture:** it is that moisture which is easily extracted by the plants and is approximately equal to 75% of the available moisture.

**5.6.6 Available Moisture:** it is the difference in water content of the soil between field capacity and permanent wilting.

**5.6.7 Soil Moisture Deficiency or Field Moisture Deficiency:** it is the water required to bring the soil moisture content of the soil to its field capacity.

**5.6.8 Frequency of Irrigation:** it depends on the amount of readily available moisture in the root zone of the plant and the rate of consumptive use, If  $C_u$  is the rate of consumptive use expressed in terms of depth of moisture lost from the soil per day, then frequency of irrigation.

$$f_w = \{d_w / C_w\}, f_w \text{ is expressed in days}$$

**5.6.9 Arid and Semi-Arid Region:** the area where irrigation is a must for agriculture is known as arid region. The area in which inferior crops can be grown without irrigation is known as semi-arid region.

**5.6.10 Gross Commanded Area (GCA):** it is the total area enclosed between the imaginary boundaries line up to which certain irrigation channel is capable of supplying water for irrigation purposes. It includes unculturable areas like small drainages, ponds, forests, buildings, roads, barren land plus the fields on which the crops are grown or can be grown.

**5.6.11 Culturable Commanded Area (CCA):** it is the land on which crops can be grown satisfactorily. CCA can be:

**5.6.11.1 Culturable Cultivated Area:** it is the area of the land on which cultivation practices are performed in the present time.

**5.6.11.2 Culturable Uncultivated Area:** it is the area on which cultivation can be done if thought of it, but presently not cultivated for various reasons.

$$CCA = \{GCA - \text{Unculturable Area of GCA}\}$$

**5.6.12 Intensity of Irrigation:** it is the ratio of irrigated land at a time in one crop season to the culturable command area.

**5.6.13 Rotation of Crops:** it means that nature of the crop sown in a particular field is changed year after year.

**5.6.14 Crop Ratio:** it is the ratio of the areas under the crops of two main seasons.

**5.6.15 Crop Season:** it is part of the year during which a particular crop is grown.

**5.6.16 Rabi Crop Season:** are also known as winter crops. Normally these crops are sown in the month of October and are harvested by the end of March.

**5.6.17 Kharif Crop Season:** are also known as monsoon crops. Normally these crops are sown in the month of April and are harvested by the end of September.

**5.6.18 Hot Weather Crops:** these are the crops sown in February and harvested in May or June.

**5.6.19 Dry Crops:** these are the crops which are ordinarily grown without irrigation, but utilizing the moisture stored in the soil during rainy season.

**5.6.20 Wet Crops:** these are the crops which are grown with irrigation.

**5.6.21 Cash Crops:** these are the crops that can be encashed in the market.

**5.6.22 Crop Period:** it is the total time in days that has elapsed between the sowing of the crop and its harvesting. Hence crop period is the total time during which the crop remains in the field.

**5.6.23 Base period:** it is the total time in days between the first watering done for the preparation of the land sowing of a crop and the last watering done before its harvesting.

**5.6.24 Overlap Allowance:** it is possible that crops of one season may extend into the other season. Hence both the crops need water simultaneously. This extra discharge of water provided for this reason is known as overlap allowance.

**5.6.25 Time Factor:** it is the ratio of the number of days the canal has actually run to the number of days the canal was supposed to run for a particular period of watering as per calculations in the design.

**5.6.26 Capacity Factor:** it is the ratio of the average discharge of a canal at any point to the full supply discharge of the canal at the same point.

**5.6.27 Berms:** they are narrow strip of land left at the ground level between the inner toe of the bank and top edge of cutting.

**5.6.28 Free Board:** is the gap or the margin of height between FSL and top of the bank.

## 5.7 KENNEDY'S THEORY:

- The salient features of Kennedy's theory for the design of earthen channels based on the critical velocity concept and its limitations.
- Kennedy selected a number of sites in upper Bari Doab canal system for carrying out investigations about velocity and depth of the channel.
- As the sites selected by him were more than thirty years old channel.
- As the sites selected by him were more than thirty years old they were assumed to be flowing with non-silting, non-scouring velocity.

Kennedy's investigation revealed the following:

- The silt is kept in suspension due to eddies, also the silt supporting power is therefore proportional to the bed width of the stream and not it's wetted perimeter.
- A velocity sufficient to generate these eddies keeps the sediment in suspension, thereby avoiding sitting up of the channel.
- He designated this velocity as the critical velocity [ $V_o$ ] defined as the mean velocity which just keeps the channel free from silting and scouring.
- Hence established a relation between critical velocity to the depth of flowing water [ $y$ ] as,

$$V_o = 0.55 y^{0.64}$$

- However, Kennedy realized the importance of silt grade on critical velocity and introduce a factors m known as critical velocity ratio in equation there by it can be rewritten as,

$$V = 0.55 m y^{0.64}$$

Where  $m$  = critical velocity =  $\{V / V_o\}$

- Kennedy and Kutter's equation for finding the mean velocity of flow ( $V$ ).

$$V = \left\{ \frac{23 + \frac{1}{N} + \frac{0.00155}{S}}{1 + \left[ 23 + \frac{0.00155}{S} \right] + \frac{N}{\sqrt{R}}} \right\} \sqrt{RS}$$

Where

- $N$  = Manning's Rugosity Coefficient
- $R$  = Hydraulic Radius = [Area / Wetted Perimeter]
- $S$  = Longitudinal slope of the channel bed

Limitations of Kennedy's Theory are:

- Limitations of Kutter's equation become incorporated in Kennedy's design procedure.
- Kennedy did not give any equation for the bed slope of the channel, it is decided and based on the slope of the ground available.

### 5.7.1 Design Procedure:

**5.7.1.1 Case 1:** given, discharge (Q), water surface slope (S), coefficient of rugosity (N) and critical velocity ratio ( $V_o$ ).

#### 5.7.1.1.1 Procedure:

- Assume a trail depth  $y$ .
- Calculate the velocity  $V_o$  for the formula,  $V_o = 0.55 y^{0.64}$ .
- Calculate the area of cross section (A) from the continuity equation,  $A = \{Q / V_o\}$ .
- Calculate the bed width B from the relation,  $A = By + ny^2$ . Where the side slopes  $n$  is assumed as 0.5.
- Calculate the wetted perimeter P from the relation,  $P = B + 2y \sqrt{1 + n^2}$  and hence calculate the hydraulic radius  $R = \{A/P\}$ .
- Calculate the mean velocity V from the Kutter's formula.

$$V = \left\{ \frac{23 + \frac{1}{N} + \frac{0.00155}{S}}{1 + \left[ 23 + \frac{0.00155}{S} \right] + \frac{N}{\sqrt{R}}} \right\} \sqrt{RS}$$

- If the values of the velocities as given by equations are identical, then the assumed depth  $[y]$  is correct, otherwise the procedure has to be repeated.

**5.7.1.2 Case 2:** given, Q, N, m and B/y ratio from wood's table.

#### 5.7.1.2.1 Procedure:

- Calculate A in terms of  $y$ .

$$\text{Let } \{B/y\} = x \text{ therefore, } B = xy$$

$$A = By + ny^2 = xy^2 + \{y^2 / 2\}$$

$$A = y^2 (x + 0.5)$$

- Calculate the velocity V from the Kennedy's equation,  $V = 0.55 m y^{0.64}$ .
- Substituting the values of A and V in the continuity equation, calculate the value of  $y$  i.e.

$$Q = AV = y^2 (x + 0.5) \times 0.55 m y^{0.64}$$

$$y = \left\{ \frac{Q}{0.55 \text{ m} (x+0.5)} \right\}^{\frac{1}{2.64}}$$

- Knowing Y calculate the bed width B and the hydraulic radius R from the relations  $B = n y$  and  $R = \{A / P\}$ .
- Calculate the velocity from the Kennedy's equation,  $V = 0.55 \text{ m} y^{0.64}$ .
- Knowing V and R, determine the slope S from the Kutter's equation by trial and error.

$$V = \left\{ \frac{23 + \frac{1}{N} + \frac{0.00155}{S}}{1 + \left[ 23 + \frac{0.00155}{S} \right] + \frac{N}{\sqrt{R}}} \right\} \sqrt{RS}$$

### 5.7.2 Draw Backs of Kennedy's Theory:

Following are the draw backs of Kennedy's theory.

- It ignores the importance of bed width and depth ratio.
- The draw backs of Kutter's equation are reflected in the Kennedy's theory.
- Adaptation of an arbitrary N value of 0.0225 is incorrect.
- Kennedys' theory aims at the design of average regime channel.
- Kennedy has not given an equation for the slope.
- Silt concentration and bed load are not considered.
- Silt grade and silt charge is not defined.
- Kennedy's procedure is by trial and error only, which means for any value of y there can be number values of B, i.e. the channel need not be an economical section.
- Kennedy simply mentioned the critical velocity ratio (CVR) m, but did not give a procedure to measure it.

## 5.8 LACEY'S THEORY:

**5.8.1 Regime Channel:** according to Lacey a regime channel is a stable channel transporting a regime silt charge. A channel is said to be in regime if it flows in incoherent unlimited alluvium of the same character as that transported and the silt grade and silt charge are all constant.

**5.8.2 Incoherent Alluvium:** it is a loosely composed granular soil which can be scoured with the same ease with which it is deposited.

**5.8.3 Regime Silt Charge:** it is the minimum transported load consistent with fully active bed.

**5.8.4 Regime Silt Grade:** this indicates the range between the small and big particles.

**5.8.5 Regime Conditions:** an irrigation channel is said to be in regime when the following conditions are satisfied:

- The channel is flowing in unlimited incoherent alluvium of the same character as that transported.
- Silt grade and silt charge is constant.
- Discharge is constant.

If all the above conditions are completely satisfied the channel is said to be in true regime. However, in practice this is not possible.

**5.8.6 Initial Regime:** it is the state of the channel that has formed its section only and not yet secured the longitudinal slope.

**5.8.7 Final Regime:** it is the state of the channel after attaining its section and the longitudinal slope.

**5.8.8 Permanent Regime:** this is stage when the channel is protected on the bed and sides with protecting material, so that neither the cross section changes nor its longitudinal slope.

**5.8.9 Design Procedure:**

- Calculate the silt factor  $F$  from the equation,  $F = 1.76 \sqrt{m}$ ,  $m$  = mean particle size in mm.
- Calculate the average velocity from the equation,  $V = \left\{ \frac{Qf^2}{140} \right\}^{\frac{1}{6}}$
- Calculate the area of cross section of the channel from the continuity equation,  $A = \{Q / V\}$ .
- Calculate the wetted perimeters of the channel from the equation,  $P = 4.75 \sqrt{Q}$ .
- Knowing  $A$  and  $P$  and assuming the side slopes of the channel as 0.5H to 1V, calculate the bed width ( $B$ ) and depth of flow ( $y$ ) from the relations
- $A = By + ny^2$  and  $P = B + 2y$ ,  $n = 0.5$  side slope
- Calculate the hydraulic radius,  $R = \{A / P\}$ .
- Also calculate the hydraulic radius  $R$  from the equation,  $R = \{5 / 2\} \times \{V^2 / f\}$ .
- Calculate the bed slope  $S$  from the equation,  $S = \{f^{5/3} / 3340 Q^{1/6}\}$ .

From the above procedure it is very clear that Lacey's method does not involve any trial and error procedure as in the case of Kennedy's theory.

### 5.8.10 Draw Backs of Lacey's Theory:

Following are the draw backs of Lacey's theory.

- The characteristics of regime channel are not precisely defined.
- The true regime conditions as given by Lacey are just theoretical and may not be achieved in practice.
- The value of silt factor  $f$  may be different for the bed and sides, hence the derivation of various equations by considering  $f$  alone is not satisfactory.
- Lacey's theory does not consider the concentration of silt.
- According to Lacey's a regime channel is inherently free from external shock, however a regime channel carries sediment and will normally have a changing pattern of bed ripple transportations, this statement is unlikely to be correct.
- Silt charge and silt grade are not properly defined by Lacey.
- Lacey's equations do not include silt charge.
- Lacey indicate that a true regime channel has a semi elliptical section but it is not supported by any equations.
- The values of  $f$  obtained from various equations of Lacey are often divergent.
- Lacey's equations are empirical, hence the constants are to be determined for different conditions of the channel.

### 5.9 COMPARISON BETWEEN LACEY'S THEORY AND KENNEDY'S THEORY:

Kennedy's Theory	Lacey's Theory
There can be many sections for a given discharge.	Only one regime section is possible for a given discharge and silt factor.
Kennedy simply stated CVR but did not give any method to measure CVR.	Lacey introduce the silt factor $f$ and correlated silt factor to the diameter of silt and rugosity coefficient.
Kennedy did not give any equation for regime velocity, he has adopted Kutter's equation, and hence any limitations of these equations are reflected in the Kennedy's theory.	Lacey has given a definite equation for calculating the velocity.
Kennedy considered depth as variable and gave critical velocity formula in terms of the depth $y$ .	Lacey has considered hydraulic mean radius $R$ as the variable and derived velocity formula in terms



	of R.
Kennedy did not specify regime slope.	Lacey specified regime slope for the given discharge and silt factor.
Basic theoretical conception of silt transportation is same as that of Lacey. The eddies generated from the sides are ignored.	Theoretical conception of silt transportation is that silt is kept in suspension by vertical components of eddies caused by friction against wetted perimeter.
Kennedy considered channel section as trapezoidal.	Lacey considered the channel to be semi elliptical.
Section is wider and shallower.	Section is tighter and deeper.
According to Kennedy channels are said to be in regime when they neither silt nor scour.	Lacey considered that channels cannot be in true regime and hence classified them into initial and final regime.
Kennedy did not consider the importance of bed width and depth ratio and has just selected these values from wood's table.	Lacey has given a definite formula for the wetter perimeter for a given discharge.
Kennedy's theory is applicable to irrigation channels only.	Lacey's theory is applicable to irrigation channels as well as rivers.

Lacey's theory has the following additional merits:

- It is more rational as it gives more quantitative relation between discharge, grain size and coefficient of rugosity.
- There is only one canal section, wetted perimeter and hydraulic radius for a given discharge slope and silt factor.
- It does not involve any trial and error procedure.
- Specified separate design equations for perfect regime.

## 5.10 RESERVOIRS:

### 5.10.1 Introduction:

Construction of a dam, barrage across a river results in the formation of a reservoir, which is nothing but huge storage of water. This water is stored during the period when the inflow is in excess of the demand on the downstream side. The water stored may be used for irrigation, hydroelectric power, domestic usage, industrial usage, recreation and so on. Apart from the said factors a reservoir helps in controlling the floods, improvement in climate, reduction in river pollution, check on spread of diseases due to improved water supply and sanitation. Finally reduction in the river section of river cross section thereby

considerable area is made available for cultivation. On the other hand formation of a reservoir would have disadvantages like: submergence of fertile lands, displacement of large population, possible adverse effects on the ecology of the area, entrapping of fertile sand and displacement of wild life.

#### **5.10.2 Definition:**

A reservoir is a large body of water stored on the upstream side of a dam constructed across a river. Therefore, a reservoir and a dam exist together.

### **5.11 CLASSIFICATION OF RESERVOIRS:**

Depending upon the purpose served, reservoir may be classified as.

#### **5.11.1 Storage Reservoir:**

- A storage reservoir also known as conservation reservoir, mainly serves the purpose of conserving water.
- Essentially water is stored during monsoon and released gradually for intended purpose like irrigation, water supply or hydropower.
- Such a reservoir also helps in moderating the floods and reducing the flood damage to a certain extent.
- However, it is not designed as a flood control reservoir.

#### **5.11.2 Flood Control Reservoir:**

- A flood control reservoir serves the purpose of flood controlling by protecting the areas on the downstream side.
- It is also known as flood mitigation reservoir or flood mitigation or flood protection reservoir.
- Flood water from this type of reservoir is discharged or let out till the outflow reaches the safe capacity of the channel.
- When once the safe capacity is exceeded flood water is stored in the reservoir.
- This type of reservoir is therefore designed to moderate the flood and not to conserve water.

#### **5.11.3 Multipurpose Reservoir:**

- A multipurpose reservoir is designed and constructed to serve more than one purpose.
- Most of the reservoirs are multipurpose reservoirs.

#### **5.11.4 Distribution Reservoir:**

- A distribution reservoir is a small storage reservoir which helps in storing water during period of lean demand and supplies during the period of high demand.
- Such type of reservoir so as take care of water supply for irrigation.

#### **5.11.5 Balancing Reservoir:**

- A balancing reservoir is a small reservoir constructed downstream of the main reservoir so as to store water released from the main reservoir.

### **5.12 INVESTIGATION FOR RESERVOIR:**

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

#### **5.12.1 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 levelling.
- 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 up to 200m upstream, 400m downstream and for adequate width beyond the two abutments.
- For a **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 up to an elevation of 3 to 5 m higher than the anticipated maximum water level.

#### **5.12.2 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.

### 5.12.3 Hydrological Investigations:

Following purpose demand the hydrological investigations.

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

### 5.13 SELECTION OF SITE FOR A RESERVOIR:

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

**5.13.1 Large Storage Capacity:** the topography of the proposed site should be such that the reservoir has large capacity for storing the water.

**5.13.2 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.

**5.13.3 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.

**5.13.4 Good Hydrological Conditions:** the hydrological conditions of the river at the reservoir should give high yield. Evaporation, transpiration and percolation losses should be minimum.

**5.13.5 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.

**5.13.6 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 submerge.

**5.13.7 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.

**5.13.8 No Objectionable Minerals:** the proposed site should be free from soluble and objectionable salts, which may pollute the reservoir.

**5.13.9 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.

## 5.14 STORAGE ZONES OF A RESERVOIR:

Based on relative water levels, the storage zones of a reservoir are represented in figure they are.

**5.14.1 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.

**5.14.2 Surcharge Storage:** is the volume of water stored above the full reservoir level (FRL) up to the maximum water level (MWL).

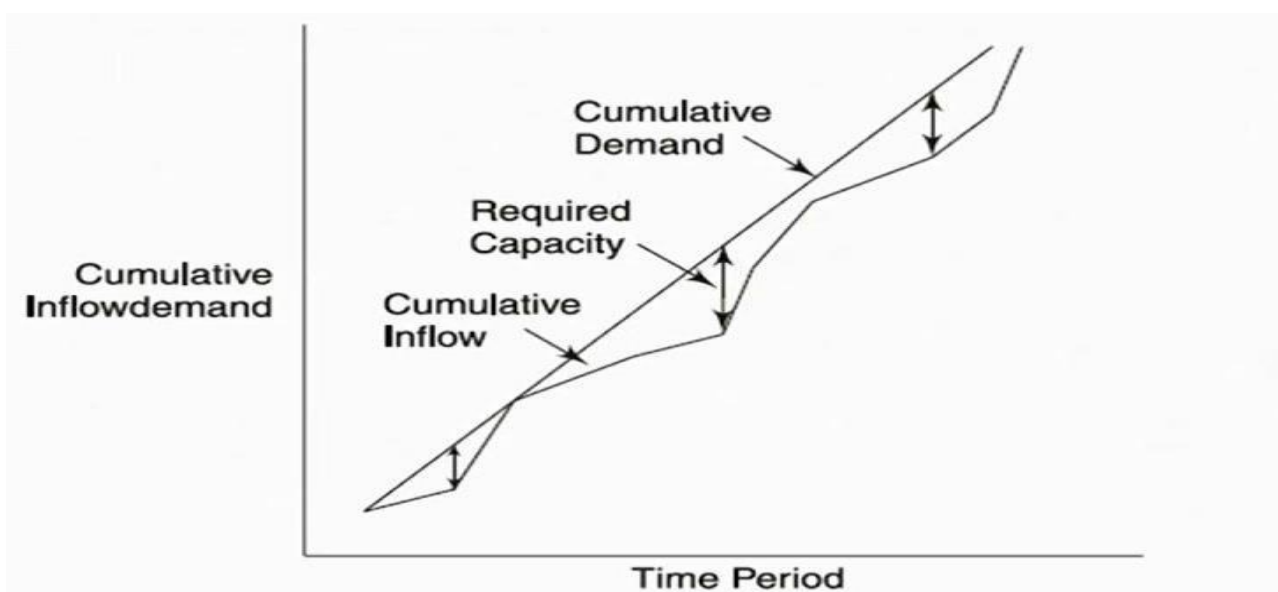
**5.14.3 Dead Storage:** is the volume of water held below the minimum pool level. This storage is not useful and hence cannot be used for any purpose under ordinary operating conditions.

**5.14.4 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.

**5.14.5 Valley Storage:** is the volume of water held by the natural river channel in its valley up to the top of its banks before the construction of the reservoir.

## 5.15 MASS CURVE:

Mass curve is a graphical representation of cumulative volume of water in the reservoir versus cumulative time. It will be a continuously raising curve as shown in figure.



## 5.16 FIXING CAPACITY OF A RESERVOIR:

Capacity of a reservoir depends on the inflow and demand. It is 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:

### 5.16.1 Mass Curve or Graphical Method:

The procedure adopted will be as follows.

- Prepare the mass inflow curve for the flow hydrograph of the site for a number of consecutive years including the most critical years i.e., when the discharge is low. Figure shows the mass inflow curve.
- 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 figure. The scale selected for plotting of the mass inflow and mass demand curve should be the same.
- 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 crest at A, F etc. of the mass inflow curve points A, F etc. indicate the beginning of dry periods marked by the depressions.
- 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:

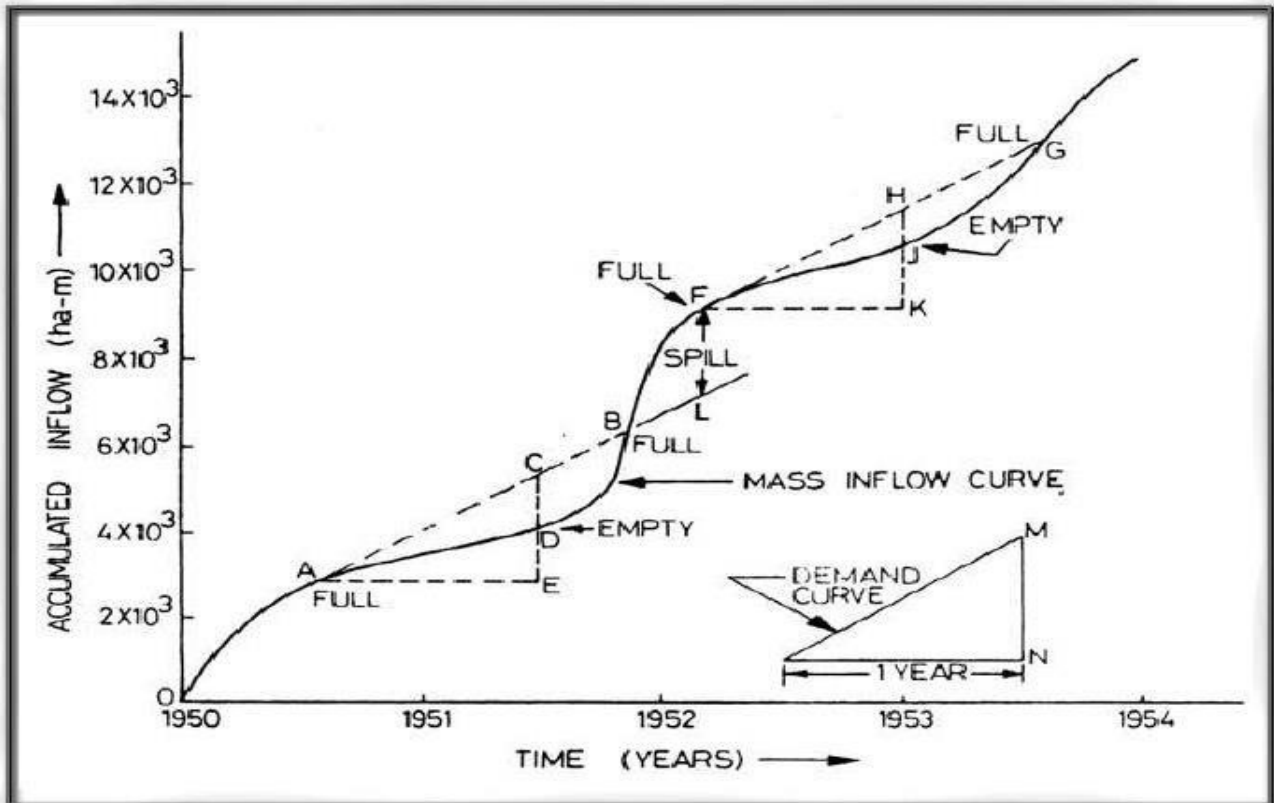
Assuming that the reservoir is full at point A, the inflow volume during the period AE is equal to ordinate DE and the demand is equal to ordinate CE. Thus the storage required is equal to the volume intercepted by the intercept CD.

- Determine the largest of the vertical intercept determined in step 4. The largest vertical intercept represents the storage capacity required.

Following important points have to be noted:

- The capacity obtained is 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 intersect 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 fall again. Many times very large reservoir may not get refilled every year.
- The vertical distance such as FL between the successive tangents represent the volume of water flowing over the spillway.

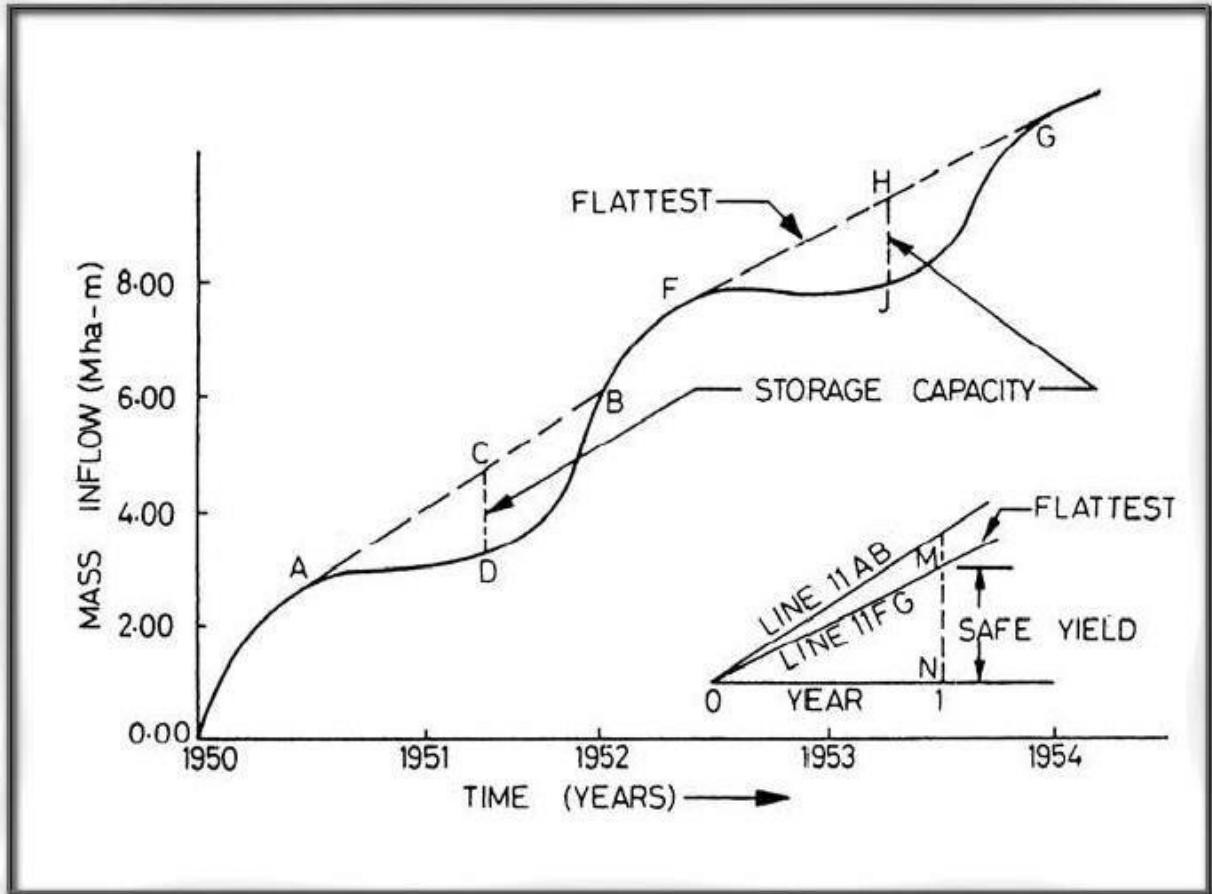


#### 5.16.1.1 Determination of Yield of a Reservoir:

Determination of yield from a reservoir of known capacity can be done by using the mass inflow curve. This method is just the reverse of the method of determining the reservoir capacity. The procedure for determining the reservoir yield is as follows:

- Prepare the mass inflow curve from the flow hydrograph of the river and shown in figure.
- Draw tangents AB, FG etc. at the crest A, F etc. of the mass inflow curve in such a way that the maximum slope (intercept) of these tangents from the mass inflow curve is equal to the capacity of the reservoir.
- Measure slopes of all tangents drawn in the previous step and determine the slope of the flattest tangent.

- Draw the mass demand curve from the slope of the flattest tangent as shown in figure. The yield is equal to the slope of this line.



#### 5.16.2 Analytical Method for Determination of Storage Capacity:

Following analytical procedure is adopted in determining the storage capacity of a reservoir.

- The stream flow data at the reservoir site is collected during dry period (month wise). In case of very large reservoir annual inflow rates may be used.
- The discharge to be released on to the downstream side in order to meet the water requirements is estimated.
- The direct precipitation falling on the reservoir is calculated month wise.
- The evaporation losses from the reservoir is estimated by a suitable method.
- The monthly demands are estimated.
- The adjustable inflow during different months are calculated as follows:

$$\text{Adjustable inflow} = \{\text{Stream flow} + \text{Precipitation} - \text{Evaporation} - \text{Downstream Discharge}\}$$

- The monthly storage capacity is computed:



$$\text{Storage required} = \{\text{Adjustable Inflow} - \text{Demand}\}$$

- The storage capacity of the reservoir would be the sum of all the storages determined in the previous step.

### **5.17 ECONOMIC HEIGHT OF DAM:**

- Economic height of a dam can be theoretically defined as that height for which the cost of the dam per million cubic meter of storage is minimum.
- The height of the dam is determined by preparing approximate estimate of cost of several heights of dam at a given site, somewhat above and below the level, where the elevation storage curve shows a fairly high rate of increase of storage per meter of elevation, while at the corresponding elevation the cross section of the dam site shows the length of the dam to be moderate.
- When once the approximate cost per million cubic meter of storage for about five or six alternatives, the cost per million cubic meter of storage is plotted against height to determine the most economical height of the dam.

### **5.18 RESERVOIR SEDIMENTATION:**

Sedimentation of a reservoir is a major problem all over the world and no economical solution is proposed to overcome this problem, except providing a dead storage for accommodating the sediments. The main reason for sedimentation are disintegration, erosion, transpiration and sedimentation.

#### **5.18.1 Mechanism of Reservoir Sedimentation:**

- Reservoir sedimentation is almost similar to those in delta made by a river, before joining the sea or ocean.
- The bottom layers comprise of fine sediments, next layer of coarser sandy sediments with the top most layers consisting of coarser particles.
- Sediment is a product of erosion in the catchment area of the reservoir and hence the rate of erosion smaller would be the sediment load entering the reservoir.

#### **5.18.2 Factors Affecting Sedimentation:**

- Extent of catchment area.
- Amount of sediment load in the river.
- Type of rainfall and snow fall.
- Mean monthly and annual temperature.

- Monthly and annual rainfall from the catchment or sub catchment.
- Slope of catchment.
- Vegetation of catchment.
- Geological formations of the catchment.
- Presence of upstream reservoir and the extent of trapping of sediment there in.
- Quantity of sediment flushed through sluices.
- Degree of consolidation of the accumulated sediment due to weathering.
- Operation schedule of the reservoir.