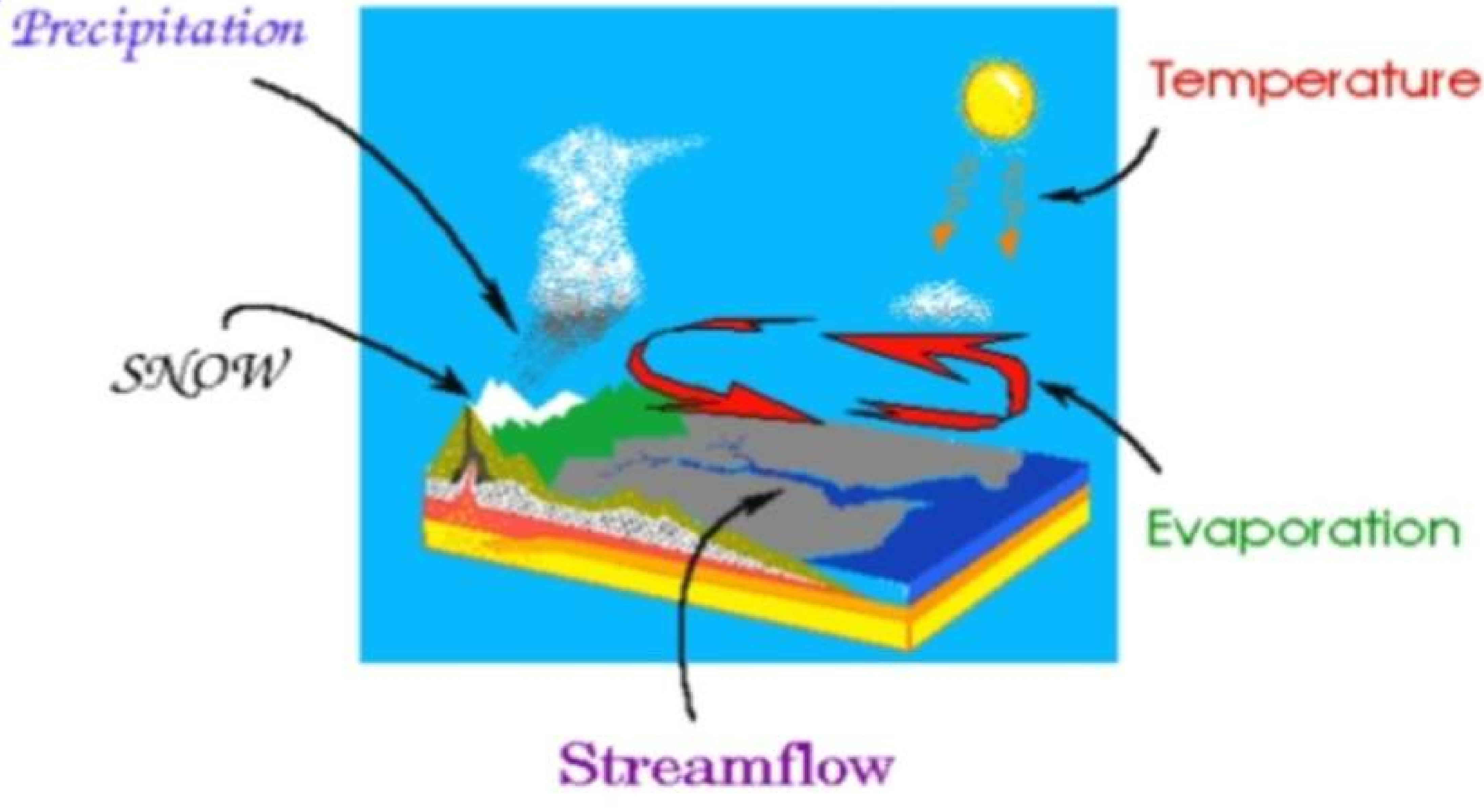
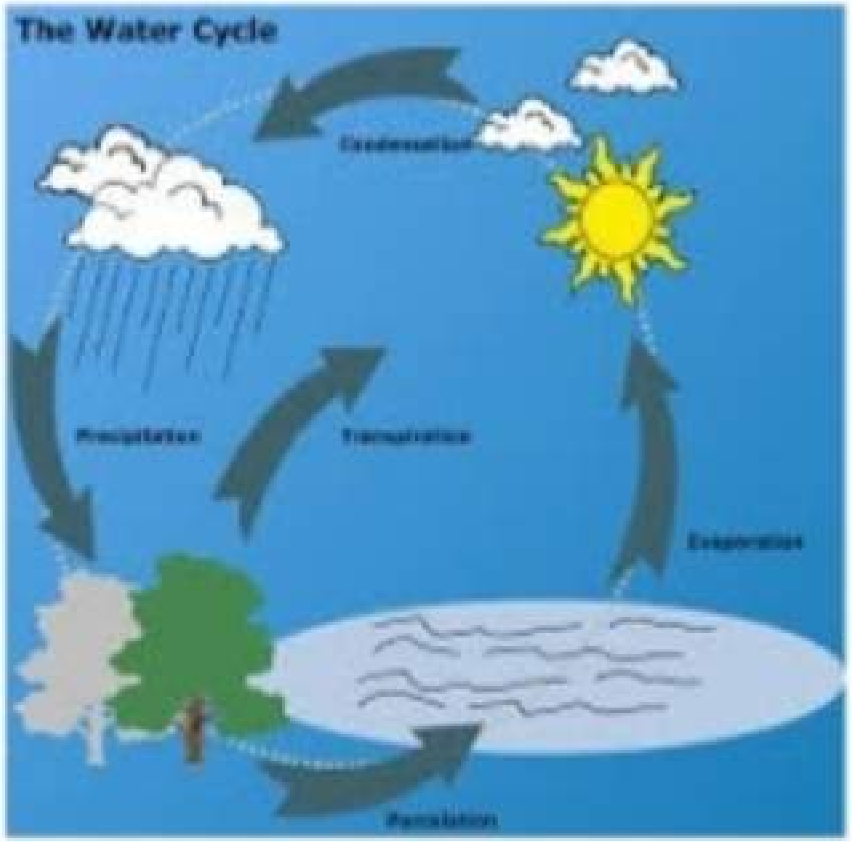
Hydrologic Cycle



This is about the movement of water on Earth

- Hydrologic Cycle is also called Water Cycle.

It deals with the origin and distribution of water on the globe.



- Complex pathways include passage of water from gaseous stage in the atmosphere to oceans, lakes, rivers etc.

Hydorlogical Process

- Hydrological cycle includes the following processes: **evaporation, condensation, precipitation, interception, infiltration, percolation, transportation, runoff and storage.**

HISTORY

The chronology of various phases of development of the science of hydrology can be broadly visualized as follows:

i. Speculation of concepts — up to 14th century
ii. Observations — 15th to 16th century
iii. Measurements — 17th century
iv. Experimentations — 18th century
v. Modernisation — 19th century
vi. Quantification of empirical formulae — 1900 to 1930
vii. Rationalisation of hydrologic theory — 1930 to 1950
viii. Theorization by mathematical analysis — 1950 to date

- Although up to the end of 14th century hydrological concepts were only speculated many hydraulic structures were constructed. The great works known in the history are the Abassinian wells, the Persian kanats, the Egyptian and Chinese irrigation systems, the water supply and drainage systems of Indus valley, the Roman aqueducts, Chinese flood control works etc.
- In the subsequent two centuries the trends of mere speculation changed to close observation. During this period Leonardo da Vinci recognized the hydrological cycle as is accepted today.

- In the eighteenth century numbers of hydraulic experimental studies in the field of hydrology were performed. As a result various hydraulic principles were discovered. Notable among them are Bernoullis piezometer, the Borda tube, the Pitot tube, Bernoulli's theorem, Chezy's formula etc. These developments vastly contributed towards taking up of quantitative hydrologic studies.
- In the nineteenth century the experimental studies were greatly modernised. All these activities laid a firm base of modern science of hydrology. Majority of the contributions were related to groundwater hydrology and surface water measurement. Darcy's law of groundwater flow, Dupit's well formula, Hagen-Poiseuille's equation of capillary flow, Francis weir discharge formula.
- Upto the end of the nineteenth century the science of hydrology was largely empirical. It was so because the physical basis for many quantitative hydrologic determination was not well known.
- During the period from 1930 to 1950 many great hydrologists emerged who gave rational basis to solve hydrological problems in place of empirical solutions.
- Since 1950, increasingly theoretical approaches have been adopted in hydrologic problems.

WATER BUDGET EQUATION

Water budget equation and world water balance:

P = R + L   or

Precipitation = Runoff + Losses

In the above equation precipitation indicates total supply of water from all forms of falling moisture and mainly includes rainfall and snowfall. The runoff represents surplus water that flows over the surface to join some river or sea.

WATER WORLD BALANCE

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Application in Engineering:

Success of any water resources development project depends on timely and sufficient availability of water. Naturally proper assessment of this natural resource assumes great importance. By assessment we try to know in detail from where the resource comes, where it goes, at what time or when it comes and how much of it is really available.

Data sources

Sources of hydrological data

If you are looking for useful sources of data, the list attached (in Excel format) is not exhaustive but provides some pointers.

For example, there are links to where you can access :

- Catchment Flood Management plans
- Climate Records
- Flood maps
- Gauged flow records
- Groundwater vulnerability maps
- Hydrological summaries
- MORECS
- Groundwater level records
- Water quality
- Water resources data

31.2. FORMS OF PRECIPITATION

The precipitation takes place in many different forms in the regions located in the middle latitudes. Typical characteristics of various forms of precipitation are explained below.

(*i*) **Rain:** It consists of water drops mostly larger than 0.5 mm in diameter.

(*ii*) **Drizzle:** They are tiny water droplets of size between 0.1 to 0.5 mm which fall with such slow settling rates that they occasionally appear to float.

(iii) **Snow:** It is that type of precipitation which results from sublimation, *i.e.*, water vapour directly changes into ice. It falls as white or translucent ice crystals often agglamrated into snow flakes. The specific gravity of snow is often taken to be 0.1.

(iv) **Hail:** It is the precipitation in form of lumps of ice. The hailstones are produced in convective clouds mostly cumulonimbus. Their shape may be conical, spheroidal or irregular. The size of hail stones may be anything more than 5 mm. The specific gravity of hail stone is about 0.8.

(v) **Snow pallets:** Some times they are called soft hail also. Snow pallets are more crisp and are of size 2 to 5 mm. Due to their, crispness upon hitting the hard ground they often break up.

(vi) **Sleet:** When the rain drops fall through the layer of sub-freezing air near the earths surface the rain drops get frozen to ice stage. It is called sleet or grains of ice.

31.5. MEASUREMENT OF RAINFALL

The yearly rainfall, is expressed in centimeters or millimetres of depth over a particular over which precipitation takes place.

Definition of one centimetre of rainfall: Suppose the water precipitated on a certain plain area in the form of a rainfall is not lost by any means and if there is no runoff and evaporation what so ever then all the water will go on accumulating on the surface of the area in the form of a sheet of water. When the sheet of this deposited water is one centimetre thick, one centimetre of rainfall is said to occur.

Rainfall can be measured by a **rain-gauge**. A rain-gauge may be of two types:

1. Non-recording type, and
2. Recording type or automatic

1. Non-recording type rain-gauge: It gives only total rainfall occurred during particula time period. Recording type rain-gauge gives hourly rainfall. Under non-recording type rain gauges, one most commonly used in **Symon's rain-gauge**. This type is mentioned below. I is the simplest in principle, construction and working.

Principle: From the definition of unit rainfall it is clear that the definition is independent of extent of area. That is so far as only measurement of rainfall is concerned area under consideration may be large or small. Now taking smallest possible area, if the water, which comes down as rainfall, is collected before the losses take place or water runoff then the depth of this water over the small area can be quite accurately determined to give the amount of rainfall occurred in proper units (centimetres). The small area should be selected in such a way that its meteorological characteristics are similar to that particular large area which it represents.

Construction: It consists of a funnel and a receiver mainly. The receiver is a cylindrical (zinc) metal bottle. The diameter of the bottle and the topmost diameter of funnel is 127 mm. The funnel is fitted in the neck of the bottle.

Both are then placed in a metal casing with suitable packings. The base of the metal casing is enlarged to 210 mm. The capacity of the bottle is such as to measure extremes of rainfall likely to occur in 24 hours. Zinc receivers hold 175 mm to 1000 mm according to size. Gauge is provided with one measuring graduated jar which measures the water in mm. The smallest division on the jar is 0.2 mm. The rainfall should be estimated to the nearest 0.1 mm. See Fig. 31.4.

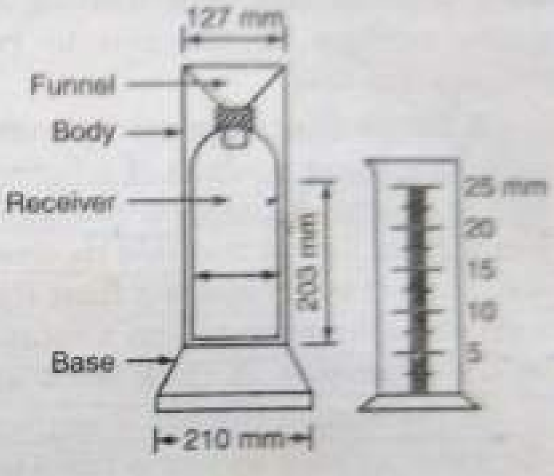


Fig. 31.4. Symons non-recording type rain-gauge

At the site where rainfall is to be measured concrete block us constructed. The base of the gauge is permanently fixed in the block in such a way that the top of the casing about 30 cm above natural surface level. While fixing the base of the gauge precaution is taken to level it perfectly. The rain-gauging station is protected by barbed. wire fencing with a gate. The size of the concrete foundation block should be 60 cm × 60 cm. The necessity to keep the rim of the funnel above the natural surface by 30 cm is two fold.

(*i*) It prevents splashing of water into the funnel almost to a negligible amount.

(*ii*) If the height is kept more than 30 cm the amount of rain water collected decreases owing to wind eddies set up by the gauge itself.

Working: The gauge is adjusted every day for measurement of rainfall. When rainfall occurs the rain water covering area of the funnel passes to the receiver before any sort of loss takes place. After every 24 hours the rainfall is measured. Usually the measurement is taken at 0830 hr. I.S.T. the received water is poured carefully in the measuring jar to measure daily rainfall. If it is raining at the time of observation, it is necessary to do the measurements very quickly. If found essential spare receiver may be placed immediately in the body after previous receiver is taken out. The total amount of rainfall measured during the previous 24 hours should invariably be entered against the date of measurement irrespective of the fact whether the rainfall was received on the date of measurement or on the previous data after yesterday's measurement.

Totaliser: Sometimes unavoidably rain-gauge is to be installed at such a location which is not easily accessible in unfavourable climate. Then it is not possible to measure the rainfall every day at 0830 hr I.S.T.

In such cases a different type of non-recording gauge is used. It is called **totaliser**. It is in the form of a can. To accommodate 1220 mm of rain upper and lower diameter of the can is kept 203 mm and 610 mm respectively. Since, the observer goes at a longer interval it is essential to provide some arrangement to minimise evaporation loss. Generally a wind screen is mounted on the can to stop evaporation loss. Some times a thin layer of oil is also kept floating at the water surface in the can to reduce evaporation loss.

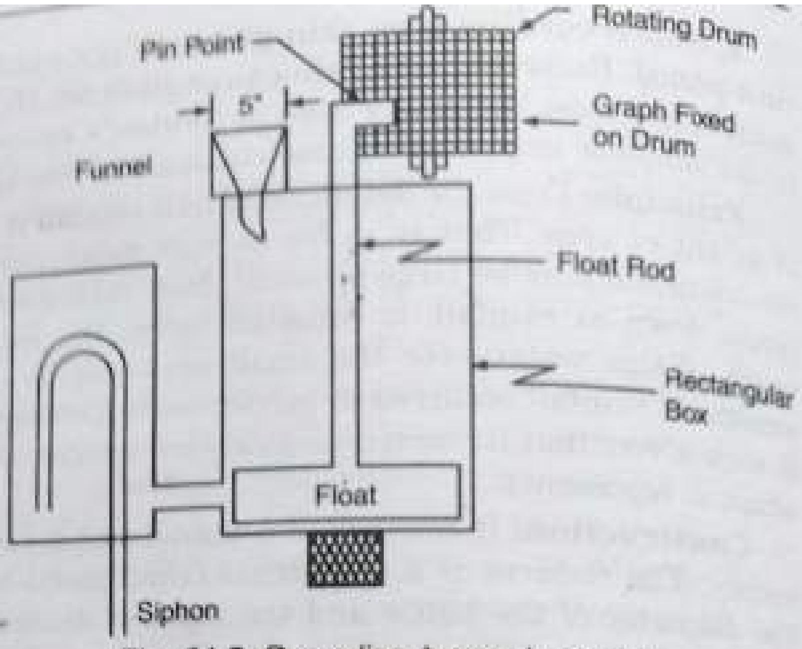


Fig. 31.5. Recording type rain-gauge

2. Recording type rain-gauge: The recording gauge consists of a funnel 127 mm in diameter fixed on one side of a rectangular box. It is called receiver also. In the rectangular box a float is adjusted. The float is connected by means of a float rod to a pin point (or a recording pen). The pin point touches a graph paper mounted on a rotating drum. The drum is mounted on the top of the receiver on the other side. A clock work arrangement revolves the drum once in 24 hours.

At the bottom the box is connected to a siphon. The siphon comes into action and releases the water as soon as box is filled to a certain level. Figure 31.5 shows complete arrangement. It is called natural siphon type recording rain-gauge.

As the rainfall starts rain water passes through the funnel into the box. As the water level in the box rises the float is also raised. In turn the pin point moves on the graph to plot a mass curve of rainfall.

When the box is filled to such an extent that the float touches the top, the siphon starts working and the rain water collected in the box is drained out.

Mass curve principle of integrating rain-gauge. The recording type rain-gauge is also called integrating rain-gauge. The reason is that the curve obtained on the graph is a cumulative curve in respect of rainfall. On y-axis we get accumulated or integrated rainfall and on x-axis we have equal time increment. This type of curve in which one ordinate gives accumulated values is called a mass curve. On the graph mounted on the rotating drum we get the mass curve of rainfall (Fig. 31.6).

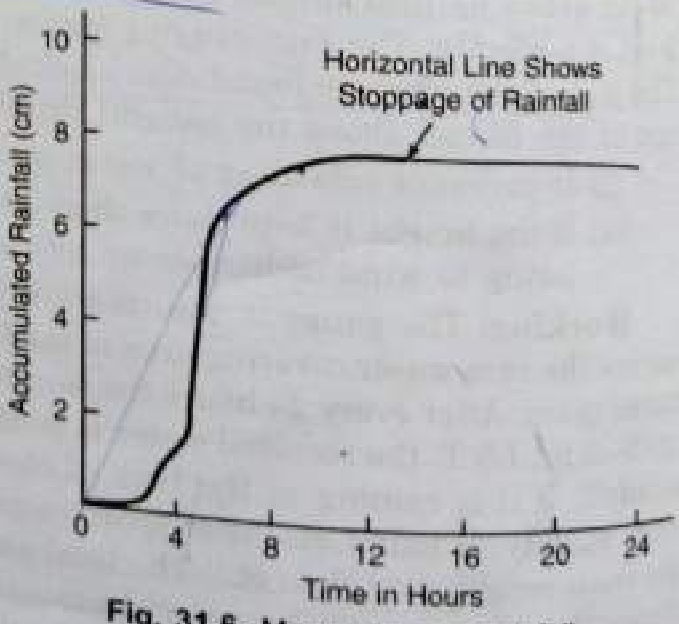


Fig. 31.6. Mass curve of rainfall

Tipping bucket type rain-gauge for remote recording: To facilitate remote recording of rainfall a new type of rain-gauge is used. It is called tipping bucket type rain-gauge. In this type a pair of tipping buckets is placed below a funnel. The bucket gets filled up by 0.25 mm of rainfall and immediately it tips and empties the water into a chamber below. At that very instant other bucket comes below the funnel to receiver rain water. The tipping of the bucket actuates an electrical circuit which moves a pointer to register the rainfall on a graph. The water collected in the chamber, below could also be measured by a measuring jar.

31.7. NETWORK OF RAIN-GAUGES

The network of observation stations has to be properly designed to cover all the representative portions of the basin area with due care to the topography, orography so as to get equitable coverage of spatial variations in the basin. The broad guide lines set up for the required network of rain-gauge stations as per World Meteorological Organisation (WMO) is as follows:

For plain areas of the basin:

1 rain-gauge for every 500 sq km.

For hilly areas of the basin:

1 rain-gauge for every 150 sq km.

Installation of self-recording gauge also needs due importance in a network of rain-gauge stations of the basin. Generally not less than 10% of the stations should have self-recording rain-gauges for proper evaluation of storm. The number of rain gauging stations in any basin will obviously depend upon extent of area in addition to the factors mentioned above. The number of rain-gauging stations for various sizes of the basin are given below to give broad indication (Table 31.1).

Table 31.1.

Area of basin (sq km)	*Number of rain gauges*
Less than 125	1
125 to 250	2
250 to 500	3
500 to 1000	4

31.12. AVERAGE OR MEAN DEPTH OF PRECIPITATION

In a particular basin if the rain gauging stations installed are more than one then while finding out the quantity of rainfall, question may arise as to which value of rainfall, question may arise as to which value of rainfall should be taken. From the existing values no one can be chosen for the purpose because each rain gauging station has its own domain to which it correctly represents. Therefore, it is essential to find one such value of rainfall which represents The whole area. When there is only one rain-gauging station then the value of rainfall recorded by the gauge will obviously by the average value. There are three main methods of calculating average depth of precipitation upon the area of the basin.

1. Arithmetic mean
2. Theissen polygon method
3. Iso-hyetal method

1. Arithmetic mean: When the area of the basin is less than 500 square km this method implies summing up of all the rainfall values from all the rain-gauging stations and then dividing it by the number of stations in that basin. The method becomes very clear by the use of a tabular forra.

Rain gauging station	*Rainfall in cm*
A	5.6
B	4.9
C	5.2
D	5.5
Σ 4	Σ 21.2

$$\text{Now average depth} = \frac{\Sigma \text{ Rainfall values}}{\text{Number of stations}} = \frac{21.2}{4} = 5.3 \text{ cm.}$$

To explain, there are in all four rain-gauging stations A, B, C, D in the basin, whose rainfall values are given in the table. Sum of the rainfall values comes out to be 21.2 cm. It is divided by number of stations to give average depth of precipitation which comes out to be 5.3 cm.

This method gives accurate results if the stations are uniformly distributed over the area. There should not be much variation in the rainfall values of the stations under consideration.

Drawback of the method is the stations just outside of the basin are not considered although these stations might have some influence on the basin under consideration.

31.19. DEPTH-AREA-DURATION CURVES

Once the sufficient rainfall records for the region are collected the basic or raw data can be analysed and processed to produce useful information in the form of curves or statistical values for use in the planning of water resources development projects.

Many hydrologic problems require an analysis of time as well as areal distribution of storm rainfall. Depth-Area-Duration (DAD) analysis of a storm is done to determine the maximum amounts of rainfall within various durations over areas of various sizes. The preparation of DAD curves is done in following steps:

1. Examine the rainfall records of the region in which catchment area under considerations is located. Also consider records of meteorologically similar regions. From it prepare a list of most severe storms with their dates of occurrence and duration.
2. For the listed severe storms prepare isohyetal maps and determine the rainfall values over the area of each isohyet (rainfall contour).
3. Draw on a graph curves connecting area and rainfall values for different durations say 1 day rainfall, 2 day rainfall, 3 days rainfall (Refer Fig. 31.12).

The curves shown in Fig. 31.12 are called Depth-Area-Duration DAD curves.

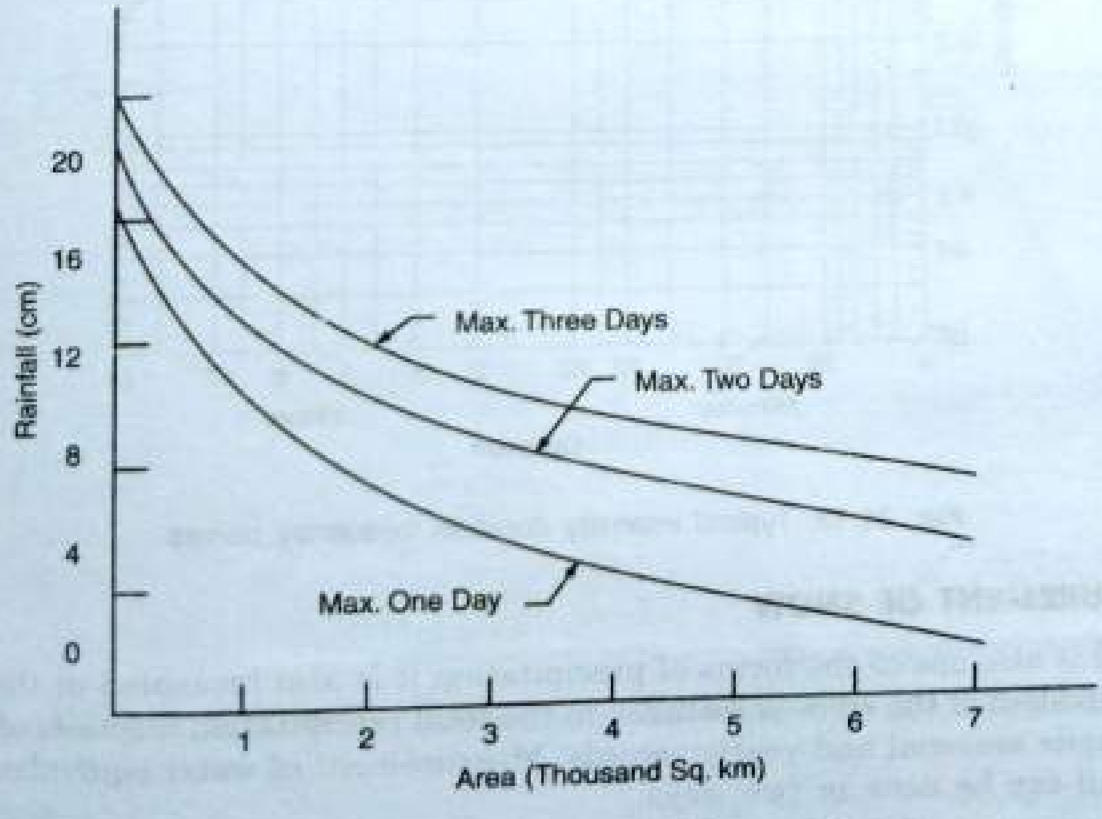


Fig. 31.12. Depth-Area-Duration curves

Use of D.A.D curves: Although most severe storm in the listed storms may not have occurred right over the catchment under consideration there is possibility of such occurrence. So from D.A.D. curves 1 day, 2 day, 3 day rainfall depths for the catchment area of the proposed project are read. These give the rainfall depths when the storms is centered over the catchment.

31.20. INTENSITY DURATION FREQUENCY CURVES

In hydrology frequency analysis of station rainfall data is done for use in design of bridges and culverts on highways, design of storm drains etc. With the advancement of science of hydrology rainfall frequency analysis is done using Gumble's extreme-value distribution and annual series data. Now the frequency analysis concept records applied on a seasonal basis and for areal frequency. The rainfall records of deficient length have to be extended by station year method. The results of frequency analysis are plotted on the log-log paper. The typical intensity-duration frequency curves are given in Fig. 31.13.

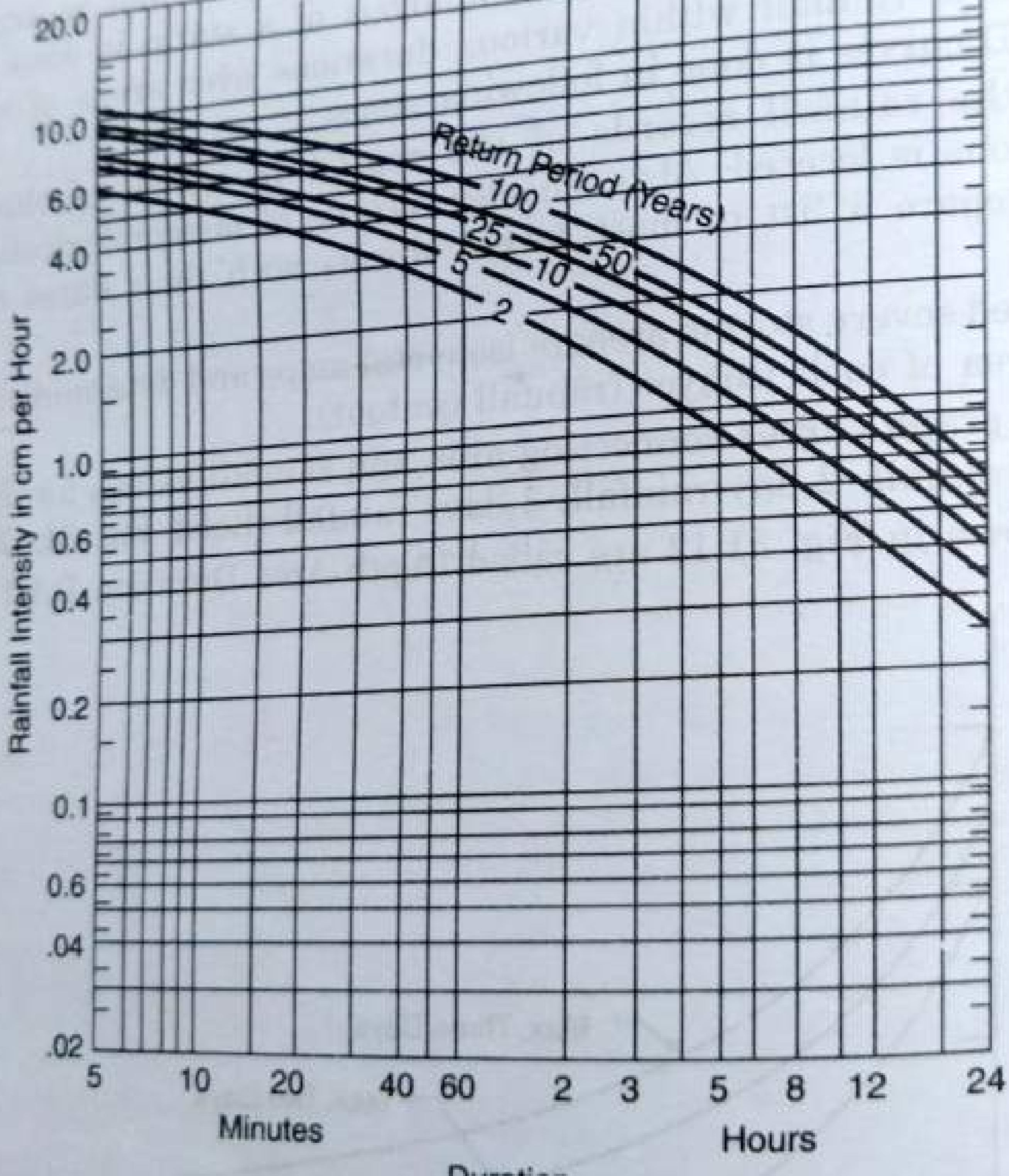


Fig. 31.13. Typical intensity duration frequency curves

31.16. HYETOGRAPH OF RAINFALL

The hyetograph shows the average rainfall rates, over the specified drainage catchment, during successive units of time during a particular storm (Fig. 31.10).

To prepare the hyetograph from given storm, the rainfall quantities during successive units of time are measured from the mass curves of stations in and near the drainage basin. A unit time of 1 to 6 hours as convenient may be selected. The average rainfall depths over the basin for successive units of time are computed from the tabulated data by the Theissen polygon method or isohyetal method. The hyetogrpah is then drawn by plotting the average rainfall depth per unit of time as shown in Fig. 31.10.

The hyetograph is very convenient in relating the rainfall over the basin with the resulting flood hydrograph. It is usually plotted on the same sheet where hydrograph is plotted. Only thing is it plotted upside down whereas hydrpgraph is plotted errect (Fig. 31.11).

The hyetograph of a storm when plotted by the side of the flood hydrograph gives the time lag between rainfall and peak flow. It also gives important information about effective duration of storm which produces run-off. The use of hyetograph is commonly made in flood estimation by unit hydrograph method.

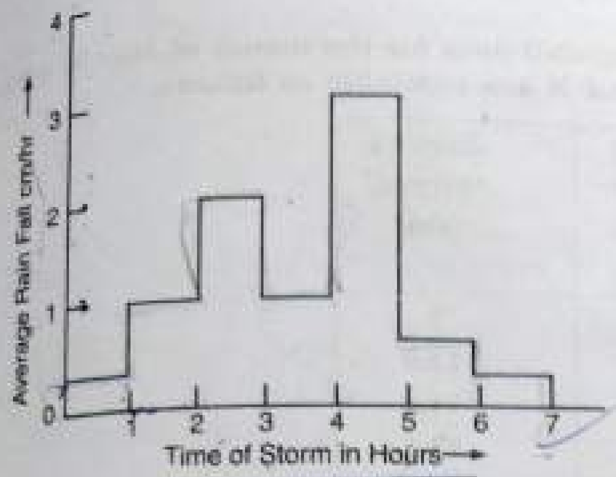


Fig. 31.10. Hyetograph of rainfall

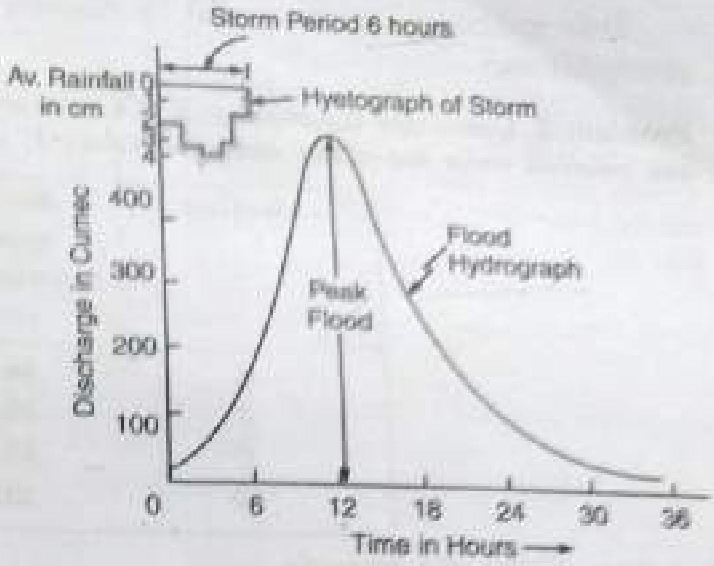


Fig. 31.11. Rainfall-peak flow relation

31.17. ESTIMATION OF MISSING RAINFALL DATA

It is a matter of common experience that due to failure of the instruments of absence of a gauge reader the rainfall record at quite a number of stations is incomplete. In such cases it is necessary for a Hydrologist to estimate the missing rainfall data to accepted accuracy. There are two methods by which estimation can be done. They are:

(i) Simple arithmetic average method; and

(ii) Method of weightage or normal ratio method.

(i) Simple arithmetic average method: In this method simultaneous rainfall records of three closeby stations are made use of. The stations should however be evenly spaced around the station with missing records. A simple arithmetic average of the rainfall of the three selected stations gives the estimate of the missing value. This method can be used to calculate monthly as well as annual missing rainfall values. This method should be used only when normal annual precipitation at each of the selected stations is within 10% of that station for which records are missing.

(ii) Method of weightage or normal ratio method: When the normal annual rainfall of any of the selected stations is more than 10% of that station with missing records simple average method cannot be used then the method to be adopted consists of weighting the rainfall value by the ratios of the normal annual rainfall values. To make the procedure clear.

Let, x be a station with missing records

A, B, and C are three selected stations from homogeneous area

P is rainfall value of certain period under consideration

N is normal annual rainfall.

Then,

$$P_x = \frac{1}{3}\left(\frac{N_x}{N_A} p_A + \frac{N_x}{N_B} . P_B + \frac{N_x}{N_C} . P_C\right)$$

or

$$\frac{P_x}{N_x} = \frac{1}{3}\left(\frac{P_A}{N_A} + \frac{P_B}{N_B} + \frac{P_C}{N_C}\right)$$

31.9. VARIATION OF RAINFALL

Factors responsible for inequitable distribution of rainfall over large area are the following:

1. **Nearness to sea:** From the sea very large quantity of water goes to the atmosphere in the form of vapour. Naturally when excessively moisture laden clouds pass over the sea coast, clouds drop off some of their load. As a result coastal area receives more rainfall.
2. **Presence of mountains:** It is already mentioned that windward side slope of the side towards which clouds travel gets excessive rains whereas on the other or lee-ward side slope there is area of rain-shadow. Mountainous region receives more rainfall than plain areas.
3. **Direction of wind:** Clouds are driven by wind. It is clear that the area over which wind brings clouds will get rainfall.
4. **Development of forest:** The forests also behave to some extent as a barrier and intercept the clouds to derive rainfall. The area with thick forest gets more rainfall.
5. **Height of a place above sea level or altitude:** The places of high altitude receive more precipitation. At high altitudes temperature of atmosphere is low and when clouds reach that area they get cooled and precipitation occurs.

31.11. CONSISTENCY OF RAINFALL DATA

It is already mentioned that as the area of the basin goes on increasing the number of rain-gauging stations is also increased. Each station is located in such a way that it represents a particular part of the total area. The total area is selected in such a way that the storm and basin characteristics are same and as a result rainfall data is consistent at all the stations. Sometimes because of certain reasons the rainfall data may not be consistent. The reasons for the lack of consistency may be any one or more of the following:

1. Shift in a rain recording gauge station.

2. Change in the method of exposure.
3. Change in the surroundings.
4. Instrumental error.
5. Personal error.
6. Accidental error.

Table 31.2.

State	*Rainfall in mm*
Rayalaseema region (A.P.)	700
Rest of Andhra Pradesh	1000
Assam (including Manipur, Tripura, Meghalaya, Nagaland and Arunachal Pradesh)	2500 – 3000
Bihar (including Jharkhand)	1000 – 1500
Gujarat region	1000
Kutch and Saurashtra (Guj.)	500 and below
Kerala	3000
Madhya Pradesh (including Chhattisgarh)	1000 – 2000
Western Ghats (Mah & Kar.)	2500 – 3800
Rest Maharashtra	700 – 1100
Rest Karnataka	1000
Orissa	1500
Punjab (including Haryana, Himachal Pradesh and Jammu and Kashmir)	600 – 1000
Western Rajashthan	150 – 300
Eastern Rajashthan	500 – 700
Tamil Nadu	1000
Uttar Pradesh (including Uttaranchal)	900 – 1300
Gangetic West Bengal	1500
Sub-Himalayan West Bengal	3000

To avoid the lack of consistency in the rainfall data abovementioned causes should be avoided so far as possible. It has been noted that if each area contains at least one self-recording gauge station then it can be used as a standard for the corrections to be done in the rainfall values of other stations. Sometimes rainfall data can be made consistent by adopting double mass curve technique. In short the procedure is as follows:

Rainfall data of at least 6 rain gauging stations is taken. The stations should be meterologically similar. Then double mass curve is plotted. It is a graph in which abscissa represents mean cumulative precipitation of all the stations under consideration. Ordinate represents cumulative precipitation of a station whose consistency is to be checked. If the curve comes out to be straightline then the rainfall data of the station under consideration is consistent. This is based on the principle that the mean accumulated precipitation of a number of stations which are meteorologically similar is not materially affected. If the curve is not a straight line data is inconsistent. Knowing the readings which are factious necessary corrections can be made in the data.

Once it is ascertained that the rainfall data is consistent then general tendency or trend of the rainfall values can be satisfactorily studied to forecast future rainfall that may occur. This can also be done by plotting what is known as rainfall frequency curve. By frequency we mean the average time interval that classes between successive occurrences of rainfall of same depth or value.

EVAPORATION

Defination:-

Theoretically,

- "Evaporation means simply vaporization from the surface of a liquid. Vaporization of a liquid below its boiling point is called evaporation."
- Thus, no boiling occurs and the rate of vaporization depends on the diffusion of vapour through the boundary layers above the liquid.

- Thus a practical definition of evaporation is
- "The removal of liquid from a solution by boiling the solution in a suitable vessel and withdrawing the vapour, leaving a concentrated liquid residue."
- This means that heat will be necessary to provide the latent heat of vaporization and, in general the rate of evaporation is controlled by the rate of heat transfer.
- Evaporators are designed, therefore, to give maximum heat transfer to the liquid, with the largest possible area, a suitable temperature gradient.

EVAPORATION PAN

OPERATING INSTRUCTIONS

Description

The evaporation pan of this standard set is made of stainless steel and has the dimensions of a "class A" evaporation pan, namely 54 mm (10 inches) in height and 1206 mm (47.5 inches) in diameter. The evaporation pan is installed on the wooden support, which is set and levelled on the ground in a grassy location, away from bushes, trees and other obstacles which obstruct a natural air flow around the pan, thus representing open water in an open area.

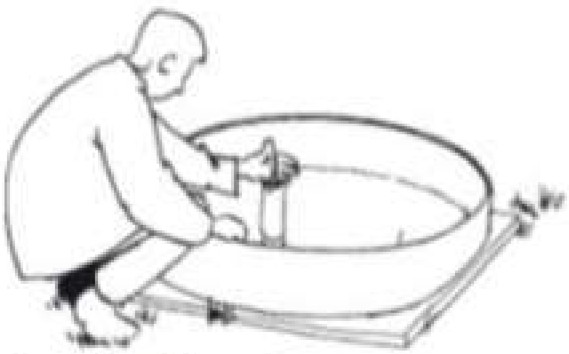
Stilling well with micrometer

Daily the result of evaporation and precipitation is measured within the still well, by means of a high quality evaporation micrometer with a measuring range of 100 mm and an accuracy of 0.02 mm. This accuracy can be obtained because the still well prevents rippling of the water surface.

The amount of evaporation is a function of temperature, humidity, wind and other ambient conditions. In order to relate the evaporation to wind current or expected conditions, the maximum and minimum temperature as well as the amount of air passed are recorded with the evaporation. For a more exact use of the evaporation pan it is recommended to use an additional wind path meter.

Level sensor for automatic

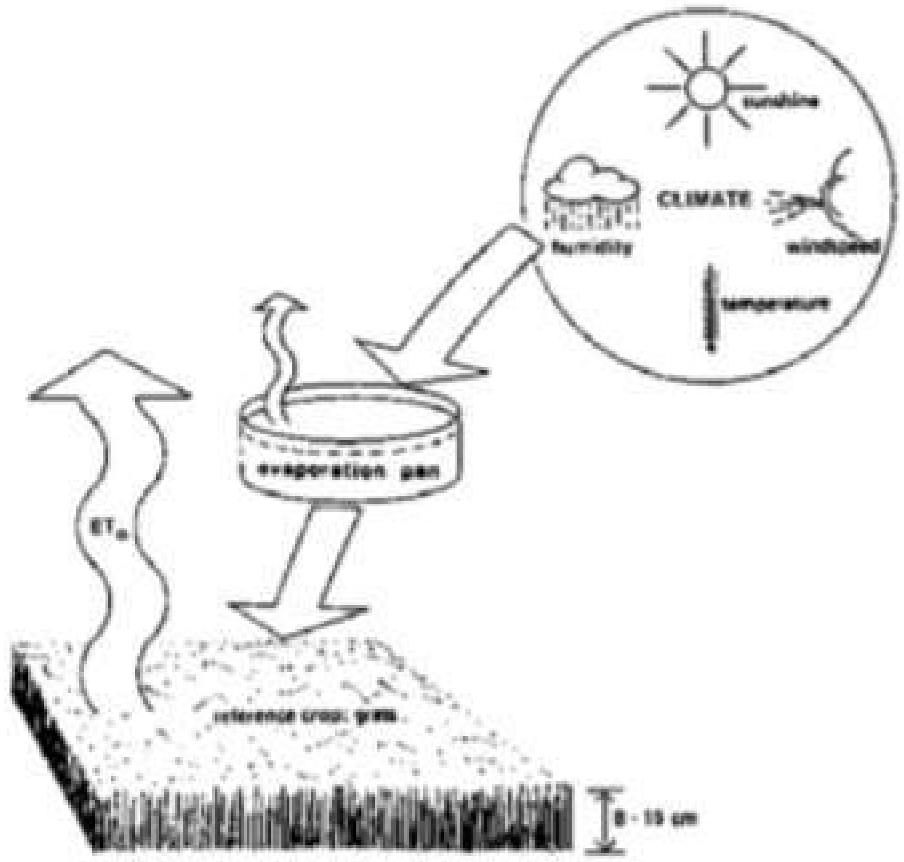
For automatic measurement of the evaporation use can be made of a level sensor. The level sensor consists of a sensitive pressure transducer built in a stainless steel housing. The sensor has a pressure range of 0-20 mbar, accuracy 0,25%. Output signal 0-20 mA, power supply voltage 8-28 V. The sensor is supplied with 5 m cable.
The sensor is read-out with a datalogger. To configure and read-out the datalogger and to process the measuring data, use is made of the evaporation pan software.



Reading the micrometer

Measuring principle

An evaporation pan provides a measurement of the combined effect of temperature, humidity, windspeed and sunshine on the reference crop evapotranspiration ET_o.



The principle of the evaporation pan is the following:

- the pan is installed in the field
- the pan is filled with a known quantity of water (the surface area of the pan is known and the water depth is measured)
- the water is allowed to evaporate during a certain period of time (usually 24 hours). For example, each morning at 7 o'clock a measurement is taken. The rainfall, if any, is measured simultaneously
- after 24 hours, the remaining quantity of water (i.e. water depth) is measured
- the amount of evaporation per time unit (the difference between the two measured water depths) is calculated; this is the pan evaporation: E pan (in mm/24 hours)
- the E pan is multiplied by a pan coefficient, K pan, to obtain the ETo.

Formula: $ET_o = K\ pan \times E\ pan$

with:

ET_o : reference crop evapotranspiration
K pan : pan coefficient
E pan : pan evaporation

If the water depth in the pan drops too much (due to lack of rain), water is added and the water depth is measured before and after the water is added. If the water level rises too much (due to rain) water is taken out of the pan and the water depths before and after are measured.

Determination of K pan

When using the evaporation pan to estimate the ET_o, in fact, a comparison is made between the evaporation from the water surface in the pan and the evapotranspiration of the standard grass. Of course the water in the pan and the grass do not react in exactly the same way to the climate. Therefore a special coefficient is used (K pan) to relate one to the other.
The pan coefficient, K pan, depends on:

- the type of pan used
- the pan environment: if the pan is placed in a fallow or cropped area
- the climate: the humidity and windspeed

Analytical Methods of Evaporation Estimation

1. Water Budget Method
2. Energy Budget Method
3. Mass Transfer Method

(1) Water Budget Method

$$P + V_{is} + V_{ig} = V_{os} + V_{og} + E_L + \Delta S + T_L$$

P = daily precipitation

V_{is} = daily surface inflow into the lake

V_{ig} = daily groundwater inflow

V_{os} = daily surface outlow from the lake

V_{og} = daily groundwater outflow

E_L = daily lake evaporation

ΔS = increase in lake storage in a day

T_L = daily transpiration loss

All quantities are expressed in units of volume or depth

P, V_{is}, V_{os}, and ΔS can only be measured.

V_{ig}, V_{og}, and T_L can only be estimated.

$V_{ig}, V_{og}, and\ T_L$ can only be estimated.

If the unit of time is kept very large, estimates of evaporation will be more accurate. It is the simplest of all the methods, but the least reliable.

(2) Energy Budget Method

- It involves application of the law of conservation of energy
- Energy available for evaporation is determined by considering the incoming energy, outgoing energy, and the energy stored in the water body over a known time interval

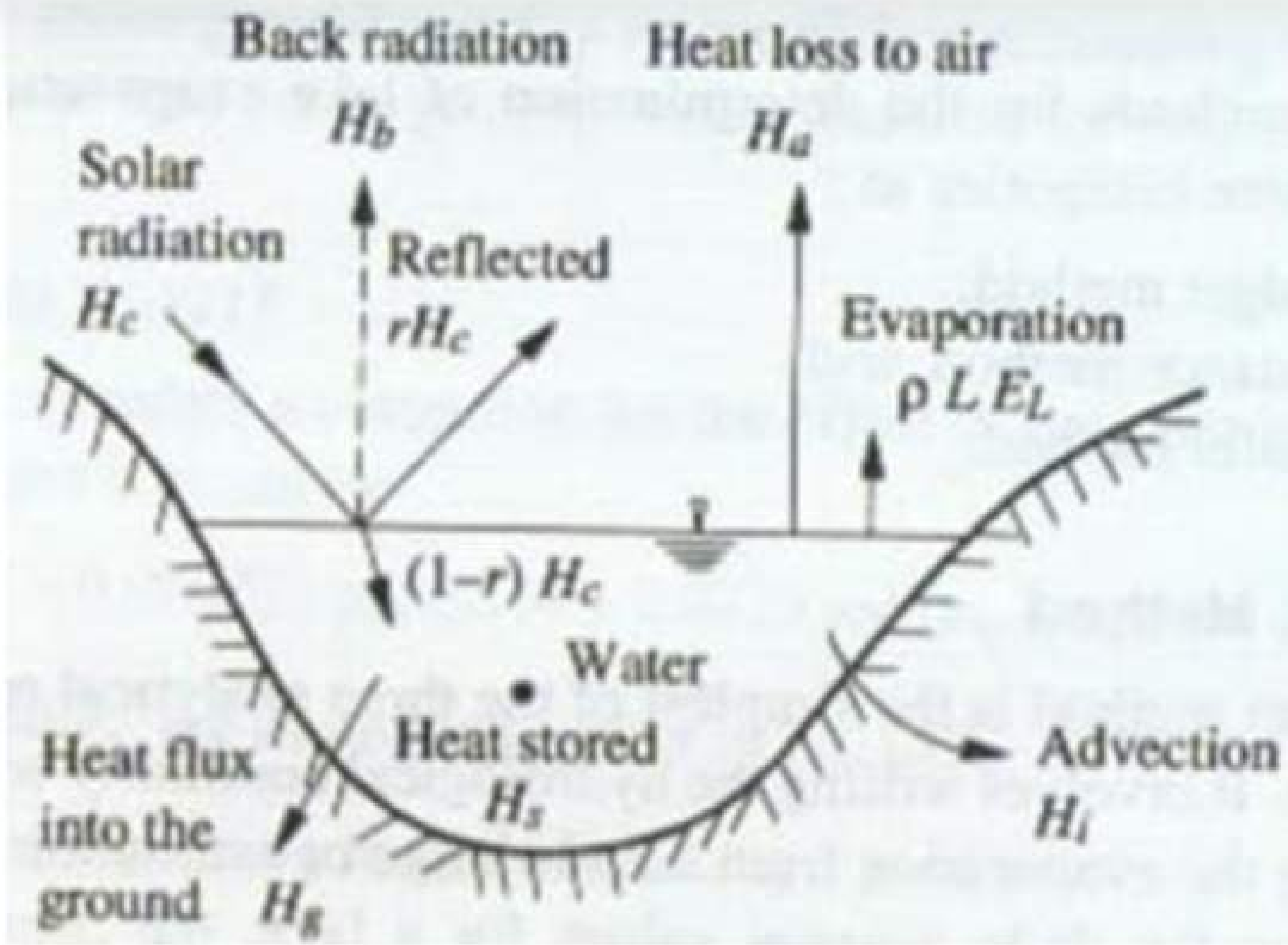


Figure: Energy Balance in a water body

This is the energy balance in a period of 1 day. All energy terms are in calories/ sq.mm/day.

If time periods are short, H_s *and* H_i can

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

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

H_b = back (long wave) radiation from the water body

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

H_g = heat flux into the ground

H_s = heat stored in the water body

H_e = heat energy used up in evaporation $= \rho L E_L$ (E_L = evaporation, L = latent heat of evaporation, ρ = mass density of the fluid)

H_i = net heat conducted out of the system

0 METHODS TO REDUCE EVAPORATION

Although evaporation losses in the country are quite substantial, the evaporation retardant methods perhaps cannot be employed to all open surface water bodies, irrespective of their size and shape. In view of this, water conservation management by control of evaporation has so far been limited generally to drought prone and scarcity areas under specified wind speed and temperature conditions of the water bodies.

The methods of evaporation control can be grouped under two broad categories :

(i) Short term measures and
(ii) Long term measures.

A number of approaches have either been applied or considered by Engineers and Scientists in their attempt to reduce evaporation losses from surface of water bodies. Since the basic meteorological factors affecting evaporation cannot be controlled under normal conditions, efforts have so far been restricted to managing the suppression or inhibition of evaporation from water surfaces by physical or chemical means. The methods generally used or being tried are broadly listed below:

i) wind breakers
ii) covering the water surface
iii) reduction of exposed water surface
iv) underground storage of water
v) integrated operation of reservoirs
vi) treatment with chemical Water Evapo Retardants (WER).

1 Wind Breakers

Wind is one of the most important factors which affect rate of evaporation loss from water surface. The greater the movement of air over the water surface, greater is the evaporation loss. Planting of trees normal to windward direction is found to be an effective measure for checking of evaporation loss. Plants (trees, shrubs or grass) should be grown around the rim of tanks in a row or rows to act as wind breaker. These wind breakers are found to influence the temperature, atmospheric humidity, soil moisture, evaporation and transpiration of the area protected.

Plants to act as wind breakers are usually arranged in rows, with tallest plants in the middle and the smallest along the end rows, so that more or less conical formation is formed.

Trees grown as wind breakers are constantly subjected to usual stress of wind, temperature, moisture, evaporation, insects and diseases. Thus, plants selected as wind breakers should be capable of resisting these stresses. The list of vegetation recommended by Indian Council for Agricultural Research, New Delhi (Technical Bulletin No. 22) for planting as wind breakers in different regions of India is given in Table 6.1. The spacing between plants varies from place to place, depending upon the climate and type of soil.

recharge of the aquifer adjoining Talaji rivulet near the town of Talaja in Bhavnagar District of Gujarat where significant water level rise was registered, after the limited monsoon. The main advantage of this method is that loss of valuable lands and forest areas due to surface submergence can be altogether avoided. The method has a great future all over India in view of the environmental advantage.

Integrated Operation of Reservoirs

This method is suitable for a system of reservoirs which can be operated in an integrated way. The method consists of operating the reservoirs in such a way that total exposed water surface area is kept minimum for the system as a whole. Consequently evaporation loss gets minimized. For achieving this objective water use should be planned in such a way that shallow reservoirs with large water spread area are depleted first. This method has been successfully practiced by Mumbai Municipal Corporation in their water supply scheme. Such techniques were also tried in the Hiran dam 1 & 2 in Junagarh district of Saurashtra region of Gujarat. The Chennai Metropolitan Water Supply and Sewerage Board has also been practicing integrated operation of Red Hills, Cholavaram and Poondi reservoirs, which supply water to Chennai City, so that the exposed water surface is kept minimum.

Treatment with Chemical Water Evapo-Retarders (WER)

Chemicals capable of forming a thin mono-molecular film have been found to be effective for reducing evaporation loss from water surface. The film so formed reflects energy inputs from atmosphere, as a result of which evaporation loss is reduced. The film allows enough passage of air through it and hence, aquatic life is not affected. The film developed by using fatty alcohols of different grades has been found most useful for control of evaporation. These materials form a film of mono-molecular layer when applied on water surface which works as a barrier between water body and the atmospheric conditions. These fatty alcohols used for evaporation control are generally termed as chemical water evapo-retardants (WERs) and these are available in the form of powder, solution or emulsion.

These chemical water evapo-retardants have the disadvantage of high cost of application. However, when adopted in scarcity period, drought, etc. the quantity of water saved by this method would work out cheaper than alternate means of bringing water from far off places by manual or mechanical transport. The economics of WERs application may however vary from site to site depending on local factors. The chemical water evapo-retardants have another limitation of the mono-layer breaking at high wind velocities. Following chemicals are generally used for water evaporation retardation:

- Cetyl Alcohol (Hexadecanol) $C_{16}H_{33}OH$
- Stearyl Alcohol (Octadecanol) $C_{18}H_{37}OH$
- Ethoxylated Alcohols and Linear Alcohols
- Linoxyd CS-40
- Acilol TA 1618 (Cetyl Stearyl Alcohol)

What is evapotranspiration ?

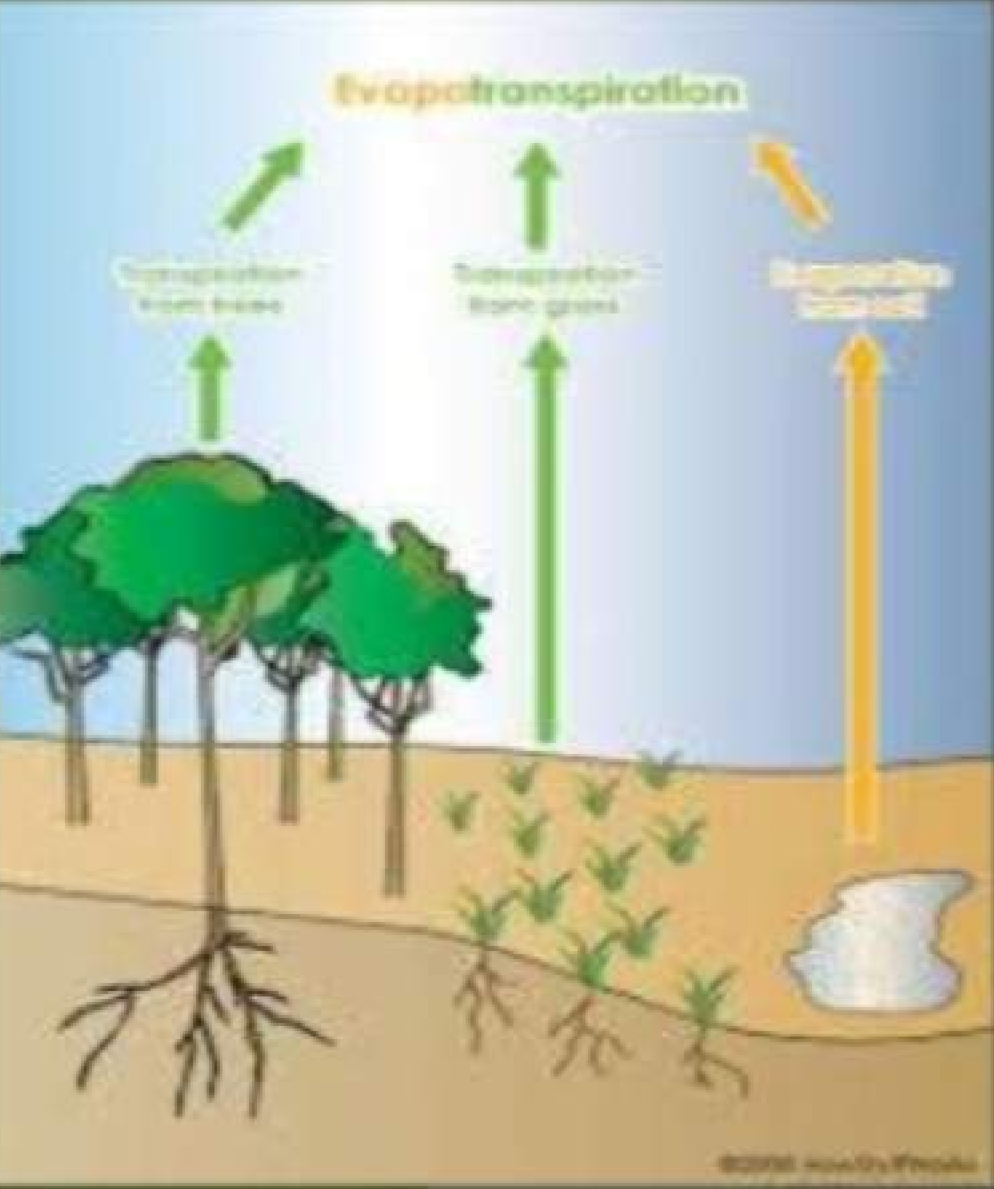
- It is a combination of two separate processes

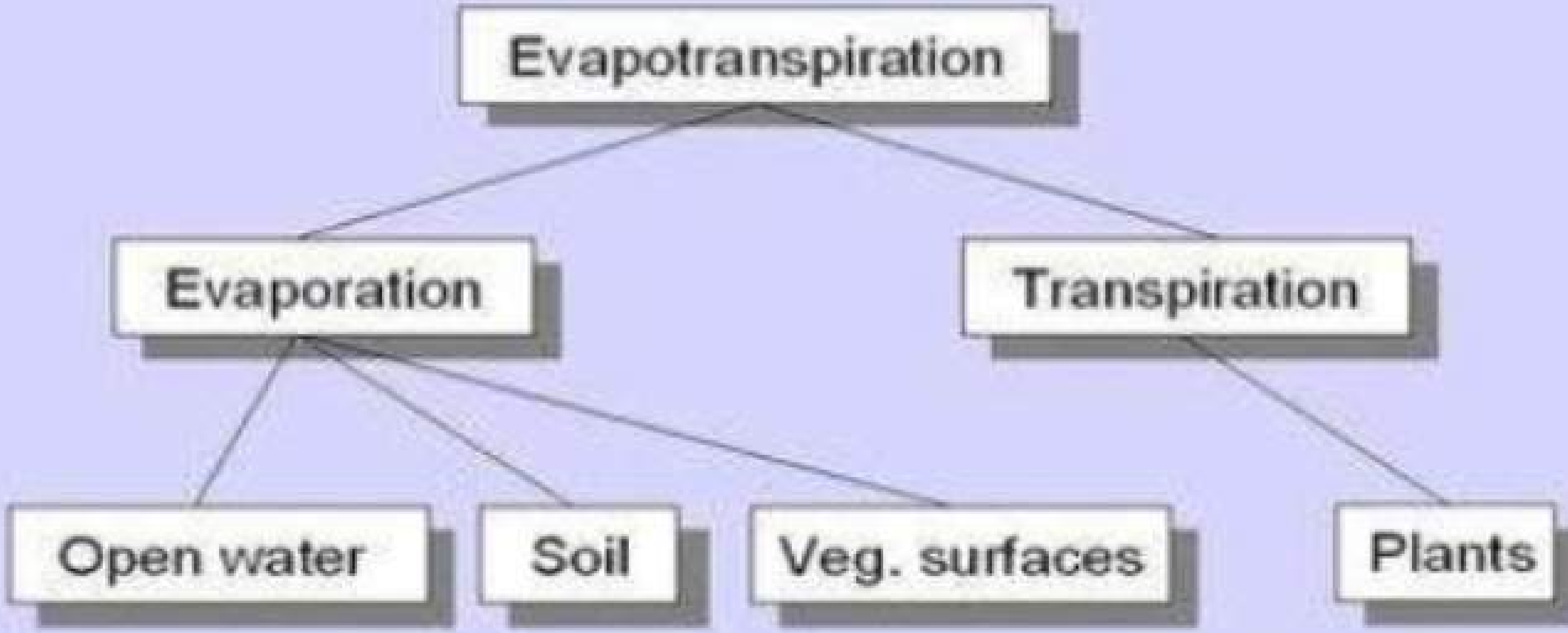
Evaporation:

Loss of water from the soil surface or any other open water body

Transpiration:

from plant surface





Evapotranspiration divided into subprocesses

Introduction

Evaporation

- Movement of water to the air from sources such as the soil, canopy interception, and water bodies.

Transpiration

- Movement of water within a plant and the subsequent loss of water as vapor through stomata of the leaves.

INTERCEPTION

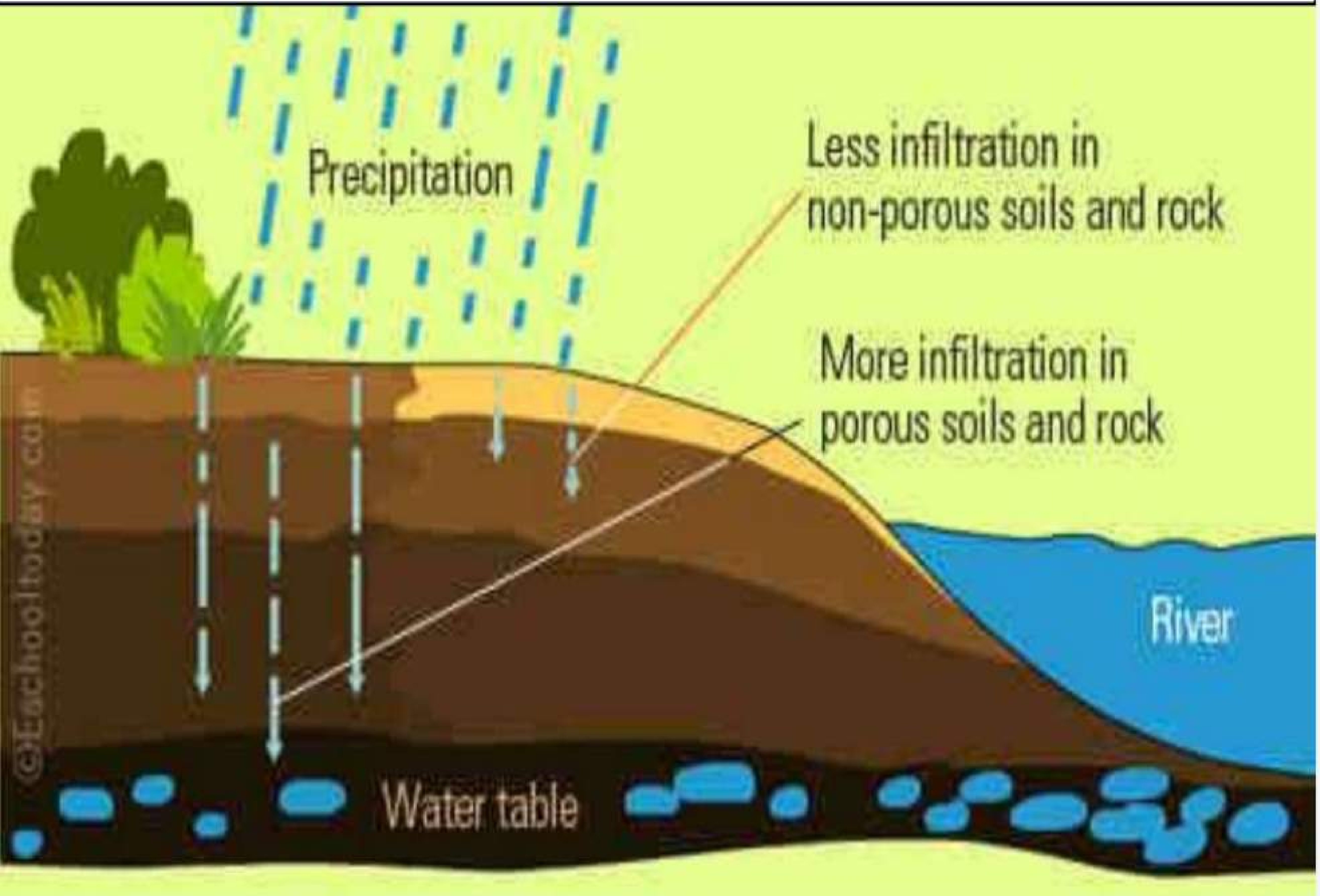
Interception can be defined as that segment of the gross precipitation input which wets and adheres to aboveground objects until it is returned to the atmosphere through evaporation

Precipitation striking vegetation may be retained on leaves or blades of grass, flow down the stems of plants and become stem flow, or fall off the leaves to become part of the through fall. The modifying effect that a forest canopy can have on rainfall intensity at the ground (the through fall) can be put to practical use in watershed management schemes.

DEPRESSION STORAGE

Precipitation that reaches the ground may infiltrate, flow over the surface, or become trapped in numerous small depressions from which the only escape is evaporation or infiltration. The nature of depressions as well as their size, is largely a function of the original land form and local land-use practices. Because of extreme variability in the nature of depressions and the paucity of sufficient measurements, no generalized relation with enough specified parameters for all cases is feasible. A rational model can, however, be suggested.

UNIT -3 (INFILTRATION)



INFILTRATION

- The process of entering rain water in to soil strata of earth is called INFILTRATION.
- The infiltrated water first meets the soil moisture deficiency if any & excess water moves vertically downwards to reach the groundwater table. This vertical movement is called **PERCOLATION.**

INFILTRATION CAPACITY

- The infiltration capacity of soil is defined as the maximum rate at which it is capable of absorbing water and is denoted by **f**.
- If $i >= f$ then $f_a = f$ (depend upon soil capacity)
- If $i < f$ then $f_a = i$ (depend upon rainfall intensity)
- where f_a = actual infiltration capacity

  i = rate of rainfall

  f = infiltration capacity

- For

  Dry Soil – (infiltration rate) f is more

  Moist Soil – (infiltration rate) f is less

- Maximum rate of water absorption by soil –**Infiltration Capacity**

- Maximum capacity of water absorption by soil –**Field Capacity**

INFILTRATION INDICES

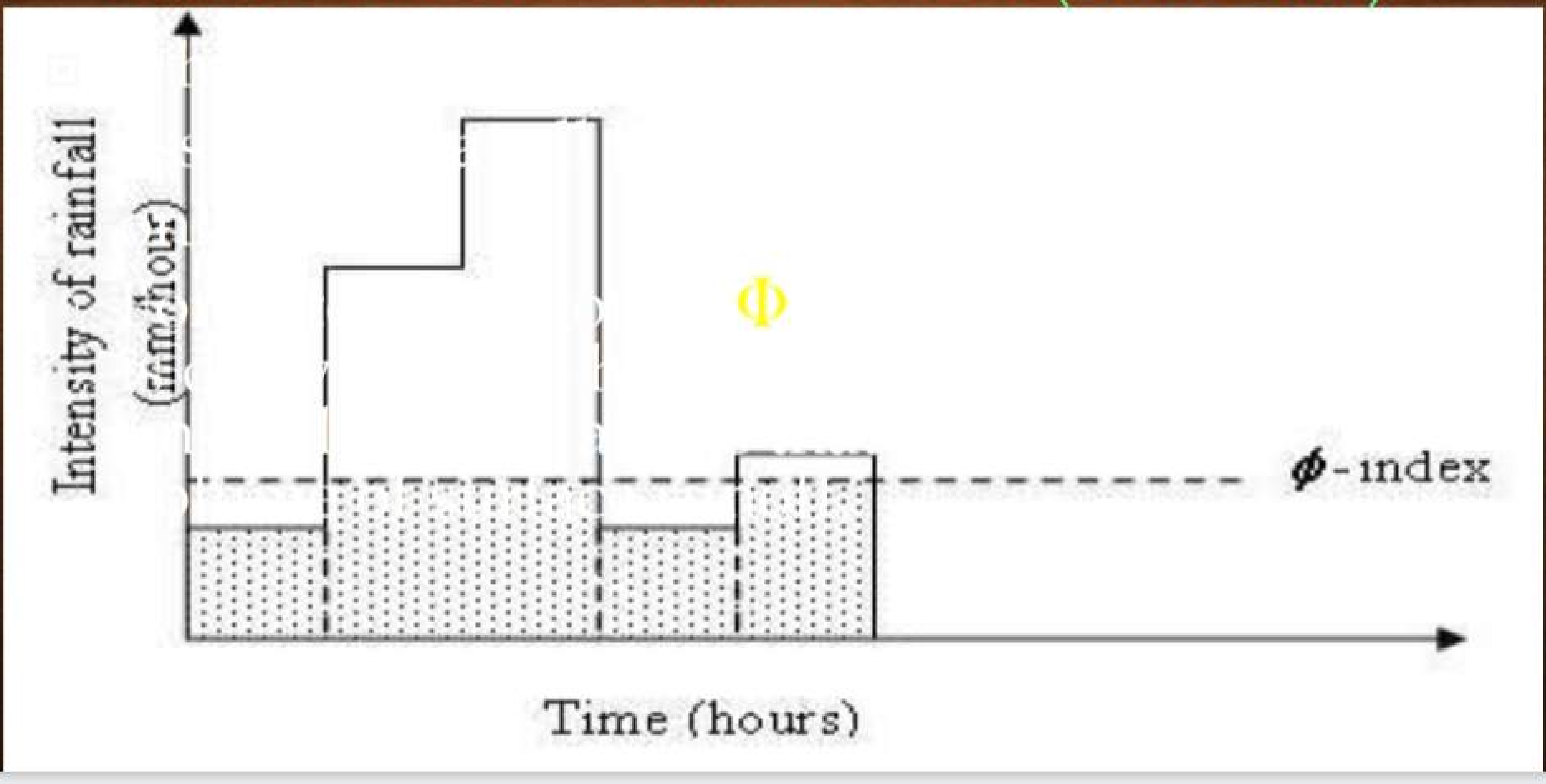
- For consistency in hydrological calculations, a constant value of infiltration rate for the entire storm duration is adopted. The average infiltration rate is called the **INFILTRATION INDEX**.
- The two commonly used infiltration indices are the following:
  - *φ – index*
  - *W – index*

There are extremely used for the analysis of major floods when the soil is wet and the infiltration rate becomes constant.

Φ – INDEX

- This is defined as the rate of infiltration above which

rainfall volume = runoff volume(saturation).



- *Φ – INDEX for a catchment, during a storm depends on*

- Soil type
- vegetation cover
- Initial moisture condition

- *Application – Estimation of flood magnitudes due to critical storms.*

MEASUREMENT OF INFILTRATION

- **Infiltrometer** is a device used to measure the rate of water infiltration into soil.

SINGLE RING INFILTROMETER

- This consist of metal cylinder of diameter 25 cm to 30 cm and length of 50 cm to 60 cm, with both ends open. length of cylinder= (2 x diameter)

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

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

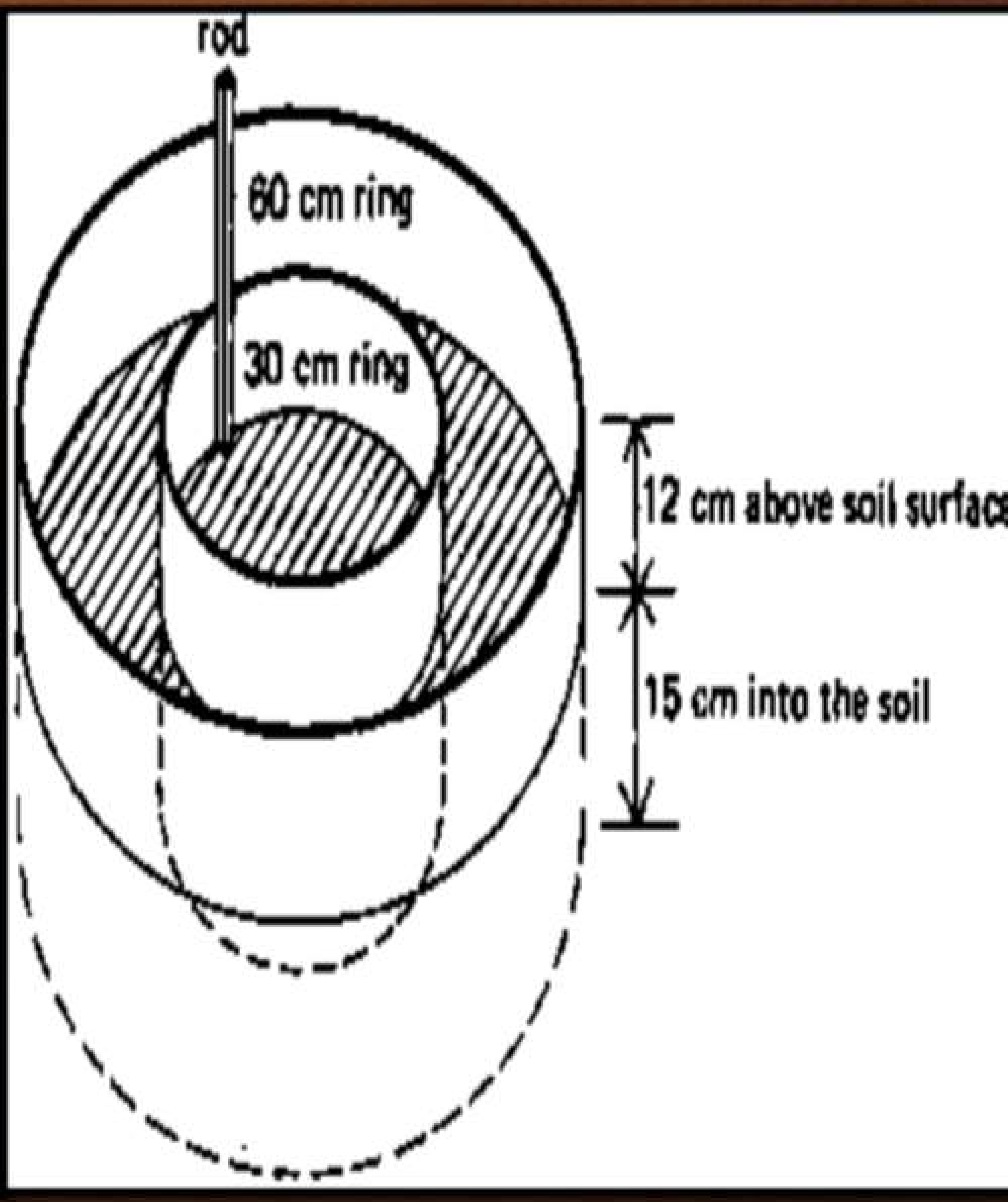
- The single ring involves driving a ring into the soil and supplying water in the ring either at constant head or falling head condition.

Constant head refers to condition where the amount of water in the ring is always held constant means the rate of water supplied corresponds to the infiltration capacity.

Falling head refers to condition where water is supplied in the ring, and the water is allowed to drop with time. The operator records how much water goes into the soil for a given time period.

DOUBLE RING INFILTROMETER

- This is most commonly used flooding type infiltrometer.
- it consists of two concentric rings driven into soil uniformly without disturbing the soil to the least to a depth of 15 cm. The diameter of rings may vary between 25 cm to 60 cm.
- An inner ring is driven into the ground, and a second bigger ring around that to help control the flow of water through the first ring. Water is supplied either with a constant or falling head condition, and the operator records how much water infiltrates from the inner ring into the soil over a given time period.



INFILTROMETERS

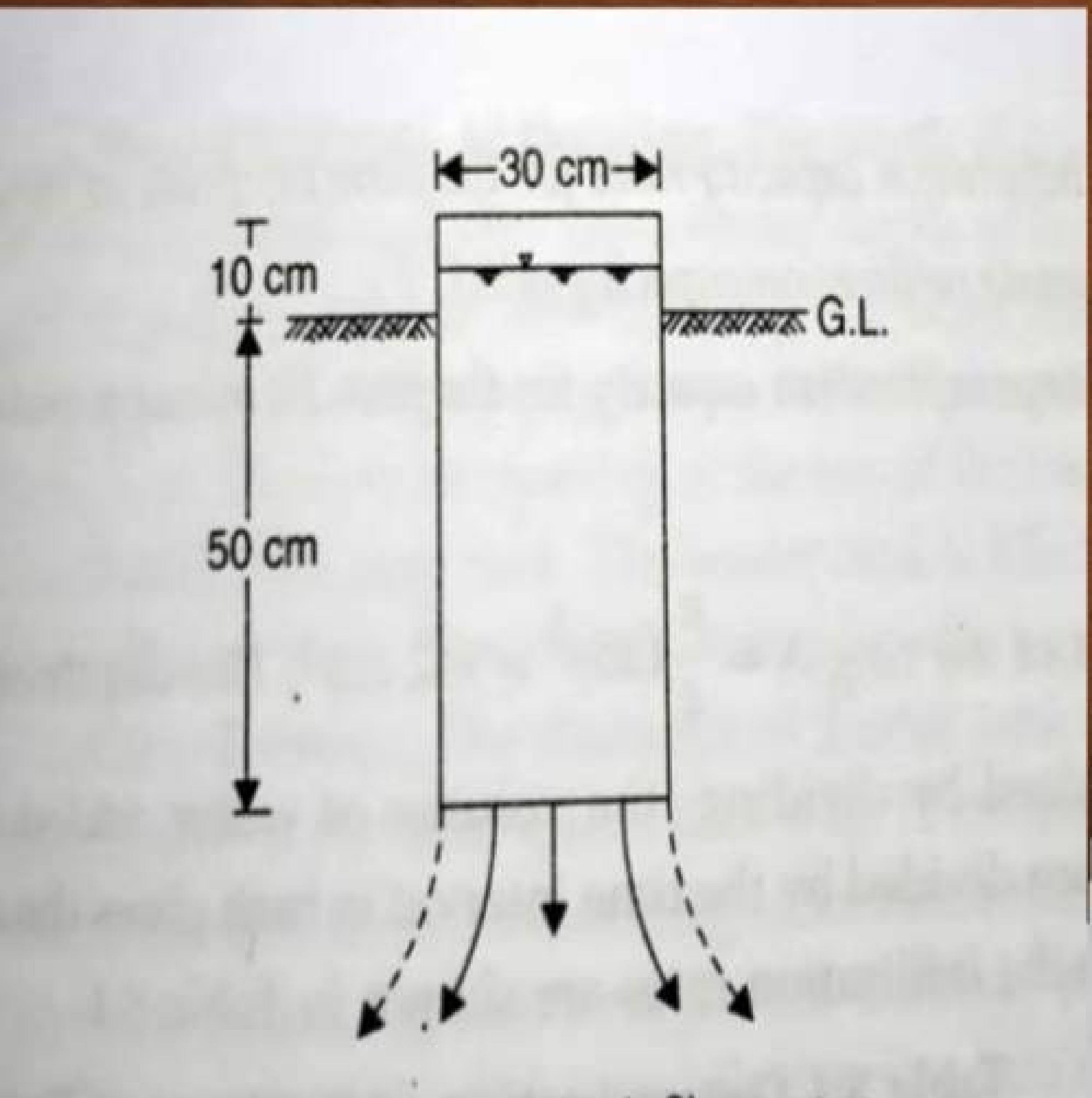


FIGURE 8.3 Tube infiltrometer.

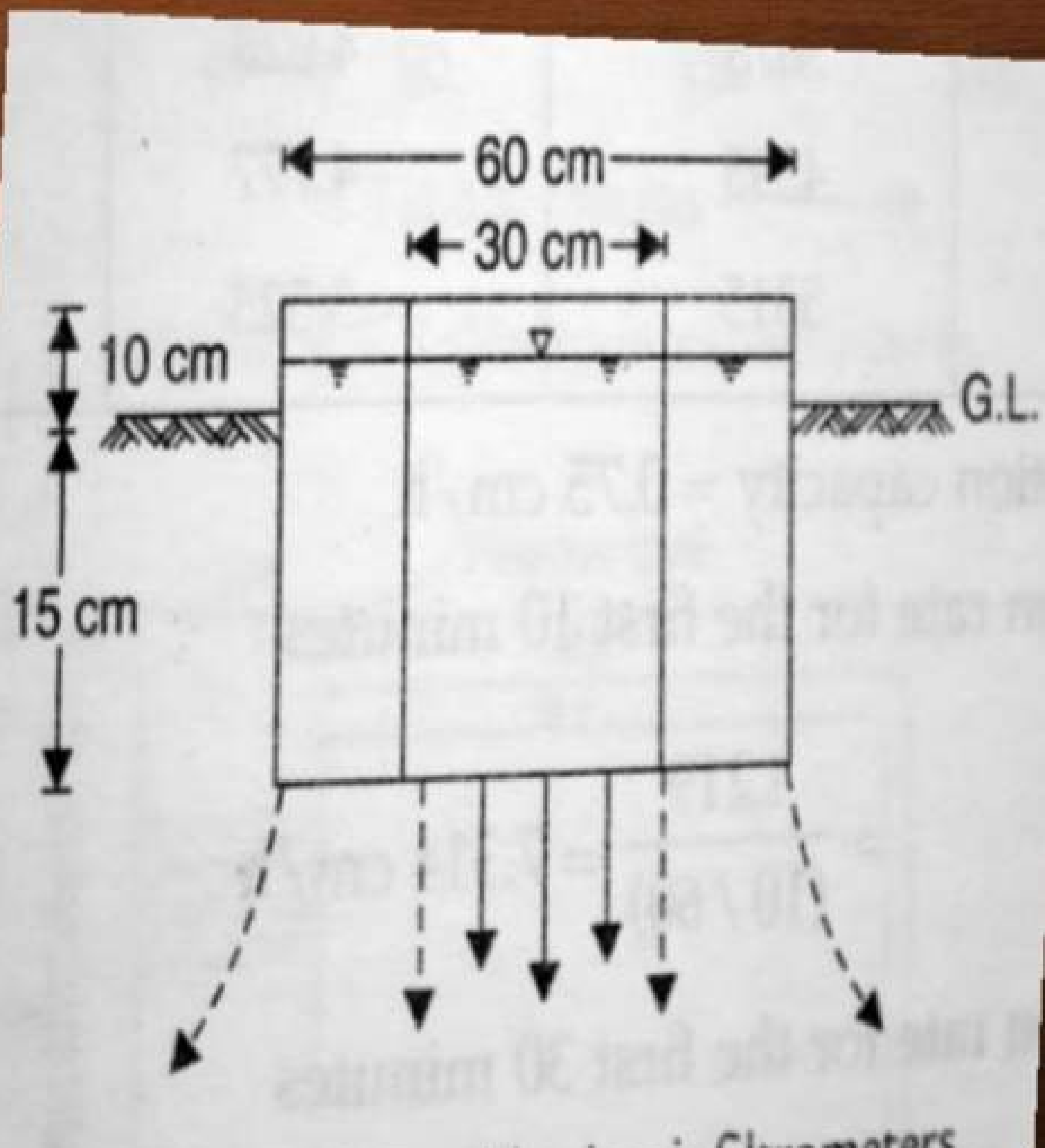


FIGURE 8.4 Double ring infiltrometers.

INFILTRATION CAPACITY

- The infiltration capacity of soil is defined as the maximum rate at which it is capable of absorbing water and is denoted by **f**.
- If $i >= f$ then $f_a = f$ (depend upon soil capacity)
- If $i < f$ then $f_a = i$ (depend upon rainfall intensity)
- where f_a = actual infiltration capacity

  i = rate of rainfall

  f = infiltration capacity

- For

  Dry Soil – (infiltration rate) f is more

  Moist Soil – (infiltration rate) f is less

- Maximum rate of water absorption by soil –**Infiltration Capacity**

- Maximum capacity of water absorption by soil –**Field Capacity**

INFILTRATION RATE

- The rate at which soil is able to absorb rainfall or irrigation .
- It is measured in (mm/hr) or (inches/hr)
- Infiltrometer is used for measurement of infiltration.
- If (i > f) runoff occurs.
- Infiltration rate is connected to hydraulic conductivity.

- Hydraulic conductivity is ability of a fluid to flow through a porous medium.

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

OR

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

Modelling of Infiltration Capacity

- **Saturated Zone** - The pore space in this zone is filled with water or saturated. Depending on the length of time elapsed from the initial application of the water, this zone will generally extend only to a depth of a few millimeters.
- **Transition Zone** – This zone is characterized by a rapid decrease in water content with depth and will extend approximately a few centimeters.
- **Transmission Zone** – This zone is characterized by a small change in water content with depth. In general, the transmission zone is a lengthening unsaturated zone with uniform water content. The hydraulic gradient in this zone is primarily driven by gravitational forces.
- **Wetting Zone** – In this zone, the water content sharply decreases with depth from the water content of the transmission zone to near the initial water content of the soil.
- **Wetting Front** – This zone is characterized by a steep hydraulic gradient and forms a sharp boundary between the wet and dry soil. The hydraulic gradient is characterized primarily by metric potentials.

RUNOFF AND COMPONENTS OF RUNOFF

- **RUNOFF :-** After infiltration remaining precipitation on the surface is called runoff.

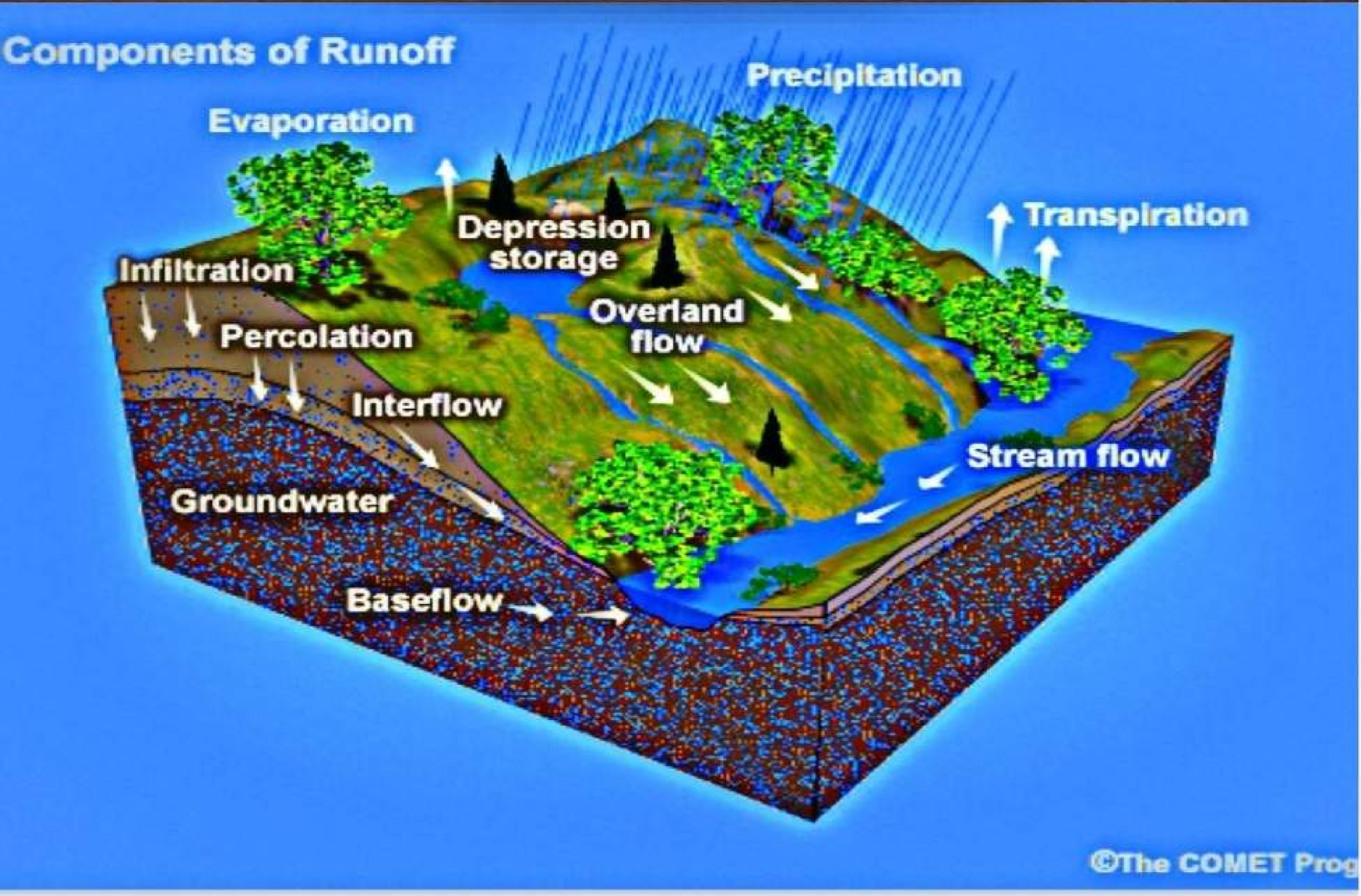
OR

Draining of precipitation from a catchment area through a surface channel.

COMPONENTS OF RUNOFF

- According to source from which the flow is derived the total runoff, consist of :-
  - Surface runoff
  - Subsurface runoff
- For the practical purpose of analysis of total runoff.
  - Direct runoff
  - Base flow

COMPONENTS OF RUNOFF



SCS Curve Number Method

The SCS curve number method is a simiple, widely used and efficient method for determining the approxient amount of runoff from a rainfall even in a particular area. Although the method is designed for a single storm event, it can be scaled to find average annual runoff values. The stat requirments for this method are very low, rainfall amount and curve number. The curve number is based on the area's hydrologic soil group, land use , treatment and hydrologic condition. The 2 former being of greatest importance.

The general equation for the SCS curve number method is as follows:

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \qquad (1)$$

Q = runoff (in)
P = rainfall (in)
S = potential maximum retention after runoff begins
I_a = initial abstratctions

$$I_a = 0.2\,S \qquad (2)$$

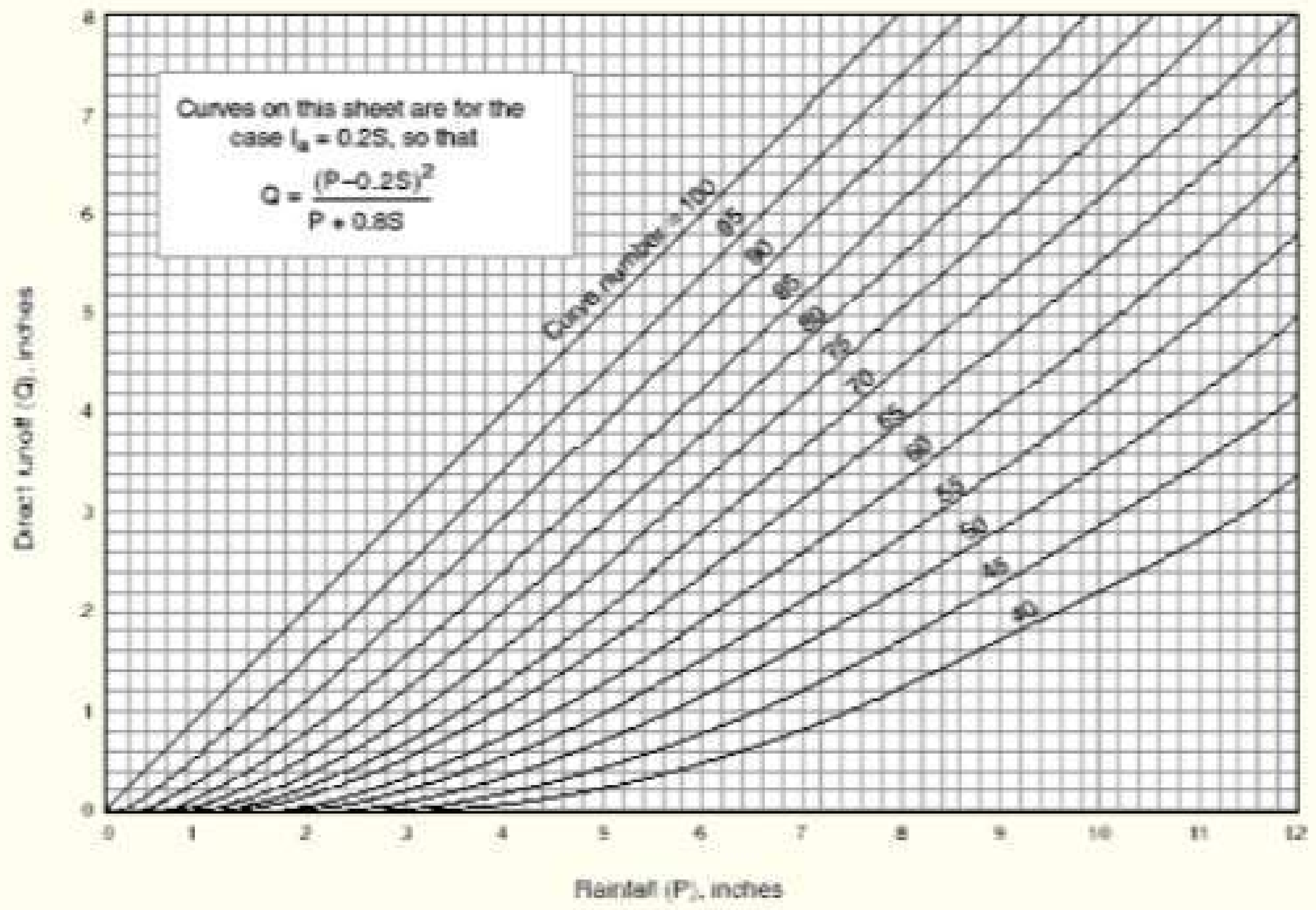
$$Q = \frac{(P - 0.2\,S)^2}{(P + 0.8\,S)} \qquad (3)$$

$$S = \frac{1000}{CN} - 10 \qquad (4)$$

The initial equation (1) is based on trends observed in data from collected sites, therefore it is an emperical equation instead of a physically based equation. After further empirical evaulation of the trends in the data base, the initial abstractions, Ia, could be defined as a percentage of S (2). With this assumption, the equation (3) could be written in a more simplified form with only 3 variables. The parameter CN is a transformation of S, and it is used to make interpolating, averaging, and weighting operations more linear (4).

With the following chart, the amount of runoff can be found if the rainfall amount (in inches) and curve number is known.

There are two advantages of using L-THIA over a manual method. One, the availablity of the data. L-THIA provides the rainfall data for any area in the United States. Two, L-THIA completes this caluculation for every rainfall event for thirty years and then reports the average annual runoff value.



Land Use Description on Input Screen	Description and Curve Numbers from TR-55					
	Cover Description		Curve Number for Hydrologic Soil Group			
	Cover Type and Hydrologic Condition	% Impervious Areas	A	B	C	D
Agricultural	Row Crops - Staight Rows + Crop Residue Cover- Good Condition [1]		64	75	82	85
Commercial	Urban Districts: Commerical and Business	85	89	92	94	95
Forest	Woods[2] - Good Condition		30	55	70	77
Grass/Pasture	Pasture, Grassland, or Range[3] - Good Condition		39	61	74	80
High Density Residential	Residential districts by average lot size: 1/8 acre or less	65	77	85	90	92
Industrial	Urban district: Industrial	72	81	88	91	93
Low Density Residential	Residential districts by average lot size: 1/2 acre lot	25	54	70	80	85
Open Spaces	Open Space (lawns, parks, golf courses, cemeteries, etc.)[4] Fair Condition (grass cover 50% to 70%)		49	69	79	84
Parking and Paved Spaces	Impervious areas: Paved parking lots, roofs, driveways, etc. (excluding right-of-way)	100	98	98	98	98
Residential 1/8 acre	Residential districts by average lot size: 1/8 acre or less	65	77	85	90	92
Residential 1/4 acre	Residential districts by average lot size: 1/4 acre	38	61	75	83	87
Residential 1/3 acre	Residential districts by average lot size: 1/3 acre	30	57	72	81	86
Residential 1/2 acre	Residential districts by average lot size: 1/2 acre	25	54	70	80	85
Residential 1 acre	Residential districts by average lot size: 1 acre	20	51	68	79	84
Residential 2 acres	Residential districts by average lot size: 2 acre	12	46	65	77	82
Water/ Wetlands		0	0	0	0	0

Color Key

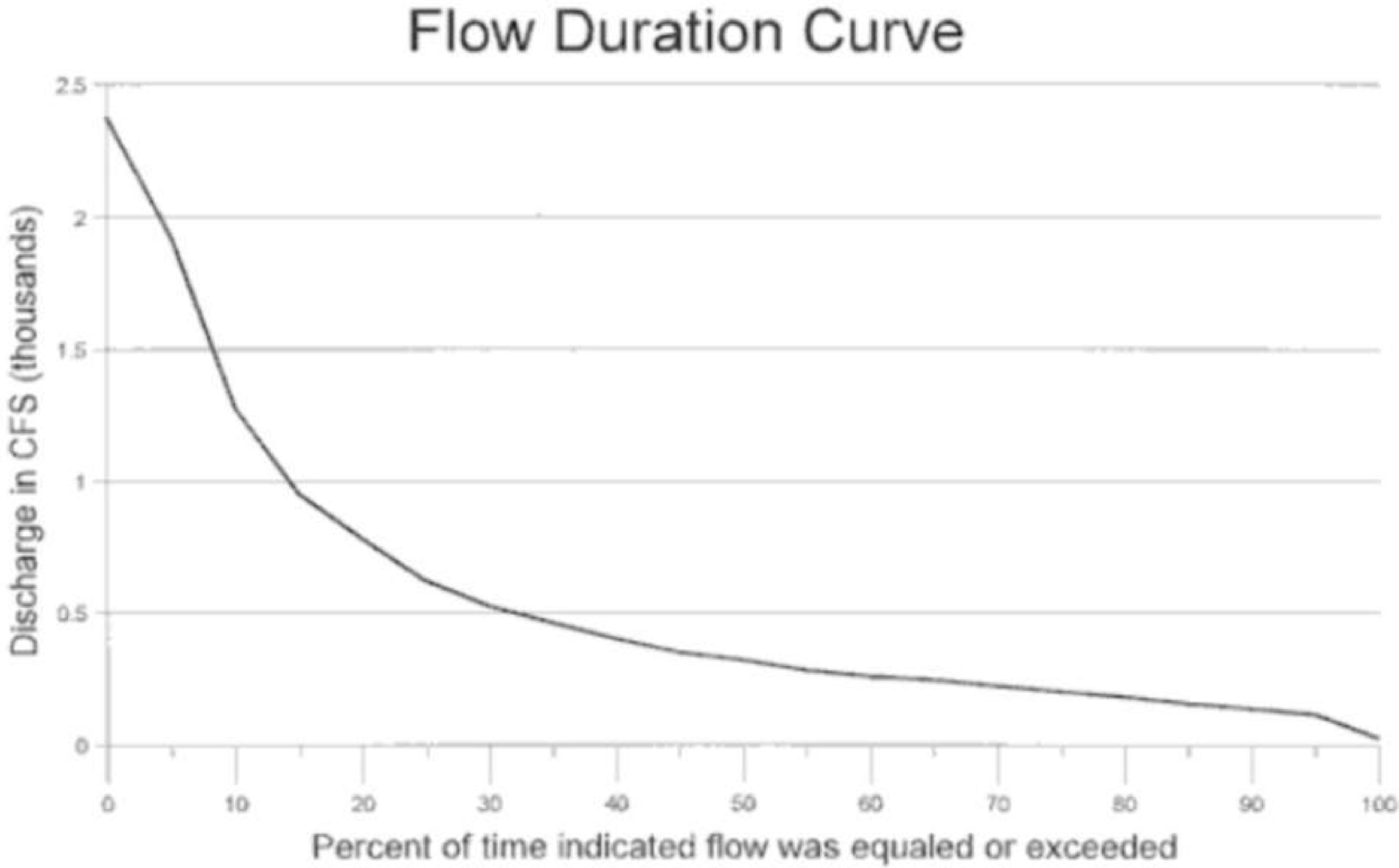
Basic Input Value	Detailed Input Value	Basic and Detailed Input Type Value

Flow duration curves

- Flow duration curve is a plot of discharge versus percentage of time for which the discharge is available. It is obtained from hydrograph data. The flow or discharge can be expressed as cubic meters per second, per week or other unit of time. If the head at which the flow is available is known, the discharge can be calculated in terms of the kilowatts power (P) using following equation,

$$P=(0.736/75)*Q\rho h\eta \text{ kW}$$

- The flow duration curve becomes the load duration curve for hydroelectric plant and thus it is possible to know the total power available at the site. The maximum and minimum conditions of flow can also be obtained by the flow duration curve where minimum flow condition decides the maximum capacity of plant that can be improved by increasing the storage capacity. Figure shows that flow duration curves are of no use where the time sequence of the flow is of importance such as in the study of floods.



Flow Duration Curve
2.5
2
1.5
1
0.5
0
Discharge in CFS (thousands)
0
10
20
30
40
50
60
70
80
90
100
Percent of time indicated flow was equaled or exceeded

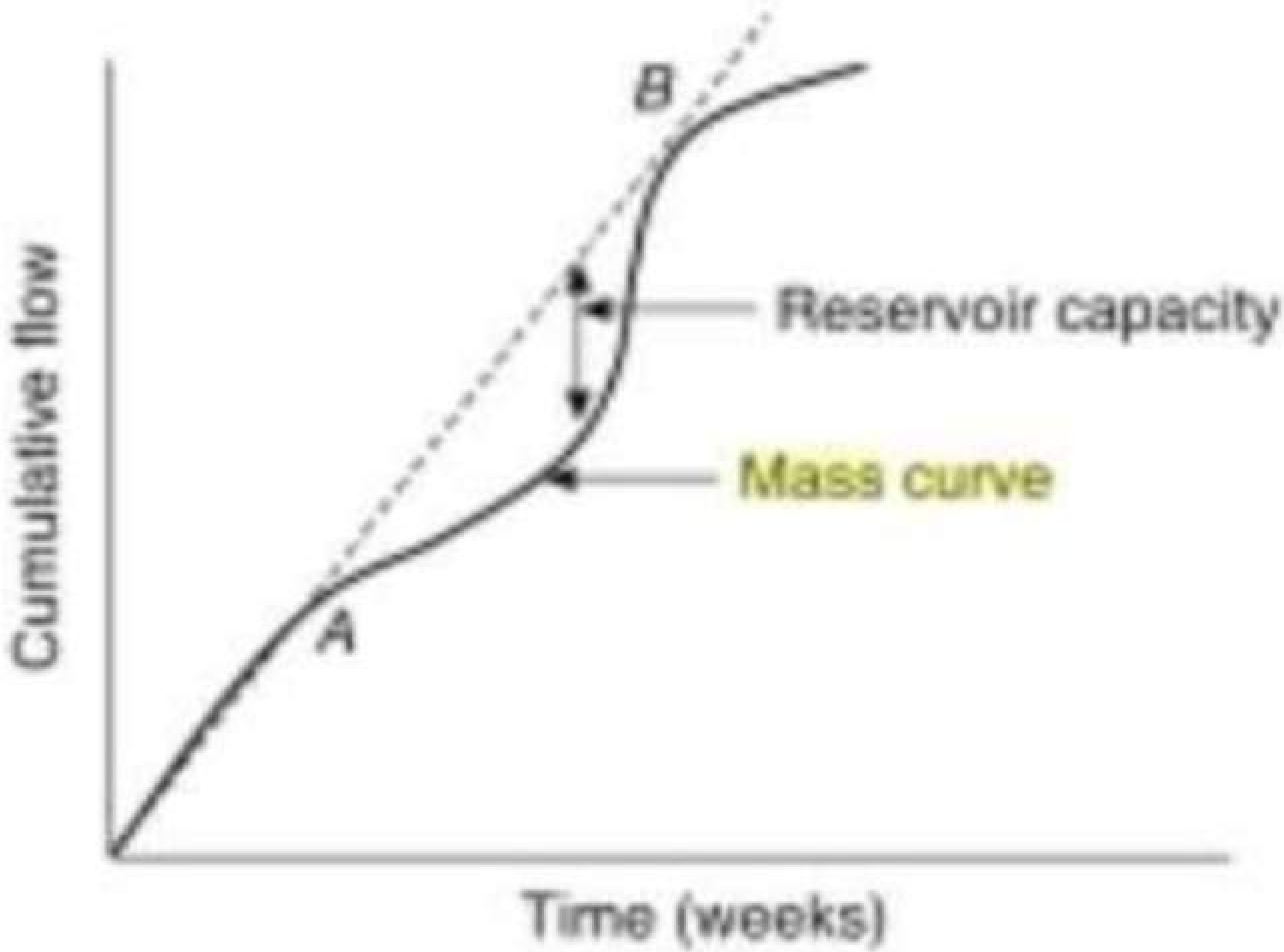
Mass Curve

- It is a plot of cumulative volume of water that can be stored from a stream flow versus time in days, weeks or months. It shows a mass curve, Maximum intercept between line AB and mass curve is known as reservoir capacity

- The unit used for storage is either cubic metre or day-second-metre. A day-second-metre is the flow at the rate of 1m3/sec for one day and equal to 60*60*24=86400 m3.

- The capacity of plant is based on the storage capacity, which can be modified by storage for the same mass curve, The water stored in dams is called pondage and water stored in upstream reservoir is called storage.

Mass curve


B
Reservoir capacity
Mass curve
A
Cumulative flow
Time (weeks)

FACTORS AFFECTING RUNOFF

- Runoff area and Runoff volume from an area mainly influenced by following two factors :-
  - CLIMATIC FACTORS.
  - PHYSIOGRAPHICAL FACTORS.

- **Climate factors associate with characteristics which includes the**
  - ✓ Type of precipitation.
  - ✓ rainfall Intensity.
  - ✓ rainfall Duration.
  - ✓ Antecedent precipitation.
  - ✓ Direction of storm movement.

- **Physiographic Factors includes both watershed and channel characteristics,** such as -
  - Size of Watershed.
  - Orientation of Watershed.
  - slope of Watershed.
  - Land Use.
  - Soil type.
  - Type of drainage network.
  - Shape of catchment.

HYDROGRAPH

- is a graph showing the rate of flow (discharge) versus time past a specific point in a river, or other channel or conduit carrying flow.
- It can also refer to a graph showing the volume of water reaching a particular outfall.

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

COMPONENTS OF A HYDROGRAPH

- **Rising limb:** The rising limb of hydro graph, also known as concentration curve, reflects a prolonged increase in discharge from a catchment area, typically in response to a rainfall event
- **Recession (or falling) limb:** The recession limb extends from the peak flow rate onward. The end of stormflow (aka quickflow or direct runoff) and the return to groundwater-derived flow (base flow) is often taken as the point of inflection of the recession limb. The recession limb represents the withdrawal of water from the storage built up in the basin during the earlier phases of the hydrograph.

- **Peak discharge:** the highest point on the hydro graph when the rate of discharge is greatest
- **Lag time:** the time interval from the center of mass of rainfall excess to the peak of the resulting hydrograph
- **Time to peak:** time interval from the start of the resulting hydro graph
- **Discharge:** the rate of flow (volume per unit time) passing a specific location in a river or other channel

Unit Hydrograph Surface Water Resources of India

(1) Time T_c of concentration is given by:

in US unitsin metric units$T_c=(11.9\,L^3/H)^{0.385}$ hours$T_c=(0.87\,L^3/H)^{0.385}$ hours

where: L=length of longest tributary (miles – km); H=fall of this tributary (feet – metres); T_c=time elapsing between onset of storm and time when all parts of the catchment begin contributing to flow to measuring point.
(2)Time to peak T_p for the hydrograph for one unit of rainfall over the catchment is given by:
Tp=0.5(rainfallduration)+0.6Tc
where T_p, T_c and rainfall duration are in hours.
(3)Peak run-off rate R_p:in US unitsin metric units$R_p=484\,AQ/T_p$ ft^{3}s (cusec)$R_p=0.2083\,AQ/T_p$ m^3/s (cumec)

where A is catchment area (sq. miles – km^2) and Q is the unit rainfall (inch – mm). If A is in acres and Q is in inches, the peak run-off in US units is given by R_p=0.756 AQ/T_p ft^3/s.

The two most common are to:

- derive a single percentage run-off value applicable throughout the whole storm; or
- adopt an initial loss x mm at the start of the design storm followed by continuing losses of y mm/h throughout the event.

CHAPTER 3: EFFECTIVE RAINFALL

Apart from soil, air and sunlight, crops need water to grow. How much water the various crops need has been explained in Chapter 2.

This water can be supplied to the crops by rainfall (also called precipitation), by irrigation or by a combination of rainfall and irrigation.

If the rainfall is sufficient to cover the water needs of the crops, irrigation is not required.

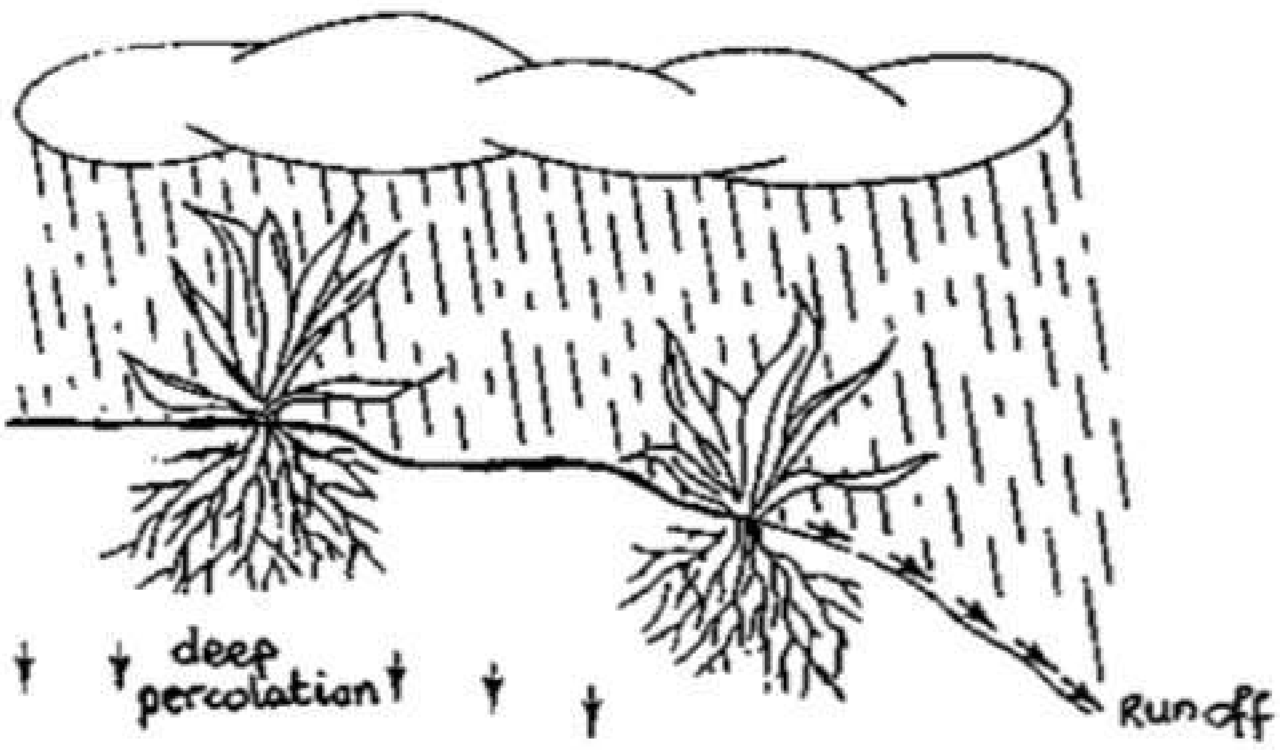
If there is no rainfall, all the water that the crops need has to be supplied by irrigation.

If there is some rainfall, but not enough to cover the water needs of the crops, irrigation water has to supplement the rain water in such a way that the rain water and the irrigation water together cover the water needs of the crop. This is often called **supplemental irrigation:** the irrigation water supplements or adds to the rain water.

As has already been explained in Volume 1, section 4.1.4, not all rain water which falls on the soil surface can indeed by used by the plants.

Part of the rain water percolates below the root zone of the plants and part of the rain water flows away over the soil surface as run-off (Fig. 9). This deep percolation water and run-off water cannot be used by the plants. In other words, part of the rainfall is **not effective.** The remaining part is stored in the root zone and can be used by the plants. This remaining part is the so-called **effective** rainfall. The factors which influence which part is effective and which part is not effective include the climate, the soil texture, the soil structure and the depth of the root zone. These factors have been discussed in some detail in Volume 1, section 4.1.4.

Fig. 9 Part of the rain water is lost through deep percolation and run-off



If the rainfall is high, a relatively large part of the water is lost through deep percolation and run-off.

Deep percolation: If the soil is still wet when the next rain occurs, the soil will simply not be able to store more water, and the rain water will thus percolate below the root zone and eventually reach the groundwater. Heavy rainfall may cause the groundwater table to rise temporarily.

Run-off: Especially in sloping areas, heavy rainfall will result in a large percentage of the rainwater being lost by surface run-off.

Another factor which needs to be taken into account when estimating the effective rainfall is the variation of the rainfall over the years. Especially in low rainfall climates, the little rain that falls is often unreliable; one year may be relatively dry and another year may be relatively wet.

In many countries, formulae have been developed locally to determine the effective precipitation. Such formulae take into account factors like rainfall reliability, topography, prevailing soil type etc. If such formulae or other local data are available, they should be used.

If such data are not available. Table 6 could be used to obtain a rough estimate of the effective rainfall.

Table 6 RAINFALL OR PRECIPITATION (P) AND EFFECTIVE RAINFALL OR EFFECTIVE PRECIPITATION (Pe) in mm/month

P (mm/month)	Pe (mm/month)	P (mm/month)	Pe (mm/month)
0	0	130	79
10	0	140	87
20	2	150	95
30	8	160	103
40	14	170	111
50	20	180	119
60	26	190	127
70	32	200	135
80	39	210	143
90	47	220	151
100	55	230	159
110	63	240	167
120	71	250	175

Environmental flow

Environmental flows describe the quantity, timing, and quality of **water flows** required to sustain freshwater and estuarine ecosystems and the human livelihoods and well being that depend on these ecosystems. In the Indian context river flows required for cultural and spiritual needs assumes significance.Through implementation of environmental flows, water managers strive to achieve a flow regime, or pattern, that provides for human uses and maintains the essential processes required to support healthy river ecosystems. Environmental flows do not necessarily require restoring the natural, pristine flow patterns that would occur absent human development, use, and diversion but, instead, are intended to produce a broader set of values and benefits from rivers than from management focused strictly on water supply, energy, recreation, or flood control.

Rivers are parts of integrated systems that include floodplains and riparian corridors. Collectively these systems provide a large suite of benefits. However, the world's rivers are increasingly being altered through the construction of dams, diversions, and levees. More than half of the world's large rivers are dammed, a figure that continues to increase. Almost 1,000 dams are planned or under construction in South America and 50 new dams are planned on China's Yangtze River alone.

Dams and other river structures change the downstream flow patterns and consequently affect water quality, temperature, sediment movement and deposition, fish and wildlife, and the livelihoods of people who depend on healthy river ecosystems.

Environmental flows seek to maintain these river functions while at the same time providing for traditional offstream benefits.

23.1 Methods of Base Flow Separation

The surface-flow hydrograph is obtained from the total storm hydrograph by separating the quick-response flow from the slow response runoff. It is usual to consider the interflow as a part of the surface flow in view of its quick response. Thus only the base flow is to be deducted from the total storm hydrograph to obtain the surface flow hydrograph.

There are three methods of base-flow separation that are in common use.

23.1.1. Method 1

In this method the separation of the base flow is achieved by joining with a straight line the beginning of the surface runoff to a point on the recession limb representing the end of the direct runoff.

In Fig. 23.1, pointA represents the beginning ofthe direct runoff off and it is usually easy to identify in view of the sharp change in the runoff rate at that point. Point B, marking the end of the direct runoff is rather difficult to locate exactly.

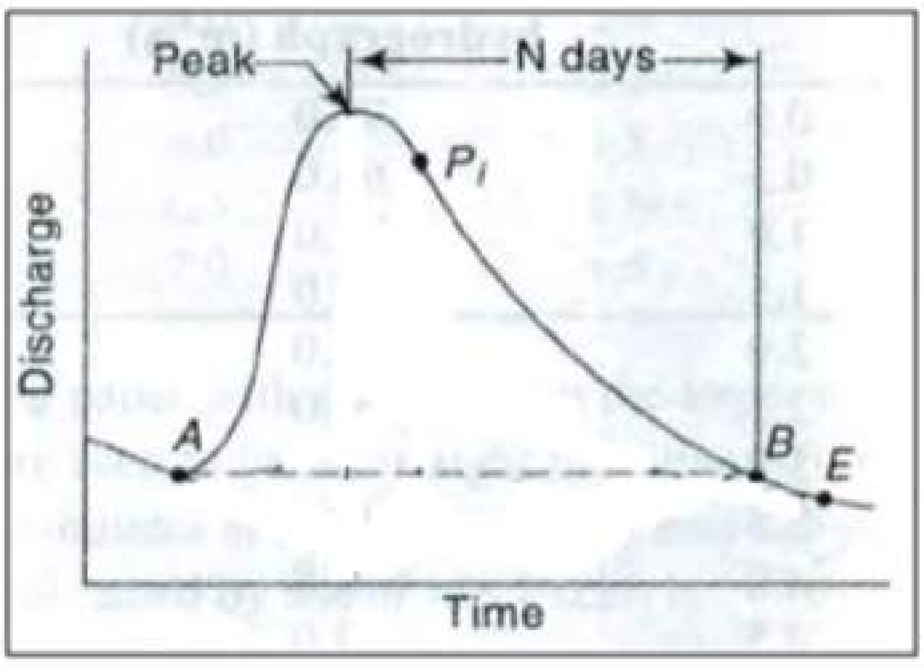


Fig. 23.1. Method 1 for base flow separation.(Source:Subramanya, 2008)

An empirical equation for the time interval N (days) from the peak to the point B is

$$N = 0.83\, A^{0.2} \quad (23.1)$$

WhereA is drainage area in km^{2}and N is in days. Points A and B are joined by a straight line to demarcate to the base flow and surface runoff. This method of base-flow separation is the simplest of all the three methods.

23.1.2 Method 2

In this method the base flow curve existing prior to the commencement of the surface runoff is extended till it intersects the ordinate drawn at the peak (point C in Fig. 23.2). This point is joined to point B by a straight line. Segment AC and CB demarcate the base flow and surface runoff. This is probably the most widely used base-flow separation procedure.

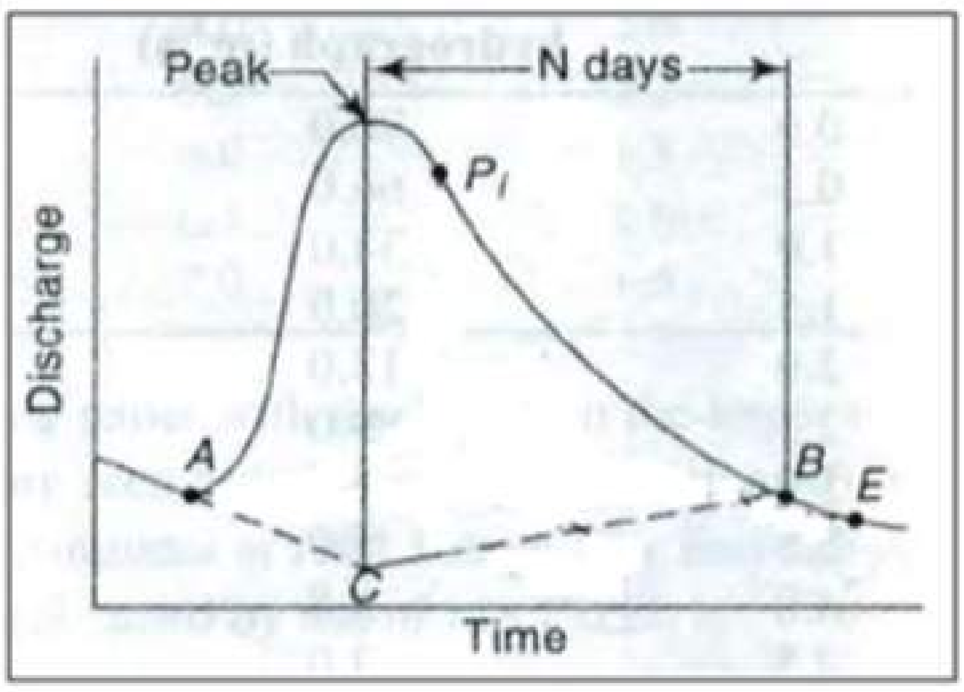


Fig. 23.2. Method 2 for base flow separation. (Source:Subramanya, 2008)

Example 3

A 4-hour storm occurs over an 80 km^2 watershed. The details of the catchment are as follows:

Sub Area	Φ index	Hourly rain (mm)			
km^2	mm/h	1^{st} hour	2^{nd} hour	3^{rd} hour	4^{th} hour
15	10	16	48	22	10
25	15	16	42	20	8
35	21	12	40	18	6
5	16	15	42	18	8

Calculate the runoff from catchment and the hourly distribution of the effective rainfall whole catchment.

Answer:

$$= \frac{(16-10)\times 15+(16-15)\times 25+(12-21)\times 35+(15-16)\times 5}{15+25+35+5}$$

$$= \frac{6\times 15+1\times 25+0\times 35+0\times 5}{80}$$

$$= 1.4375 \text{ mm}$$

2^{nd} hour,

$$= \frac{(48-10)\times 15+(42-15)\times 25+(40-21)\times 35+(42-16)\times 5}{15+25+35+5}$$

$$= \frac{38\times 15+27\times 25+19\times 35+24\times 5}{80}$$

$$= 25.375 \text{ mm}$$

3^{rd} hour,

$$= \frac{(22-10)\times 15+(20-15)\times 25+(18-21)\times 35+(18-16)\times 5}{15+25+35+5}$$

$$= \frac{12\times 15+5\times 25+0\times 35+2\times 5}{80}$$

$$= 3.9375 \text{ mm}$$

4^{th} hour,

$$= \frac{(10-10)\times 15+(8-15)\times 25+(6-21)\times 35+(8-16)\times 5}{15+25+35+5}$$

$$= \frac{0\times 15+0\times 25+0\times 35+0\times 5}{80}$$

$$= 0 \text{ mm}$$

$$\text{Total runoff} = 1.4375 + 25.375 + 3.9375 = 30.75 \text{ mm}$$

$$\text{Total runoff} = \left(\frac{30.75}{1000}\right)\times 80 \times 10^{6}$$

Totalrunoff = 2.46Mm^3

Hourly distribution of the effective rainfall for the whole catchment:

	Effective rainfall (mm)
1^{st} hour	1.4375
2^{nd} hour	25.375
3^{rd} hour	0
4^{th} hour	3.9375

Water energy

- Water, like many substances, contains two kinds of energy. The first kind of energy is called kinetic energy. This is energy that is used during the execution of processes, such as movement. Because of kinetic energy water can flow and waves can exist.
- But water can also contain potential energy. This is energy that is stored in the water. Stored, but not used. This energy can become useful when water starts to flow. It will be transferred to kinetic energy and this will cause movement.

Can energy be generated through water?

- When water flows or falls, energy can be generated. The generation of energy through water is usually carried out in large water power plants, with a number of process steps and the use of several devices, such as turbines and generators. The energy in water can be used to produce electricity.
- The energy from moving water can be used to create electricity in several different ways. For example: A hydroelectric dam captures energy from the movement of a river. Dam operators control the flow of water and the amount of electricity produced.

1.4. NECESSITY FOR IRRIGATION

There is no single requirement of plant life which is more vital than provision of water. Adequate quantities of water should be readily available within the root-zone of all kinds of plant life. Such water if not present in the soil naturally it may be applied by irrigation or derived directly from the rainfall during the crop season. Even today rainfall is beyond the control of a man. It is estimated that one-third of the earth's surface receives less than 250 mm of yearly rainfall and that another one-third receives only 250 to 500 mm of yearly rainfall. Even in remaining areas rainfall is received within few months during the year. It is essential that for good results rainfall process fulfils following characteristics:

(*a*) Rainfall should be sufficient to make good moisture deficiency in the root-zone.

(*b*) Rainfall frequency should be such as to replenish soil moisture deficiency in time so that plants do not suffer from drought.

(*c*) Rainfall intensity should be low to permit the soil to absorb water to the maximum extent.

It shows that we cannot afford to depend exclusively on the rainfall. Necessity for adopting some method or irrigation is four fold.

Firstly, when the seasonal rainfall is less than the minimum required for satisfactory crop growth. Obviously **irrigation is needed when rainfall is insufficient**. Such situation prevails in semi-arid areas of the country where unless some assured source of water is created agriculture is likely to fail year after year (*e.g.*, Rayalaseema region of Andhra Pradesh).

Secondly, every crop requires a certain quantity of water after fixed intervals of time till the crop matures. It is well known that rainfall cannot supply water at fixed intervals of time in measured quantities. Naturally **irrigation is required when rainfall is unevenly distributed** according to the crop requirements. This phenomenon is common in the semi-arid areas lying out of the path of prevailing rain bearing winds. (*e.g.*, Southern part of Rajasthan).

Thirdly, some crops (for example, sugarcane) require regular supply for long time which rainfall can not provide. Thus, **irrigation is needed to give regular supply** for long duration (*e.g.*, Areas east to Westernghat in Maharashtra).

Fourthly, areas with nominal rainfall are always exposed to drought conditions. Arid regions rain shadow areas come under this category. **Irrigation makes it possible to cultivate lands where rain usually fails** (*e.g.*, Rajasthan desert).

All these factors have made provision of irrigation facility a real necessity. It is befitting that irrigation is given pivotal status in agricultural development programmes of the country.

Water Use for Power Generation

Power or electricity is mostly generated at a power plant using various forms of energy. Various types of electric generators include electromechanical fueled by chemical combustion of fossil fuels or nuclear fission, and kinetic energy such as flowing water and steam. Power generation technologies considered in this article include hydroelectric, fossil fuel thermoelectric, nuclear, geothermal and solar thermoelectric. Table 4 shows calculated water use efficiency for power generation systems. The processes how water is used are described below.

Hydroelectric Power

Hydroelectricity is electricity generated by from energy extracted from water through use of the gravitational force of falling or flowing water and a water turbine. Hydroelectric power plant uses water that turns the turbines which operate the electric generator. Hydroelectric power generation systems are highly water efficient because used water is mostly returned to the river or lake with marginal losses through the turbines. Water evaporation loss through the system is mostly attributed to natural processes and other water uses such as recreation (Gleick 1994; USDOE 2006).

CROP WATER REQUIREMENT-FACTORS AFFECTING CROP WATER REQUIREMENT

➢Crop water requirement is the water required by the plants for its survival, growth, development and to produce economic parts.

➢This requirement is applied either naturally by precipitation or artificially by irrigation.

Hence the crop water requirement includes all losses like:

a) Transpiration loss through leaves (T)

b) Evaporation loss through soil surface in cropped area (E)

c) Amount of weather used by plants (WP) for its metabolsm These three components cannot be separated so easily.

Hence the ET loss is taken as crop water use or crop water consumptive use.

d) Other application losses are conveyance loss, percolation loss, runoff loss, etc., (WL).

e) The water required for special purposes (WSP) like puddling operation, ploughing operation, land preparation, leaching, requirement, for the purpose of weeding, for dissolving fertilizer and chemical, etc.

Hence the water requirement is symbolically represented as:

$$WR = T + E + WP + WL + WSP$$

or

$$WR = IR + ER + S$$

or

$$WR = CU + WL + WSP$$

$$CU = E + T + WP$$

IR - Irrigation requirement; ER - Effective rainfall

S - Contribution from ground water table.

Consumptive use of water: It is a matter of common experience that water losses are simultaneously taking place from the soil adjacent to the plant through transpiration from the plant structure. Hence the term evapo-transpiration is commonly used to denote combined water loss. It is designed by abbreviation ET also. In addition, some water is utilized in the plant metabolism. The consumptive use of water is the sum total of ET and water used up in plant metabolism. But since water used in metabolism is negligible, for all practical purposes.

$$ET = CU$$

where *ET* is evapo-transpiration.

Application losses: The amount of water required to replenish the soil moisture deficit back to field capacity (F.C.) in the root-zone of a crop cannot be applied exactly by means of irrigation. Some loss of water is, therefore, unavoidable under field conditions. These unavoidable losses are called application losses.

Water applied in excess of field capacity are avoidable losses. Such losses include surface run off and percolation losses beyond crop root-zone. In scientific management of water occurrence of such losses is to be prevented.

Special needs: Depending upon the field conditions and soil characteristics extra water is needed to meet purposes like leaching of excess salts, pudding, pre-planting (paleo) irrigation etc.

Irrigation Requirement (IR): It is the depth of water exclusive of precipitation, stored soil moisture or ground water that is required to meet evapo-transpiration needs of a crop. It can be expressed as

$$IR = WR - (ER + S)$$

It is also called net irrigation water requirement (NIR). Irrigation requirement of a field will be IR plus transit losses in the farm distribution system.

Similarly, irrigation requirement at head of an outlet will constitute farm irrigation requirement (FIR) plus losses taking place below outlet.

Gross irrigation requirement (GIR) will, therefore, be net irrigation requirement plus all losses in transit upto the point where water is drawn in the conveyance system from the storage or by diversion.

Effective Rainfall (ER

2.12. CROP SEASONS AND CROPS OF VARIOUS SEASONS

Taking natural seasons into account together with the number of times different crops can be grown in a year on the same land, the agriculturists have given the following crop seasons for various parts of India in a broad sense:

1. For **Southern India** the weather conditions are moderate neither touching extreme hot or extreme cold. As a result three crop seasons can be recognized. They are Hot weather **crop season**, **rabi season** and **kharif season**. The hot weather crop season ranges from February to May and the crops which can sustain heat and humid conditions are grown. Kharif season ranges from June to October. The crops are sown in the beginning of the monsoon and are harvested in autumn. Rabi season ranges from October to March. The crops are sown in the beginning of winter and are harvested in spring.
2. For **Northern India** there are two distinct crop seasons in a year. They are **rabi season** and **kharif season**. Rabi season starts in the month of November and ends in the month of March. While kharif season starts in June and ends in October. As

a matter of fact the crops of one season may extend in other season depending upon the prevailing climatic conditions of the area.

Apart from these there are some crops which take comparatively longer time for maturing. Cotton takes 8 months for maturing. It is, therefore, known as a **eight months'** crop. Crop season extends from June to February.

Sugarcane takes full 12 months for maturing. It is, therefore, known as a **perennial crop**. Garden crops also come under this category.

Crops of various seasons: A crop is said to pertain to a particular season when the crop extends from the time of sowing to the time of harvesting in that season mostly.

The following is the division of crops according to the two main seasons **rabi** and **kharif** over which the crops extend.

The extent of cultivated areas under the Principal crops in India is given in brackets. The areas are given in million hectares in Table 2.6.

Table 2.6. Area under Principal Crops

(Figure in Mha)

Rabi crops	*Kharif crops*	*Other crops*
Wheat (26.48) Gram (6.90) Rapeseed and Mustard (7.28)	Rice (43.66) Great millet (8.67) Spiked millet (9.58)	Tea (0.38) Coffee (0.08) Sugarcane (4.20)
Linseed (1.02) Castor (0.56)	Maize (7.59) Arhar (3.58) Pulses (4.09) (Urd, Mung, Moth, Kulthi etc.)	Cotton (8.68) Tobacco (0.37)
Barley (1.23) Other pulses (7.88) (Peas, Masur, etc.) Onion (0.26)	Jute (0.81) Seasame (1.83) Groundnut (6.74)	Potato (0.84)

(Figures relate to 2005-06)

Cash crops: There is one more classification of crop which has nothing to do with the season in which it is grown. There are certain crops which a farmer mostly grows for selling in the market to meet his financial requirements. They are called cash crops. Wheat, rice, various millets, maize are used by the farmers to run their household and to pay wages to workers as food for work. All other crops listed in Table 2.5 above and many others like various vegetables could be termed as cash crops.

Sometimes a cash crop is sown on the some field together with a food crop (for example wheat and mustard) then the field is said to have a **mixed crop**.

When on the same field two crops are grown one after the other in one calender year the farmer is said to have grown **double crop**.

fertility.

2.19. CROP ROTATION

The method of crop rotation is most natural and at the same time economical. The crop rotation means simply changing the crop to be grown every year on the same field. Under lying principle is that each crop requires different nutrients and in different proportions. By changing a crop every year in a way soil is given rest as the same nutrients are not used every year. At the same time cultivated land is not kept idle.

In this method only precaution to be taken is to select the crops properly for rotation. So far as crop rotation is concerned there is no distinction between rabi and kharif crops. Rabi crops can be brought in rotation with kharif crops. For this best and quick results manure may also be added to the field.

For rotation some crop groups are given below to order of sequences.

1. Wheat — Great millet — Gram.
2. Rice — Gram.
3. Cotton — Wheat — Gram.
4. Cotton — Wheat — Sugarcane
5. Cotton — Great millet — Gram.

From the above information on the crop rotation the following three inferences can be drawn:

1. In most of the crop rotation groups gram is the crop which completes a cycle. The reason for gram being last is rotation is, it is a leguminous crop and when sown on the field gives nitrogen to the soil to make a rich.
2. Crop rotation keeps the soil free from soil diseases. If the same crop is grown on the field it will make soil poorer at the same time crop may impart some peculiar diseases of its own to the soil.
3. Each crop has different depth of root-zone. Naturally maximum possible usage of the available soil moisture of a field can be made by growing different crops, some of which have shallow roots and others deep roots.

Delta (Δ): Each crop requires certain amount of water depending upon the area under that crop. If the area under crop is large, amount of water required will be more, on the other hand if area is small amount of water required will be less. This is the amount of water required directly depends upon the area under crop. However, for the same crop the amount of water required per hectare of area will be the same on both large and small areas. Now this amount of water on one hectare land can be expressed in hectare-metre or hectare-centimetres.

"Suppose certain amount of water is applied to a crop from the time of sowing till the crop matures and if the applied water is not lost or used up by any means then there will be a thick layer of water standing all over the field. The depth or height of this water layer is known as delta for the crop."

Obviously the unit of delta will be a meter or a centimeter.

Duty: It is a relationship between the amount of water and the area over which this amount of water is applied to the crop. It shows the degree of efficient utilization of irrigation water supplied from a canal to any crop. Suppose in a channel the rate of discharge is one cubic meter per second and this water is constantly allowed over the land for irrigation purpose. If this rate of applying water is continued for a particular crop from the time of sowing till the crop matures then the total amount of water applied in the abovementioned time period will cover particular area in hectares to give the total depth of water equal to the delta to the crop. This area measured in hectares will be called the **duty of the canal water**.

Precisely "Duty of the canal water is the number of hectares under a particular crop, brought to the state of maturity by a constant supply of one cubic meter of water per second flowing continuously for the base period." It is expressed in hectares per cubic meter per second.

Base Period: It is the time elapsed from first watering at the time of sowing to the last watering when the crop matures.

2.13. INFILTRATION

"Infiltration is a process in which water enters the surface strata of the soil mass and moves downwards or percolates to join ground water reservoir."

Ground water reservoir is nothing but the soil mass saturated with water. The soil mass above the surface of ground water reservoir is unsaturated. The surface of ground water reservoir is called water table. The extent to which moisture is held in soil pores depends on texture and structure of the soil mass. This is due to the fact that intermolecular forces and tensions in unsaturated soils are influenced by soil texture and structure. These forces give rise to capillary phenomenon in unsaturated zone of the soil mass.

Infiltration water first fulfils the moisture, deficiency if any, in the unsaturated zone of the soil mass and then contributes to the ground water storage. Rate of infiltration is influenced by soil properties and also by hydraulic gradient. Usually infiltration rate is very high at the beginning of application of water to the land than it is several hours later. The decrease in rate of infiltration with time is of importance in irrigation practices and also in rain fall-run-off studies. Rate of infiltration can be conveniently expressed as lowering of water surface in centimetres per hour.

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All these factors have made provision of irrigation facility a real necessity. It is befitting that irrigation is given pivotal status in agricultural development programmes of the country.

Water quality varies with the source.

It may or may not contain

- dissolved minerals
- dissolved gases
- organic matter
- microorganisms
- combinations of these impurities that cause deterioration of metalworking fluid performance.

Why do we need to analyze water?

- If water is badly polluted-- like raw sewage--- it might be obvious from its appearance or odor.
- It might be colored or turbid (cloudy), or have solids, oil or foam floating on it.
- It might have a rotten odor, or smell like industrial chemicals.

TWO ASPECTS OF WATER

There are two aspects of water analysis that we need to consider:

what substances or organisms are we interested in testing for-- and why?

what procedures and equipment do we use to make the measurements, and how do they work?

35.8. FREQUENCY ANALYSIS

Definition of frequency analysis: Frequency analysis is a method which involves study and analysis of past records (historical data) of hydrologic events to predict the future probabilities (chances) of occurrence. It is based on the assumption that the past data are indicative of the future.

Frequency analysis is done to estimate various things like annual runoff variations, frequencies of floods, droughts, rainfall's etc. In other words the primary objective of the frequency analysis of hydrologic data (say flood events) is to determine the recurrence interval of the hydrologic event of a given magnitude.

For such analysis so called probability curves have been used. Given the observed data (for example maximum discharges for estimating maximum flood, average annual, discharges for annual variations etc.) the task is to find a tneoretical curve the ordinates of which will coincide with those observed. Good agreement of a theoretical curve with an empirical one ensures that the extrapolation can be rightly done.

When stream flood records of sufficient length and reliability are available they may yield satisfactory estimates. The accuracy of the estimates reduces with the degree of extrapolation. It is considered by some that extrapolation may be done only upto double the period for which data is available. For example, to get a 100 year flood 50 years record is necessary. However, insufficiency of recorded data makes it obligatory to use short term data to predict 1000 and 10,000 year floods also.

Frequency analysis is a method which involves statistical analysis of recorded data to estimate flood magnitude of a specified frequency. It, therefore, requires knowledge of statistics to clearly appreciate the methods of frequency analysis.

35.9. DEFINITIONS OF STATISTICAL TERMS

Before proceeding with the methods of frequency analysis it is useful to understand the definitions of some basic statistical terms and parameters commonly used in frequency analysis.

(*i*) **Population:** In statistic the whole collection of objects under consideration is called a population. It may be finite or infinite collection. It includes complete set of values that the object under consideration has taken in the part and/or can or will take in the future.

(*ii*) **Sample:** A sub-population drawn from a larger population is called a sample. The size of the sample is the number of units it contains. If a sample is representative of a population important conclusions about the population can be drawn from analysis of the sample.

(*iii*) **Random Sample:** When every unit in a population has an equal chance of being chosen the sample is called a random sample.

(iv) **Variable:** It represents one or more characteristics of a segment of a population. It has at lest one property which can be measured and numerically defined. In hydrology, for example, rain intensity, rate of evaporation, stream discharge are hydrologic variables (but only terms evaporation, rainfall, runoff etc. are hydrologic phenomenon). There are two types of variables namely continuous and discrete or discontinuous. Continuous variable can be measured along a continuous scale. For example, a hydrograph presents the stage or discharge of a stream as a continuous variable. Also depth of rainfall is a continuous variable.

On the other hand discrete variable is one which can be counted. For example, number of rainy days in a week or a month is a discrete variable.

(v) **Variate:** The value of a variable is called variate.

For example in hydrology variables like rainfall, annual flood peak, minimum flow is usually designated by X whereas, the variate which represents individual observation is usually designated by x.

(vi) **Array:** An array is an arrangement of raw numerical data in ascending of descending order of magnitude.

(vii) **Range of data:** The difference between the largest and smallest number is called the range of the data.

(viii) **Time series:** It is a sequence of values arranged in order of their occurrence.

(ix) **Frequency:** It is the number of occurrences of an item in the sample. It is also called absolute frequency.

(x) **Probability:** It is also called relative frequency. Probability is the number of occurrences of a variate divided by the total number of occurrences. It is designated by 'P'. The total probability for all variates is equal to unity, *i.e.*, $\Sigma P = 1$. *The probability cannot be less than zero and more than one*. Probability of zero means an impossible event whereas probability of one means a sure event. For example, there are 10 variates of stream discharge values with discharges ranging as shown in Table 35.4 below. (It is called grouped data)

Table 35.4.

Class interval (cumec)	*Frequency*	*Probability or (relative frequency)*
< 100	1	$\frac{1}{10}$
100 – 200	2	$\frac{2}{10}$
200 – 300	4	$\frac{4}{10}$
300 – 400	2	$\frac{2}{10}$
> 400	1	$\frac{1}{10}$
Σ	10	$\frac{10}{10} = 1$

(xi) **Frequency distribution:** It is a (pattern of distribution) graph obtained by plotting the number of occurrences or the frequency against the variate as the abscissa (Fig. 35.5).

Frequency distribution can be plotted as block values or as point values with class mark as abscissa and absolute, relative or % frequency as ordinate.

If the adjacent points are joined by straight lines a *frequency polygon* is obtained. The polygon converges to the *frequency distribution curve* as the number of observations and classes increase indefinitely.

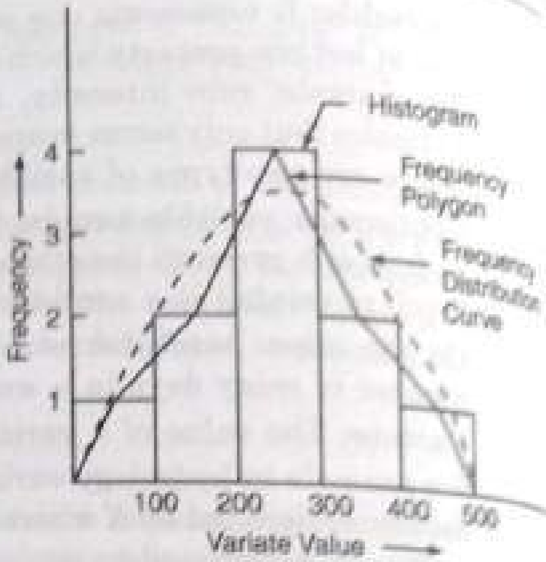

Fig. 35.5. Frequency distribution

(xii) **Probability distribution:** It is a pattern of distribution obtained by plotting relative frequency (percent frequency) against variate as abscissa.

It may be mentioned here that the ordinates of the frequency distribution and its corresponding probability distribution are proportional to each other.

(xiii) **Cumulative or mass frequency diagram:** For grouped data (as given in a table above) the cumulative frequency of variates not exceeding a given value is the sum of all frequencies less than or equal to the given value.

The cumulative probability curve is plotted on rectangular coordinates by taking cumulative probability on the ordinate and magnitude of the variate on the abscissa. This type of curve is shown in Fig. 35.6.

The cumulative probability represents the probability that the random variable has a value equal to or less than certain assigned value say x. Then the cumulative probability is designated as

$P(X \leq x)$

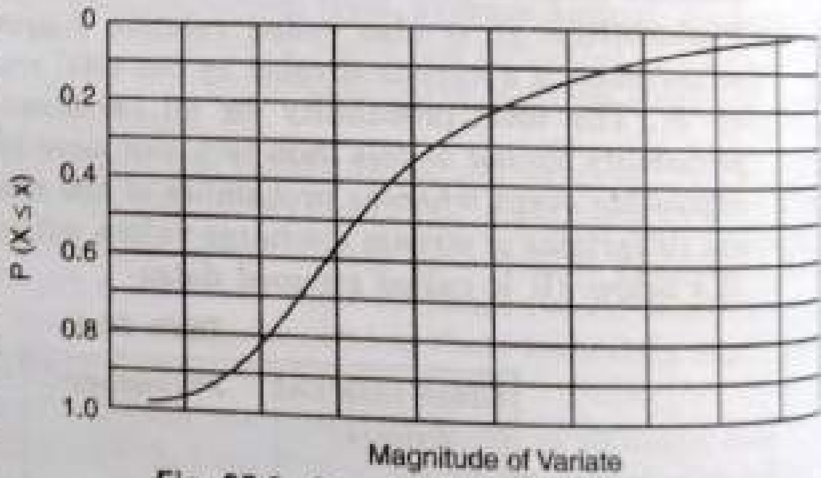

Fig. 35.6. Cumulative probability curve

Since the total probability is unity. The probability of being equal to or greater than x is given by

$P(X \geq x) = 1 - P(X \leq x)$

In order to linearize the distribution a probability paper is used (Fig. 35.7). It is a specially ruled paper on which the ordinate and/or abscissa scales are so designed that the distribution plots more nearly on a straight line. It permits better definition of the upper and lower parts of the frequency curve and facilitates extrapolation.

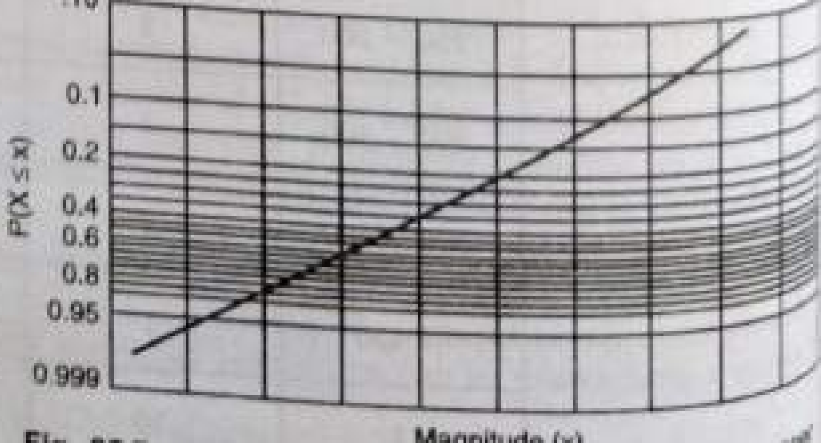

Fig. 35.7. Cumulative probability curve pn probability paper

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Root Zone Soil Water Relationships | Irrigation

(i) Volume of solids Vs
(ii) Volume of liquid (water) Vw, and
(iii) Volume of gas (air) Va

The porosity n, the volumetric moisture content w and the saturation s are defined as N = Vv/VFurther, if the weight of water in a wet soil sample is W_w and the dry weight of the sample is W_s, then the dry weight moisture fraction, W is expressed as

The bulk density (or the bulk specific weight or the bulk unit weight) of a soil mass is then dry weight of the soil per unit bulk volume, i.e., W_s/V (Fig. 3.1). The specific weight (or the unit weight) of the soil particles is the ratio of dry weight of the soil particles W_s to the volume of the soil particles V_s, i.e., W_s/V_s. Thus,

Here, y_w is the unit weight of water and G_b and G_s are, respectively, bulk specific gravity of the soil and relative density of soil grains. Further,

- Considering a soil of root zone depth d and surface area A (i.e., bulk volume = Ad),
- This volume of water can also be expressed in terms of depth of water which would be obtained when this volume of water is spread over the soil surface area A.

IV. SOIL AND WATER RELATION

Perfect knowledge about soil and water relationship is very essential for irrigation engineers to improve irrigation, practices. This knowledge is also helpful to the cultivators who seek maximum economic use of water supplied to them for irrigation purposes.

2.14. PERMEABILITY AND ITS MEASUREMENT

Definition of Permeability: It is that property of soil which allows water to move throu the soil mass. Permeability of a soil mass is defined as, 'the velocity of flow under a u hydraulic gradient in which driving force is one dyne per gramme of water.' It has a dimensi of length divided by time.

Permeability is largely dependent on soil texture and structure. It may be influenced al by the presence of plant roots, earth worm excavations or the activities of other forms of s life. It may also be influenced by reactions of base exchange, depending upon the sal present in the soil. Changes in temperature of water influence permeability slightl Permeability is not influenced by the hydraulic gradient and it is the main different betwe infiltration and permeability. Unlike infiltration permeability designates flow through soi in any direction.

To ensure continuous good yield from irrigated crops soil should be sufficiently permeabl In sandy soils of coarse texture pore spaces are relatively large and the soil has hig permeability. In clayey soils of fine texture pore spaces are relatively less and the flow o water is retarded. Puddled soils and clayey soils of usually fine texture are practically impermeable to water. Soils having medium texture are sufficiently permeable for satisfactory irrigation farming so long as crumbly or granular structures can be maintained.

Sodium salts when present in soil tend to deflocculate the soil particles. It reduces volume of pore spaces and as a result permeability of the soil is reduced. To make such soils permeable sometimes calcium salts are added to the soil externally. Then due to chemical base exchange reaction between sodium and calcium salts soil becomes granular and permeability is increased.

In saturated soils permeability varies over a long range. The permeability varies from less than 0.1 mm per hour for the lowest permeability class, *e.g.*, compact clay soils upto 250 mm per hour for the highest permeability class, *e.g.*, gravel formations.

Measurement of Permeability: There are two main subdivisions of permeameter.

(*i*) **Constant-head Permeameter:** It is used for measuring permeability of coarse and medium textured soils. Figure 2.9 shows the permeameter with all accessories.

A metal cylinder is filled with soil of thickness 'L' cm. Thickness 'L' represents flow length. The cross sectional area of the cylinder is 'A' sq cm. Over the soil water is stored to

8.8. SUB-SURFACE IRRIGATION

Natural sub-irrigation: Sometimes topographic conditions and soil formation are such that the water contributes to sub-soil directly. Then it is termed as natural sub-surface-irrigation.

When the top soil zone of about 2 metres depth is formed of highly previous soil which rests on impervious layer, the formation makes an ideal locality. The surface slope should be moderate. The method of applying water directly to subsoil is as follows:

Small ditch 50 to 100 cm deep and 30 cm wide are dug at a spacing of 60 to 90 metres. From the parent channel flexible pipe siphons are taken into the ditches at various places over the bank. The distributed water flows through the ditches and during its journey seeps into the soil to fulfil water needs.

Artificial sub-irrigation: Sometimes in the root zone of crops a pipeline with open joints can be laid. Water passes through this pipe line. The water comes out of the open joints and satisfies soil-moisture requirement of the subsoil. The soil should be such that it allows free material movement of water and capillary movement. In this method operation and deep percolation losses are avoided. This method of irrigation does not interface with cultivation. This method is useful for the production of cash crops on small area. Main drawback is its high cost.

8.2. SURFACE IRRIGATION

In this method water flows and spreads over the surface of the land. Varied quantities of water are allowed on the fields at different times. Hence, flow of water under surface irrigation comes under unsteady flow. As a result it is very difficult to understand the hydraulics of surface irrigator. However, suitable and efficient surface irrigation method can be adopted after taking into consideration various factors which are involved in the hydraulics of surface irrigation. They are:

(*i*) Surface slope of the field
(*ii*) Roughness of the field surface
(*iii*) Depth of water to be applied
(*iv*) Length of run and time required
(*v*) Size and shape of water-course
(*vi*) Discharge of the water-course
(*vii*) Field resistance to erosion.

If the surface irrigation method is correctly chosen it fulfils following requirements:

(*a*) It helps in storing required amount of water in the root-zone-depth.
(*b*) It minimizes the wastage of irrigation water from the field in the form of run-off water.
(*c*) It reduces the soil erosion to minimum.
(*d*) It helps applying uniform application of water to the fields.
(*e*) Amount of manual labour required is minimum.
(*f*) It is best suited to the size of the field and at the same time it uses minimum land for making ditches, furrows, strips, etc.
(*g*) It does not prevent use of machinery for land preparation, cultivation, harvesting, etc.

8.9. OVERHEAD OR SPRINKLER IRRIGATION

In this method an attempt is made to simulate natural rainfall. Irrigation water is applied to the land in the form of a spray. This method is also known as sprinkler irrigation.

Sprinklers can be used on all soil types of any topography. According to the equipment and procedure used the sprinkler method may fall in fixed type or portable type. The sprinkler irrigation may also be subdivided according to the functions it has to perform, namely:

(*i*) the main irrigation system,

(*ii*) the supplementary irrigation system, and

(*iii*) the protective irrigation system.

The sprinkler irrigation system is in use since 1920. A.D. in some advanced countries. In India this method has come into use since 1950. It is mostly adopted in tea and coffee gardens. But the time has come to explore the possibilities of using this method on large scale. Experiments have already been undertaken on this aspect at various research centres in the country. There is great scope and likelihood of this system becoming popular in our country in the coming years. By introduction of spray irrigation about 35 percent of water can be saved which is otherwise wasted in surface methods. Following conditions favour implementation of sprinkler irrigation:

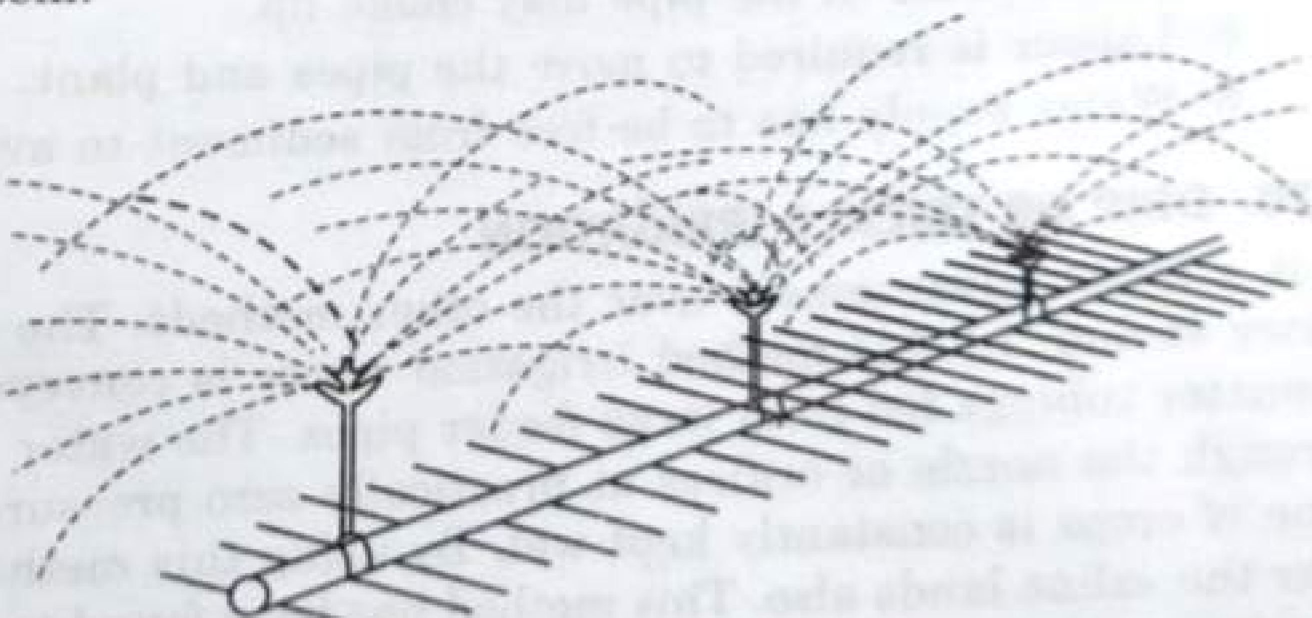


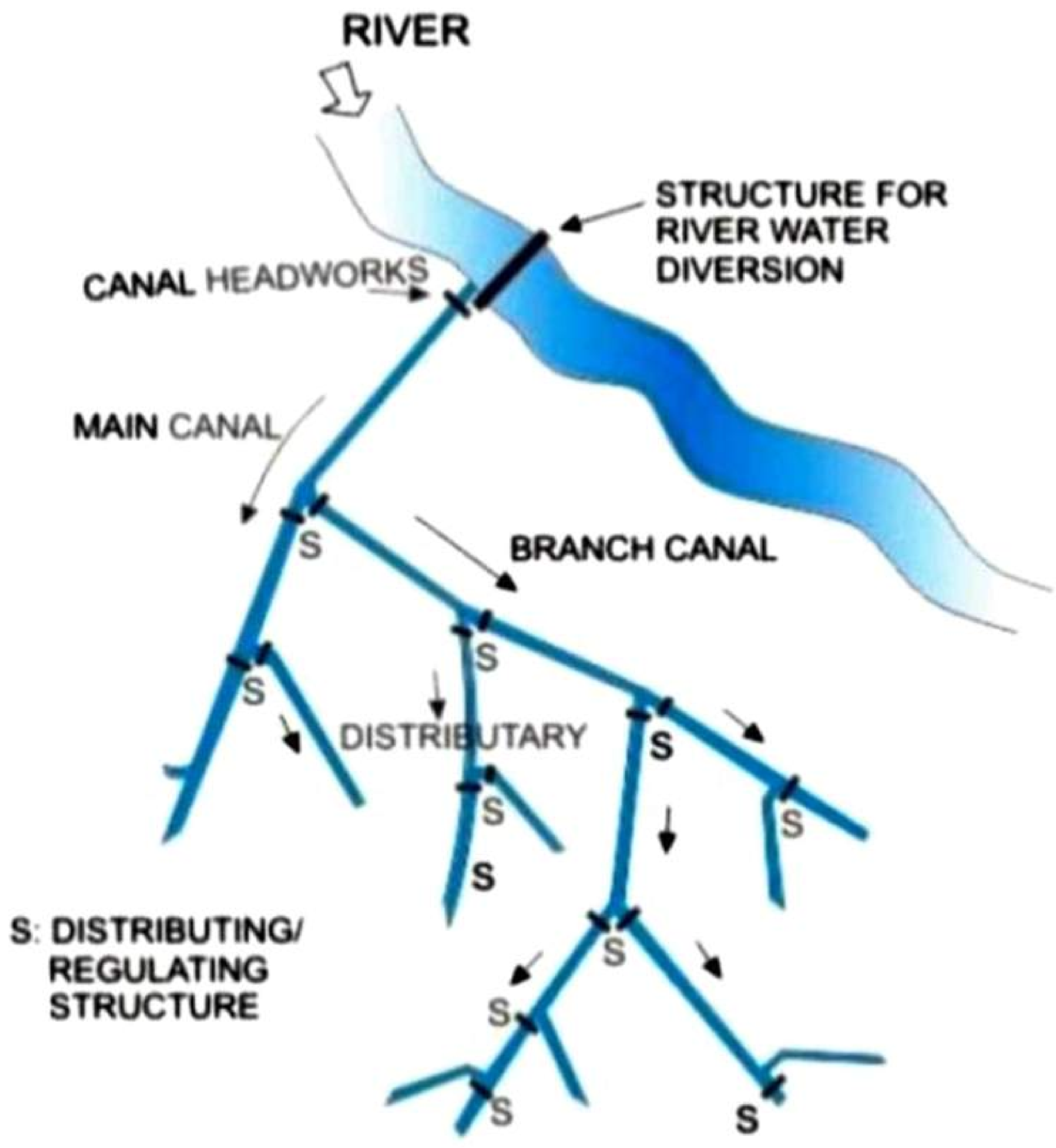
Fig. 8.8. Sprinkler Irrigation

8.10. DRIP OR TRICKLE IRRIGATION

It is a latest advancement over the other methods. The name of the method itself implies water saving. In this method irrigation water is conveyed on the surface in 12 to 16 mm diameter tubings fed from large feeder pipes. The water is allowed to drip or trickle slowly through the nozzle or orifices at practically zero pressure. In this way the soil in the root-zone of crops is constantly kept wet. By using this method crops can be grown successfully over the saline lands also. This method has been found to be of great value in reclaiming and developing desert and arid areas. The main drawback of this method is its high cost. But when growing realisation of the value of water this method has been introduced in other countries of the world particularly in desert areas. The method is still in initial stages of development in our country.

DEFINITION OF CANAL:

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



CANAL ALIGNMENT:

- A canal has to be aligned in such a way that it covers the entire area proposed to be irrigated, with shortest possible length and at the same time its cost including cost of drainage works is a minimum.

Types of canal Alignment:

- Ridge / watershed Canal
- Contour Canal
- Side slope Canal

INTRODUCTION

- The loss of water due to seepage and evaporation from irrigation canals constitutes a substantial percentage of the usable water .
- From the point of the head works where the water enters in the main channel up to the final point where water is supplied to the agriculture field , considerable amount water is lost (not available for the field-irrigation) is called water losses or transit losses or transmission losses.

CAUSES OF WATER LOSSES

- There are three basic causes of such water losses which are as stated below :-
- 1. Losses due to Evaporation.
- 2. Losses due to Percolation.
- 3. Losses due to Transpiration (through the weeds and the vegetation on the bank of channels).

ESTIMATION OF PEAK FLOOD

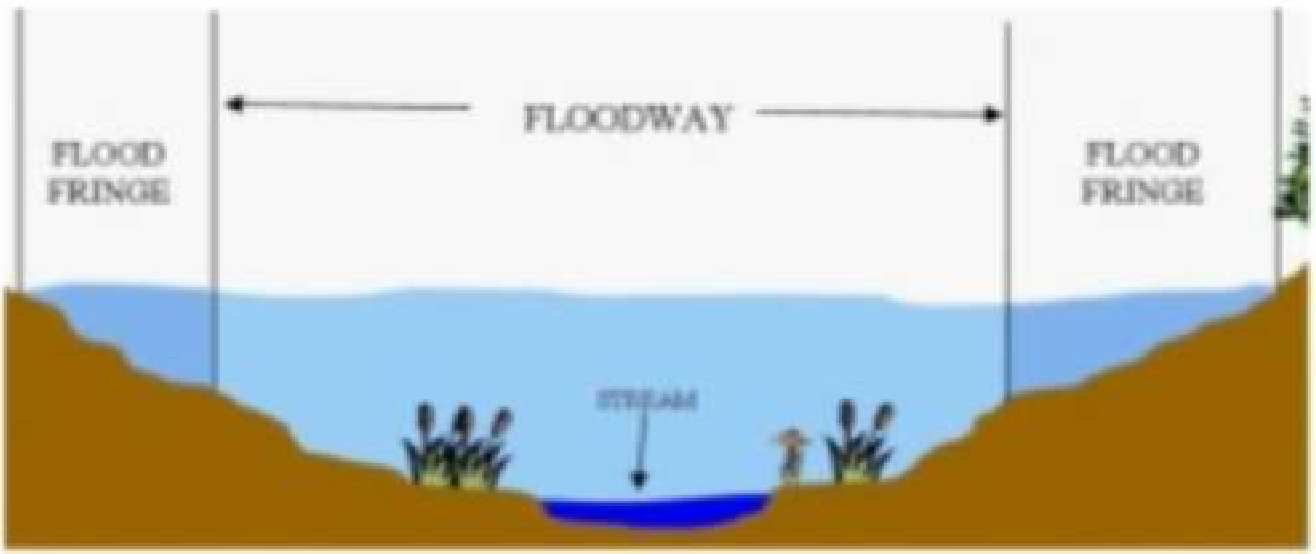
- The maximum flood discharge (peak flood) in a river may be determined by the following methods:

- *(i) Physical indications of past floods—flood marks and local enquiry*
- *(ii) Empirical formulae and curves*
- *(iii) Concentration time method*
- *(iv) Overland flow hydrograph*
- *(v) Rational method*
- *(vi) Unit hydrograph*
- *(vii) Flood frequency studies*

ESTIMATION OF PEAK FLOOD

- *(i) Physical indications of past floods—flood marks and local enquiry*

- By noting the flood marks (and by local enquiry), depths, affluxes (heading up of water near bridge openings, or similar obstructions to flow) and other items actually at an existing bridge, on weir in the vicinity, the maximum flood discharge may be estimated by use of Manning's or Chezy equation



Estimate, A, P, R, S
n or C for actual site

ESTIMATION OF PEAK FLOOD

- *(ii) Empirical formulae and curves*

- *There are plenty of empirical formulae relating Q with drainage area, A, of basin.*

- <u>For example:</u>
- Burkli Ziegler formula for USA: $Q = 412\,A^{3/4}$
- DICKENS Formula (1865): $Q=C_D A^{3/4}$
- RYVES Formula (1884): $Q=C_R A^{2/3}$
- INGLIS Formula (1930): $Q=124A/(A+10.4)^{0.5}$

- *Where, Q is the peak flood in m^3/s and A is the area of the drainage* basin in km^2. C_D and C_R dickens constant and Ryves coefficient respectively.

ESTIMATION OF PEAK FLOOD

- *(iii) Envelope Curves.*
- Areas having similar topographical features and climatic conditions are grouped together. All available data regarding discharges and flood formulae are compiled along with their respective catchment areas.

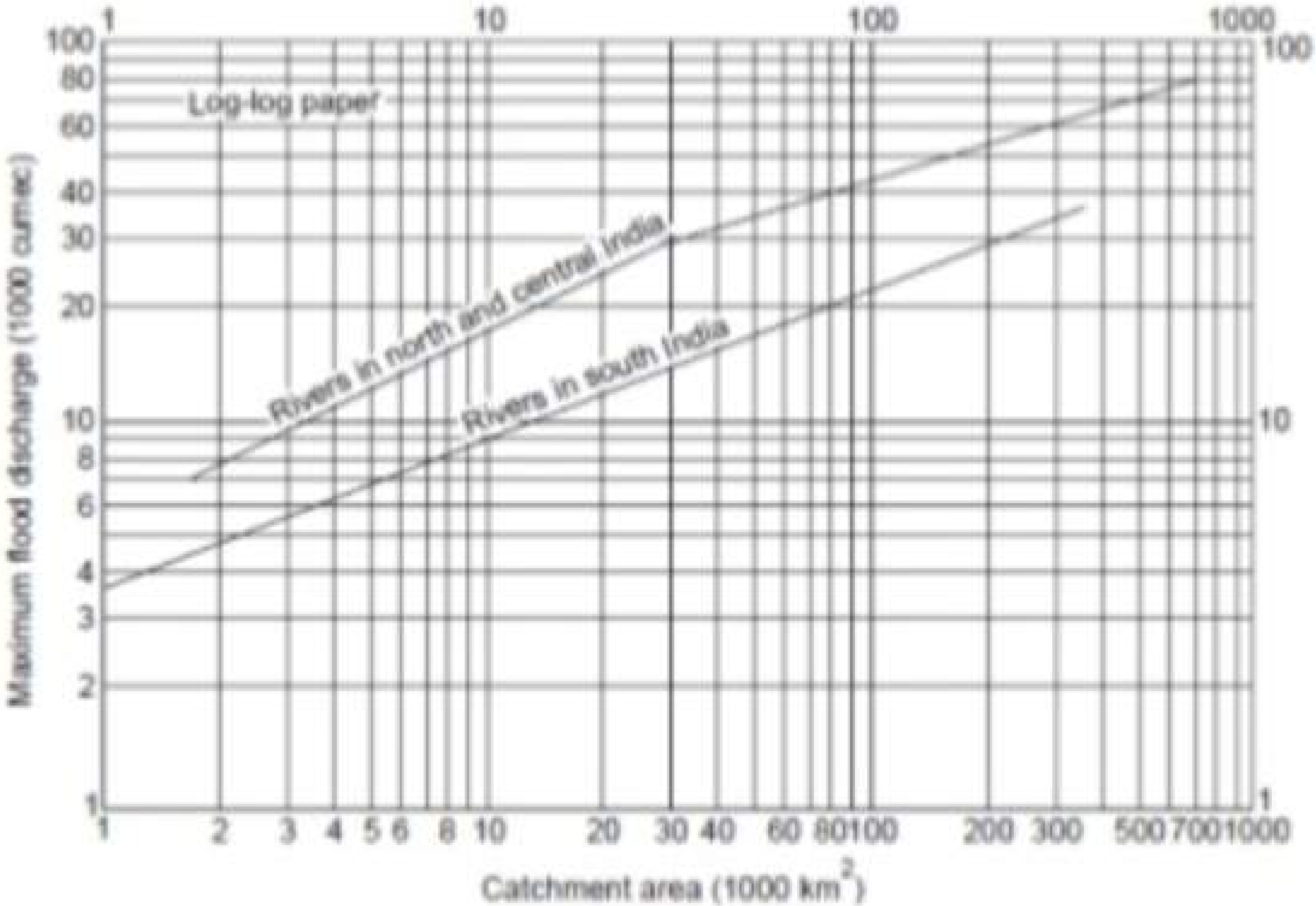


Fig. Enveloping curves of Kanwar Sain and Karpov

ESTIMATION OF PEAK FLOOD

- *(v) Rational Method:*
- The Rational Method is most effective in urban areas with drainage areas of less than 200 acres. The method is typically used to determine the size of storm sewers, channels, and other drainage structures.
- The rational method is based on the application of the formula

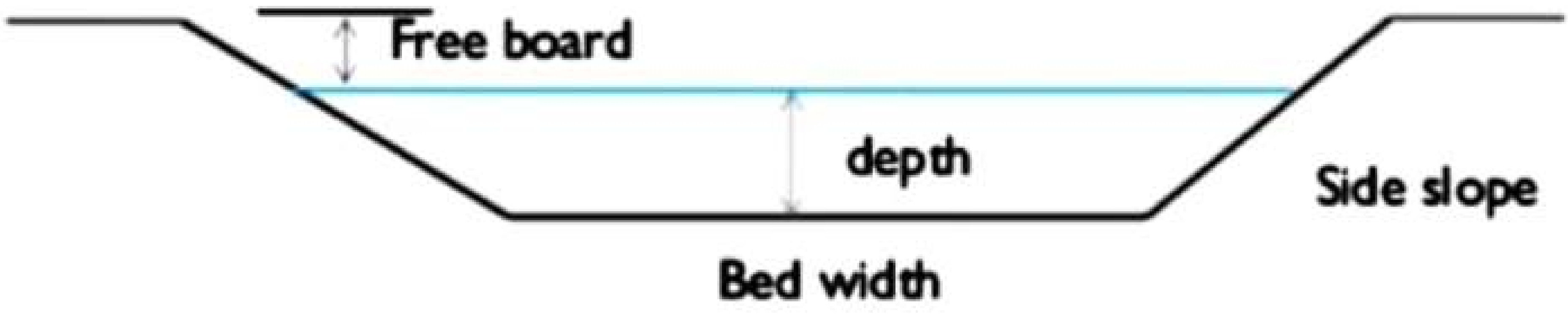
$$Q = kCiA$$

- where C is a coefficient depending on the runoff qualities of the catchment called the runoff coefficient (0.2 to 0.8), A is the area of catchment, i is rainfall intensity and k is conversion factor.

- For English units of acres and in/hr, $k = 1.008$ to give flow in cfs
- For SI units of hectares and mm/hr, $k = 0.00278$ to give flow in m^3/sec.

Open Channel Design

- It is the process to obtain a shape, slope and geometry of channel/canal which should not have objectionable silting and scouring.



- For example for a trapezoidal channel, it consists of determining;
  - (1) depth,
  - (2) bed width,
  - (3) side slope and
  - (4) longitudinal slope of the channel so as to produce a non-silting and non-scouring velocity for the given discharge and sediment load.

Open Channel Design: Channel types

- Types of channels based on material
  - Lined channels (Rigid boundary channels)
  - Unlined channels (erodible or earthen channels)

- Types of channels based on shape
  - Circular channel
  - Triangular channel
  - Rectangular channel
  - Trapezoidal channel

Channel Design: Rigid Boundary-Rectangular Channels

- In rigid channels a layer of rigid material (e.g., Concrete, bricks and stone etc) is used at the periphery of channel to reduce seepage, to increase discharge capacity and prevent erosion.
- Dimension of rectangular channels are based on most efficient rectangular section. i.e ($b=2y$ or $y=b/2$) where b and y are width and depths of channel respectively.
- For trapezoidal channels, side slopes varies from 1:1 for small channels to 1.5(H):1(v) for large channels.
- These channels can be used for both subcritical and supercritical flows.
- The design if primarily based on Manning's Equation

$$Q = \frac{C_o}{n} A R^{2/3} S_o^{1/2} \Rightarrow A R^{2/3} = nQ / \left(C_o S_o^{1/2}\right)$$

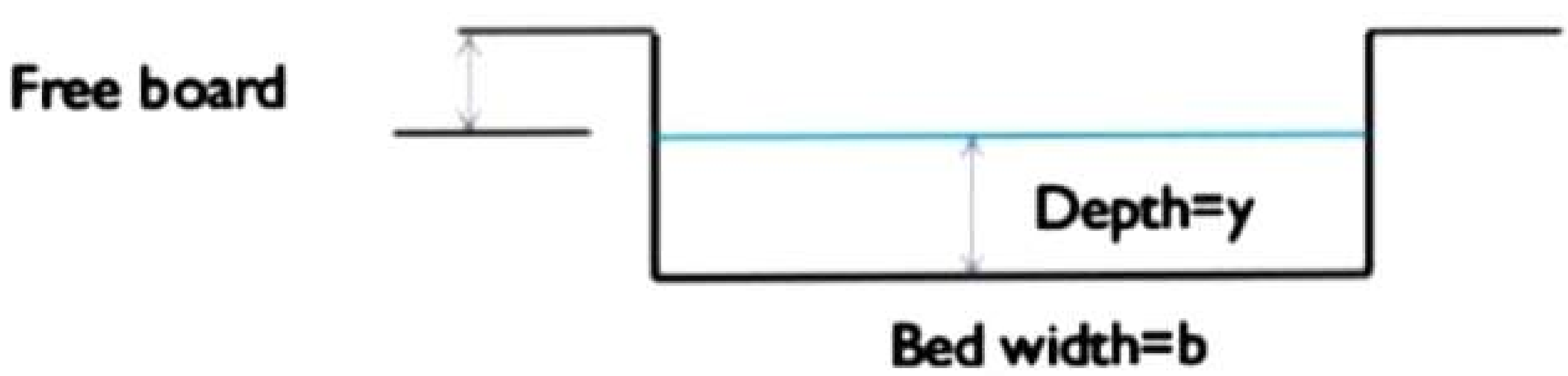
- Where Q is discharge, n is roughness coefficient, A is area of flow, R is hydraulic radius, So is channel bed slope, and Co is coefficient (1 for SI unit and 1.49 for U.S. customary units)

Channel Design: Rigid Boundary Channels

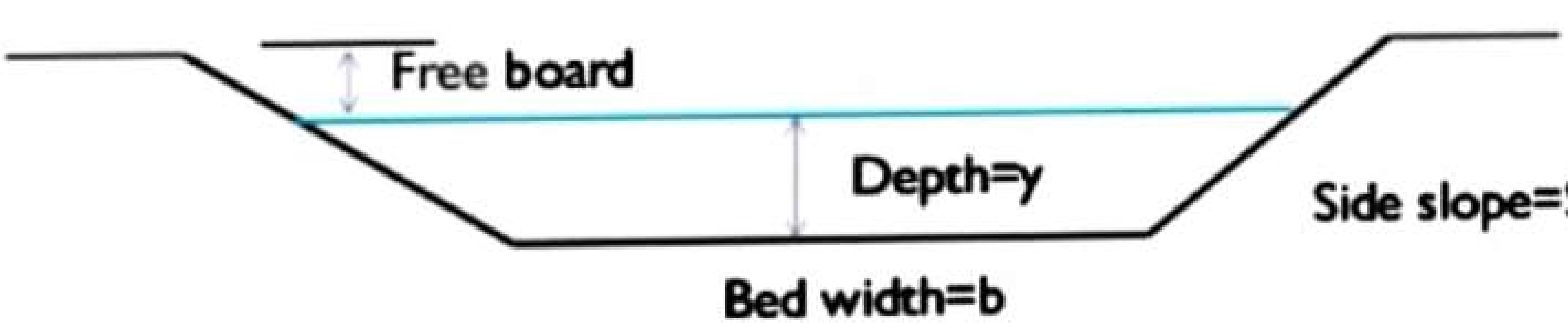
- **Design Procedure:**
- 1. Select a value of roughness coefficient ,*n*, and bottom slope, *So*, for the flow surface
- 2. Compute section factor from $AR^{2/3} = nQ/(CoSo^{0.5})$,
- 3. Determine the channel dimensions and the flow depth for which $AR^{2/3}$ is equal to the value determined in step 2. For example, for a trapezoidal section, select a value for the side slope, *z*, and compute several different ratios of bottom width *Bo* and flow depth *y* for which $AR^{2/3}$ is equal to that determined in step 2. Select a ratio *Bo/y* that gives a cross section near to the best hydraulic section
- 4. Check that the minimum velocity is not less than that required to carry the sediment to prevent silting.
- 5. Add a suitable amount of freeboard.
- 6. Make a sketch providing all the dimensions.

Geometric relation for most efficient Section

- Rectangular $b = 2y$



- Trapezoidal $\frac{b+2Sy}{2} = y\sqrt{S^2+1} \Rightarrow b+2Sy = 2y\sqrt{S^2+1}$



Channel Design: Rigid Boundary Channels

- **Example:** Design a trapezoidal channel to carry a discharge of 10 m^3/s. The channel will be excavated through rock by blasting. The topography in the area is such that a bottom slope of 1 in 4000 will be suitable.
- **Solution:** For the blasted rock surface, $n = 0.030$ and let us select a value for the side slope, Z as 1 horizontal to 4 vertical. The substitution of these values into the Manning equation yields

$$AR^{\frac{2}{3}} = \frac{nQ}{C_o S_o^{0.5}} = \frac{0.030 \times 10}{(0.00025)^{\frac{1}{2}}} = 18.97$$

$$B_o + 2Zy = 2y\sqrt{Z^2+1}$$
$$B_o = 2y\sqrt{Z^2+1} - 2Zy$$
$$B_o = 2y\sqrt{0.25^2+1} - 2(0.25)y$$
$$B_o = 1.56y$$

$$AR^{2/3} = 18.97$$
$$1.81y^2(0.495y)^{2/3} = 18.97$$
$$1.31y^{2.67} = 18.97$$
$$y = 2.72m$$

$$A = (B_o + \frac{1}{4}y)y = (1.56y + 0.25y)y = 1.81y^2$$
$$P = B_o + 2y\sqrt{(1/4)^2-1} = 1.56y + 2.06y = 3.66y$$
$$R = \frac{A}{P} = \frac{1.81y^2}{3.66y} = 0.495y$$

Channel Design: Rigid Boundary Channels

- Solving this equation for y, we get

$y = 2.72$ m.

Then, $Bo = 1.56 \times 2.72 = 4.24$m.

- Based on Eq. of Freeboard,

$FB = 0.8 \times (2.72)^{0.5} = 1.32$m.

Therefore, total depth = 2.72 + 1.32 = 4.04 = 4.05 m.

- The flow area for a flow depth of 2.72 m is 13.31 m^2.

Therefore, the flow velocity = 10/13.31 = 0.75m/s

Froude No. $= V/(gy)^{0.5} = 0.75/(9.81 * 2.72)^{0.5} = 0.14$

ALLUVIAL CHANNEL

An ***alluvial river*** is river in which the bed and banks are made up of mobile sediment and soil. The river's shape and size are determined by the river itself through the processes of erosion, sediment transport, sedimentation, and resuspension. Alluvial rivers are free to adjust section, pattern, and profile in response to hydraulic changes. Alluvial channel design approaches fall into five general categories: regime, analogy, hydraulic geometry, extremal, and analytical methods. Each method has its advantages and disadvantages, depending on the stream reach being restored

TYPES

- **Straight channels** (single thread).

- **Braided channels** (multiple thread with many sand bars that migrate frequently).

- **Anastomosing** (multiple thread but do not migrate).

- **Meandering** (single thread having many curves)

Canal Outlet/modules

Requirement:

Structurally strong

With out any moving parts

Difficult for the cultivators to interfere and if so easily detectable

Work efficiently for small working heads

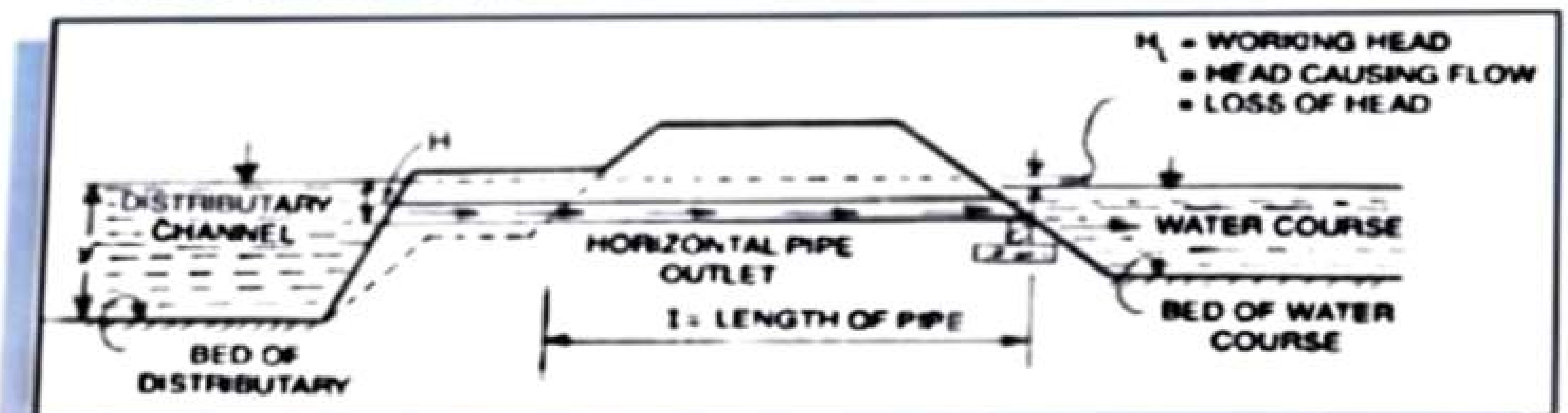
Can draw fair share of silt and economical.

Non-Modular outlets:

These outlets operate in such a way that the flow passing through them is a function of the difference in water levels of the distributing channel and the watercourse.

Types of Outlet/modules

- **Non-modular modules**



Semi-modular outlets :

The discharge through these outlets depend on the water level of the distributing channel but is independent of the water level in the watercourse so long as the minimum working head required fo their working is available.

Module outlets:

The discharge through modular outlets is independent of the water levels in the distributing channel and the watercourse, within reasonable working limits. This type of outlets may or may not be equipped with moving parts.

Lacey's Regime Theory

Gerald Lacey -- 1930

Lacey followed Lindley's hypothesis:

"dimensions and slope of a channel to carry a given discharge and silt load in easily erodable soil are uniquily determined by nature".

According to Lacey:

"Silt is kept in suspension by the vertical component of eddies generated at all points of forces normal to the wetted perimeter".

Regime Channel

"A channel is said to in regime, if there is neither silting nor scouring".

According to Lacey there may be three regime conditions:

(i) True regime;

(ii) Initial regime; and

(iii) Final regime.

Lacey's Channel Design Procedure

(1) Calculate the velocity from equation

$$V = \left[\frac{Qf^2}{140}\right]^{1/6} \text{ m/sec.}$$

where Q is in cumecs :
V is in m/s ; and
f is the silt factor, given by

$$f = 1.76 \cdot \sqrt{d_{mm}}$$

where d_{mm} = Average particle size in mm

(2) Work out the hydraulic mean depth (R) from the equation

$$R = \frac{5}{2}\left(\frac{V^2}{f}\right)$$

where V is in m/sec ;
R is in m.

$$D = \frac{P - \sqrt{P^2 - 6.944A}}{3.742}$$

$$B = P - \sqrt{5}D$$

(3) Compute area of channel section $A = \dfrac{Q}{V}$

(4) Compute wetted perimeter, $P = 4.75\sqrt{Q}$

(5) Knowing these values, the channel section is known ; and finally the bed slope S is determined by the equation

$$S = \left[\frac{f^{5/3}}{3340\,Q^{1/6}}\right]$$

Problem:

Design an irrigation channel in alluvial soil from following data using Lacey's theory:

Discharge = 15.0 cumec; Lacey's silt factor = 1.0; Side slope = ½ : 1

Solution:

$$V = \left(\frac{Qf^2}{140}\right)^{1/6} = \left(\frac{15\times1}{140}\right)^{1/6} = 0.689\ m/\sec$$

$$A = \frac{Q}{V} = \frac{15}{0.689} = 21.77\ m^2$$

$$P = 4.75\sqrt{Q} = 4.75\sqrt{15} = 18.4\ \text{m}$$

$$D = \frac{P-\sqrt{P^2-6.944A}}{3.742} = \frac{18.4-\sqrt{(18.4)^2-6.944(21.77)}}{3.742} = 1.36\ \text{m}$$

$$B = P-\sqrt{5}D = 18.4-\sqrt{5}(1.36) = 15.36\ \text{m}$$

$$R = \frac{5}{2}\frac{V^2}{f} = \frac{5}{2}\frac{(0.689)^2}{1} = 1.185\ \text{m}$$

$$S = \frac{f^{5/3}}{3340Q^{1/6}} = \frac{(1)^{5/3}}{3340\times(15)^{1/6}} = 1/5245$$

INTRODUCTION

- Water-logging refers to the saturation of soil with water. Soil may be regarded as waterlogged when the water table of the groundwater is too high to conveniently permit an anticipated activity, like agriculture.
- In agriculture, various crops need air (specifically, oxygen) to a greater or lesser depth in the soil. Water-logging of the soil stops air getting in. How near the water table must be to the surface for the ground to be classed as waterlogged, varies with the purpose in view. A crop's demand for freedom from water-logging may vary between seasons of the year, as with the growing of rice (Oryza sativa).
- In irrigated agricultural land, water-logging is often accompanied by soil salinity as waterlogged soils prevent leaching of the salts imported by the irrigated water.
- From a gardening point of view, water-logging is the process whereby the soil blocks off all water and is so hard it stops air getting in and it stops oxygen from getting in.

CAUSES

- · Over irrigation.
- · Canal irrigation in areas adjoining agricultural lands where subsoil water table steadily rises.
- · Inadequate drainage.
- · Surface flooding.
- · Presence of high water table.
- · During monsoon & soon after some areas remains totally submerged by the discharge of the rivers & accumulation of runoff from the surrounding catchment.
- · Water logging conditions are also caused in depressions along roads, canals & railway sides during rainy season.
- · Sea water comes to a particular area during high tidal surges.

PROBLEMS DUE TO WATER LOGGING

- · It creates anaerobic condition in soils for which microbial activity is hampered.
- · The availability of nutrient elements in soil is reduced & leaching loss is higher.
- · Increases soil pH in coastal & dry area which leads salinity & alkalinity.
- · Pollutes soil water & favors excessive weed growth.

MEASURES TO REDUCE IT

- · Construction of dams & embankments along the coast to restrict saline to enter the agricultural lands. Could be an effective measure of reducing the water logging.
- · Providing adequate number of bridges & culverts, along the roads, railroads, highways, across the canal etc could be a handy measure against water logging.

DEFINITION....

An impervious layer which is provided at the bed and sides of the canal to increase the life, discharge and hydraulic efficiency of the channel is known as Lining.

***An artificial channel filled with water and designed for navigation , or for Irrigating land. ***

RIGID LINING

- STONE PITCHED LINING
- BURNT CLAY TILE/BRICK LINING
- PRECAST CEMENT CONCRETE
- IN-SITU CEMNT CONCRETE LINING
- STONE MASONRY LINING
- SOIL CEMENT LINING
- SHOTCRETE LINING
- ASPHALTIC CEMENT/CONCRETE LINING

EARTH TYPE LINING

- **Soil cement Lining**
- **Clay puddle Lining**
- **Sodium carbonate Lining**.

Def..

- In this method, the earth itself is used, for the purpose of lining, to provide smooth flow to maintain the velocity.
- To reduce the losses of water through the side and seepages etc..

DEFINITIONS TO BE REMEMBER:

- **DRAINAGE:**

Drainage means the removal of water from the soil it have two main goals prevention of seepage, improvement of soil properties.

- **DRAINAGE SYSTEM:**

Drainage system means the different methods to be used for dewatering the foundation and to keep the foundation safe.

6.1 Need for drainage

During rain or irrigation, the fields become wet. The water infiltrates into the soil and is stored in its pores. When all the pores are filled with water, the soil is said to be saturated and no more water can be absorbed; when rain or irrigation continues, pools may form on the soil surface (Fig. 96).

Fig. 96. During heavy rainfall the upper soil layers become saturated and pools may form. Water percolates to deeper layers and infiltrates from the pools.

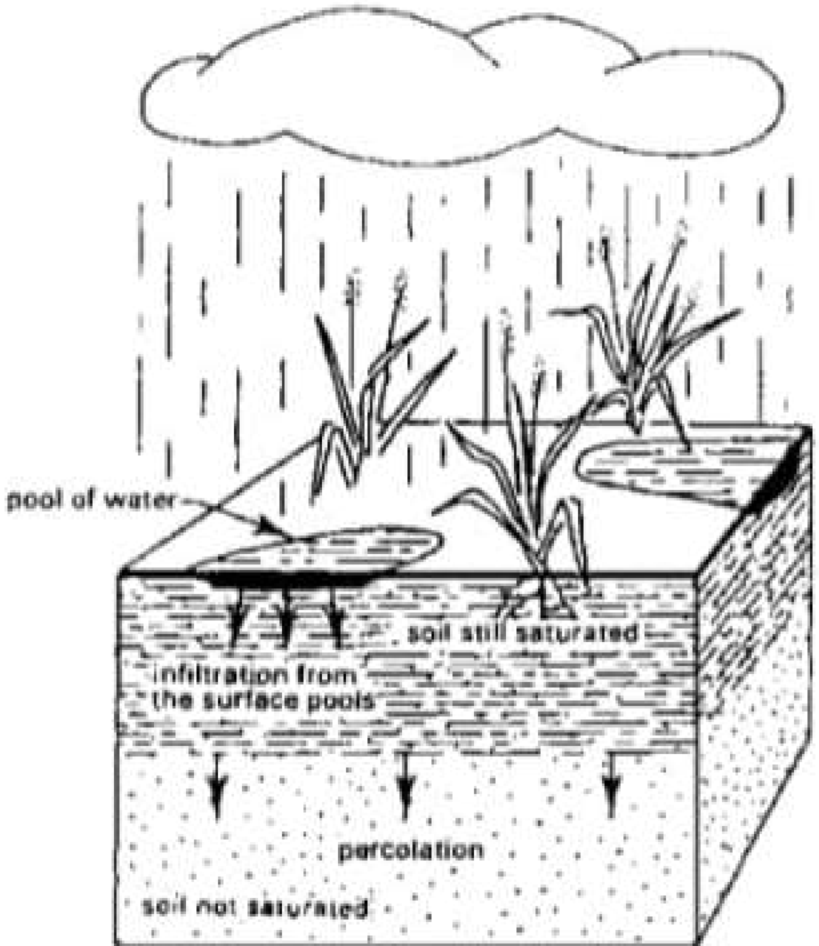
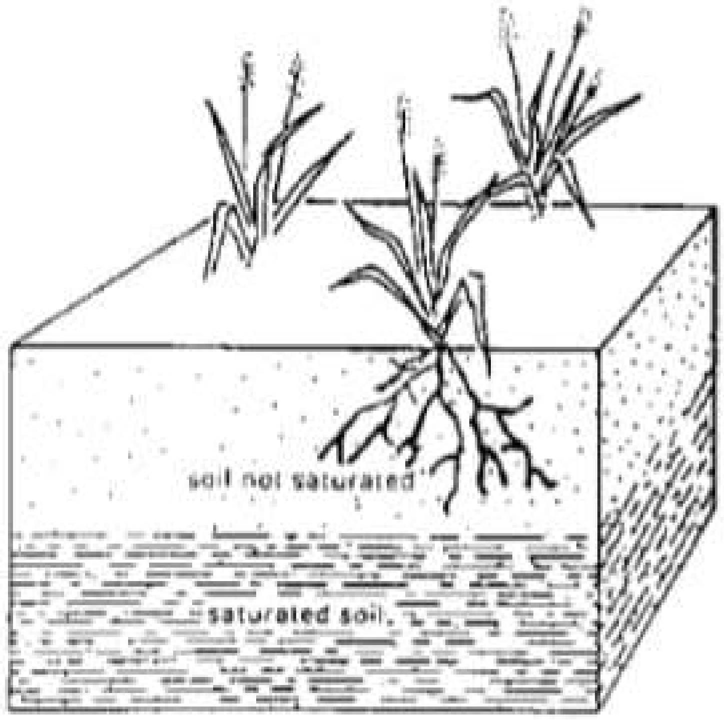
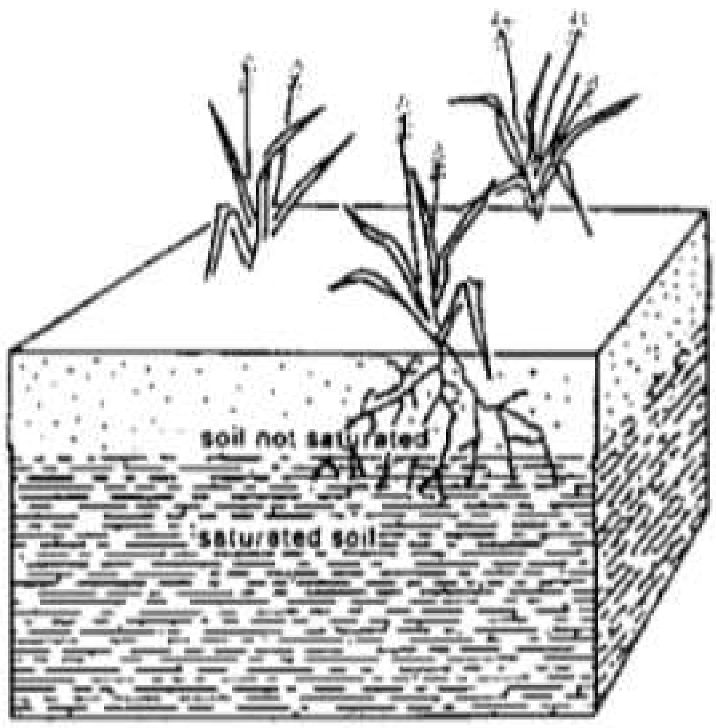


Fig. 97. After heavy rainfall the groundwater table may rise and reach the rootzone

BEFORE HEAVY RAINFALL



AFTER HEAVY RAINFALL



The removal of excess water either from the ground surface or from the rootzone, is called drainage.

Excess water may be caused by rainfall or by using too much irrigation water, but may also have other origins such as canal seepage or floods.

6.2 Different types of drainage

Drainage can be either natural or artificial. Many areas have some natural drainage; this means that excess water flows from the farmers' fields to swamps or to lakes and rivers. Natural drainage, however, is often inadequate and artificial or man-made drainage is required.

There are two types of artificial drainage: surface drainage and subsurface drainage.

6.2.1 Surface drainage

Surface drainage is the removal of excess water from the surface of the land. This is normally accomplished by shallow ditches, also called open drains. The shallow ditches discharge into larger and deeper collector drains. In order to facilitate the flow of excess water toward the drains, the field is given an artificial slope by means of land grading (see Fig. 98).

Fig. 98. The field is given an artificial slope to facilitate drainage

6.2.2 Subsurface drainage

Subsurface drainage is the removal of water from the rootzone. It is accomplished by deep open drains or buried pipe drains.

What is earthen dam?

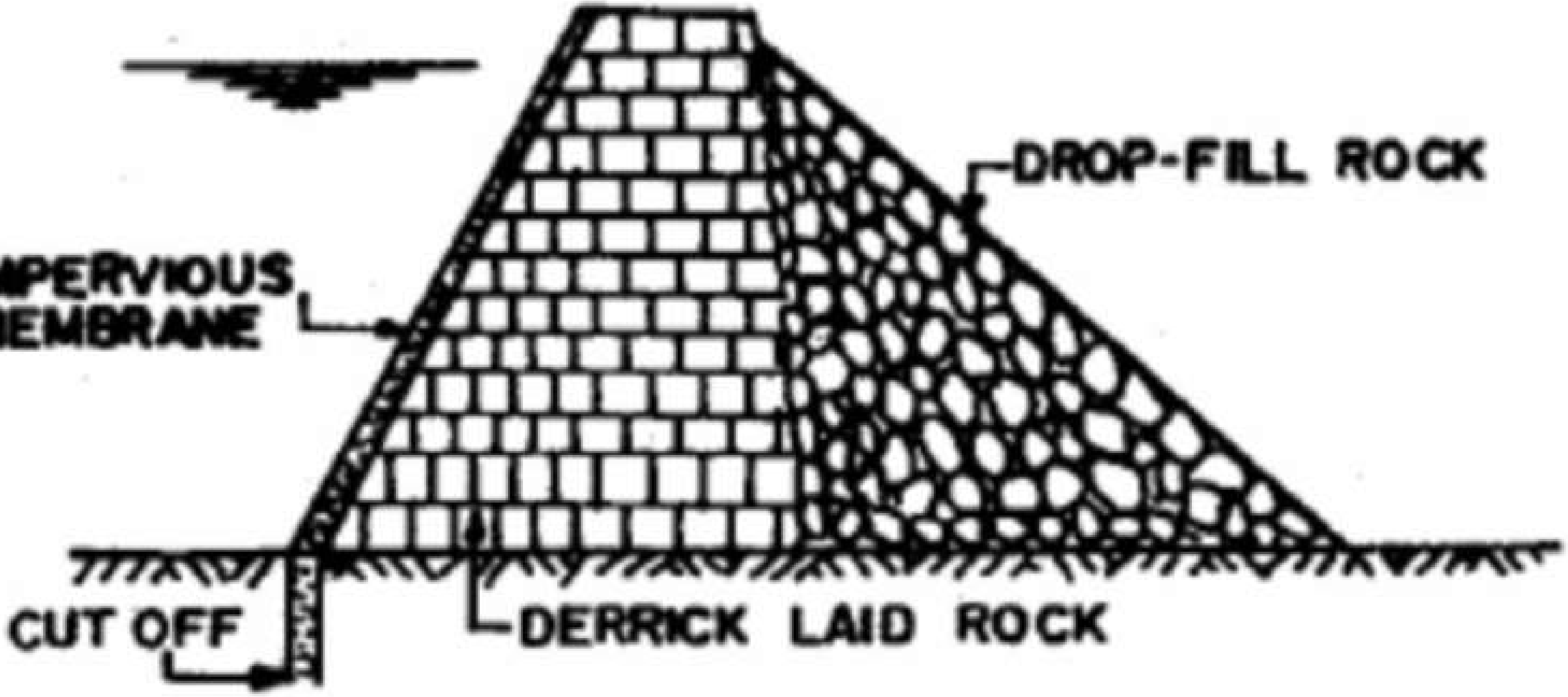
- Earth fill **dam**, also called **Earth Dam**, or Embankment **Dam**.
- **Dam** built up by compacting successive layers of **earth**, using the most impervious materials to form a core and placing more permeable substances on the upstream and downstream sides.
- A dam built of soil materials (sand, loam, clay, and so on), with a trapezoidal or nearly trapezoidal cross section.

Embankment Classified

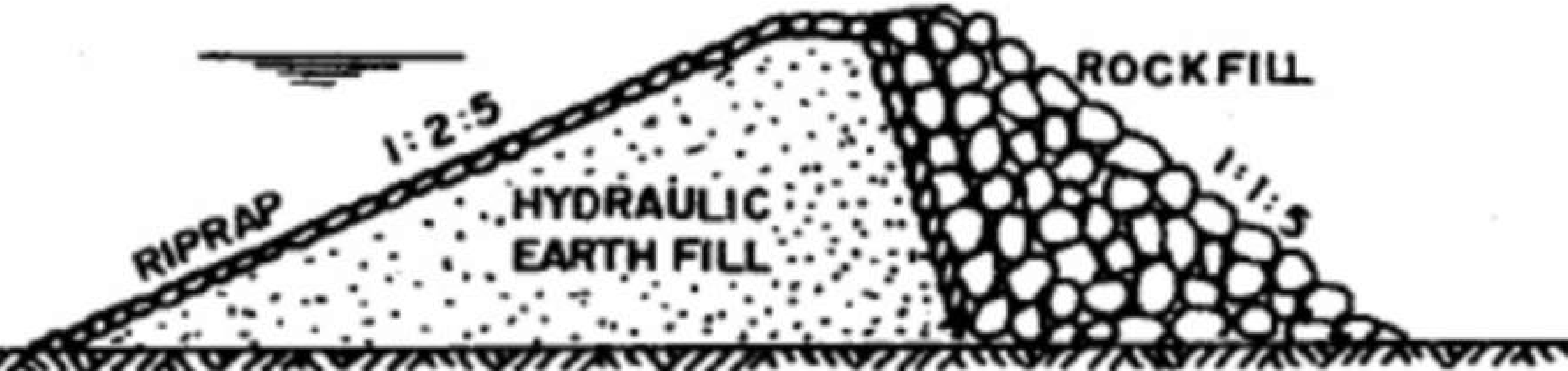
Earthen embankment dam

Rockfill dam

Composite dam



ROCKFILL DAM



COMBINED EARTH AND ROCKFILL DAM

Embankment dam types

EARTHEN DAM

Earth dams have been built since the early days of civilization. They are constructed mainly from earth (or soil). Fig..

ROCKFILL DAM

Rockfill dams are constructed mainly from rockfill or pieces of rocks. Fig. 2.1(1

They require somewhat stronger foundations as compared to earth dams,

DESIGN AND ANALYSIS

- Although the loads acting on the concrete gravity dam (discussed SOON) is the same acting on the embankment dam, the method of design and analysis of the two **differ considerably**.
- This is mostly because the gravity dam acts as **one monolithic structure**, and it has to resist the destabilizing forces with its own self weight mainly.
- Failure to do so may lead to its topping, sliding or crushing of some of the highly stressed regions.

An embankment dam, on the other hand, **cannot** be considered **monolithic.** It is actually a **conglomerate of particles** and on the action of the various modes, which are much different from those of a gravity dam.

Hence, the design of an embankment dam is done in a different way than that of a gravity dam. In fact, the design procedures are targeted towards resisting the failure of an embankment dam under different modes, which are explained in the next section.

Safety against seepage failures

i) Amount of seepage water passing through the embankment and foundation should be limited so as to control piping, erosion, sloughing and excessive loss of water. Seepage control measures are required to control seepage through the dam have to be made according to the recommendations provided in the Bureau of Indian Standards code IS: 9429-1999 "Drainage systems for earth and rockfill dams-code of practice", which has been discussed in section 4.7.4. Design for control of seepage through foundation have to be made as per IS: 8414-1977 "Guidelines for design of under-seepage control measures for earth and rockfill dams". Salient features of these are also summarized in section 4.7.4.

ii) The phreatic line should be well within the downstream face of the dam to prevent sloughing. Methods to estimate the location of the phreatic line is discussed in section 4.7.5

iii) Seepage water through the dam or foundation should not be so high that may cause removal of fine materials from the body of the dam leading to piping failures.

iv) These should not be any leakage of water from the upstream to the downstream face, which may occur through conduits, at joints between earth and concrete dam sections, or through holes made by burrowing animals.

Safety against structural instability

The slopes of the embankment on the upstream and downstream should be stable under all loading conditions. Embankment slopes have to be designed in accordance with Bureau of Indian Standards Code IS: 7894-1975 "Code of practice for stability analysis of earth dams", which has been discussed separately in section 4.7.6.

The embankment slopes should also be flat enough so as not to impose excessive stresses on the foundation, and as much, be within the permissible limits of the shear strength of the material

Gravity Dams

Gravity Dams

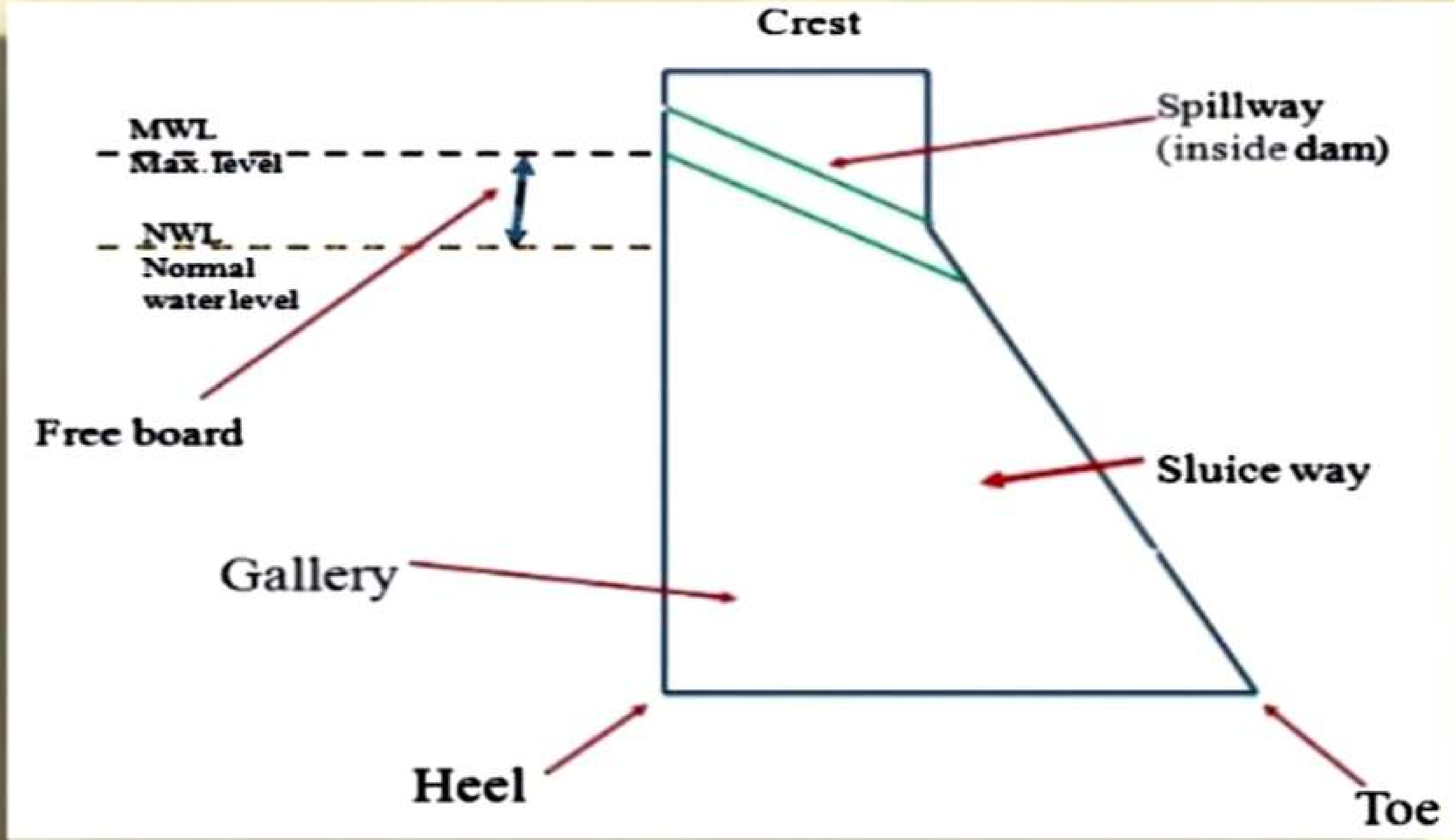
- Criteria for **selection of dam site**, construction material, **forces acting on gravity dam, modes of failure**, stability analysis, safety criteria, methods of design , stress analysis and stress contours, galleries, instrumentation, joints, keys, water seals, temperature control in concrete dams, foundation treatment.

Gravity Dams

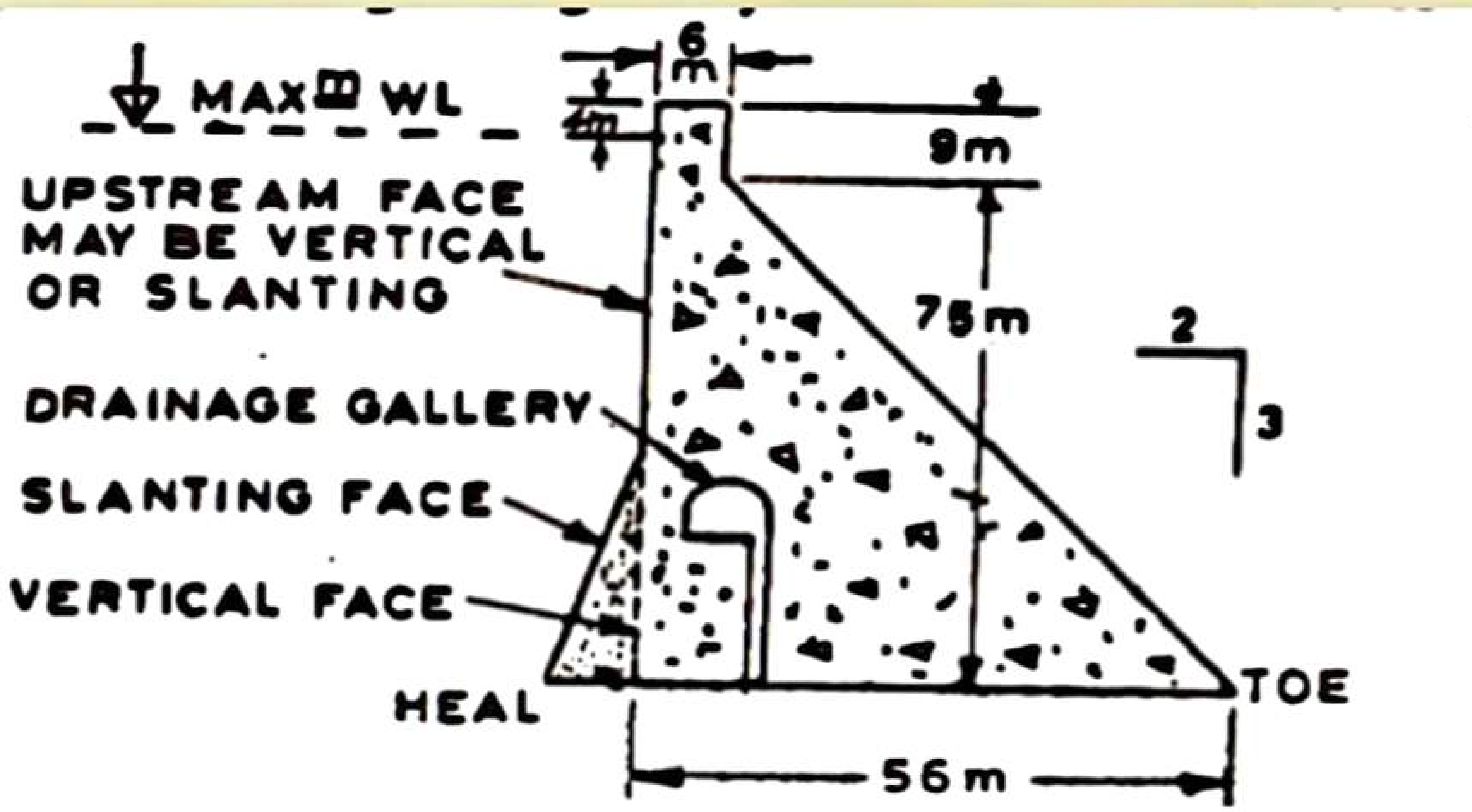
- A Gravity dam has been defined as a **"structure which is designed in such a way that its own weight resist the external forces"**. This type of a structure is most durable and solid and requires very less maintenance.
- Such dams are constructed of **masonry or Concrete.**
- However, **concrete gravity dams are preferred these days** and mostly constructed.

Gravity Dams

- **Typical Cross-Section**



Gravity Dams



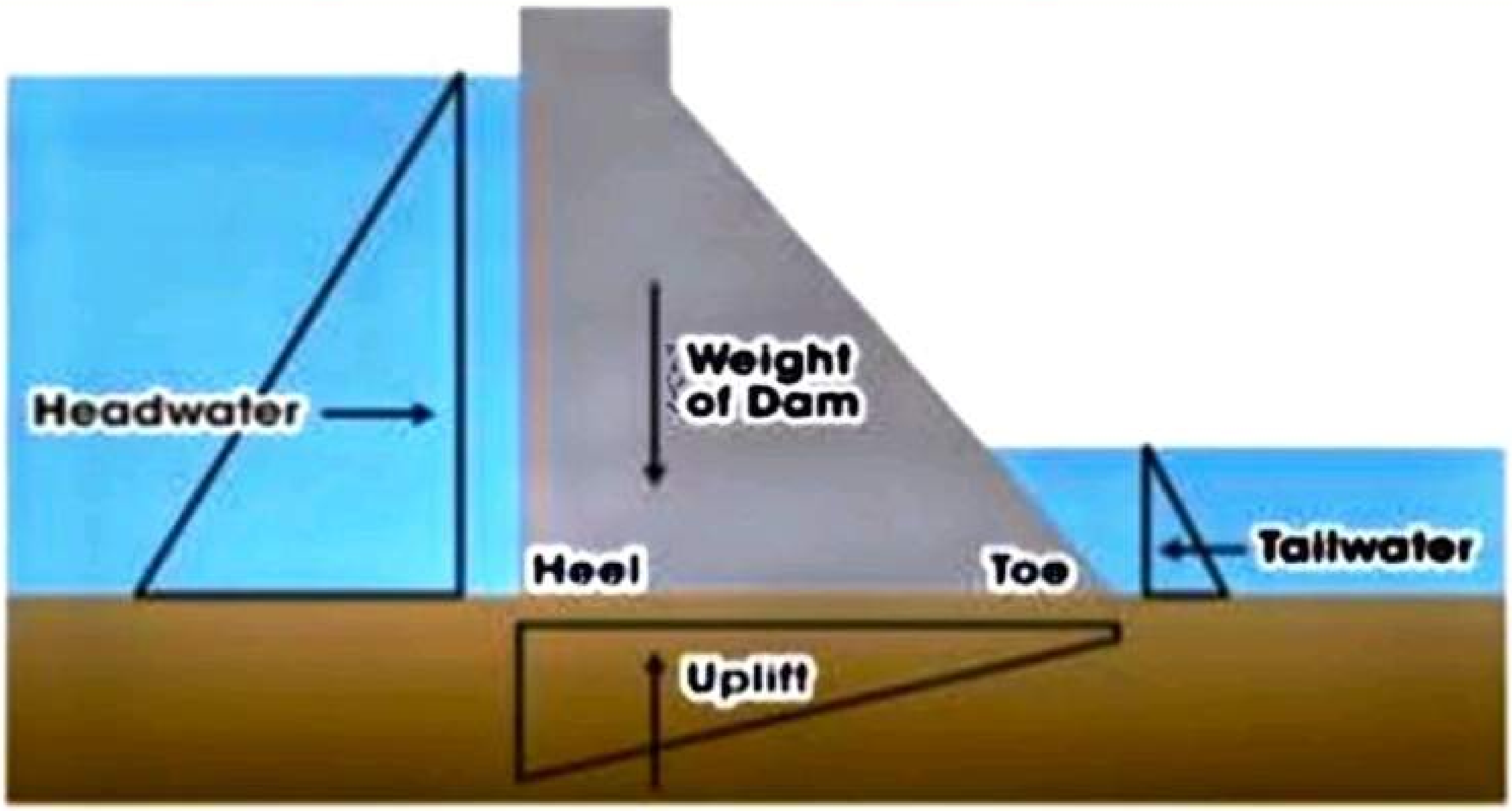
Gravity Dams

Forces Acting on Gravity Dam

- The Various external forces acting on Gravity da may be:
- ***Water Pressure***
- ***Uplift Pressure***
- ***Pressure due to Earthquake forces***
- ***Silt Pressure***
- ***Wave Pressure***
- ***Ice Pressure***
- ***The stabilizing force is the weight of the dam itself***

Gravity Dams

FIGURE 1 Typical Forces for a Gravity Dam



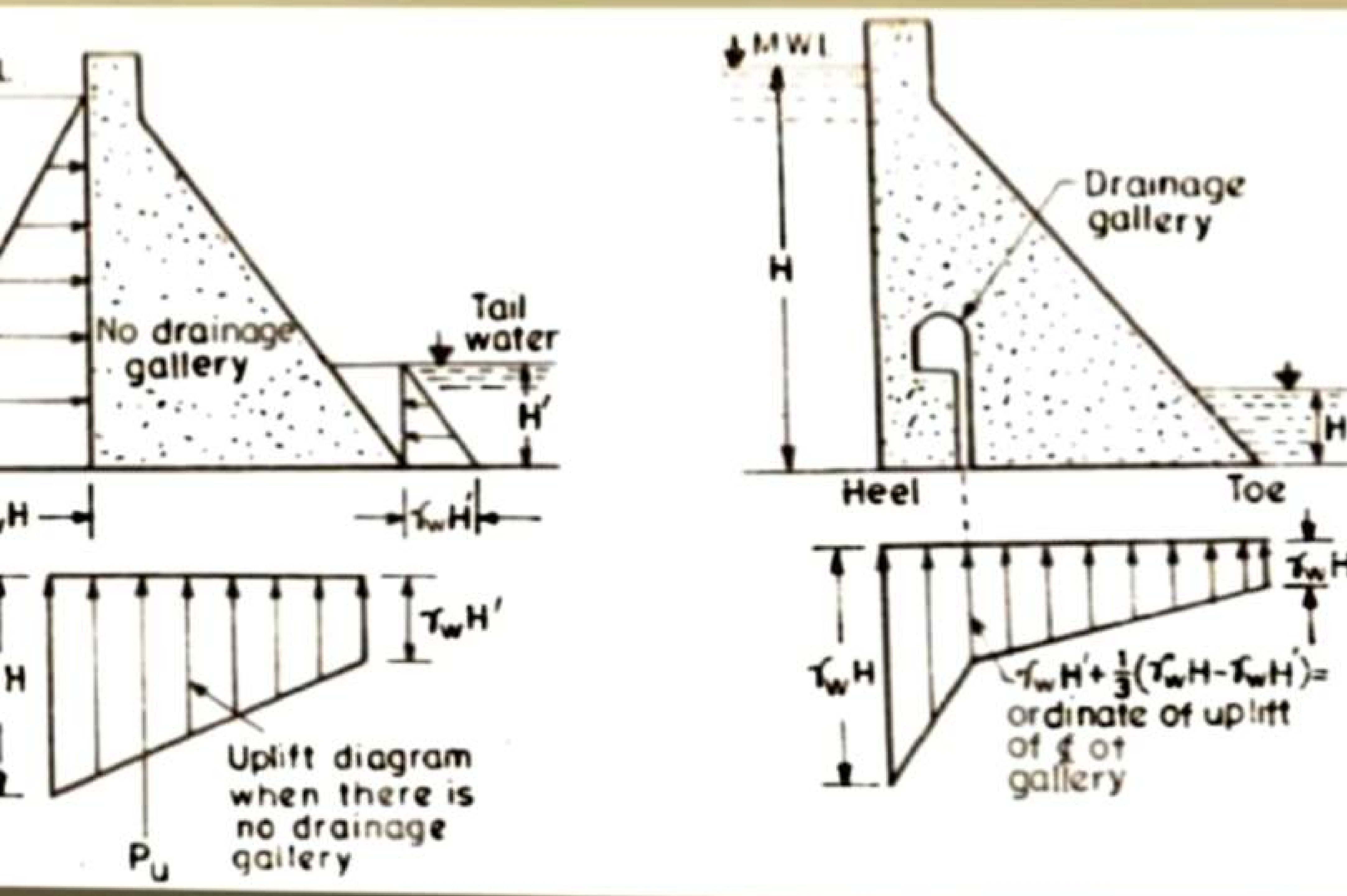
For any size of gravity dam, typical forces included in a two-dimensional stability analysis include headwater and tailwater, weight of the dam, and uplift.

Gravity Dams

Uplift Pressure

- Water Seeping through the pores, cracks and fissures of the foundation material, and water seeping through dam body and then to the bottom through the joint between the body of the dam. It is the second major external force and must be accounted for in all calculations. Such an uplift force virtually reduces the downward weight of the body of the dam and hence, acts against the dam stability.

Uplift Pressure



Gravity Dams

Earthquake Forces

- If the dam is to be designed, is to be located in a region which is **susceptible to earthquakes**, allowance must be made for stresses generated by the earthquakes.
- **An earthquake produces waves which are capable of shaking the Earth upon which the dam is resting, in every possible direction.**

Gravity Dams

- The effect of an earthquake is therefore, equivalent to impairing an acceleration to the foundation of the dam in the direction in which the wave is traveling at the moment, **Earthquake waves may move in any direction and for design purpose, it has to be resolved in vertical and horizontal components.** Hence, two accelerations, i.e.. one horizontal acceleration ($\acute{\alpha}_h$) and one vertical acceleration ($\acute{\alpha}_v$) are induced by an earthquake. The value of these acceleration are generally expressed as percentage of the acceleration due to **gravity (g) i.e.. $\acute{\alpha}$ = 0.1 g or 0.2 g etc.**

Causes of Failure of Dam

1. Overturning
2. Sliding
3. Compression or Crushing
4. Tension

Overturning Failure

The overturning of the dam section takes place when the resultant force at any section cuts the base of the dam downstream of the toe.

$$F.S. = \frac{\Sigma \text{ Righting moments}}{\Sigma \text{ Overturning moments}}$$

Factor of Safety (F.S.) should not be less than 1.5

Sliding Failure

A dam will fail in sliding at its base, or at any other level, if the horizontal forces causing sliding is more than the resistance available to it that level

Sliding Factor, $S.F. = \tan\theta = \dfrac{\Sigma H}{\Sigma (V - U)}$

Factor of Safety against Slidig, F.S.S. $= \dfrac{\mu}{\tan\theta} = \dfrac{\mu (V - U)}{\Sigma H}$

For Low Gravity Dams, Factor of Safety against Sliding (F.F.S.) should be greater than 1

Coefficient of friction μ varies from 0.65 to 0.75

Compression or Crushing

The ... t

the ...

gre ... ss

for ...

normal stress at the toe

$(p_n)_{toe} =$

where

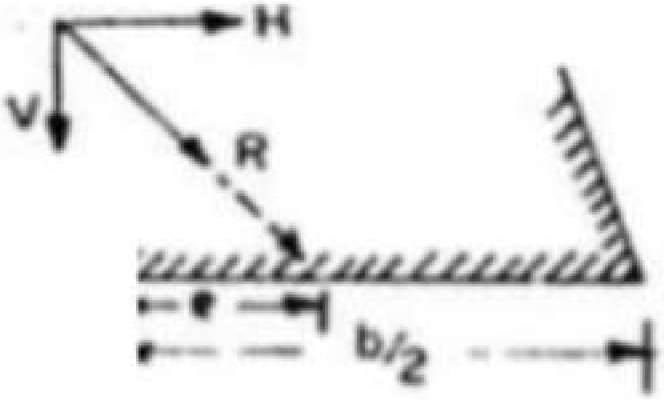
eccentricity $e = \frac{b}{2} - \bar{x}$

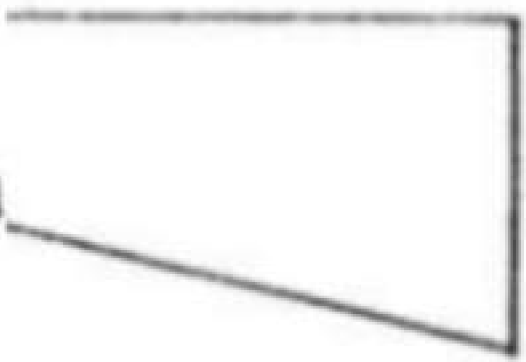
normal stre...

$\bar{x} = \frac{\Sigma M}{\Sigma V}$

$(p_n)_{heel} =$

b=base width of the section





Tension Failure

If eccentricity $e > b/6$, then Tension will be developed at the heel of the dam.

Since concrete can not resist Tension, No tension is permitted at any point of the dam under any circumstances

Principal Stresses

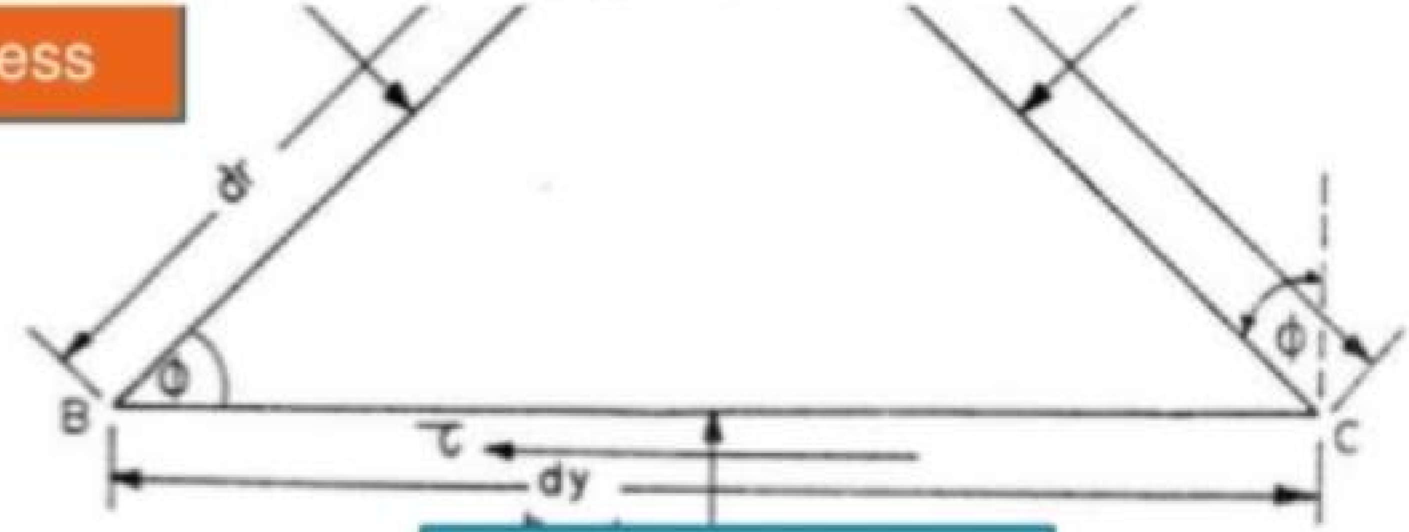
Principal Stress, $\sigma_1 = p_n \sec^2\phi - p\tan^2\phi$

Shear Stress, $\tau = +(p_n - p)\tan\phi$ **for Downstream side**

Shear Stress, $\tau = -(p_n - p)\tan\phi$ **for Upstream side**

r Pressure
ce of dam

Principal Stress



Compre:

Intensity

p may cl ssure

$\boldsymbol{p = p - p_e}$:ream

Uplift Pressure

Elementary Profile of Gravity Dam

Base Widith:

1. Stress Criterion

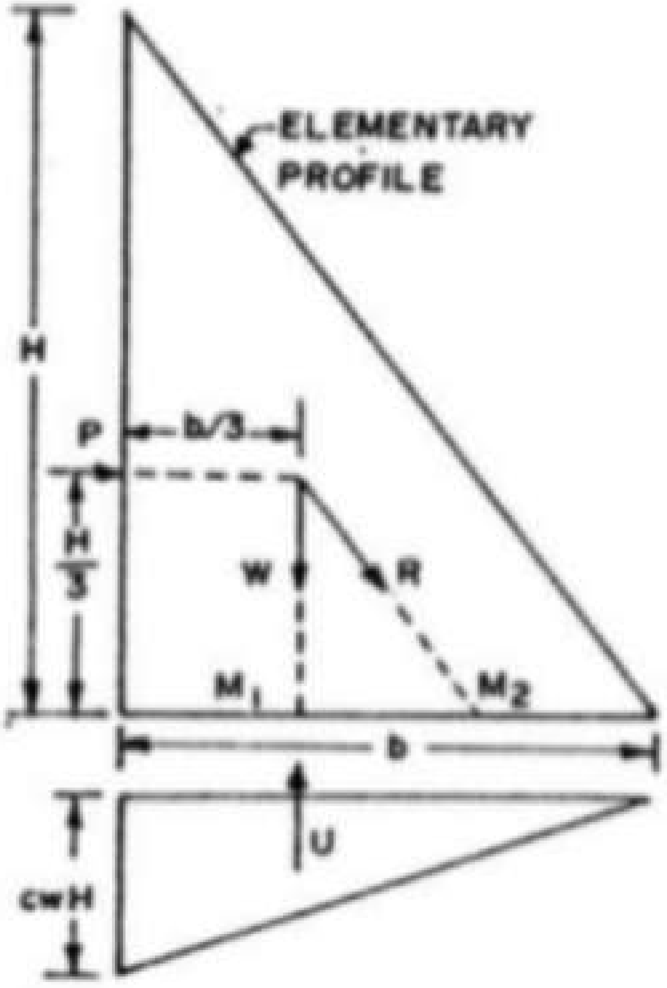
$$b = \frac{H}{\sqrt{\rho - c}}$$

2. Sliding Criterion

$$b = \frac{H}{\mu(\rho - c)}$$

where
b = base width
H = Height of dam
ρ = specific gravity of material
c = uplift pressure intensity coefficient
μ = coefficient of static friction

If Reservoir is empty, then c= 0



pressure distribution diagram

3. e = b/6

Practical Profile of a Gravity Dam

Free Board:

Free board is the margin provided between top of dam and HFL in the reservoir to prevent the splashing of the waves over the non-overflow dam.

$$\text{Fee Board} = 3/2\ h_w$$

Where h_w is wave pressure

Modern Practice is to provide a maximum Free Board equal to 3 to 4% of the height of dam and it should not be less than 1m in any case

Top Width = 14% of height of water level

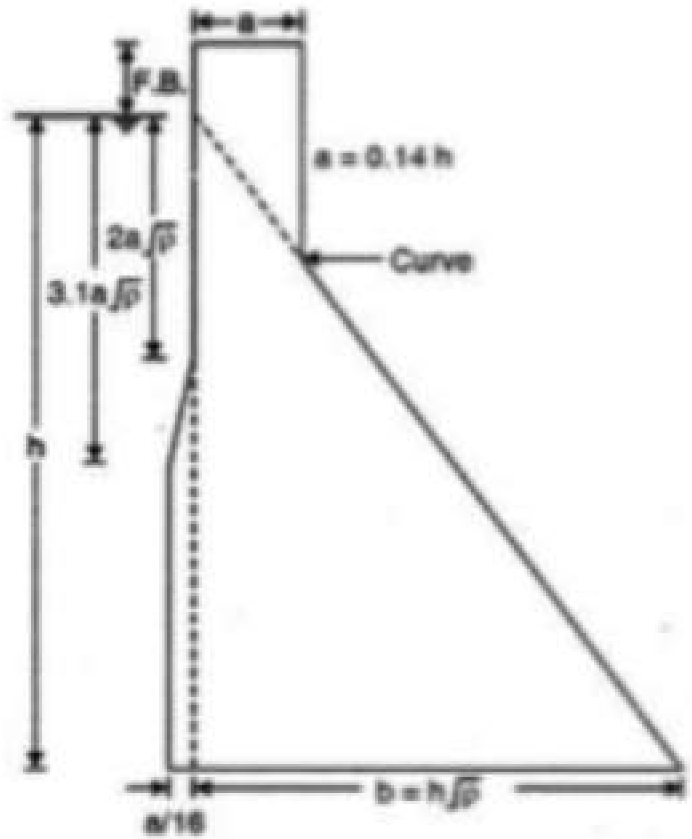


FIG. 8.19. PRACTICAL PROFILE OF A GRAVITY DAM.

Arch Dam

- An **Arch Dam is just a Curved Beam**, the ends of which are **restrained and the way in which the loads are resisted is termed a arch action**.
- An **arch dam** may be defined as a **solid wall, curved in plan, standing across the entire width of the river valley, in a single span**. This dam body is usually made of **cement concrete, although rubble and stone masonry has also been used in the past.**

Arch Dam

- This wall will structurally behave ; **partly as a cantilever retaining wall standing up from its base, and partly, the load will be transferred to the ends of the arch span by horizontal arch action.**
- **The arch load will, thus be transferred to the side walls of the canyon, which must be strong, stable and rocky.**

Arch Dam

Buttress Dams

- **In a gravity dam the quantity of concrete is determined by the dead weight required for the stability of the dam, rather than by the strength of the concrete**. Thus in gravity dams there are **lower stresses in the dam body in central part of the dam and the high strength concrete there is not stressed as it could** be, and hence **lesser efficient use of concrete strength,** large uplift force on dam base and hence increased dam section for stability.

Buttress Dams

Buttress Dams

- A buttress dam envisages to reduce the total volume of concrete by constricting the material where the stresses are higher and other undesirable features of gravity dam but has higher cement content per cubic metre of concrete than a gravity dam.

SPILL WAYS

- When the water in the reservoir increases, the large accumulation of water endangers the stability of the dam structure. To avoid this a structure is provided in the body of a dam or near the dam or periphery of the reservoir. This structure is called as spillway.
- Mainly used to discharge water during flood period.

Requirements:

- Provide structural stability to the dam under all condition
- Should able to pass the designed flood without raising the reservoir level above H.F.L.
- Should have an efficient operation
- Should be economical

Component parts of Spillway :

- Approach channel
- Control structure
- Discharge carrier
- Discharge channel
- Energy dissipators.

Approach channel

- Entrance structure or the path to draw water from reservoir and convey it to the control structure.

- It may be straight or curved in plan.

- Its banks may be parallel, convergent, divergent or combination of these and may be vertical or sloping.

- It may insure minimum head loss through the channel and to obtain uniformity of flow over the control structure.

Control structure

- Major component of spillway provided with bridge and gates.

- Regulates and controls the surplus water from the reservoir.

- It does not allow discharge of water below the fixed reservoir level.

Discharge carrier

- It is the waterway provided to convey the flows released from the control structure to the downstream side of spillway.
- The cross section may be rectangular, trapezoidal or of other shape.
- Waterway may be wide or narrow, long or short.

Discharge channel

- Provided to convey the water from bottom of the discharge carrier to the downstream flowing river.
- It may be the downstream face of spillway itself.
- The width of discharge channel depends on amount of water to be conveyed.

Energy dissipators

- At the end of discharge carrier, the water released from control structure has great velocities enough to cause scour.
- Thus, energy dissipators are provided to avoid the scouring of downstream side of spillway.
- These are to be provided before water entering the discharge channel.

The following are the different types of dissipators:

1. Bucket type energy dissipators
2. Stilling basin type dissipators
3. Baffle type dissipators.

Bucket type dissipators

- The high kinetic energy of water is reduced by providing a hydraulic jump at the end of spillway.

- The hydraulic jump can be achieved by providing bucket type dissipators.

- By hydraulic jump of water some part of energy is dissipated by aeration.

Stilling basin

- Stilling basins are usually provided after the buckets.
- Due to the hydraulic jump of water, the water falling on the ground may cause cavitations on the ground.
- These cavitations can be avoided by providing the stilling basin.
- The stilling basin consists of water which reduces some part of energy of water.

Baffle type dissipators

- After passing the stilling basin water has still some energy.
- If any amount of energy exist, it can be fully dissipated by providing baffle dissipators.
- In this, baffle type structures are provided in a number of series depending on the amount of energy.

TYPES OF SPILLWAYS

- Overfall spillway
- Chute spillway
- Saddle spillway
- Shaft spillway
- Side channel spillway
- Emergency spillway
- siphon spillway

FIGURES

Overfall spillway:

- that allows water to pass over its crest widely used on gravity, arch, & buttress dam
- This is a simplest type

Chute spillways:

In this type water is conveyed from the reservoir to the river or to nalla below the dam through an excavated open channel, through fairly steep slope

Overfall spillways

SHAFT SPILLWAY

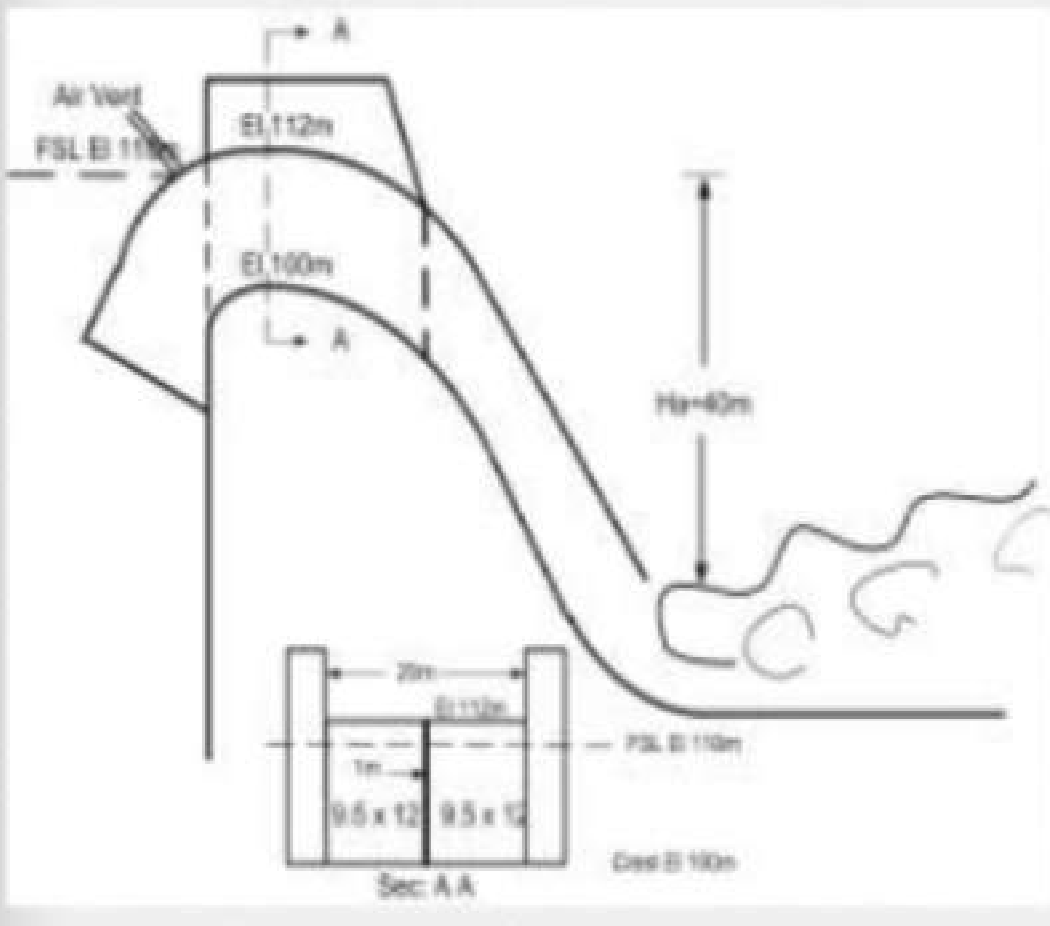
- The shape is just like a funnel .
- water drops through a vertical shaft in a the foundation material to a horizontal conduit that conveys the water past the dam.
- Lower end of shaft is turned at right angle and then water taken out below the dam horizontally.
- Also called as glory hole spillway.

SIDE CHANNEL SPILLWAY

- When the dam is not rigid and it is undesirable to pass flood water over the dam , this type of spillway is used.
- After passing crossing over the spillway crest ,water flows parallel to the crest.

SIPHON SPILLWAYS

- It is designed by the principle of a siphon.
- When water rises over the FRL then water start spilling.
- There is a air vent for removing the entrapped pressure from the water.



EMERGENCY SPILLWAY

- This type is rarely used .
- Extra spillways provided on a project in rare case of extreme floods(emergency)
- Used to convey frequently occurring outflow rates.

What is a Reservoir?

- It is an area developed by water body due to construction of dam.

Tarbela Dam

JungHua Dam (Taiwan)

Storage reservoir serve the following purpose :

- Irrigation
- Water supply
- Hydroelectric power generation
- Flood control
- Navigation
- Recreation
- Development of fish & wild life
- Soil conservation

Classification

- **Storage Reservoirs:** Storage reservoirs are also called conservation reservoirs because they are used to conserve water. Storage reservoirs are constructed to store the water in the rainy season and to release it later when the river flow is low

- **Flood Control Reservoirs:** A flood control reservoir is constructed for the purpose of flood control. It protects the areas lying on its downstream side from the damages due to flood.

- **Retarding Reservoirs:** A retarding reservoir is provided with spillways and sluiceways which are ungated. The retarding reservoir stores a portion of the flood when the flood is rising and releases it later when the flood is receding.

- **Detention Reservoirs :** A detention reservoir stores excess water during floods and releases it after the flood. It is similar to a storage reservoir but is provided with large gated spillways and sluiceways to permit flexibility of operation.

- **Distribution Reservoirs:** A distribution reservoir is a small storage reservoir to tide over the peak demand of water for municipal water supply or irrigation. The distribution reservoir is helpful in permitting the pumps to work at a uniform rate. It stores water during the period of lean demand and supplies the same during the period of high demand.

- **Multipurpose Reservoirs:** The are constructed for more than single purpose.

- **Balancing Reservoirs:** A balancing reservoir is a small reservoir constructed d/s of the main reservoir for holding water released from the

Reservoir capacity

- depends upon the inflow available and demand
- inflow in the river is always greater than the demand, there is no storage required
- if the inflow in the river is small but the demand is high, a large reservoir capacity is required

- The required capacity for a reservoir can be determined by the following methods:

1. Graphical method, using mass curves.

2. Analytical method

Graphical method

1. Prepare a mass inflow curve from the flow hydrograph of the site for a number of consecutive years including the most critical years (or the driest years) when the discharge is low.

2. Prepare the mass demand curve corresponding to the given rate of demand. If the rate of demand is constant, the mass demand curve is a straight line. The scale of the mass demand curve should be the same as that of the mass inflow curve.

Analytical method

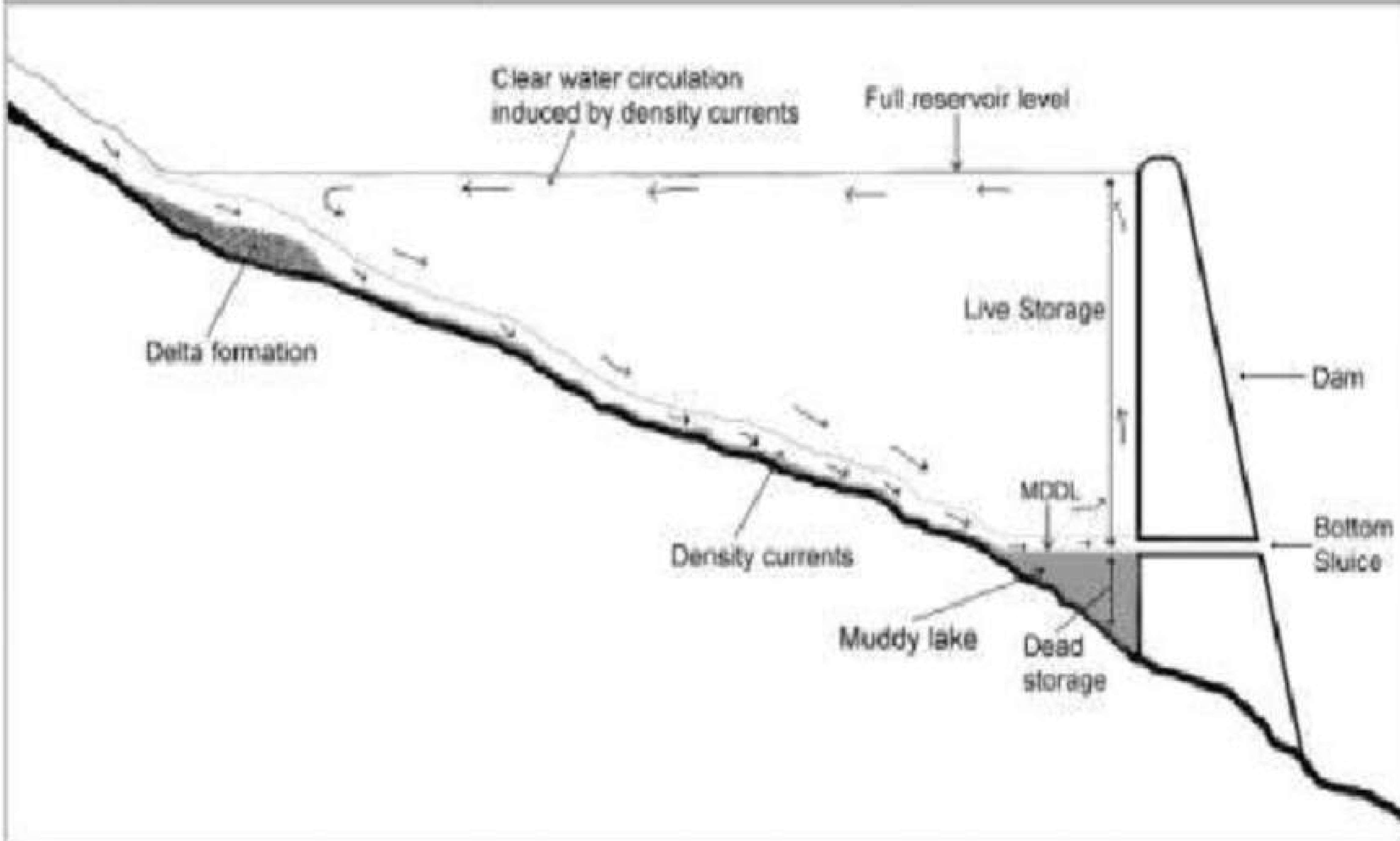
- capacity of the reservoir is determined from the net inflow and demand.
- storage is required when the demand exceeds the net inflow.
- the total storage required is equal to the sum of the storage required during the various periods.

Reservoir Sedimentation

- is a difficult problem for which an economical solution has not yet been discovered, except by providing a “dead storage” to accommodate the deposits during the life of the dam.

- Disintegration, erosion, transportation, and sedimentation, are the different stages leading to silting of reservoir.

Conceptual Sketch of Density Currents and Sediment Deposits in a Reservoir



Causes of sedimentation

- Nature of soil in catchment area
- Topography of the catchment area
- Cultivation in catchment area
- Vegetation cover in catchment area
- Intensity of rainfall in catchment area

Sediment Management

- Maximum efforts should water should be released so that less sediments should retain in reservoir. Following options are:
  - Catchment Vegetation
  - Construction of coffer dams/low height barriers
  - Flushing and desilting of sediments
  - Low level outlets / sediment sluicing

Safe yield

- Yield is the volume of water which can be withdrawn from a reservoir in a specified period of time.

- Safe yield is the maximum quantity of water which can be supplied from a reservoir in a specified period of time during a critical dry year.

- **Secondary yield:** is the quantity of water which is available during the period of high flow in the rivers when the yield is more than the safe yield.

- **Average yield:** The average yield is the arithmetic average of the firm yield and the secondary yield over a long period of time.

- **Design yield:** The design yield is the yield adopted in the design of a reservoir. The design yield is usually fixed after considering the urgency of the water needs and the amount of risk involved.

ACCORDING to HEIGHT of DAM

- *High Dam or Large Dam*
  - If the height of the dam is bigger than 100m
- *Medium Dam*
  - If the height of the dam is between 50m and 100m
- *Low Dam or Small Dam*
  - If the height of the dam is lower than 50m

Types of dam?

ACCORDING to the SIZE of the DAM

1. ***Large (Big) dam***
2. ***Small dam***

International Commision on Large Dams, (ICOLD) assumes a dam as big when its height is bigger than 15m.

If the height of the dam is between 10m and 15m and matches the following criteria, then ICOLD accepts the dam as big:

If the crest length is bigger than 500m
If the reservoir capacity is larger than 1 million m^3
If the flood discharge is more than 2000 m^3/s
If there are some difficulties in the construction of foundation

Example of gravity dam.

Bhakhra Dam

- ***Bhakra Dam is the highest Concrete Gravity dam in Asia and Second Highest in the world.***

LOCATION - BILASHPUR

LENGTH – 1700ft

HEIGHT – 741ft

BASE – 625ft

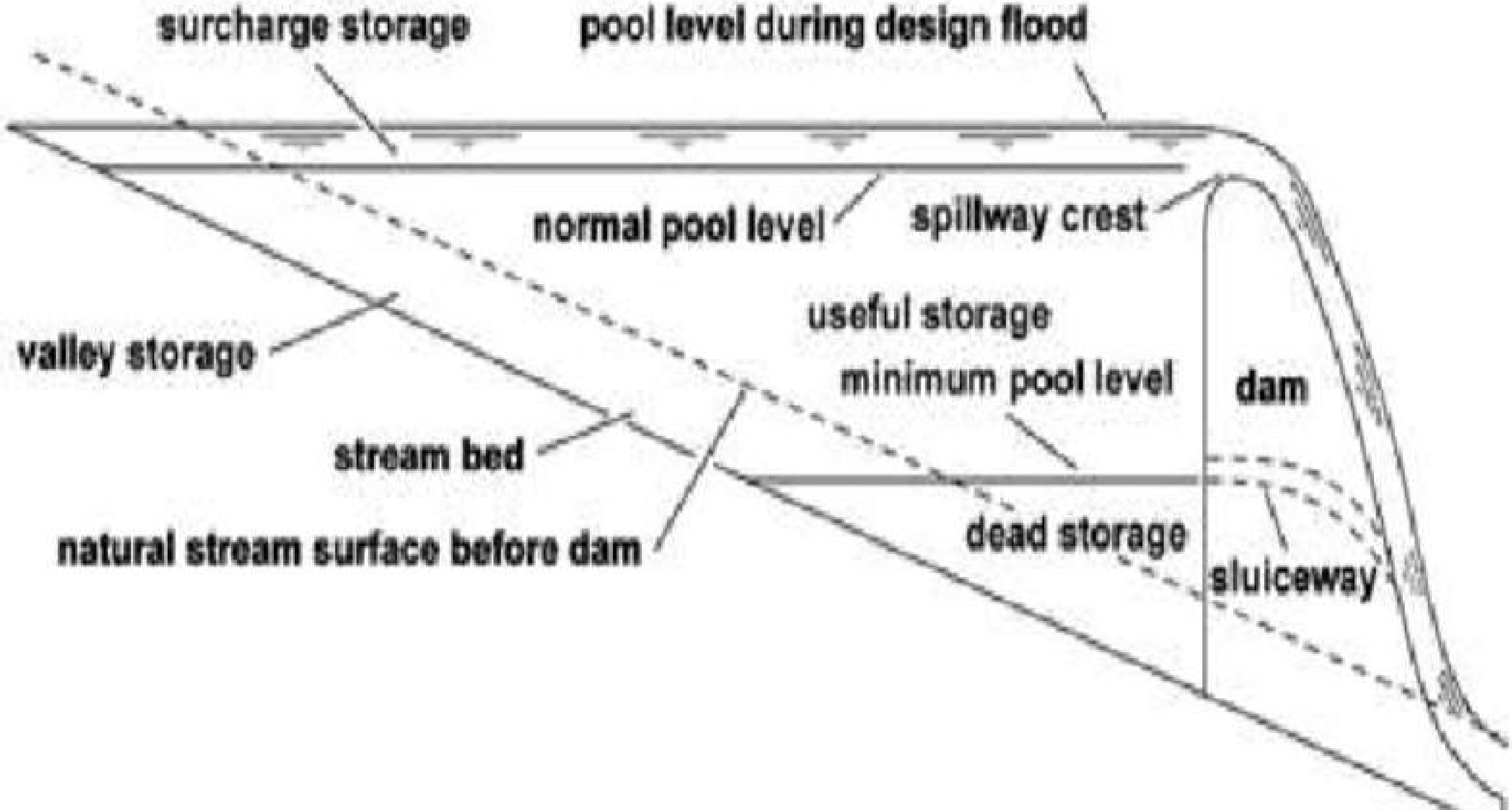
CAPACITY – 9.3km2

Site selection

- Large storage capacity
- River valley should be narrow, length of dam to constructed is less.
- Watertightness of reservoir.
- Good hydrological conditions
- Deep reservoir

- Small submerged area
- Low silt inflow
- No objectionable minerals
- Low cost of real estate
- Site easily accessible

Zones of storage



- **Full reservoir level (FRL):** The full reservoir level (FRL) is the highest water level to which the water surface will rise during normal operating conditions.

- **Maximum water level (MWL):** The maximum water level is the maximum level to which the water surface will rise when the design flood passes over the spillway.

- **Minimum pool level:** The minimum pool level is the lowest level up to which the water is withdrawn from the reservoir under ordinary conditions.