**HYDROLOGY & WATERRESOURCES ENGINEERING**
**UNIT-I**
**HYDROLOGIC CYCLE**

**SYLLABUS:**

Introduction Engineering hydrology and its applications, Hydrologic cycle. Precipitation: Types and forms of precipitation, rainfall measurement, types of rain gauges, rain gauge network, average rainfall over a basin, consistency of rainfall data, frequency of rainfall, intensity-duration-frequency curves, probable maximum precipitation.

**LEARNING MATERIAL**

**INTRODUCTION:**

Hydrology means the science of water. It is the science that deals with the occurrence, circulation and distribution or water of the earth and earth's atmosphere. As a branch of earth science, it is concerned with the water in streams and lakes, rainfall and snow fall, snow and ice on the land and water occurring below the earth's surface in the pores of the soil and rocks. In a general sense, hydrology is a very broad subject of an inter-disciplinary nature drawing support from allied sciences, such as meteorology, geology, statistics, chemistry, physics and fluid mechanics. The importance of hydrology in the assessment, development, utilisation and management of the water resources, of any region is being increasingly realised at all levels.

Hydrology is basically an applied science. To further emphasise the degree of applicability. The subject is sometimes classified as

1. Scientific hydrology- the study which is concerned chiefly with academic aspects.
2. Engineering or applied hydrology- a study concerned with engineering applications.

In a general sense engineering hydrology deals with

i. Estimation of water resources.
ii. The study of processes such as precipitation, runoff, evapotranspiration and their interaction and
iii. The study of problems such as floods and droughts and strategies to combat them

**WORLD'S WATERRESOURCES:**

The World's total water resources are estimated at $1.36 \times 10^8$M ha-m. Of these global water resources, about 97.2% is salt water mainly in oceans, and only 2.8% is available as fresh water at any time on the planet earth. Out of this 2.8% of fresh water, about 2.2% is available as surface water and 0.6% as ground water. Even out of this 2.2% of surface water, 2.15% is fresh water in glaciers and icecaps and only of the order of 0.01% is available in lakes and streams, the remaining 0.04% being in other forms. Out of 0.6% of stored ground water, only about 0.25% can be economically extracted with the present drilling technology (the remaining being at greater depths). It can be said that the ground water potential of the Ganga Basin is roughly about forty times the flow of water in the river Ganga.

The geographical area of the country (India) is 3.28 $Mkm^2$ and the annual runoff (from rainfall) is 167 M ha-m (or 167 × 104 $Mm^3$), which is approximately two-and half-times of the Mississippi-Missouri river Basin, which is almost equal in area to the whole of India. Due to limitations of terrain, non-availability of suitable storage sites, short period of occurrence of rains, etc. the surface water resources that can be utilised has been estimated as only 67 M ha-m. The total arable land in India is estimated to be 1.47 $Mkm^2$ which is 45% of the total geographical area against 10% for USSR and 25% for USA. India has a great potential for agriculture and water resources utilisation.

## HYDROLOGY AND HYDROLOGIC CYCLE:

Hydrology is the science, which deals with the occurrence, distribution and disposal of water on the planet earth, it is the science which deals with the various phases of the hydrologic cycle. Hydrologic cycle is the water transfer cycle, which occurs continuously in nature; the three important phases of the hydrologic cycle are: (*a*) Evaporation and evapotranspiration (*b*) precipitation and (*c*) runoff and is shown in Figure 1.1. The globe has one-third land and two-thirds Ocean. Evaporation from the surfaces of ponds, lakes, reservoirs, ocean surfaces, etc. and transpiration from surface vegetation *i.e.,* from plant leaves of cropped land and forests, etc. take place. These vapours rise to the sky and are condensed at higher altitudes by condensation nuclei and form clouds, resulting in droplet growth. The clouds melt and sometimes burst resulting in precipitation of different forms like rain, snow, hail, sleet, mist, dew and frost. A part of this precipitation flows over the land called runoff and part infilters into the soil which builds up the ground water table. The surface runoff joins the streams and the water is stored in reservoirs. A portion of surface runoff and ground water flows back to the ocean again. Evaporation starts from the surfaces of lakes, reservoirs and ocean, and the cycle repeats. Of these three phases of the hydrologic cycle, namely, evaporation, precipitation and runoff, it is the 'runoff phase', which is important to a civil engineer since he is concerned with the storage of surface runoff in tanks and reservoirs for the purposes of irrigation, municipal water supply hydroelectric power etc.

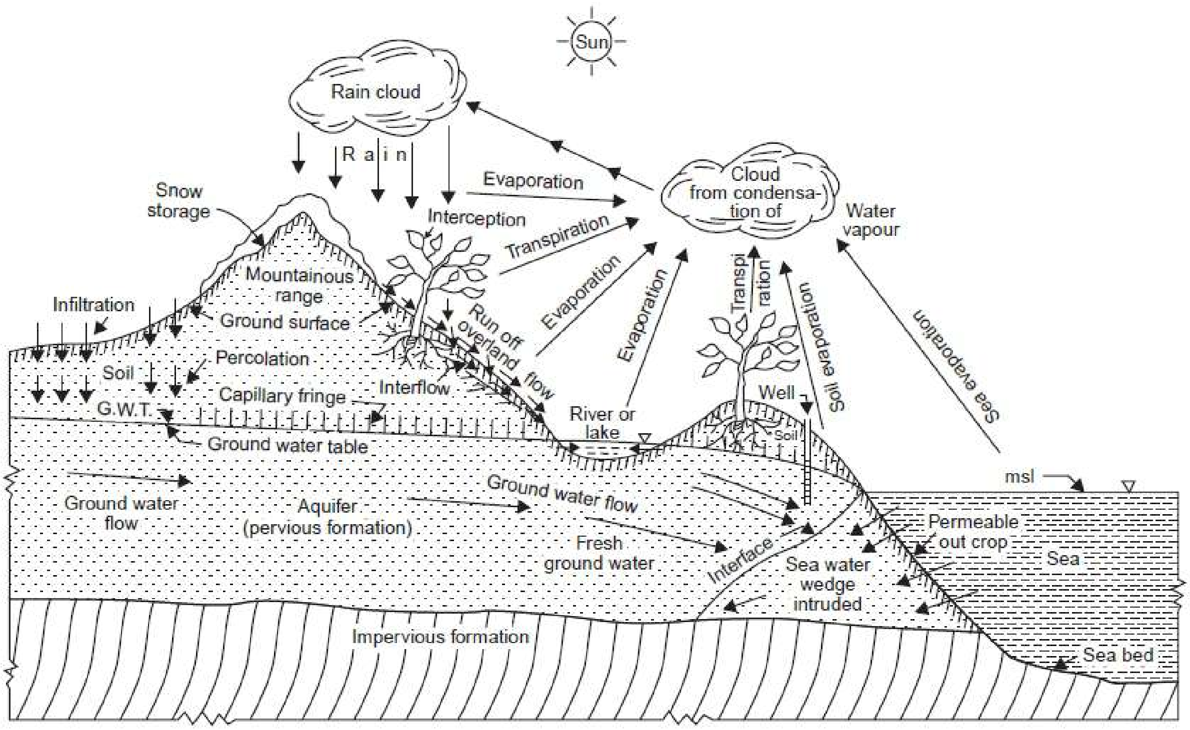



**Figure 1.1: The Hydrologic Cycle**

## FORMS OF PRECIPITATION:

| | |
|---|---|
| Drizzle | - a light steady rain in fine drops (0.5 mm) and intensity <1 mm/hr |
| Rain | - the condensed water vapour of the atmosphere falling in drops (>0.5 mm, maximum size-6 mm) from the clouds |
| Glaze | - freezing of drizzle or rain when they come in contact with cold objects |
| Sleet | -frozen rain drops while falling through air at subfreezing temperature. |
| Snow | -ice crystals resulting from sublimation (*i.e.,* water vapour condenses to ice) |
| Snowflakes | -ice crystals fused together. |
| Hail | -small lumps of ice (>5 mm in diameter) formed by alternate freezing and melting, when they are carried up and down in highly turbulent air currents. |

## SCOPE OF HYDROLOGY:

The study of hydrology helps us to know

i. The maximum probable flood that may occur at a given site and its frequency, this is required for the safe design of drains and culverts, dams and reservoirs, channels and other flood control structures.
ii. The water yield from a basin-its occurrence, quantity and frequency, etc, this is necessary for the design of dams, municipal water supply, water power, river navigation, etc.
iii. the ground water development for which a knowledge of the hydrogeology of the area, *i.e.,* of the formation soil, recharge facilities like streams and reservoirs, rainfall pattern, climate, cropping pattern, etc. are required.
iv. The maximum intensity of storm and its frequency for the design of a drainage project in the area.

**HYDROLOGIC EQUATION:**

The hydrologic equation is simply the statement of the law of conservation of matter and is given by

$$I = O + \Delta S \text{ ---------------Eq. 1.1}$$

Where I = inflow
O = outflow
ΔS = change in storage

This equation states that during a given period, the total inflow into a given area must equal the total outflow from the area plus the change is storage. While solving this equation, the ground water is considered as an integral part of the surface water and it is the subsurface inflow and outflow that pose problems in the water balance studies of a basin.

**PRECIPITATION:**

The **precipitation** in the country (India) is mainly in the form of rain fall though there is appreciable snowfall at high altitudes in the Himalayan range and most of the rivers in north India are perennial since they receive snow-melt in summer (when there is no rainfall).

**TYPES OF PRECIPITATION:**

i. Convective precipitation: This type of precipitation is in the form of local whirling thunder storms and is typical of the tropics. The air close to the warm earth gets heated and rises due to its low density, cools adiabatically to form a cauliflower shaped cloud, which finally bursts into a thunder storm. When accompanied by destructive winds, they are called 'tornados'.

ii. Frontal precipitation: When two air masses due to contrasting temperatures and densities clash with each other, condensation and precipitation occur at the surface of contact, Figure 1.2. This surface of contact is called a 'front' or 'frontal surface'. If a cold air mass drives out a warm air mass' it is called a 'cold front' and if a warm air mass replaces the retreating cold air mass, it is called a 'warm front'. On the other hand, if the two air masses are drawn simultaneously towards a low pressure area, the front developed is stationary and is called a 'stationary front'. Cold front causes intense precipitation on comparatively small areas, while the precipitation due to warm front is less intense but is spread over a comparatively larger area.

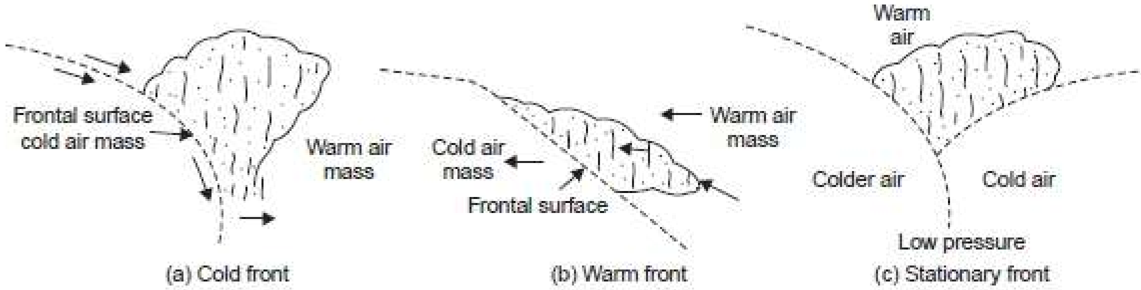



**Figure 1.2: Frontal precipitation**

iii. Orographic precipitation: The mechanical lifting of moist air over mountain barriers causes heavy precipitation on the windward side (Figure 1.3). For example

Cherrapunji in the Himalayan range and Agumbe in the western Ghats of south India get very heavy orographic precipitation of 1250 cm and 900 cm (average annual rainfall), respectively.

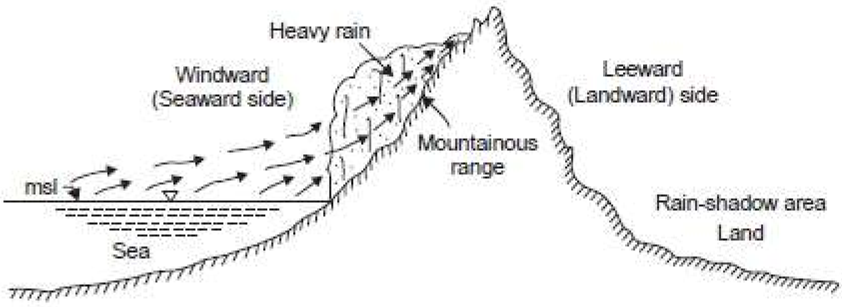



**Figure 1.3: Orographic precipitation**

iv. Cyclonic precipitation: This type of precipitation is due to lifting of moist air converging into a low pressure belt, *i.e.,* due to pressure differences created by the unequal heating of the earth's surface. Here the winds blow spirally inward counter clockwise in the northern hemisphere and clockwise in the southern hemisphere. There are two main types of cyclones- tropical cyclone (also called hurricane or typhoon) of comparatively small diameter of 300-1500 km causing high wind velocity and heavy precipitation, and the extra-tropical cyclone of large diameter up to 3000 km causing wide spread frontal type precipitation.

**MEASUREMENT OF PRECIPITATION:**
Rainfall may be measured by a network of rain gauges which may either be of non-recording or recording type.

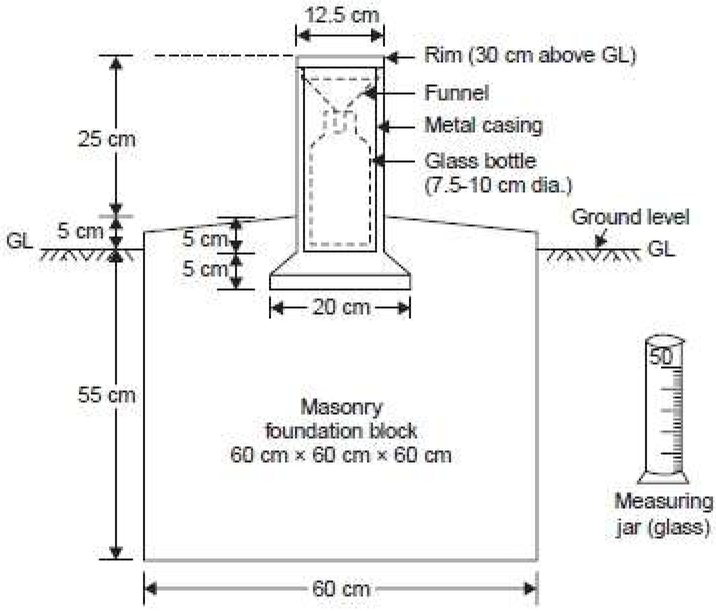



**Figure 1.4: Symon's rain gauge**

The non-recording rain gauge used in India is the Symon's rain gauge (Figure 1.4). It consists of a funnel with a circular rim of 12.7 cm diameter and a glass bottle as a receiver. The cylindrical metal casing is fixed vertically to the masonry foundation with the level rim 30.5 cm above the ground surface. The rain falling into the funnel is collected in the receiver and is measured in a special measuring glass graduated in mm of rainfall; when full it can measure 1.25 cm of rain.

The rainfall is measured every day at 08.30 hours IST. During heavy rains, it must be measured three or four times in the day, lest the receiver fill and overflow, but the last measurement should be at 08.30 hours IST and the sum total of all the measurements during the previous 24 hours entered as the rainfall of the day in the register. Usually, rainfall measurements are made at 08.30 hr IST and sometimes at 17.30 hr IST also. Thus the non-recording or the Symon's rain gauge gives only the total depth of rainfall for the previous 24 hours (*i.e.,* daily rainfall) and does not give the intensity and duration of rainfall during different time intervals of the day.

It is often desirable to protect the gauge from being damaged by cattle and for this purpose a barbed wire fence may be erected around it.

**Recording Rain Gauge:**

This is also called self-recording, automatic or integrating rain gauge. This type of rain gauge has an automatic mechanical arrangement consisting of clockwork, a drum with a graph paper fixed around it and a pencil point, which draws the mass curve of rainfall. From this mass curve, the depth of rainfall in a given time, the rate or intensity of rainfall at any instant during a storm, time of onset and cessation of rainfall, can be determined. The gauge is installed on a concrete or masonry platform 45 cm square in the observatory enclosure by the side of the ordinary rain gauge at a distance of 2-3 m from it. The gauge is so installed that the rim of the funnel is horizontal and at a height of exactly 75 cm above ground surface. The self-recording rain gauge is generally used in conjunction with an ordinary rain gauge exposed close by, for use as standard, by means of which the readings of the recording rain gauge can be checked and if necessary adjusted.

There are three types of recording rain gauges- tipping bucket gauge, weighing gauge and float gauge.

**Tipping bucket rain gauge:**

This consists of a cylindrical receiver 30 cm diameter with a funnel inside. Just below the funnel a pair of tipping buckets is pivoted such that when one of the bucket receives a rainfall of 0.25 mm it tips and empties into a tank below, while the other bucket takes its position and the process is repeated. The tipping of the bucket actuates on electric circuit which causes a pen to move on a chart wrapped round a drum which revolves by a clock mechanism. This type cannot record snow.

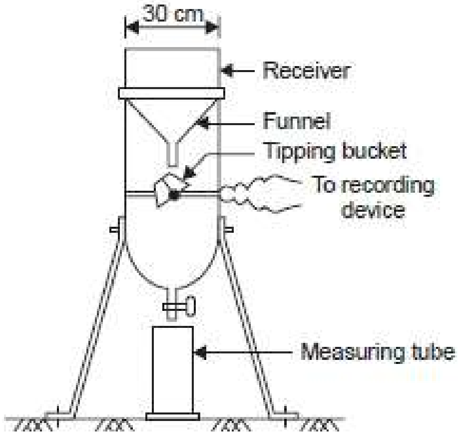


**Figure 1.5: Tipping bucket gauge**

**Weighing type rain gauge:**

In this type of rain-gauge, when a certain weight of rainfall is collected in a tank, which rests on a spring-lever balance, it makes a pen to move on a chart wrapped round a clockdriven drum. The rotation of the drum sets the time scale while the vertical motion of the pen records the cumulative precipitation.

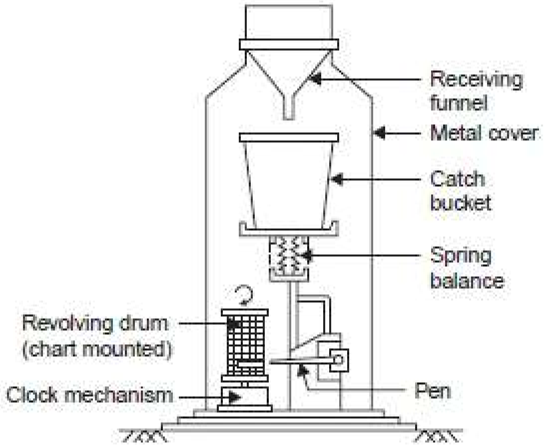



**Figure 1.6: Weighing type rain gauge**

**Float type rain gauge:**

In this type, as the rain is collected in a float chamber, the float moves up which makes a pen to move on a chart wrapped round a clock driven drum. When the float chamber fills up, the water siphons out automatically through a siphon tube kept in an interconnected siphon chamber. The clockwork revolves the drum once in 24 hours. The clock mechanism needs rewinding once in a week when the chart wrapped round the drum is also replaced. This type of gauge is used by IMD. The weighing and float type rain gauges can store a moderate snow fall which the operator can weigh or melt and record the equivalent depth of rain.

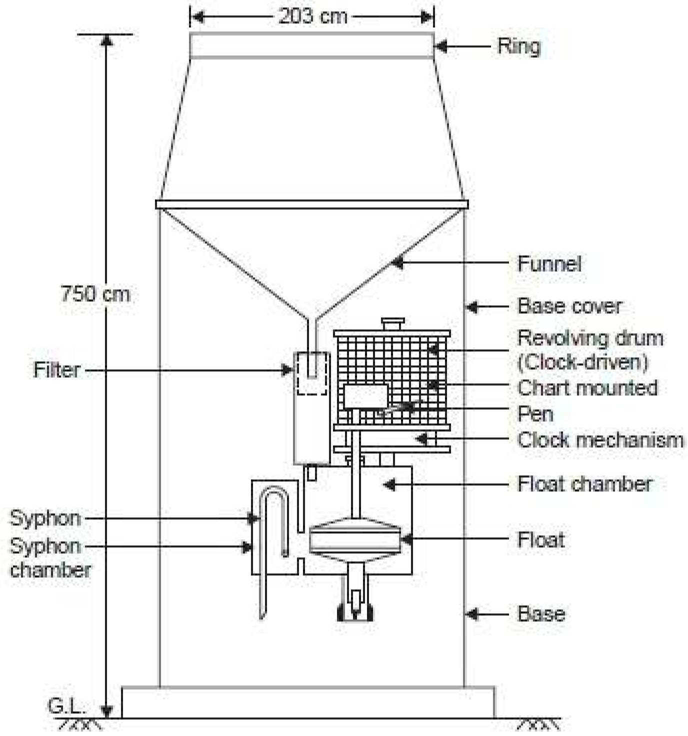



**Figure 1.7: Float type rain gauge**

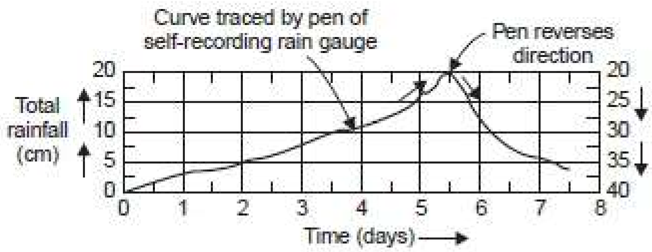



**Figure 1.8: Mass curve of rainfall**

**Raingauge Network**: The rain gauge density or network density is defined as the ratio of total area of catchment to the total number of gauges in the catchment. Thus raingauge density gives the average area served by each gauge.

The World Meteorological Organisation, WMO, has laid down certain norms regarding the minimum network density as given below:

Region I : Flat regions of temperate, mediterranean and tropical zones:

Minimum = 1 gauge for 600 to 900 $km^2$

Tolerance = 1 gauge for 900 to 3000 $km^2$

Region II : Mountainous areas of temperate, mediterranean and tropical zones:

Minimum = 1 gauge for 100 to 250 $km^2$

Tolerance = 1 gauge for 250 to 1000 $km^2$

Region III : Arid zones :

Minimum = 1 gauge for 1500 to 10000 $km^2$

For small mountainous islands with irregular precipitation one gauge for every 25 $km^2$ is suggested. Ten percent of these gauges should be of recording type to enable the determination of rainfall intensities.

**IS code recommendations(IS: 4987-1968):**

1. One guage per 520$km^2$ in plain areas, with denser network for the areas lying in the path of low pressure systems.
2. One guage per 260 to 390 $km^2$ in regions with average elevation of 1000m above mean sea level.
3. One guage per 130 $km^2$ in predominantly hilly regions with heavy rainfall, higher density being preferred wherever possible.

**OPTIMUM RAIN-GAUGE NETWORK DESIGN:** The aim of the optimum rain-gauge network design is to obtain all quantitative data averages and extremes that define the statistical distribution of the hydro meteorological elements, with sufficient accuracy for practical purposes. When the mean areal depth of rainfall is calculated by the simple arithmetic average, the optimum number of rain-gauge stations to be established in a given basin is given by the equation (IS, 1968)

$$N = \left(\frac{C_v}{p}\right)^2 \qquad \text{---------------Eq.1.2}$$

where $N$ = optimum number of raingauge stations to be established in the basin
$C_v$ = Coefficient of variation of the rainfall of the existing rain gauge stations (say, $n$)
$p$ = desired degree of percentage error in the estimate of the average depth of rainfall over the basin.

The number of additional rain-gauge stations ($N–n$) should be distributed in the different zones (caused by isohyets) in proportion to their areas, *i.e.,* depending upon the spatial distribution of the existing rain-gauge stations and the variability of the rainfall over the basin.

**Average rainfall over a basin:**

Point rainfall - It is the rainfall at a single station. For small areas less than 50 km2, point rainfall may be taken as the average depth over the area. In large areas, there will be a network of rain-gauge stations. As the rainfall over a large area is not uniform, the average depth of rainfall over the area is determined by one of the following three methods:

**(*i*) Arithmetic average method** - It is obtained by simply averaging arithmetically the amounts of rainfall at the individual rain-gauge stations in the area, *i.e.,*

$$P_{ave} = \frac{\Sigma P_1}{n} \qquad \text{---------------Eq.1.3}$$

where $P_{ave}$ = average depth of rainfall over the area
$\sum P1$ = sum of rainfall amounts at individual rain-gauge stations
$n$ = number of rain-gauge stations in the area

This method is fast and simple and yields good estimates in flat country if the gauges are uniformly distributed and the rainfall at different stations do not vary very widely from the mean. These limitations can be partially overcome if topographic influences and aerial representativity are considered in the selection of gauge sites.

(*ii*) **Thiessen polygon method** - This method attempts to allow for non-uniform distribution of gauges by providing a weighting factor for each gauge. The stations are plotted on a base map and are connected by straight lines. Perpendicular bisectors are drawn to the straight lines, joining adjacent stations to form polygons, known as Thiessen polygons (Fig. 1.9). Each polygon area is assumed to be influenced by the raingauge station inside it, *i.e.,* if $P1$, $P2$, $P3$, .... are the rainfalls at the individual stations, and $A1$, $A2$, $A3$, .... are the areas of the polygons surrounding these stations, (influence areas) respectively, the average depth of rainfall for the entire basin is given by

$$P_{ave} = \frac{\Sigma A_1 P_1}{\Sigma A_1} \quad \text{---------------Eq.1.4}$$

where $\sum A_1 = A$ = total area of the basin.

The results obtained are usually more accurate than those obtained by simple arithmetic averaging. The gauges should be properly located over the catchment to get regular shaped polygons. However, one of the serious limitations of the Thiessen method is its non-flexibility since a new Thiessen diagram has to be constructed every time if there is a change in the raingauge network.

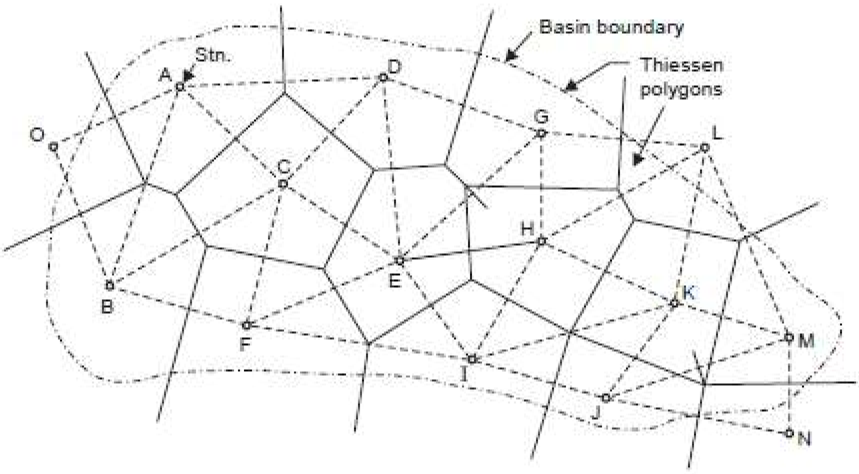



**Figure 1.9** Thiessen polygon method

(*iii*) **The isohyetal method** - In this method, the point rainfalls are plotted on a suitable base map and the lines of equal rainfall (isohyets) are drawn giving consideration to orographic effects and storm morphology, Fig.1.10. The average rainfall between the succesive isohyets taken as the average of the two isohyetal values are weighted with the area between the isohyets, added up and divided by the total area which gives the average depth of rainfall over the entire basin, *i.e.,*

$$P_{ave} = \frac{\Sigma A_{1-2} P_{1-2}}{\Sigma A_{1-2}} \quad \text{---------------Eq.1.5}$$

where $A_{1-2}$ = area between the two successive isohyets $P1$ and $P2$

$$P_{1-2} = \frac{P_1 + P_2}{2} \quad \text{---------------Eq.1.6}$$

$\sum A1\text{–}2 = A$ = total area of the basin.

This method if analysed properly gives the best results.

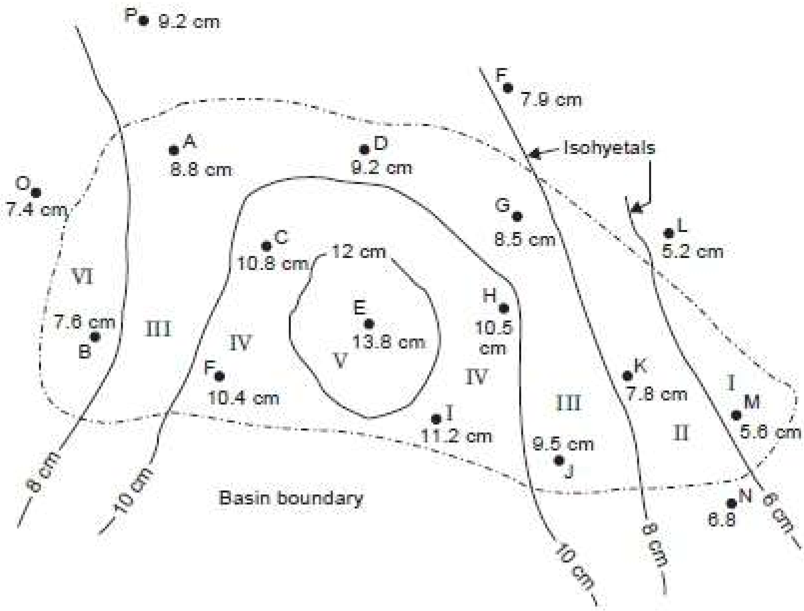
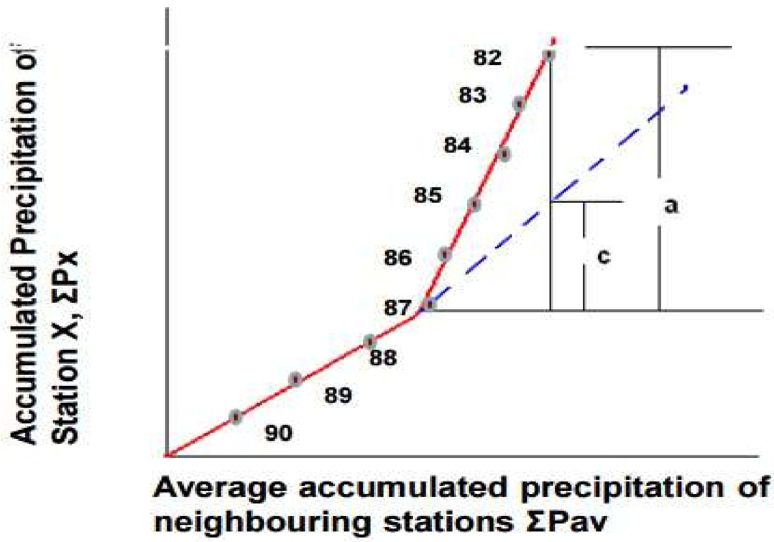



**Figure 1.10** Isohyetal method

**Consistency of rain fall data**

**Double Mass Curve Technique**: The trend of the rainfall records at a station may slightly change after some years due to a change in the environment (or exposure) of a station either due to coming of a new building, fence, planting of trees or cutting of forest nearby, which affect the catch of the gauge due to change in the wind pattern or exposure. It is a commonly used data analysis approach for investigating the behaviour of records made of hydrological or meteorological data at a number of locations. It is used to determine whether there is a need for corrections to the data - to account for changes in data collection procedures or other local conditions. Double mass analysis for checking consistency of a hydrological or meteorological record is considered to be an essential tool before taking it for analysis purpose.




Correction Ratio : $M_c/M_a = c/a$

$Pcx = Px*M_c/M_a$

Pcx – corrected precipitation at any time period t1 at station X

Px – Original recorded precipitation at time period t1 at station X

$M_c$ – corrected slope of the double mass curve $M_a$ – original slope of the mass curve

**Frequency of rainfall**: The frequency of rainfall of a specified period is determined by assuming that the rainfall is a random variable and mathematical theory of probability is applicable. The frequency of a rainfall is the number of time that a given magnitude of rainfall may occur in a given period. The study of the probability of occurrence of a particular extreme rain fall is of extreme importance to the determination of design flood. This is determined with help of frequency analysis. The recurrence interval is the interval in years for occurrence of the event of the same magnitude and is the reciprocal of the frequency. The recurrence interval, also known as return period

California formula : $P_r$= m/N or T= N/m N=number of years of record , m=descending order of magnitude

Hazen formula : $p_r$ = 2m-1/2N

Weibull formula : $p_r$ = m/(n+1) most commonly used formula

Frequency (f) : The probability of occurrence of an event, expressed as percentage is known as frequency, f=100*$p_r$

**Intensity-Duration-Frequency (IDF) curves**

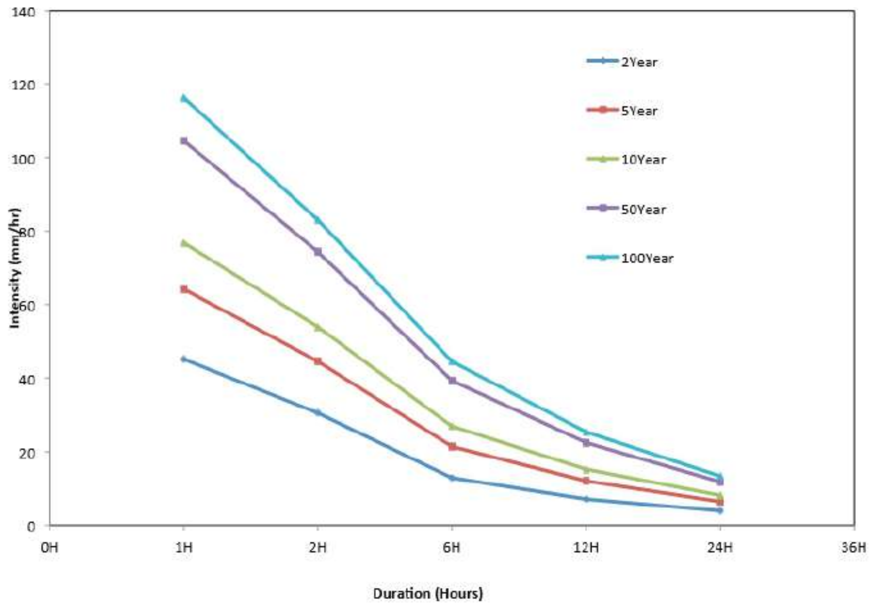
It is necessary to know the rainfall intensities of different durations and different return periods, in case of many design problems such as runoff disposal , erosion control, highway construction, culvert design etc. The curve that shows the inter-dependency between i (cm/hr), D (hour) and T (year) is called IDF curve.

The relation can be expressed in general form as:

i = i – Intensity (cm/hr), T – Return period

D – Duration (hours)

K, x, a, n – are constant for a given catchment




**Depth-Area-Duration relationships**

It indicates the areal distribution characteristic of a storm of given duration.

The development of maximum depth-area-duration relationship is known as DAD analysis. It is an important aspect of hydro-meteorological study.

**Depth-Area relationship**

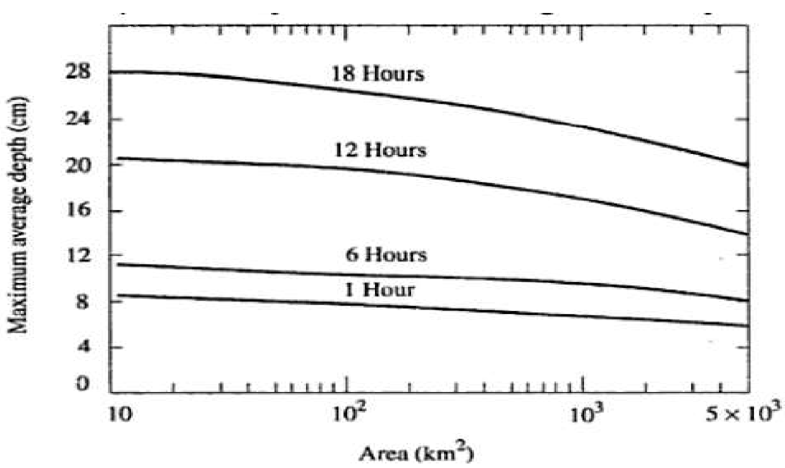
For a rainfall of given duration, the average depth decreases with the area in an exponential fashion given by:

$P=P_0\exp(-kA^n)$

where :P= average depth in cms over an area A $km^2$,

Po : highest amount of rainfall in cm at the storm centre

K, n : constants for a given region




**Depth area duration curves**

**Probable Maximum Precipitation (PMP)**

- This is the amount of rainfall over a region which cannot be exceeded over at that place.
- The PMP will of course vary over the Earth's surface according to the local climatic factors.
- Naturally, it would be expected to be much higher in the hot humid equatorial regions than in the colder regions of the mid-latitudes when the atmospheric is not able to hold as much moisture.
- PMP also varies within India, between the extremes of the dry deserts of Rajasthan to the ever humid regions of South Meghalaya plateau**.**

PMP = P +Ks

P = mean of annual maximum rainfall series

s = standard deviation of the series

K = frequency factor

**HYDROLOGY & WATERRESOURCES ENGINEERING**

**UNIT-II**

**ABSTRACTIONS**

**Syllabus:** Abstractions Evaporation, factors affecting evaporation, measurement of evaporation, evaporation reduction, evapotranspiration, factors affecting evapotranspiration, measurement of evapotranspiration - Infiltration, factors affecting infiltration, measurement of infiltration, infiltration indices.

**LEARNING MATERIAL**

**LOSSES OR ABSTRACTIONS FROM PRECIPITATION:**

When precipitation takes place on the land surface, whole of it is not available as runoff because of losses that take place during or after the precipitation.

Precipitation – surface runoff = total loss

Total loss = interception+ evaporation+ transpiration+ infiltration+ depression storage+ watershed leakage

**EVAPORATION:** It is the process of a substance in a liquid state changing to a gaseous state due to an increase in temperature and/or pressure. Evaporation is a fundamental part of the water cycle and is constantly occurring throughout nature.

The rate of evaporation depends of following factors

1) Vapour pressure
2) Air & water temperature
3) Solar radiation
4) Wind speed
5) Atmospheric pressure
6) Nature and size of evaporating surface
7) Quality of water

**Dolton's law of evaporation**

$E = C(e_s - e_a) = (a+b\upsilon)(e_s - e_a)$

$E$ =evaporation loss (mm/day)

$e_s$= saturated vapour pressure

$e_a$ = actual vapour pressure

a,b = constants

$\upsilon$ = wind speed in km/h

**FACTORS AFFECTING EVAPORATION:**

**Nature of the evaporating surface:** Different evaporating surfaces like soil barren land, forest area, houses & lakes affect evaporation to the extent they have the potential. Black cotton soil evaporates soil water faster than red soil.

**Area of water surface:** We know that Evaporation is a surface phenomenon. Hence with increase in surface area, the rate of evaporation also increases. For example: Wet clothes become dries quickly when spread out.

**Depth of water in water body:** Deep water bodies evaporate slower than shallow water bodies in summer while in winter season, they evaporate faster.

**Temperature of air:** Rate of evaporation Increases with the rise in temperature as increasing temperature increases the kinetic energy of molecules of the liquid which facilitates the molecule to convert into vapour.

**Humidity:** The rate of evaporation decreases with the rise in Humidity. Humidity is defined as the amount of the water vapour in the air. On a particular or defined temperature, air cannot hold or carry definite amount of moisture. Hence this high humidity reduces the rate of evaporation as air cannot hold any more water vapour.

**Wind velocity**: The rate of evaporation increases with the winds speed. An increase in speed of wind causes water vapour particles to move away with the winds and this decreases the amount of water vapour in the surroundings. As a result, the rate of evaporation increases. Thus on a windy day, wet clothes dry faster.

**Atmospheric pressure:** Evaporation is also affected by the atmospheric pressure exerted on the evaporating surface. Evaporation will be less if the atmospheric pressure is more while in deep valleys evaporation is less.

**Quality of water:** Evaporation is inversely proportional to the salinity of water. Rate of evaporation is always greater over fresh water than over salt water. Under similar conditions, the ocean water evaporates about 5 per cent slowly than the fresh water.

**MEASUREMENT OF EVAPORATION**

This is done by the following methods

1. Measurement using evaporation pans (evaporimeters)
2. Using empirical equations
3. Analytical methods of evaporation estimation

**Evaporimeters:** These are pans containing water which are exposed to the atmosphere. Loss of water by evaporation from these pans is measured at regular intervals (daily). Meteorological data such as humidity, wind velocity, air and water temperatures, and precipitation are also measured and noted along with evaporation.

**1. IS STANDARD PAN**

1Specified by IS: 5973 and known as the modified Class A Pan

2. A pan of diameter 1220mm and depth 255mm.

3. The pan is made of copper sheet 0.9mm thick, tinned inside and painted white outside.

4. The pan is placed on a square wooden platform of width 1225mm and height 100mm above ground level to allow free air circulation below the pan.

5. A fixed point gauge indicates the level of water.

6. Water is added to or removed from the pan to maintain the water level at a fixed mark using a calibrated cylindrical measure.

7. The top of the pan is covered with a hexagonal wire net of GI to protect water in the pan from birds.

8. Presence of the wire mesh makes the temperature of water more uniform during the day and night.

9. Evaporation from this pan is about 14% lower as compared to that from an unscreened pan.

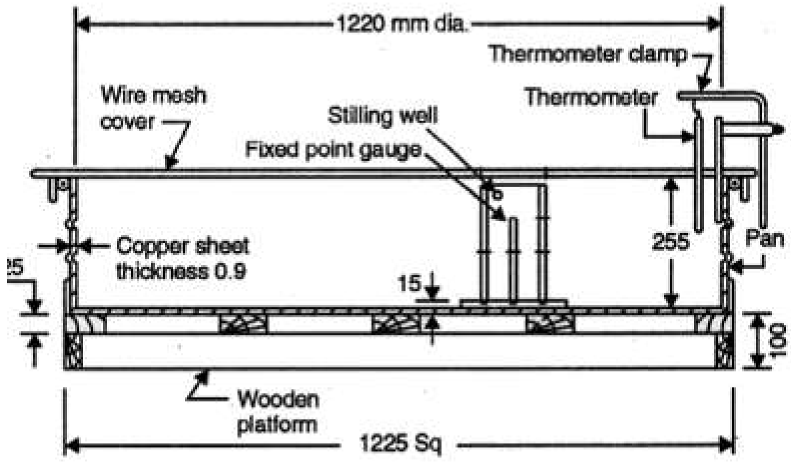



Figure2.1 IS Evaporation Pan

**2. COLORADO SUNKEN PAN**

1. 920mm square pan made of unpainted GI sheet, 460mm deep, and buried into the ground within 100mm of the top.

2. Main advantage of this pan – its aerodynamic and radiation characteristics are similar to that of a lake.

3. Disadvantages – difficult to detect leaks, expensive to install, extra care is needed to keep the surrounding area free from tall grass, dust etc.

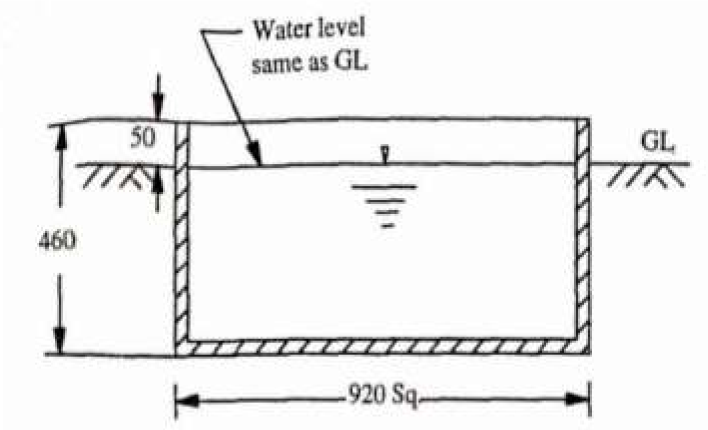



Figure 2.2 Colorado Sunken Pan

**Pan Coefficient**

• Evaporation pans are not exact models of large reservoirs

Their major drawbacks are the following:

- They differ from reservoirs in the heat storage capacity and heat transfer characteristics from the sides and the bottom (sunken and floating pans aim to minimise this problem). Hence evaporation from a pan depends to some extent on its size (Evaporation from a pan of about 3m dia. is almost the same as that from a large lake whereas that from a pan of about 1m dia. is about 20% in excess of this).
- The height of the rim in an evaporation pan affects wind action over the water surface in the pan. Also it casts a shadow of varying size on the water surface.
- The heat transfer characteristics of the pan material are different from that of a reservoir.
- Hence evaporation measured from a pan has to be corrected to get the evaporation from a large lake under identical climatic and exposure conditions.

  **Lake Evaporation = Pan Coefficient x Pan Evaporation**

**Table: Values of Pan Coefficients**

| **Sl. No.** | **Types of Pan** | **Average Value** | **Range** |
|---|---|---|---|
| **1** | Class A Land Pan | 0.70 | 0.60 – 0.80 |
| **2** | ISI Pan (Modified Class A) | 0.80 | 0.65 – 1.10 |
| **3** | Colorado Sunken Pan | 0.78 | 0.75 – 0.86 |
| **4** | USGS Floating Pan | 0.80 | 0.70 – 0.82 |

**EMPIRICAL EQUATIONS**

Most of the available empirical equations for estimating lake evaporation:

**(1) Meyer's Formula**

**$E = K_m (e_s - e_a) [1 + ]$**

E = evaporation (mm/day)

$e_s$ = saturation vapour pressure at the water surface temperature (mm of mercury)

$e_a$=actual vapour pressure of the overlying air at a specified height (mm of mercury)

$v_9$ = monthly mean velocity (kmph) at a height of 9 m above the ground

$K_m$= coefficient accounting for other factors (0.36 for large deep waters and 0.50 for small shallow lakes)

**(2) Rohwer's Formula**

**$E = 0.771(1.465 - 0.000732\, p_a)(0.44 + 0.0733\, v_{0.6})(e_s - e_a)$**

$P_a$=mean barometric pressure (mm of mercury)

$V_{0.6}$=mean wind velocity in kmph at ground level 0.6

(taken as the wind velocity at 0.6m height above the ground)

E,$e_w$ and $e_a$ are as mentioned earlier

**Wind Velocity**

In the lower part of the atmosphere, up to a height of about 500m above the ground level, wind velocity follows the one-seventh power law as

$V_h = c\, h^{1/7}$

$V_h$ = wind velocity (in kmph) at a height h(in m) above the ground level

C = constant

**ESTIMATION OF EVAPORATIONBY USING ANALYTICAL METHODS:**

**Water budget or water balances method**:

This method balances all the incoming, outgoing and stored water in a lake or reservoir over a period of time, using the following equation:

∑Inflow-∑Outflow = change in storage + evaporation loss

(or) $E = \sum I - \sum O \pm \Delta S$

The above equation can be generalised as under, taking all the factors of inflow and outflow:

$E = (P + I_{sf} + I_{gf}) - (O_{sf} + O_{gf} + T) \pm \Delta S$

P = precipitation

$I_{sf}$ = surface water inflow

$I_{gf}$ = ground water inflow

$O_{sf}$ = surface water outflow

$O_{gf}$ = ground water outflow

T = transpiration loss, which may be neglected.

$\Delta S$ = change in storage.

The above method does not give accurate results because it is very difficult to measure $I_{sf}$ and $O_{gf}$ for a lake/reservoir.

**Energy budget or energy balance:**

this method uses the conservation of energy by incorporating all the incoming, outgoing and stored energy of lake/reservoir in the following form:

$H_n = H_a + H_e + H_g + H_s + H_i$ -------------------(1)

Where $H_n$ =net heat energy received by water surface $+H_c(1\text{-}r) - H_b$

$H_c(1\text{-}r)$ = Incoming solar radiation into a surface of reflection coefficient 'r'

The value of r for water surface approximates 0.05. for newly laid snow,r=0.90

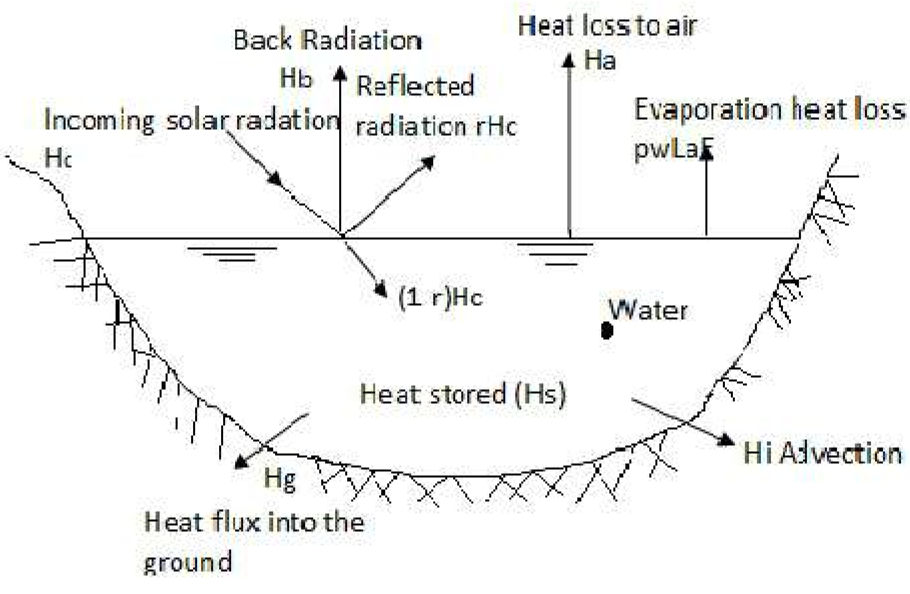



Fig.4.. Energy balance in a water body

$H_b$= back radiation from the body

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

$H_e$ = heat energy used up in evaporation = $\rho_w L_a E$

Where $\rho_w$ =density of water,

$H_g$ = heat flux into the ground,

$H_i$ = net heat conducted out of the system by water flow

$H_s$ = heat stored in water body

$L_a$ =latent heat of evaporation.

In the above equation, all the energy terms are in calories per square mm per day. All the terms except $H_a$ can either be measured or evaluated. For small time period, the terms $H_s$ and $H_i$ can be neglected. However, the sensible heat term H can be estimated by using Bowen's ratio (β) by the following expression:

$$\beta = H_a / \rho_w L_a E = 6.1 X 104pa (Tw - T_a/e_s - e_a) \text{------------------}(2)$$

Where Tw = temperature of water surface

$T_a$ = temperature of air in °c

$P_a$ =Atmospheric pressure in mm of mercury

Combining eqs. 1 and 2 we obtain the following equation for evaporation E :

E =

The above method gives satisfactory results, with errors of the order of about 5%, when applied to periods less than a week.

**EVAPORATIONREDUCTION**

There are a wide range of products available for controlling evaporation loss. These systems include:

- Continuous floating covers.
- Modular covers.
- Shade structures.
- Chemical covers

**Continuous floating covers**

Continuous floating plastic covers act as an impermeable barrier that floats on the water surface and can achieve above 90% evaporation savings for full cover of the dam. Most of these products have a high capital cost and replacement life varies (typically between 10 and 20 years). The structural integrity of the product under windy conditions and fluctuating water levels is important. Water quality can be impacted by reduced dissolved oxygen, light penetration and change in water temperature. This can have a positive impact on reducing algal growth. Significant difficulties can be encountered with installation on large storages above 5ha. In some cases these covers can be deployed as a series of large rafts covering up to 1Hour.

**Modular systems**

Modular floating covers come in a range of sizes typically up to 3m2 in area and act in a similar manner to floating covers. However they do not have the structural challenges of a continuous sheet. Modular floating covers can also be deployed to cover only a portion of the storage, for example that portion always holding water.

Modules can be free-floating or connected together to form a larger raft. Modules are typically made from a plastic material and can generally provide up to 90% savings for 100% area covered. The actual area covered will depend on the number, shape and size of the module and storage characteristics.

Generally these systems have a very high capital cost (in excess of US$17/m2). Repair and replacement of modules is possible and water quality impacts will depend on the relative area covered oxygen transfer and changes to water temperature.

**Shade structures**

Shade structures in general are suspended above the water surface using cables creating a web-like structure with shade cloth fitted between the cables. The shade cloth can come in a range of UV ratings (to describe the amount of UV blocked by the shade cloth). Evaporation savings of 70 to 80% have been demonstrated in trials.

Floating shade cloth modules or rafts have recently been marketed. Most of these products have a relatively high capital cost. In general shade structures are not as effective in reducing evaporation as floating covers. They allow free flow of oxygen to the water, although wind velocity and wave action will be reduced, which impacts dissolved oxygen levels. Algae may be reduced owing to less light penetration.

**Chemical covers**

Chemical covers have been promoted as a low cost method to reduce evaporation losses. Some products are true monolayers (i.e. a single molecule thick) while others are multiple layers with different water saving characteristics and water quality impacts. These products are generally biodegradable and there is a need to reapply frequently (between three and ten days). Water savings have been shown to be highly variable, from less than 10% to up to 50% and are impacted by prevailing wind, temperature and water quality.

True monolayer's are applied at very low application rates and rely on the self spreading ability of the chemical. Advantages of these products are the low capital cost and choice to apply only when needed. Monolayers offer much potential for affecting evaporation savings but inconsistent evaporation saving performance has limited their adoption in Australia. It has been recognised that further research is needed and the Cooperative Research Centre for Irrigation Futures (CRC-IF) is currently working on such a project.

**EVAPOTRANSPIRATION**

Evapo-transpiration is the combined term of evaporation and transpiration, defined as the total loss of water through evaporation and transpiration from the plants. It is denoted by ET, the sum of water used by plants in a given area in transpiration and water evaporated from the adjacent soil in the area in any specified time.

$$ET = CU$$

CU is the Evapo-transpiration from an area plus the water used directly in the metabolic process of building plant tissue. (if it is covered with vegetation so, we find ET directly).It represents most important aspect of water loss in hydrologic cycle.

Potential Evapo-transpiration (PET) is defined as the Evapo-transpiration which would occur if there was always an adequate water supply available to a fully vegetated surface.

Actual Evapo-transpiration (AET) is defined as the real Evapo-transpiration occurring in a specific situation.

Seasonal consumptive use (SCU) of a crop is the total quantity of water used by it in ET during the entire grow season.

PET, AET, SCU is useful in designing the irrigation system.

**FACTORS THAT AFFECT EVAPOTRANSPIRATION**

The rate of Evapo-transpiration at any location on the Earth's surface is controlled by several factors:

- **Energy availability**. The more energy available, the greater the rate of Evapo-transpiration. It takes about 600 calories of heat energy to change 1 gram of liquid water into a gas.
- **The humidity gradient away from the surface**. The rate and quantity of water vapour entering into the atmosphere both become higher in drier air.
- **The wind speed immediately above the surface**. The process of Evapo-transpiration moves water vapour from ground or water surfaces to an adjacent shallow layer that is only a few centimetres thick. When this layer becomes saturated Evapo-transpiration stops. However, wind can remove this layer replacing it with drier air which increases the potential for Evapo-transpiration. Winds also affect Evapo-transpiration by bringing heat energy into an area. A 5-mile-per-hour wind will increase still-air Evapo-transpiration by 20 percent; a 15-mile-per-hour wind will increase still-air Evapo-transpiration by 50 percent.

- **Water availability**. Evapo-transpiration cannot occur if water is not available.
- **Physical attributes of the vegetation**. Such factors as vegetative cover, plant height, leaf area index and leaf shape and the reflectivity of plant surfaces can affect rates of Evapo-transpiration. For example coniferous forests and alfalfa fields reflect only about 25 percent of solar energy, thus retaining substantial thermal energy to promote transpiration; in contrast, deserts reflect as much as 50 percent of the solar energy, depending on the density of vegetation.
- **Stomata resistance**. Plants regulate transpiration through adjustment of small openings in the leaves called stomata. As stomata close, the resistance of the leaf to loss of water vapour increases, decreasing to the diffusion of water vapour from plant to the atmosphere.
- **Soil characteristics**. Soil characteristics that can affect Evapo-transpiration include its heat capacity, and soil chemistry.

Seasonal trends of Evapo-transpiration within a given climatic region follow the seasonal declination of solar radiation and the resulting air temperatures. Minimum Evapo-transpiration rates generally occur during the coldest months of the year. Maximum rates generally coincide with the summer season. However since Evapo-transpiration depends on both solar energy and the availability of soil moisture and plant maturity the seasonal maximum Evapo-transpiration actually may precede or follow the seasonal maximum solar radiation and air temperature by several weeks.

**MEASUREMENT OF EVAPOTRANSPIRATION**

The consumptive use or Evapo-transpiration can be measured by five principal methods:

1. Tank and Lysimeter
2. Field Experiment plots

**1. Tank and Lysimeter:**

Tanks are containers set flush with the ground level having an area of 10 $m^2$ and three 3 m deep. Larger the size of the tank greater is the resemblance to root development. The tank is filled with soil of the field and crop is grown in it. Consumptive use is determined by measuring the quantity of water required to maintain constant moisture conditions within the tank for satisfactory proper growth of the crop. In lysimeters, the bottom is pervious. Consumptive use is the difference of water applied and that draining through pervious bottom and collected in a pan.

**2. Field Experiment:**

This method is more dependable than the tank and lysimeter method. In this method, irrigation water is applied to the selected field experimental plots in such a way that there is neither runoff nor deep percolation. Yield obtained from different fields are plotted against the total water used, and, as basis for arriving at the consumptive use, those yields are selected which appear to be most profitable. It is seen from observations that for every type of crop, the yield increases rapidly with an increase of water used to a certain point, and then decreases with further increase in water. At the 'break in the curve" the amount of water used is considered as the consumptive use.

EVAPOTRANSPIRATION EQUATIONS

**1. Blaney- Criddle formula**

This method is used throughout the world for the consumptive use determinations and is given by

$$U = \Sigma \frac{ktp}{100} \quad \text{in FPS units}$$

$$U = \Sigma \frac{kp\,(4.6t + 813)}{100} \quad \text{in metric units}$$

$$U = \Sigma\, kf = K\, \Sigma f = KF$$

$$f = \frac{tp}{100} \quad \text{in FPS units}$$

$$f = \frac{p(4.6t + 813)}{100} \quad \text{in metric units}$$

where $U$ = seasonal consumptive use (inches in FPS units and cm in metric units)

$t$ = mean monthly temperature (°F in FPS units and °C in metric units)

$p$ = monthly percentage of hours of bright sunshine (of the year)

$k$ = monthly consumptive use coefficient determined from experimental data

$f$ = monthly consumptive use factor

$K, F$ = seasonal values of consumptive use coefficient and factor, respectively

$\sum$ refers for the summation for all the months of the growing season.

**INFILTRATION:** It is the process by which water on the ground surface enters the soil. Infiltration rate in soil_science is a measure of the rate at which soil is able to absorb rainfall or irrigation. It is measured in inches per hour or millimetres per hour. The rate decreases as the soil becomes saturated. If the precipitation rate exceeds the infiltration rate, runoff will usually occur unless there is some physical barrier. It is related to the saturated hydraulic conductivity of the near-surface soil. The rate of infiltration can be measured using an infiltrometer.

**FACTORS AFFECTING INFILTRATION:**

**(i)Intensity and duration of rainfall:**

When the precipitation takes place with heavy intensity, the impact of water causes mechanical compaction and in wash of fine particles, resulting in faster decrease in the rate of infiltration. However, rainfall of lesser intensity results in higher infiltration rate. The rainfall with higher duration will result in lower infiltration in comparison to the same quantity of rain falling as n number of isolated storms.

**(ii) Soil Texture and Structure:**

It is already made clear that the water cannot continue to enter soil more rapidly than it is transmitted downward. The conditions at the surface, therefore, cannot increase infiltration unless the transmission capacity of the soil profile is adequate.

The continuity of non-capillary or large pores provides easy paths for percolating water. If the subsoil formation has coarse texture the water may infiltrate into the soil so quickly that no water will be left for runoff even if rainfall is quite heavy. On the contrary clayey soils after soaking some water in the initial stages of the rainfall may swell considerably. It makes the soil almost watertight and infiltration may get reduced to practically negligible extent.

**(iii) Conditions at Soil Surface:**

Even if the subsoil has excellent under drainage but at the surface soil pores are sealed due to turbid water or by in wash of fine soil particles it may prevent entry of water into the soil and infiltration rate will be low.

**(iv)Soil-Moisture Content:**

When the soil is fairly dry the rate of infiltration into the soil is quite high. The infiltration rate diminishes as the soil-moisture storage capacity is exhausted. After this infiltration rate equals transmission rate. The rate of infiltration in early phases of a rainfall will be less if the soil pores are still filled from previous rain storm.

**(v)Movement of man and animal activities:**

When there is heavy movement of man and/ or animal, the soil gets compacted, resulting in reduction in the infiltration rate

**(vi)Type of Vegetative Cover:**

Vegetative cover affects surface entry of water significantly. The vegetation or mulches protect the soil surface from impact of rain drops. The lengthy and extensive root system penetrates the soil and increases its porosity. Organic matter from crops promotes a crumbly by structure and improves soil permeability. Forest canopy protects soil surface whereas row crops provide less protection to soil.

**(vii) Soil Temperature:**

If saturated soil mass gets frozen due to severe low temperature it becomes nearly impermeable. It affects the infiltration.

**(viii) Human Activities on Soil Surface:**

If the soil surface gets compacted due to construction of roads, operation of tractors and other farm implements and machinery the porosity of the soil is decreased. As a result bigger pores are almost eliminated making soil impermeable. It reduces the infiltration rates appreciably.

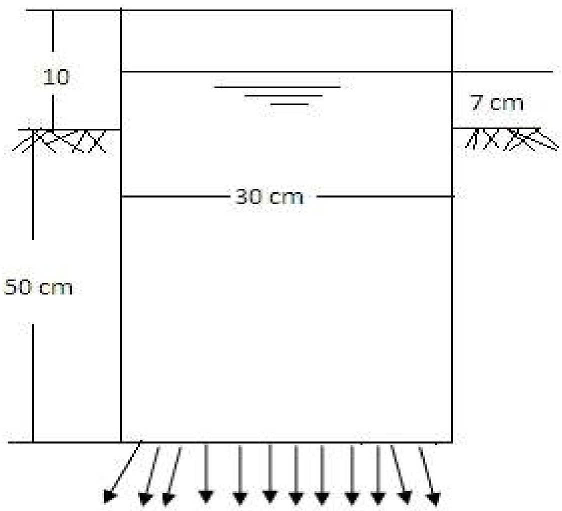
**MEASUREMENT OF INFILTRATION:**

Infiltration in the field can be measured with the help of two types of infiltrometers:

(a) Single cylindrical or single tube infiltration and (b) concentric double cylindrical or double ring infiltrometers.

**Single tube infiltrometer:**

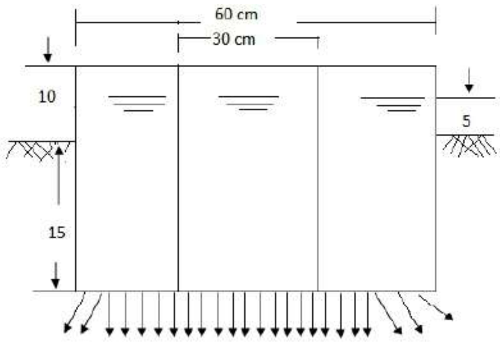
It consists of a hollow metal cylinder of 30 cm diameter and 60 cm length with both ends open. The cylinder is driven in the ground such that 10 cm of it projects above the ground. The cylinder is filled with water, such that a head of 7 cm within the infiltrometer is maintained above ground level. Due to infiltration of water, the level in the cylinder will go on decreasing. Water is added to the cylinder, through graduated jar or burette, so as to maintain constant level. The volume of water added over a predetermined time interval gives the infiltration rate for that time interval. The observations are continued till almost uniform infiltration rate is obtained, which may take about 3 to 6 hour, depending upon the type of soil. A plot of in abscissa against rate of water added in mm/h gives the infiltration capacity curve for the area. The major drawback of single tube infiltrometer is that infiltrated water percolates laterally at the bottom of the ring as shown in fig. Hence it does not truly represent the area through which infiltration takes place.




Single tube infiltrometer

**Double tube (or double ring) infiltrometer:**

The above defect of lateral percolation of water is rectified in the double tube infiltrometer which consists of two concentric hollow rings (or cylinders) driven into the soil uniformly without any tilt and disturbing the soil, to the least depth of 15cm. The diameter of the rings may vary from 25 to 60 cm water is applied in both the inner and outer rings to maintain a constant depth of about 5 cm. Water is replenished after the level falls by about 1 cm.the water depth in the inner and outer rings should be kept the same during the observation period. However, the measurement includes the recording of volume of water added into the inner compartment, to maintain the constant water level and the corresponding elapsed time . as the purpose of the outer ring is to suppress the lateral percolation of water from the inner ring ,the water added to it need not be measured though water is added to it to maintain the same depth as the inner ring. Observations are continued till constant infiltration rate is observed.



Double ring infiltrometer

**INFILTRATIONINDICES:**

In the hydrological calculations involving flood it is found convenient use a constant value of infiltration rate for the duration of the storm. The defined average infiltration index .Various infiltration indices give rates of infiltration in different ways to help assessment of the water lost by way of infiltration.

The two important types of indices are the following**:**

**(ii) ф Index:**

The ф index is that portion of average rate of rainfall during any storm which gets lost by the processes of interception, depression storage and infiltration taken together. It can, therefore, be defined as that rate of average rainfall during any storm beyond which the volume of remaining rainfall equals the volume of direct surface runoff. The index can be calculated from a hyetograph (time versus intensity of rainfall graph) of the storm in such a way that the rainfall volume in excess of this rate will equal the volume of the storm runoff . If the rainfall intensity throughout the storm remains equal to or more than ϕ index then the ϕ index represents basin recharge because ϕ index represents sum total of infiltration, interception and depression storage.

**(ii) W-Index:** This index gives the average rate of infiltration for that time period of the storm rainfall during which rainfall intensity is greater than W. Thus it can be said to be refinement over ϕ index which apart from infiltration also includes interception and depression storage.

The W index can be obtained from the following equation:

$$\mathbf{W = P\text{-}R\text{-}Sa/t_r}$$

Where

W is average rate of infiltration

P is total storm rainfall corresponding to t

Q is total storm run-off.

t is time during which rainfall intensity is more than W and

S is effective surface retention.

W = ϕ average rate of retention

For all practical purposes ϕ index can be taken to represent average rate of infiltration. Since ϕ indices assume average rate of infiltration which in fact is less than initial infiltration rate and more than ultimate infiltration rate their utility is limited to major flood producing storms. Such storms generally occur on wet soil and storms are of such intensity and duration that the infiltration rate could be very nearly taken to be constant for whole storm or majority period of storm. Obviously for short isolated storms ϕ and W indices are not useful.

**HYDROLOGY & WATER RESOURCES ENGINEERING**
**UNIT-III**
**RUNOFF**

**Syllabus:**

Factors affecting runoff ,components of runoff, computation of runoff-rational and SCS methods, separation of base flow ,Unit Hydrograph, assumptions, derivation of Unit Hydrograph, unit hydrographs of different durations, principle of superposition and S-hydrograph methods, limitations and applications of UH.

**COMPONENTS OF STREAM FLOW**: When a storm occurs, a portion of rainfall infiltrates into the ground and some portion may evaporate. The rest flows as a thin sheet of water over the land surface which is termed as overland flow. If there is a relatively impermeable stratum in the subsoil, the infiltrating water moves laterally in the surface soil and joins the stream flow, which is termed as underflow (subsurface flow) or interflow, Fig. 1. If there is no impeding layer in the subsoil the infiltrating water percolates into the ground as deep seepage and builds up the ground water table (GWT or phreatic surface). The ground water may also contribute to the stream flow, if the GWT is higher than the water surface level of the stream, creating a hydraulic gradient towards the stream. Low soil permeability favors overland flow. While all the three types of flow contribute to the stream flow, it is the overland flow, which reaches first the stream channel, the interflow being slower reaches after a few hours and the ground water flow being the slowest reaches the stream channel after some days. The term direct runoff is used to include the overland flow and the interflow. If the snow melt contributes to the stream flow it can be included with the direct runoff (from rainfall).

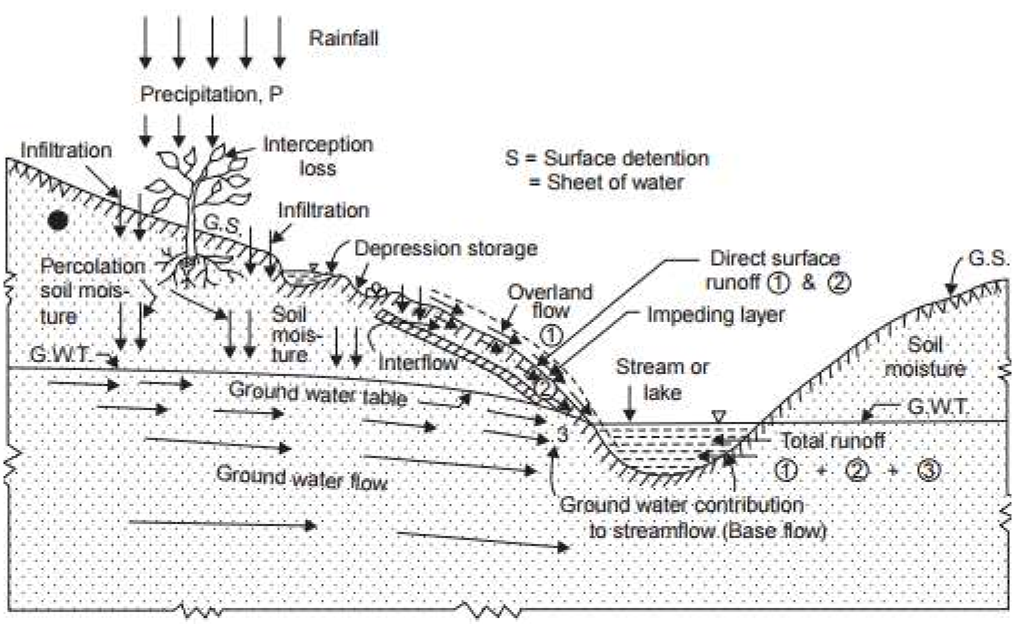



**Figure 1: Disposal of rain water**

Direct surface flow can be analysed for relatively large drainage areas by the unit hydrograph method and for smaller areas by overland flow analysis. The direct runoff results from the occurrence of an immediately preceding storm while the ground water contribution, which takes days or months to reach the stream, in all probability has no direct relation with the immediately preceding storm. The ground water flow into the stream would have continued even if there had been no storm immediately preceding. It is for this reason it is termed as base flow in hydrograph analysis. When the overland flow starts (due to a storm) some flowing water is held in puddles, pits and small ponds; this water stored is called depression storage. The volume of water in transit in the overland flow which has not yet reached the stream channel is called surface detention or detention storage. The portion of runoff in a rising flood in a stream, which is absorbed by the permeable boundaries of the stream above the normal phreatic surface is called bank storage, Fig. 2.

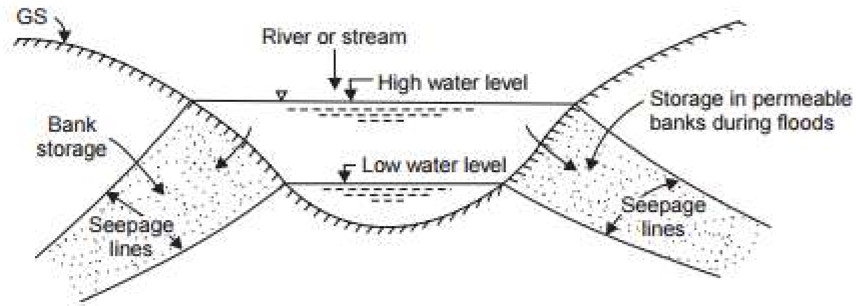



**Figure 2: Bank Storage**

**FACTORS AFFECTING RUNOFF**: The various factors, which affect the runoff from a drainage basin depend upon the following characteristics:

Low intensity storms over longer spells contribute to ground water storage and produce relatively less runoff. A high intensity storm or smaller area covered by it increases the runoff since the losses like infiltration and evaporation are less. If there is a succession of storms, the runoff will increase due to initial wetness of the soil due to antecedent rainfall. Rain during summer season will produce less runoff, while that during winter will produce more. Greater humidity decreases evaporation. The pressure distribution in the atmosphere helps the movement of storms. Snow storage and specially the frozen ground greatly increase the runoff. Peak runoff (if expressed as cumec/km$^2$) decreases as the catchment area increases due to higher time of concentration. A fan-shaped catchment produces greater flood intensity than a fern-shaped catchment. Steep rocky catchments with less vegetation will produce more runoff compared to flat tracts with more vegetations. If the vegetation is thick greater is the absorption of water, so less runoff. If the direction of the storm producing rain is down the stream receiving the surface flow, it will produce greater flood discharge than when it is up the stream. If the catchment is located on the orographic side (windward side) of the mountains, it receives greater precipitation and hence gives a greater runoff. If it is on the leeward side, it gets less precipitation and so less runoff. Similarly, catchments located at higher altitude will receive more precipitation and yield greater runoff. The land use pattern—arable land, grass land, forest or cultivated area, greately affect runoff. The storage in channels and depressions (valley storage) will reduce the flood magnitude. Upstream reservoirs, lakes and tanks will moderate the flood magnitudes due to their storage effects. For drainage basins having previous deposits, large ground water storage may be created, which may also contribute to the stream flow in the form of delayed runoff.

**ESTIMATION OF RUNOFF:** Runoff is that balance of rain water, which flows or runs over the natural ground surface after losses by evaporation, interception and infiltration. The yield of a catchment (usually means annual yield) is the net quantity of water available for storage, after all losses, for the purposes of water resources utilization and planning, like irrigation, water supply, etc. Maximum flood discharge. It is the discharge in times of flooding of the catchment area, i.e., when the intensity of rainfall is greatest and the condition of the catchment regarding humidity is also favorable for an appreciable runoff.

## Runoff Estimation

The runoff from rainfall may be estimated by the following methods:
(i) Empirical formulae, curves and tables
(ii) Infiltration method
(iii) Rational method
(iv) Overland flow hydrograph
(v) Unit hydrograph method

**(i) Empirical formulae:**

- C.C. Inglis' formula for Bombay—Deccan catchments (Ghat areas)

$$R = 0.85P + 30.5$$

and for plains $R = \frac{(P - 17.8)P}{254}$

- Lacey's formula for Indo- $R = \frac{P}{1 + \frac{304.8}{P}\left(\frac{F}{S}\right)}$ Gangetic plain

where $F$ is a monsoon duration factor varying between 0.5 to 1.5 and $S$ is the catchment factor depending upon the slope and varies from 0.25 for flat areas to 3.45 for hilly areas.

- A.N. Khosla's formula for north India

$$R = P - \frac{T}{3.74}$$

Formulae for some of the drainage basins in India:

- Ganga basin $R = 2.14\ P^{0.64}$
- Yamuna basin (Delhi) $R = 0.14\ P^{1.1}$
- Rihand basin (U.P.) $R = P — 1.17\ P^{0.86}$
- Chambal basin (Rajasthan) $R = 120P – 4945$
- Tawa basin (M.P.) $R = 90.5P – 4800$
- Tapti basin (Gujarat) $R = 435P – 17200$

**(ii) Infiltration Method.** By deducting the infiltration loss, i.e., the area under the infiltration curves, from the total precipitation or by the use of infiltration indices, which are already discussed. These methods are largely empirical and the derived values are applicable only when the rainfall characteristics and the initial soil moisture conditions are identical to those for which these are derived.

**(iii) Rational Method:** A rational approach is to obtain the yield of a catchment by assuming a suitable runoff coefficient.

$$\text{Yield} = CAP$$

where A = area of catchment P = precipitation C = runoff coefficient The value of the runoff coefficient C varies depending upon the soil type, vegetation geology etc. (shown in table 1)

Table 1 Runoff coefficients for various types of catchments

| *Type of catchment* | *Value of C* |
|---|---|
| Rocky and impermeable | 0.8–1.0 |
| Cultivated or covered with vegetation | 0.4–0.6 |
| Sandy soil | 0.2–0.3 |
| Rocky and impermeable | 0.8–1.0 |
| Cultivated or covered with vegetation | 0.4–0.6 |
| Sandy soil | 0.2–0.3 |

**HYDROGRAPH**: A hydrograph is a graph showing discharge (i.e., stream flow at the concentration point) versus time. The various components of a natural hydrograph are shown in Fig.3. At the beginning, there is only base flow (i.e., the ground water contribution to the stream) gradually depleting in an exponential form. After the storm commences, the initial losses like interception and infiltration are met and then the surface flow begins.

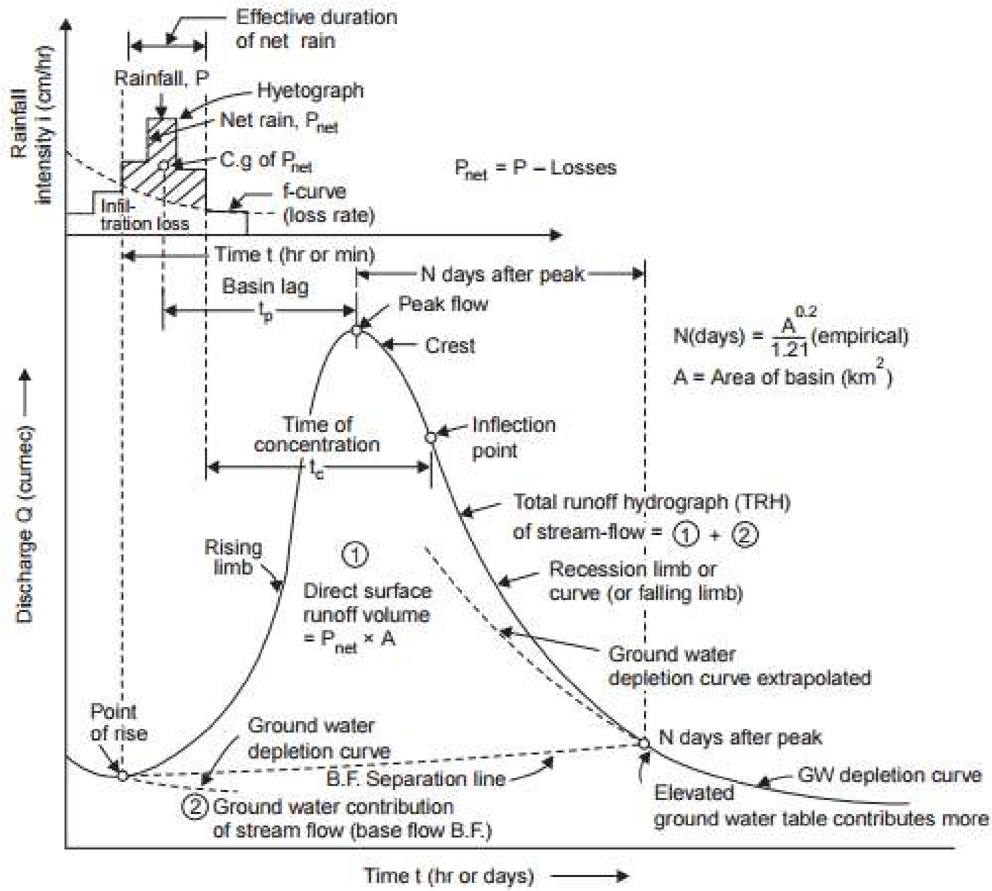



**Figure 3: Components of stream flow hydrograph**

The hydrograph gradually rises and reaches its peak value after a time tp (called lag time or basin lag) meaured from the controid of the hyetograph of net rain. Thereafter it declines and there is a change of slope at the inflection point, i.e., there has been, inflow of the rain up to this point and after this there is gradual withdrawal of catchment storage. By this time the ground water table has been built up by the infiltrating and percolating water, and now the ground water contributes more into the stream flow than at the beginning of storm, but thereafter the GWT declines and the hydrograph again goes on depleting in the exponential form called the ground water depletion curve or the recession curve. If a second storm occurs now, again the hydrograph starts rising till it reaches the new peak and then falls and the ground water recession begins, Fig. 4.

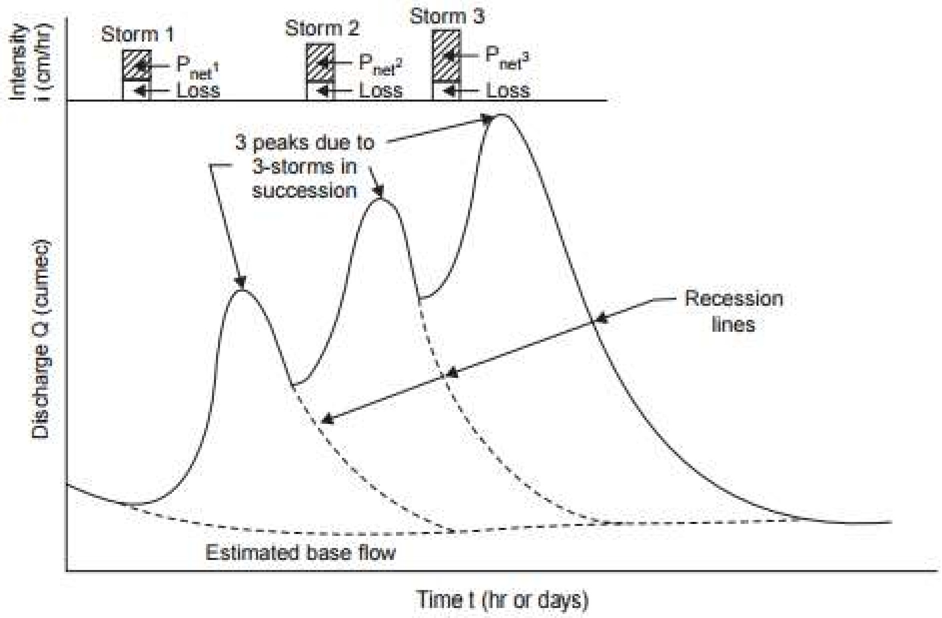



**Figure 4: Hydrograph with Multiple Peaks**

Thus, in actual streams gauged, the hydrograph may have a single peak or multiple peaks according to the complexity of storms. For flood analysis and derivation of unit hydrograph, a single peaked hydrograph is preferred. A complex hydrograph, however, can be resolved into simple hydrographs by drawing hypothetical recession lines as shown in Fig. 4.

## HYDROGRAPH SEPARATION

For the derivation of unit hydrograph, the base flow has to be separated from the total runoff hydrograph (i.e., from the hydrograph of the gauged stream flow). Some of the well-known base flow separation procedures are given below, Fig. 5.

(i) Simply by drawing a line AC tangential to both the limbs at their lower portion. This method is very simple but is approximate and can be used only for preliminary estimates.

(ii) Extending the recession curve existing prior to the occurrence of the storm up to the point D directly under the peak of the hydrograph and then drawing a straight line DE, where E is a point on the hydrograph N days after the peak, and N (in days) is given by $N=0.83A^{0.2}$

(iii) Simply by drawing a straight line AE, from the point of rise to the point E, on the hydrograph, N days after the peak. (iv) Construct a line AFG by projecting backwards the ground water recession curve after the storm, to a point F directly under the inflection point of the falling limb and sketch an arbitrary rising line from the point of rise of the hydrograph to connect with the projected base flow recession. This type of separation is preferred where the ground water storage is relatively large and reaches the stream fairly rapidly, as in lime-stone terrains.

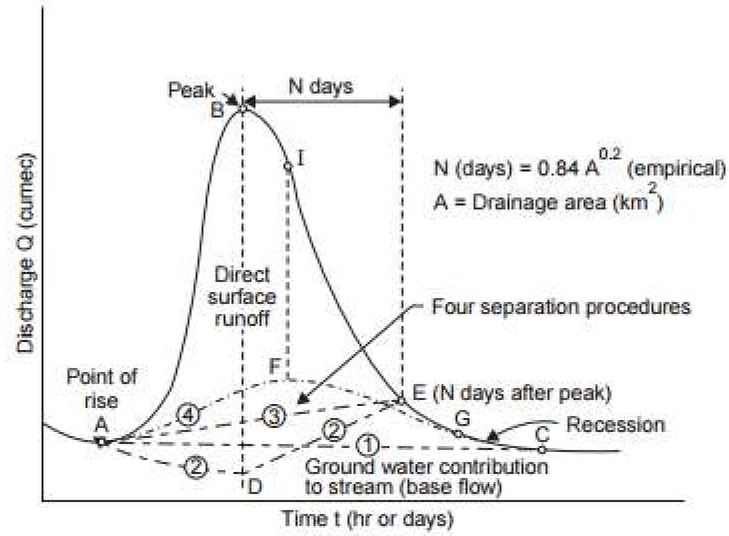



**Figure 5: Hydrograph separation**

**UNIT HYDROGRAPH:**

The unit hydrograph is defined as the hydrograph of storm runoff resulting from an isolated rainfall of some unit duration occurring uniformly over the entire area of the catchment, produces a unit volume (i.e., 1 cm) of runoff. Derivation of the unit hydrographs. The following steps are adopted to derive a unit hydrograph from an observed flood hydrograph.

(i) Select from the records isolated (single-peaked) intense storms, which occurring uniformly over the catchment have produced flood hydrographs with appreciable runoff (>1 cm, say, 8 to 16 cm). The unit period selected should be such that the excess rainfall (i.e., Pnet) occurs fairly uniformly over the entire drainage basin. Larger unit periods are required for larger basins. The unit periods may be in the range of 15-30% of the 'peak time' period, i.e., the time from the beginning of surface runoff to the peak, and the typical unit periods may be 3, 6, 8, 12 hours. (The time of concentration may be a little longer than the peak time). The unit storm is a storm of such duration that the period of surface runoff is not much less for any other storm of shorter duration.

(ii) Select a flood hydrograph, which has resulted from a unit storm chosen in item (i) above.

(iii) Separate the base flow from the total runoff (by the well-known base flow separation procedures).

(iv) From the ordinates of the total runoff hydrograph (at regular time intervals) deduct the corresponding ordinates of base flow, to obtain the ordinates of direct runoff.

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

(vi) Divide each of the ordinates of direct runoff by the net precipitation depth to obtain the ordinates of the unit hydrograph.

(vii) Plot the ordinates of the unit hydrograph against time since the beginning of direct runoff. This will give the unit hydrograph for the basin, for the duration of the unit storm (producing the flood hydrograph

**Unit hydrograph assumptions**

- Effective rainfall should be uniformly distributed over the basin, that is, if there are 'N' rain gauges spread uniformly over the basin, then all the gauges should record almost same amount of rainfall during the specified time**.**
- Effective rainfall is constant over the catchment during the unit time
- The direct runoff hydrograph for a given effective rainfall for a catchment is always the same irrespective of when it occurs. Hence, any previous rainfall event is not considered.
- The ordinates of the unit hydrograph are directly proportional to the effective rainfall hyetograph ordinate

**Unit hydrograph limitations**

- ➢ Under the natural conditions of rainfall over drainage basins, the assumptions of the unit hydrograph cannot be satisfied perfectly.
- ➢ However, when the hydrologic data used in the unit hydrograph analysis are carefully selected so that they meet the assumptions closely, the results obtained by the unit hydrograph theory have been found acceptable for all practical purposes
- ➢ In theory, the principle of unit hydrograph is applicable to a basin of any size. However, in practice, to meet the basic assumption in the derivation of the unit hydrograph as closely as possible, it is essential to use storms which are uniformly distributed over the basin and producing rainfall excess at uniform rate
- ➢ The size of the catchment is, therefore, limited although detention, valley storage, and infiltration all tend to minimize the effect of rainfall variability. The limit is generally considered to be about 5000 sq. km. beyond which the reliability of the unit hydrograph method diminishes.
- ➢ When the basin area exceeds this limit, it has to be divided into sub-basins and the unit hydrograph is developed for each sub-basin. The flood discharge at the basin outlet is then estimated by combining the subbasin floods, using flood routing procedures.

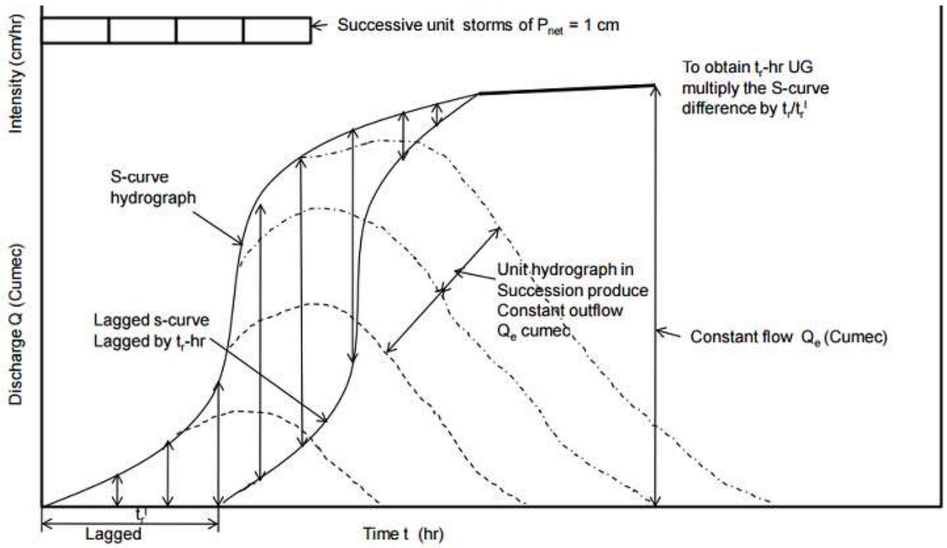
**Application of the unit hydrograph**

- ➢ The development of flood hydrographs for extreme rainfall magnitudes (for use in the design of hydraulic structures)
- ➢ Extension of flood flow records based on rainfall records
- ➢ Development of flood forecasting and warning systems based on rainfall
- ➢ Calculations of direct runoff hydrograph in catchment due to a given rainfall event (with recorded rainfall values), is easy if a unit hydrograph is readily available.

**S – CURVE METHOD**

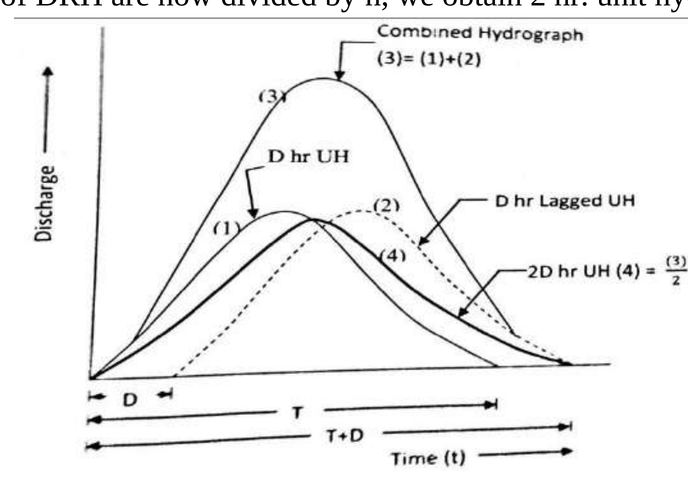
It is the hydrograph of direct surface discharge that would result from a continuous succession of unit storms producing 1cm(in.)in tr –hr .If the time base of the unit hydrograph is $T_{bs}$hr, it reaches constant outflow (Qe) at T hr, since 1 cm of net rain on the catchment is being supplied and removed every tr hour and only T/tr unit graphs are necessary to produce an S-curve and develop constant outflow given by, $Qe = (2.78 \cdot A) / t_r$

Where Qe = constant outflow (cumec) $t_r$ = duration of the unit graph (hr) A = area of the basin ($km^2$ or acres)




**SUPERPOSITION METHOD:**

If a D – h unit hydrograph is available, and it is desired to develop a unit hydrograph of nD h, where n is the integer, it is easily accomplished by superposing n unit hydrograph with each graph separated from the previous one by D h. if two-unit hydrograph is added graphically or analytically, the combined hydrograph curve (3) is obtained. It gives a direct runoff of 2 cm. Now if the ordinates of DRH are now divided by n, we obtain 2 hr. unit hydrograph



# UNIT-IV

# FLOODS

## LEARNING MATERIAL

Floods are natural phenomena which cannot be prevented. Floods have the adverse impact on human health, the environment, cultural heritage and economic activity. Flood is a temporary covering by water of land normally not covered by water. This shall include floods from rivers, mountain torrents, Mediterranean ephemeral water courses, and floods from the sea in coastal areas, and may exclude floods from sewerage systems (EFD).Floods are extreme events /actions of nature, in which the flow of water cannot be contained within the banks of rivers and/or retention areas. As a result it overflows into areas with human settlements, infrastructure facilities and economic activities.

## 1) CAUSES AND EFFECTS OF FLOODS

1) Meteorological 2) Hydrological 3) Anthropogenic

**Meteorological Cause**:

Most flood damages are the result of extreme, intense and long duration floods caused by meteorological phenomena such as: 1) Prolonged and intense rainfall 2) Cyclones 3)Typhoons, storms and tidal surges

**Hydrological:**

Flooding can also be caused by increased run off due to: 1) Ice and snow melt 2) Impermeable surfaces 3) Saturated land 4) Poor infiltration rates 5) Land erosion

**Anthropogenic Cause**:

Mankind plays a very important role in the magnitude and frequency of floods in many different ways.

1) Actually, it is the human activities in water catchments, which drastically intensify floods.
2) In this connection, human actions associated with land use change are the most important.
3) Population growth
4) Land use change, deforestation, intensive agriculture, unplanned flood control measures
5) Socio economic and development activities
6) Urbanization
7) Climate change
8) Global Warming.

### 1.1 Effects of Floods:

**a) Primary effects**

The primary effects of flooding include loss of life and damage to buildings and other structures, including bridges, sewerage systems, roadways, and canals.

Floods also frequently damage power transmission and sometimes power generation, which then has knock-on effects caused by the loss of power. This includes loss of drinking water treatment and water supply, which may result in loss of drinking water or severe water contamination. It may also cause the loss of sewage disposal facilities. Lack of clean water combined with human sewage in the flood waters raises the risk of waterborne diseases, which can include typhoid, cholera and many other diseases depending upon the location of the flood.

Damage to roads and transport infrastructure may make it difficult to mobilize aid to those affected or to provide emergency health treatment. Flood waters typically inundate farm land, making the land unworkable and preventing crops from being planted or harvested, which can lead to shortages of food both for humans and farm animals. Entire harvests for a country can be lost in extreme flood circumstances. Some tree species may not survive prolonged flooding of their root systems.

**b) Secondary and long-term effects**

Economic hardship due to a temporary decline in tourism, rebuilding costs, or food shortages leading to price increases is a common after-effect of severe flooding. The impact on those affected may cause psychological damage to those affected, in particular where deaths, serious injuries and loss of property occur.

Urban flooding can cause chronically wet houses, leading to the growth of indoor mold and resulting in adverse health effects, particularly respiratory symptoms.Urban flooding also has significant economic implications for affected neighbourhoods.

**Occurrence**

Flooding occurs along rivers, in coastal areas of the sea and along lakes. There are a lot of causes of flooding, for example: Intensive rainfall, Snowmelt, Collapse of dikes or other protective structures, Etc. The effects are always the same water and/or sediments in an unwanted place outside the watercourse, irrespective of the cause of flood.

## 2) FLOOD FREQUENCY ANALYSIS

Exact sequence of stream flow for future years cannot be predicted, probability concepts must be used to study the probable variations in flow so that the design can be completed on the basis of a calculated risk.

**Flood frequency**: flood frequency denotes the likely hood of flood being equalled or exceeded. A 10 % frequency means that the flood has 10 out of 100 chances of being equalled or exceeded.

**Recurrence interval**: recurrence interval denotes the number of year in which a flood can be expected once .it is the period of the time between the equalling and exceeding of a specific flood. This is usually denoted by a symbol T

**Return period**: it is the average recurrence interval for a certain event or flood.

Probability of occurrence (p): the probability of an event bring equalled or exceeded in any one year is the probability of its occurrence.

**The probability** (p) of occurrence of a flood having a recurrence interval of T years in any year or the probability of exceedance is

$$P = 1/T$$

The probability that is will not occur in a year, is known as probability of non- exceedance (q) and is given by

$$Q = 1-P$$

**Frequency** (f): the probability of occurrence of an event expressed as a percent is known as frequency (f).thus f =100 P =100/T

**Frequency studies for flood**

1) Partial duration series

2) Annual duration series

In the annual series, the largest flood observed in each water year only is taken. It ignores the second and lower order events of each year which may sometimes exceed many of the annual maximum. In this series consists of the values of annual maximum flood from a given catchment area, for large number of successive years. The data of the series are arranged in the decreasing order of magnitude. The probability (p) of each event being equalled to or exceeded (known as plotting position) is computed from one of the following plotting position formula:

**gumbel's method :**

P = or T =

Where c is known as gumbel's correction depends upon m/n ratio and can be found from table given below

| m/N | 1 | 0.9 | 0.8 | 0.7 | 0.6 | 0.5 | 0.4 | 0.3 | 0.2 | 0.1 | 0.08 | 0.04 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C | 1 | 0.95 | 0.88 | 0.845 | 0.78 | 0.73 | 0.66 | 0.59 | 0.52 | 0.4 | 0.38 | 0.28 |

Gumbel's extreme value distribution

It is useful for obtaining the values of flood discharges for a high recurrence interval. According to gumbel (1941) the probability of occurrence of an event equal to or larger than a value $x_0$ is given by

(1)

In the above equation, y is a dimensionless variable, given by the expression

Where p=1/T

(2)

(3)

$In_e = 2.303\log_{10}$

The value $x_T$ for the variable x with a return period T is given by

(4)

Where K= (4a)

Eq. 4 are the basic gumbel's equation which are applicable to an infinite series (where N )
in actual practice, N is finite and hence eq 4 is modified as under:

(5)

Where = standard deviation of the sample of size

$Y= a(x-x_f)$

(or)

Y =

For small samples a & to be estimated by following equation.

Let denotes the magnitude of flood with a return period of $T_r$ years then

$Y_T =$

Substitute & in $Y_T$ = then we obtain

$Y_T$ =

$Y_T$ =

= modified frequency factor (5a)

$Y_T$ = reduced variate given by eq (2)

= reduced mean, a function of sample size N, the values of which are given in table.

When N ,= 0.577,$S_n$=1.2825

$S_n$ =reduced standard deviation ,a function of sample size N, the values of which are given in table

Procedure:

1) For a given annual flood discharge data of size N, find mean ( and standard deviation (
2) Find the reduced mean for the given value of N
3) Find reduced standard deviation $S_n$ for the given value N
4) For the given value of recurrence interval T, determine $Y_T$ from equation (3)
5) Knowing $Y_T$, and $S_n$ calculate the value of $K_T$ from equation (5a)
6) Lastly compute the value of $X_T$(i.e desired flood discharge at recurrence interval T) from equation (5) in which (,$K_T$ and are known.

**3) FLOOD CONTROL METHODS (OR) FLOOD MANAGEMENT:**

The term flood control is commonly used to denote all the measures adopted to reduce damages to life and property by floods. Currently, many people prefer to use the term flood management instead of flood control as it reflects the activity more realistically. As there is always a possibility, however remote it may be, of an extremely large flood occurring in a river the complete control of the flood to a level of zero loafs is neither physically possible nor economically feasible. The flood control measures that are to use can be classified as:

1. Structural measures:

Storage and detention reservoirs

Levees (flood embankments)

Flood ways (new channels)

Channel improvement Watershed management

2. Non-structural methods:

Flood plain zoning

Flood forecast/warning

Evacuation and relocation Flood insurance

## STRUCTURAL METHODS

- **Storage Reservoirs**:

Storage reservoirs offer one of the most reliable and effective methods of flood control. Ideally, in this method, a part of the storage in the reservoir is kept apart to absorb the incoming flood. Further, the stored water is released in a controlled way over an extended time so that downstream channels do not get flooded. Figure 8.15 shows an ideal operating plan of a flood control reservoir. As most of the present-day storage reservoirs have multipurpose commitments, the manipulation of reservoir levels to satisfy many conflicting demands is a very difficult and complicated task. It so happens that many storage reservoirs while reducing the floods and flood damages do not always aim at achieving optimum benefits in the flood-control aspect. To achieve complete flood control in the entire length of the river, a large number of reservoirs at strategic locations in the catchment will be necessary.

- **Detention reservoirs:**

A detention reservoir consists of an obstruction to river with an uncontrolled outlet. These are essentially small structures and operate t reduce the flood peak by providing temporary storage and by restriction of the outflow rate. These structures are not common in India.

- **Levees:**

Levees, also known as dikes or flood embankments are earthen banks constructed parallel to the course of the river to confine it to a fixed course and limited cross-sectional width. The heights of levees will be higher than the design flood level with sufficient free board. The confinement of the river to a fixed path frees large tracts of land from inundation and consequent damage.

Levees are one of the oldest and most common methods of flood-protection works adapted to the world. Also, they are probably the Cheapest of structural flood-control measures. While the protection offered by a levee against food damage is obvious, what is not often appreciated is the potential damage in the event of a levee failure.

The levees, being earth embankments require considerable care and maintenance, In the event of being overtopped, they fail and the damage caused can be enormous. In fact, the sense of protection offered by a levee encourages economic activity along the embankment and if the levee is overtopped the loss would be more than what would have been if there were no levees. Confinement of flood banks of a river by levees to a narrower space leads to higher flood levels for a given discharge. Further, if the bed levels of the river also rise, as they do in aggrading rivers, the top of the levees have to be raised at frequent time intervals to keep up its safety margin.

The design of a levee is a major task in which costs and economic benefits have to be considered. The cross section of a levee will have to be designed like an earth dam. Regular maintenance and contingency arrangements to fight floods are absolutely necessary to keep the levees functional. Masonry structures used to confine the river in a manner similar to levees are known as flood walls. These are used to protect important structures against floods, especially where the land is at a premium.

- **Flood ways:**

Floodway's are natural channels into which a part of the flood will be diverted during high stages. A floodway can be a natural or man-made channel and its location is controlled essentially by the topography. Generally, wherever they are feasible, floodway's offer an economical alternative to other structural flood-control measures. To reduce the level of the river Jhelum at Srinagar, a supplementary channel has been constructed to act as a floodway with a capacity of 300 $m^3/s$. This channel is located 5 km upstream of Srinagar city and has its outfall in Lake Wullar. In Andhra Pradesh a floodway has been constructed to transfer a part of the flood waters of the river Budamaru to river Krishna to prevent flood damages to the urban areas lying on the downstream reaches of the river Budamaru.

- **Channel improvement:**

The works under this category involve:

1. Widening or deepening of the channel to increase the cross-sectional area.
2. Reduction of the channel roughness, by clearing of vegetation from the channel perimeter.
3. Short circuiting of meander loops by cut-off channels, leading to increased slopes.

All these three methods are essentially short-term measures and require continued maintenance.

- **Watershed management:**

Watershed management and land treatment in the catchment aims at cutting down and delaying the runoff before it gets into the river. Watershed management measures include developing the vegetative and soil cover in conjunction with land treatment words like Nalabunds, check dams, contour bunding, zing terraces etc. These measures are towards improvement of water infiltration capacity of the soil and reduction of soil erosion. These treatments because increased infiltration, greater evapotranspiration and reduction in soil erosion; all leading to moderation of the peak flows and increasing of dry weather flows. Watershed treatment is nowadays an integral part of flood management. It is believed that while small and medium floods are reduced by watershed management measures, the magnitude of extreme floods are unlikely to be affected by these measures.

**NON-STRUCTURAL METHODS**

The flood management strategy has to include the philosophy of Living with the floods. The following non-structural measures encompass this aspect.

- **Flood plain zoning:**

When the river discharges are very high, it is to be expected that the river will overflow its banks and spill into flood plains. In view of the increasing pressure of population this basic aspects of the river are disregarded and there are greater encroachment of flood plains by man leading to distress. Flood plain management identifies the flood prone areas of a river and regulates the land use to restrict the damage due to floods. The locations and extent of areas likely to be affected by floods of different return periods are identified and development plans of these areas are prepared in such a manner that the resulting damages due to floods are within acceptable limits of risk.

- **Flood forecasting and warning**

Forecasting of floods sufficiently in advance enables a warning to be given to the people likely to be affected and further enables civil authorities to take appropriate precautionary measures. It thus forms a very important and relatively inexpensive non-structural flood management measure. However, it must be realized that a flood warning is meaningful only if it is given sufficiently in advance. Further, erroneous warnings will cause the populace to lose confidence and faith in the system. Thus the dual requirements of reliability and advance notice are the essential ingredients of a flood-forecasting system.

The flood forecasting techniques can be broadly divided into three categories:

(i) Short range forecasts

(ii) Medium range forecasts

(iii) Long range forecasts.

- **Short-Range Forecasts**

In this the river stages at successive stations on a river are correlated with hydrological parameters, such as rainfall over the local area, antecedent precipitation index, and variation of the stage at the upstream base point during the travel time of a flood. This method can give advance warning of 12-40 hours for floods. The flood forecasting used for the metropolitan city of Delhi is based on this technique.

- **Medium-Range Forecasts**

In this method rainfall-runoff relationships are used to predict flood levels with warning of 2-5 days. Coaxial graphical correlations of runoff, with rainfall and other parameters like the time of the year, storm duration and antecedent wetness have been developed to a high stage of refinement by the US Weather Bureau.

- **Long-Range Forecasts:**

Using radars and meteorological satellite data, advance information about critical storm-producing weather systems, their rain potential and time of occurrence of the event are predicted well in advance.

- **Evacuation and relocation**:

Evacuation of communities along with their live stocks and other valuables in the chronic flood affected areas and relocation of them in nearby safer locations is an area specific measure of flood management. This would be considered as non-structural measure when this activity is a temporary measure confined to high floods. However, permanent shifting of communities to safer locations would be termed as structural measure. Raising the elevations of buildings and public utility installations above normal flood levels is termed as flood proofing and is sometimes adopted in coastal areas subjected to severe cyclones.

- **Flood insurance:**

Flood insurance provides a mechanism for spreading the loss over large numbers of individuals and thus modifies the impact of loss burden. Further, it helps, though indirectly, flood plain zoning, flood forecasting and disaster preparedness activities.

## 4) FLOOD ROUTING

It may be defined as the procedure where by the shape of a flood hydrograph at a particular location on the stream is determined from know or assumed flood hydrograph at some other location upstream. Flood routing is the technique in hydrology to compute the effect of storage on the shape and movement of flood wave. It is used in establishing the height of a flood peak at a downstream location. Flood routing is the technique of determining the flood hydrograph at a section of a river by utilizing the data of flood flow at one or more upstream sections. The hydrologic analysis of problems such as flood forecasting, flood protection, reservoir design and spillway design invariably include flood routing. In these applications two broad categories of routing can be recognized.

These are:

HYDRAULIC ROUTING**:**

In this we use continuity equation and moment's equation

= 0

Moment equation

HYDROLOGIC ROUTING**:**

Inflow –outflow = change in storage

I – O =

1. **Reservoir routing:**

- **Level pool routing**: In this we assume that reservoir level is horizontal.

  Where I is a f(t)

  For small interval

  Where = Average outflow

  = Average inflow

  =$S_2$-$S_1$

  $I_1$ = before time period

  $I_2$ = after time period

- **Good rich method**:

  This is same as modified plus method

  Now,

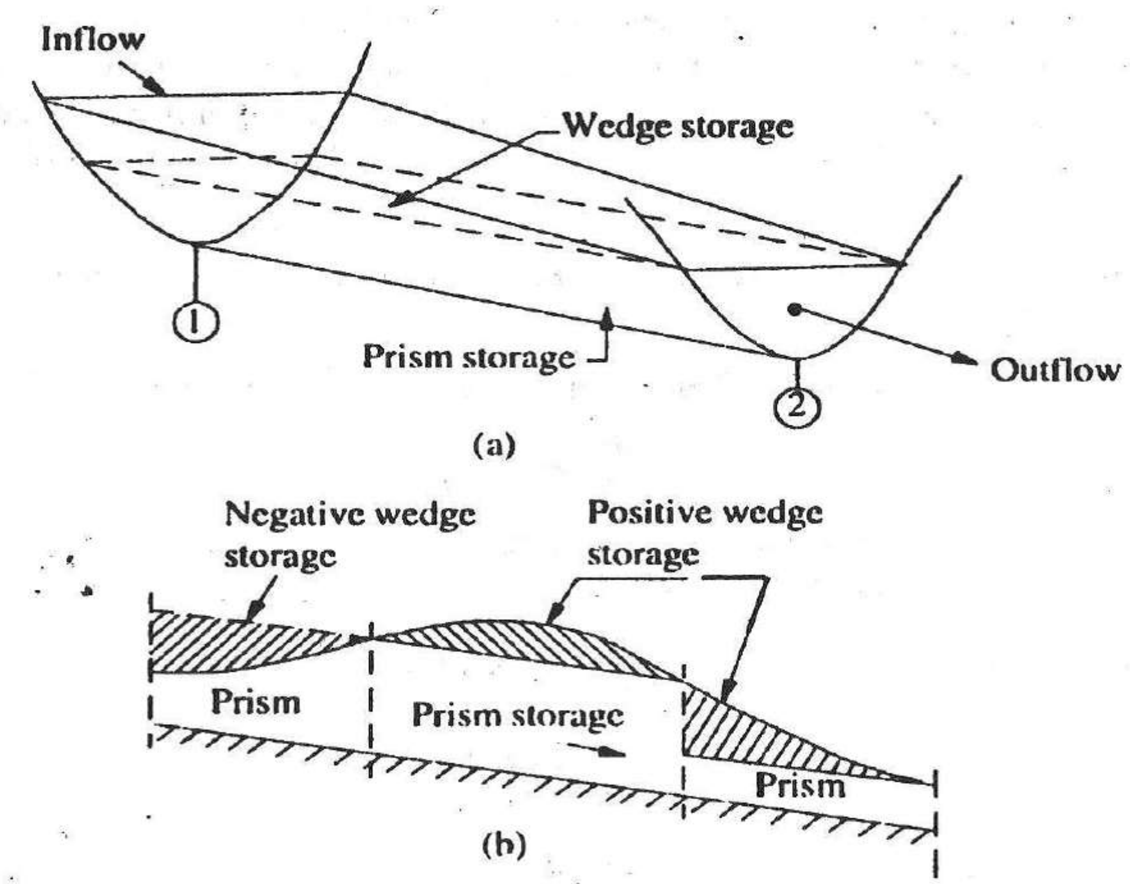
  =

**2) Channel routing**

Channel routing the storage is a function of both outflow and inflow discharges. The total volume in storage can be considered fewer than two categories as:

1. Prism storage,

2. Wedge storage.




storage in a channel reach

$$S_{\text{Prism}} = KQ$$

$$S_{\text{Wedge}} = KX(I - Q)$$

K = travel time of peak through the reach

X = weight on inflow versus outflow ($0 \le X \le 0.5$)

X = 0 ➔ Reservoir, storage depends on outflow, no wedge

X = 0.0 - 0.3 ➔ Natural stream

$S = S_p + S_w$ $S_p = f(Q)$, $S_w = f(Q)$

**Muskingum method of routing**:

$$S = KQ + KX(I - Q)$$

$$S = K[XI + (1 - X)Q]$$

Where X =0+0.05

If X= 0then S= KQ

The continuity equation is

$$\frac{I_1 + I_2}{2} - \frac{O_1 + O_2}{2} = \frac{S_2 - S_1}{\Delta \quad t} \qquad (1)$$

Now,

$= K[x(I_2-I_1) +(I-X)(Q_2-Q_1)]$ (2)

By solving eq 1 and 2 we write

$$Q_2 = C_0 I_2 + C_1 I_1 + C_2 Q_1$$

$C_0 = (- Kx + 0.5t) / k (1-X)+0.5t$

$C_1 = (Kx + 0.5t) / k (1-X)+0.5t$

$C_2 = ((K - Kx) - 0.5t) / k(1-X)+0.5t$

Subtract equation (2) from (1) we get

$Q_2 = I_2 C_0 + I_1 C_1 + Q_1 C_2$

UNIT-V

# GROUND WATER

## Types of aquifers and formations

Ground water is widely distributed under the ground and is a replenishable resource unlike other resources of the earth. The problems in Ground Water Investigation are the zones of occurrence and recharge.A water bearing geologic formation or stratum capable of transmitting water through its pores at a rate sufficient for economic extraction by wells is called **'aquifer'.**

Formations that serve as good aquifers are:

- Unconsolidated gravels, sands, alluvium
- Lake sediments, glacial deposits
- Sand stones
- Limestone's with cavities (caverns) formed by the action of acid waters
- Granites and marble with fissures and cracks, weathered gneisses and schist

A geologic formation, which can absorb water but cannot transmit significant amounts is called an **'aquiclude'**. Examples are clays, shale's, etc.

A geologic formation with no interconnected pores and hence can neither absorb nor transmit water is called an **'aquifuge'**. Examples are basalts, granites, etc.

A geologic formation of rather impervious nature, which transmits water at a slow rate compared to an aquifer (insufficient for pumping from wells) is called an **'aquitard'.** Examples are clay lenses interbedded with sand.

## CONFINED AND UNCONFINED AQUIFERS

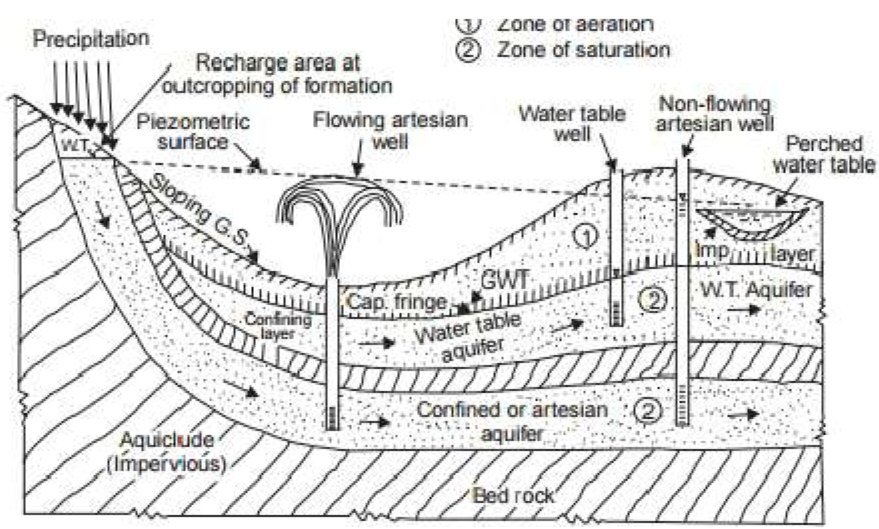



**Figure 5.1 Types of aquifers and location of wells**

If there is homogeneous porous formation extending from the ground surface up to an impervious bed underneath (Fig. 5.1), rainwater percolating down in the soil saturates the formation and builds up the ground water table (GWT). This aquifer under water table conditions is called an unconfined aquifer (water-table aquifer) and well drilled into this aquifer is called a water table well.

On the other hand, if a porous formation underneath is sandwiched between two impervious strata (aquicludes) and is recharged by a natural source (by rain water when the formation outcrops at the ground surface—recharge area, or outcrops into a river-bed or bank) at a higher elevation so that the water is under pressure in the aquifer (like pipe flow), i.e., artesian condition. Such an aquifer is called an artesian aquifer or confined aquifer. If a well is drilled into an artesian aquifer, the water level rises in the well to its initial level at the recharge source called the piezometric surface. If the piezometric surface is above the ground level at the location of the well, the well is called 'flowing artesian well' since the water flows out of the well like a spring, and if the piezometric surface is below the ground level at the well location, the well is called a non-flowing artesian well. In practice, a well can be drilled through 2-3 artesian aquifers (if multiple artesian aquifers exist at different depths below ground level). Sometimes a small band of impervious strata lying above the main ground water table (GWT) holds part of the water percolating from above. Such small water bodies of local nature can be exhausted quickly and are deceptive. The water level in them is called '**perched water table'**

**ACQUIFIER PARAMETERS**

**Specific yield** : While porosity (n) is a measure of the water bearing capacity of the formation, all this water can not be drained by gravity or by pumping from wells as a portion of water is held in the void spaces by molecular and surface tension forces. The volume of water expressed as a percentage of the total volume of the saturated aquifer, that will drain by gravity when the water table (Ground Water Table (GWT) drops due to pumping or drainage, is called the 'specific yield (Sy)' and that percentage volume of water, which will not drain by gravity is called 'specific retention (Sr )' and corresponds to 'field capacity' i.e., water holding capacity of soil (for use by plants and is an important factor for irrigation of crops). Thus, porosity = specific yield + specific retention n = Sy + Sr. Specific yield depends upon grain size, shape and distribution of pores and compaction of the formation. The values of specific yields for alluvial aquifers are in the range of 10–20% and for uniform sands about 30%

**Storage coefficient**: The volume of water given out by a unit prism of aquifer (i.e., a column of aquifer standing on a unit horizontal area) when the piezometric surface (confined aquifers) or the water table (unconfined aquifers) drops by unit depth is called the storage coefficient of the aquifer (S) and is dimensionless (fraction). It is the same as the volume of water taken into storage by a unit prism of the aquifer when the piezometric surface or water table rises by unit depth. In the case of water table (unconfined) aquifer, the storage coefficient is the same of specific yield (Sy ). Since the water is under pressure in an artesian aquifer, the storage coefficient of an artesian aquifer is attributable to the compressibility of the aquifer skeleton and expansibility of the pore water (as it comes out of the aquifer to atmospheric pressure when the well is pumped) and is given by the relationship

$$S = \gamma_w n b \left( \frac{1}{K_w} + \frac{1}{nE_s} \right)$$

S = storage coefficient (decimal)
$\gamma_w$ = specific weight of water
n = porosity of soil (decimal)
b = thickness of the confined aquifer
$K_w$ = bulk modulus of elasticity of water
$E_s$ = modulus of compressibility (elasticity) of the soil grains of the aquifer.
The storage coefficient of an artesian aquifer ranges from 0.00005 to 0.005, while for a water table aquifer S = Sy = 0.05–0.30.
**Porosity (n):** Those portions of soil, not occupied by solids; Ratio of volume of pores or interstices to total volume.
**Permeability** – an expression of movement of water in any direction

**Vertical Distribution of ground water:**

Water in the subsurface may be divided into two major zones: i) water stored in the unsaturated zone also known as vadose zone or zone of aeration and ii) water stored in the saturated zone. Soil pore spaces in the vadose zone, lying immediately below the surface. Here the small pore spaces between soil particles are filled with a mixture of water and air resulting in an area which is less than saturated zone. This zone may be divided with respect to occurrence and circulation of water into the uppermost zone of soil water, the intermediate zone and the capillary fringe, immediately above the water table. Water in this zone is called capillary water. This water moves upward from the water table by capillary action. Capillary water moves slowly in any direction. Water cannot be withdrawn from this zone for residential or commercial water supply purpose because the capillary forces hold it too tightly.

The roots of trees, plants and crops, however, can tap into this water. The capillary fringe moves upwards and downwards together with the water table due to seasonal pattern. Fig shows the distribution of water in the subsurface regions. Groundwater is water below the water table, falling entirely all rock interstices (void spaces) in the saturated zone. The water located in this zone can be withdrawn for various uses. The variation in the flow of groundwater depends on the type of rocks or other permeable material, the size of the pore spaces in the soil or rock, connectivity of pore spaces, and the configuration of the underground strata. Water Table: The upper surface of the zone of saturation is known as water table. At the water table, the water in the pores of the aquifer is at atmospheric pressure.

The hydraulic pressure at any level within a water table aquifer is equal to the depth from the water table point and is referred to as the hydraulic head. When a well is dug in a water table aquifer, the static water level in the well stands at the same elevation as the water table. The groundwater table, sometimes called the free or phreatic surface, is not a stationary surface. This water table moves up and down due to various reason. It may rises when more water is added to the saturated zone by vertical percolation, and drops down during drought periods when the stored water flows out towards springs, streams, well and other points of groundwater discharge.

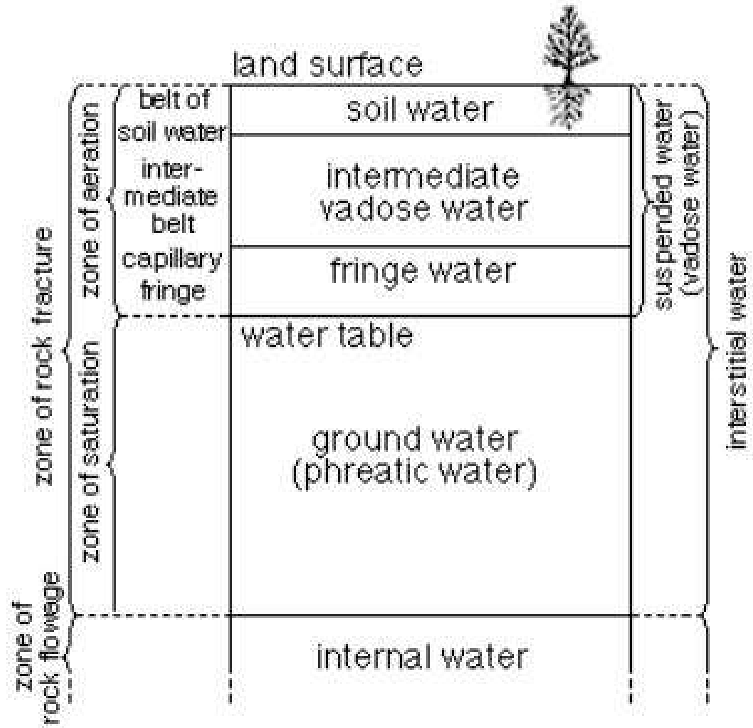



Fig: Subsurface Distribution of water

**DARCY'S LAW**

Flow of ground water except through coarse gravels and rockfills is laminar and the velocity of flow is given by Darcy's law (1856), which states that 'the velocity of flow in a porous medium is proportional to the hydraulic gradient', Fig. 5.2

$V = Ki$, ...(1)

$i = \Delta h / L$ ...(2)

$Q = AV = AKi$,..(3)

$A = Wb$, $T = Kb$

$Q = WbKi$

$Q = T\ iw$..(4)

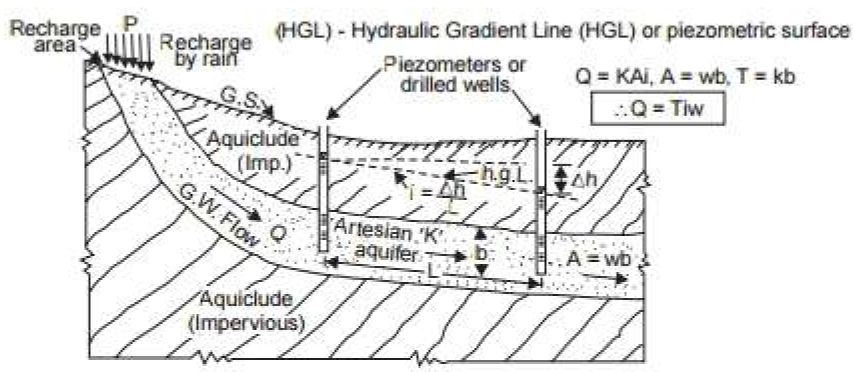



**Figure 5.2 : Flow of ground water**

where V = velocity of flow through the aquifer

K = coefficient of permeability of aquifer soil

i = hydraulic gradient = Δh/ L ,
Δh = head lost in a length of flow path L
A = cross-sectional area of the aquifer (= wb) w = width of aquifer b = thickness of aquifer
T = coefficient of transmissibility of the aquifer
Q = volume rate of flow of ground water (discharge or yield)
Darcy's law is valid for laminar flow, i.e., the Reynolds number (Re ) varies from 1 to 10, though most commonly it is less than 1

**TRANSMISSIBILITY**

It can be seen from Eq. (4) that T = Q, when i = 1 and w = 1; i.e., the transmissibility is the flow capacity of an aquifer per unit width under unit hydraulic gradient and is equal to the product of permeability times the saturated thickness of the aquifer. In a confined aquifer, T = Kb and is independent of the piezometric surface. In a water table aquifer, T = KH, where H is the saturated thickness. As the water table drops, H decreases and the transmissibility is reduced. Thus, the transmissibility of an unconfined aquifer depends upon the depth of GWT.

**WELL HYDRAULICS**

Steady radial flow into a well (Dupuit 1863, Thiem 1906)
Assuming that the well is pumped at a constant rate Q for a long time and the water levels in the observation wells have stabilised, i.e., equilibrium conditions have been reached, Fig. 5.3 (a).

From Darcy's law,
Q = K i A
Q = K (2π xy)
Q = 2 π K

$$Q = \frac{\pi K(h_2^2 - h_1^2)}{2.303 \log_{10}\left(\frac{r_2}{r_1}\right)} \quad .....6$$

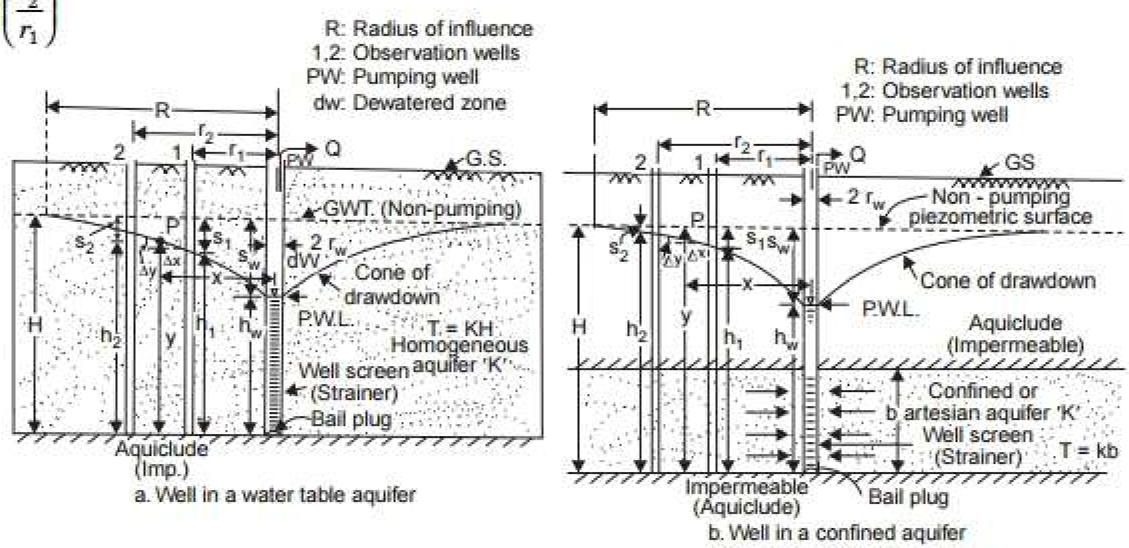



**Figure 5.3: Steady radial flow into a well**

Applying the Eq. (6) between the face of the well ($r = r_w$, $h = h_w$) and the point of zero drawdown ($r = R$, $h = H$)

$$Q = \frac{\pi K(H^2 - h^2)}{2.303 \log_{10}\left(\frac{R}{r_w}\right)}$$ ……..7

If the drawdown in the pumped well ($S_w = H - h_w$) is small

$H^2 - hw^2 = (H + hw)(H - h_w)$, $H + h_w \approx 2H$

$= 2H (H - h_w)$

$$Q = \frac{2\pi KH(H - h_w)}{2.303 \log_{10}\left(\frac{R}{r_w}\right)},$$ ……8

**(b) Artesian conditions (confined aquifer)**

If the well is pumped at constant pumping rate Q for a long time and the equilibrium conditions have reached, Fig. 5.3 (b).

From Darcy's law, $Q = K\, i\, A$

$Q = K\ (2\pi\, xb)$

$Q = 2\,\pi\, K$

$$Q = \frac{2\pi(kb)(h_2 - h_1)}{2.303 \log_{10}\left(\frac{r_2}{r_1}\right)}$$ ………9

Applying Eq. (7.9) between the face of the well ($r = r_w$, $h = h_w$) and the point of zerodrawdown ($r = R$, $h = H$), simplifying and putting $T = Kb$,

$$Q = \frac{2.72\, T(H - h_w)}{\log_{10}\left(\frac{R}{r_w}\right)}$$

**Dupuit's Equations Assumptions**:

The following assumptions are made in the derivation of the Dupuit Thiem equations:

(i) Stabilized drawdown—i.e., the pumping has been continued for a sufficiently long time at a constant rate, so that the equilibrium stage of steady flow conditions have been reached.

(ii) The aquifer is homogeneous, isotropic, of infinite areal extent and of constant thickness, i.e., constant permeability.

(iii) Complete penetration of the well (with complete screening of the aquifer thickness) with 100% well efficiency.

(iv) Flow lines are radial and horizontal and the flow is laminar, i.e., Darcy's law is applicable.

(v) The well is infinitely small with negligible storage and all the pumped water comes from the aquifer.

**SPECIFIC CAPACITY**

The specific capacity $Q / Sw$ of a well is the discharge per unit drawdown in the well and is usually expressed as lpm/m. The specific capacity is a measure of the effectiveness of the well; it decreases with the increase in the pumping rate (Q) and prolonged pumping (time, t). In Eq. (8) by putting $r_w = 15$ cm, $R = 300$ m, $KH=T$ $H–h_w = Sw$, the specific capacity

= T/1.2

## HYDRAULICS OF OPEN WELLS

Theis equation does not apply for shallow dug open wells since there is no instantaneous release of water from the aquifer, most of the water being pumped only from storage inside the well (Fig. 5.4).

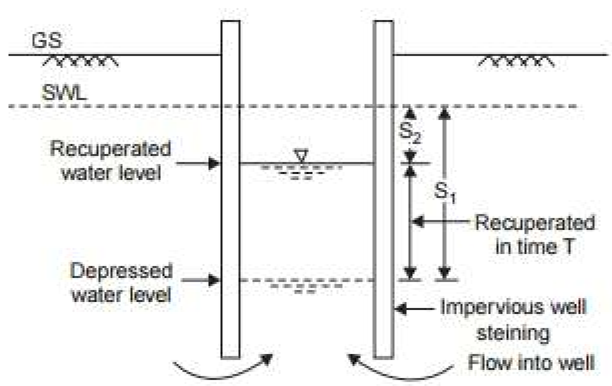



**Figure 5.4: Recuperation test in open wells**

In alluvial soil, if the water is pumped at a high rate the depression head (static water level–water level inside the well during pumping) will increase, which may cause excess gradients resulting in loosening of sand particles (quick sand phenomenon). This limiting head is called 'critical depression head'. The 'safe working depression head' is usually one-third of the critical head and the yield under this head is called the maximum safe yield of the well.

### Yield Tests

The following tests may be performed to get an idea of the probable yield of the well: (a) Pumping test (b) Recuperation test

(b) Recuperation Test. In the recuperation test, the water level in the well is depressed by an amount less than the safe working head for the subsoil. The pumping is stopped and the water level is allowed to rise or recuperate. The depth of recuperation in a known time is noted from which the yield of the well may be calculated as follows (Fig. 5.4).

Let the water level inside the well rise from s1 to s2 (measured below static water level, swl) in time T. If s is the head at any time t, from Darcy's law

Q = Kai

if a head s is lost in a length L of seepage path

Q = KA

Q = CAs

where the constant C = K/ L and has dimensions of $T^{-1}$.

If in a time dt, the water level rises by an amount ds Q dt = – A ds

the –ve sign indicates that the head decreases as the time increases. Putting Q = CAs

CAs dt = – A ds

C  T dt  =

C =

Assuming the flow is entirely from the bottom (impervious steining of masonry), the yield of thewell

Q = CAH

From this equation ,if Q = C when A = 1, H = 1, i.e., the specific yield of the soil is the discharge per unit area under a unit depression head and has dimension of $T^{-1}$ (1/time) and the usual values are

C = 0.25 $hr^{-1}$ for clayey soil

C = 0.50 $hr^{-1}$ for fine sand

C = 1.00 $hr^{-1}$ for coarse sand

# UNIT-VI

# IRRIGATION

### LEARNING MATERIAL

**Introduction**:

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

**Necessity of Irrigation**

Necessity of irrigation is generally because of the following situations.

1. Rainfall is less than the water requirement of the plants.
2. Rainfall is sufficient, but the spatial distribution of rainfall is not as per requirement.
3. Rainfall is sufficient and the spatial distribution is also good, but the temporal distribution is not as per requirement.
4. Advanced scientific development (HYV-High yield variety).

Increase in agricultural production and productivity depends, to a large extent, on the availability of water. Hence, the importance of irrigation is however, the availability of irrigation facilities which is highly inadequate in India. For example, in 1950-51, gross irrigated area as percentage of gross cropped area was only 17%. Even now 60% of gross cropped area depends on rain. That is why Indian agriculture is called a gamble in the monsoon.

**Importance of Irrigation**

Control of Drought and Famines Insufficient, uncertain and irregular rain causes uncertainty in agriculture. The period of rain is restricted to only four months in a year, June to September, when monsoon arrives. The remaining eight months are dry. There is some rainfall during the months of December and January in some parts of the country. Even during monsoon, the rainfall is scanty and undependable in many parts of the country.

Sometimes the monsoon delayed considerably while sometimes they cease prematurely. This pushes large areas of the country into drought conditions. With the help of irrigation, droughts and famines can be effectively controlled.

**1. Higher productivity on irrigated land:**

Productivity on irrigated land is considerably more than the productivity on un-irrigated land.

**2. Multiple cropping possible:**

Since India has a tropical and sub-tropical climate, it has potentialities to grow crops on a year round basis. However, since 80% of the annual rainfall is received in less than four months, multiple cropping is generally not possible. Provision of irrigation facilities can make possible the growing of two or three crops in a year in most areas of the country. This will considerably enhance agriculture production and productivity.

**3. Role in new agricultural strategy:**

The successful implementation of the High Yielding Programme enhances agricultural production in a great intent.

**4. Bringing more land under cultivation:**

Total reporting area for land utilization statistics was 306.05 million hectares in 1999-2000. of this 19.44 million hectares was current fallow land. Current fallowed include lands which are lying fallow for less than one year other than current fallows includes land lying un-ploughed for one to five years. Cultivable waste land comprises another 13.83 million hectares. Cultivation on all such lands is impossible in some cases while in others it requires substantial capital investment to make land fit for cultivation. Provision of irrigation facilities can make some portion of this land cultivable.

**5. Reduces instability in output levels:**

Irrigation helps in stabilizing the output and yield levels. It also plays a protective role during drought years. Since, both income and employment are positively and closely related to output, prevention of fall in output during drought is an important instrument for achieving stability of income and employment in the countryside. Irrigation has enabled many states to acquire 'partial immunity' from drought.

**6. Indirect benefits of irrigation:**

Irrigation confers indirect benefits through increased agricultural production. Employment potential of irrigated lands, increase production, helps in developing allied activities means of water transport etc. are improve income of government from agriculture. Availability of regular water supply will increase the income of farmers imparting a sense of security and stability in agriculture.

**Benefits of Irrigation**

1. Increase in Crop Yield
2. Protection from femine
3. Cultivation of superior crops
4. Elimination of mixed cropping:
5. Economic development
6. Hydro power generation
7. Domestic and industrial water supply:

**Advantages of Irrigation**

Some of the advantages of irrigation are as follows.

- Increase of food production.
- Modify soil or climate environment – leaching.
- Lessen risk of catastrophic damage caused by drought.
- Increase income & national cash flow.
- Increase labor employment.
- Increase standard of living.
- Increase value of land.
- National security thus self sufficiency.
- Improve communication and navigation facilities.

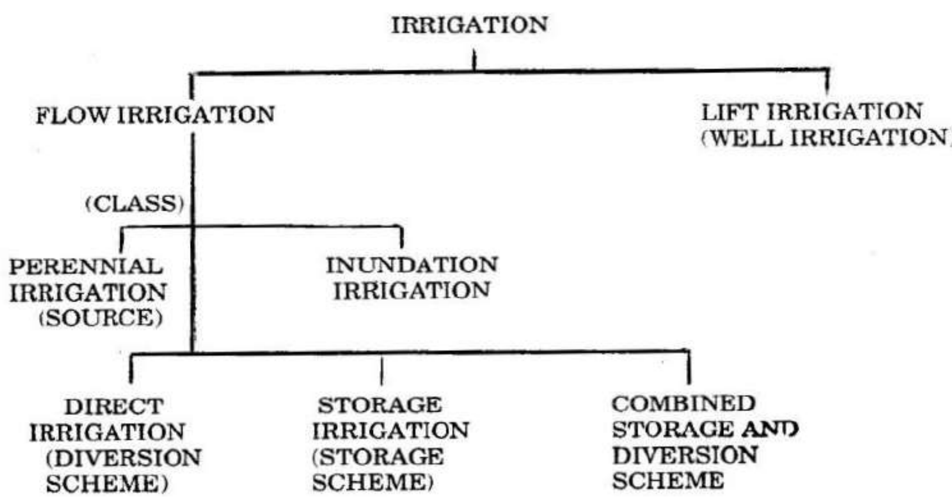
- Domestic and industrial water supply.
- Improve ground water storage.
- Generation of hydro-electric power.

**Disadvantages of Irrigation**

The following are the disadvantages of irrigation.

- Water logging.
- Salinity and alkalinity of land.
- Ill aeration of soil.
- Pollution of underground water.
- Results in colder and damper climate causing outbreak of diseases like malaria.

**Types or Systems of Irrigation**:

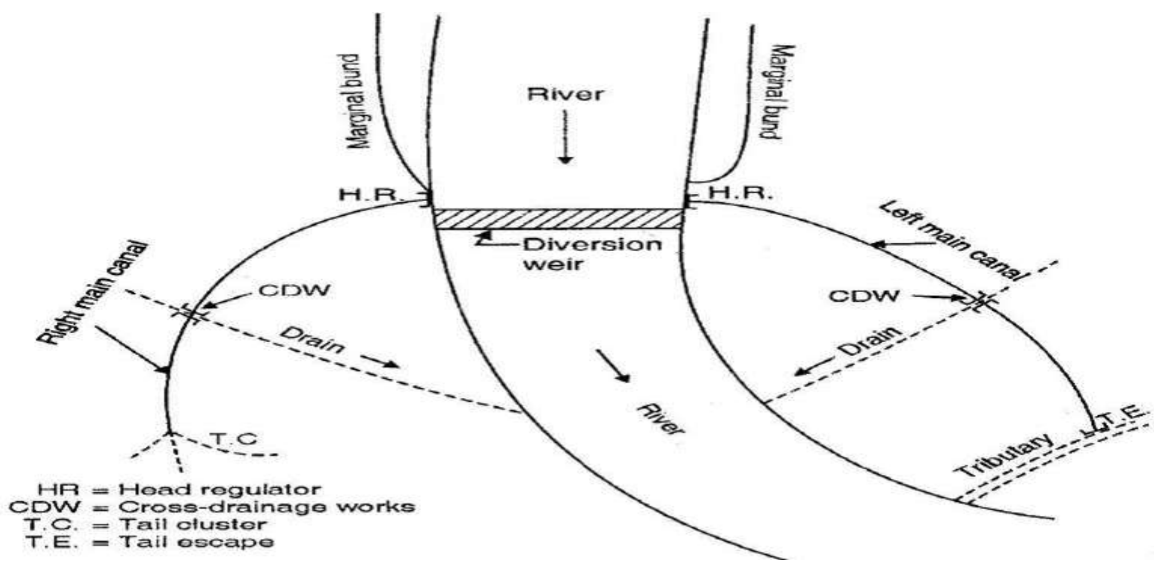



**Lift Irrigation**: It is that system of irrigation in which irrigation water is available at a level lower than that of the land to be irrigated and hence water is lifted by pumps or other mechanism (Hydraulic ram and siphon action) and then conveyed to agriculture fields by gravity flow. Irrigation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

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

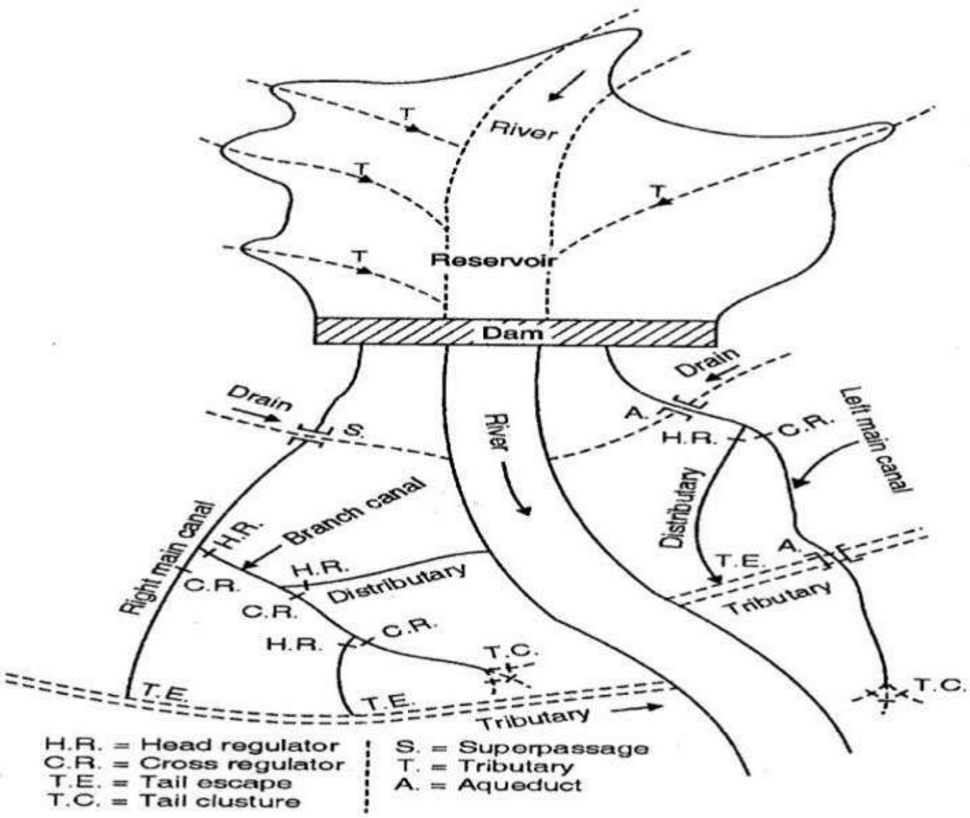
**Perennial Irrigation**: It is that system of irrigation in which irrigation water is supplied as per the crop requirements at regular intervals throughout the crop period. The source of irrigation water may be a perennial river, stored water in reservoirs or ground water drawn from open wells or bore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

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

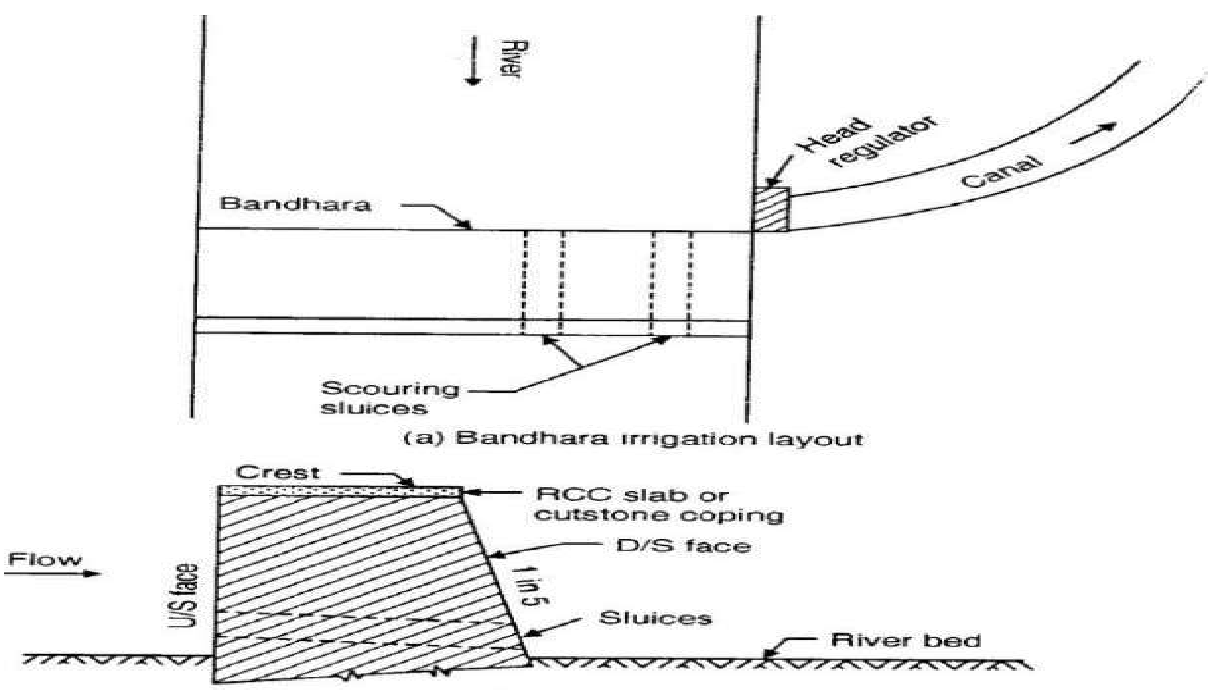



**Storage Irrigation**:

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




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

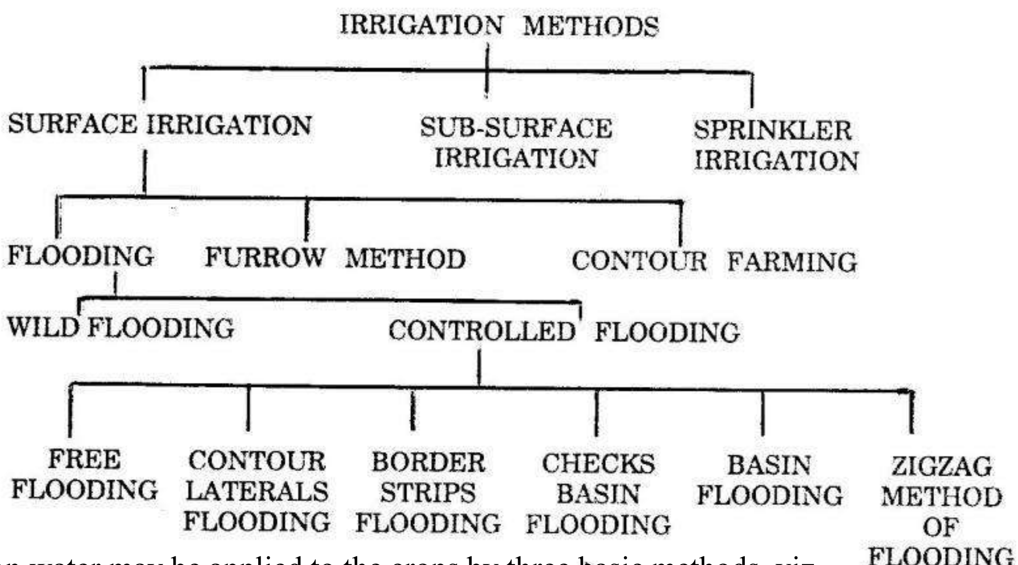



(b) Section of Bandhara

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

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

**Methods of Application of Irrigation water**:




Irrigation water may be applied to the crops by three basic methods, viz.

a. Surface irrigation methods
b. Subsurface irrigation methods
c. Sprinkler irrigation

Good irrigation methods result in increased yield, conservation of soil productivity and economic utilization of water. Over irrigation results in soil erosion, water logging, salt accumulation,

nutrient leeching etc. The overall objective of an irrigation method is to see that the required amount of moisture is available in the root zone of the crops.
The objectives or reasons for adopting any irrigation method for applying water to fields are as follows.

1. For light irrigation uniform water distribution with a small depth of application, as small as cm should be possible

2. For heavy irrigation uniform water depth application of 15 to 20 cm should be possible.
3. Large concentrated flow should be possible for reducing conveyance losses and labour costs.
4. Mechanical farming should be facilitated.

**a. Surface irrigation method**: In this method the irrigation water is applied by spreading water as a sheet or as a small stream on the land to be irrigated.

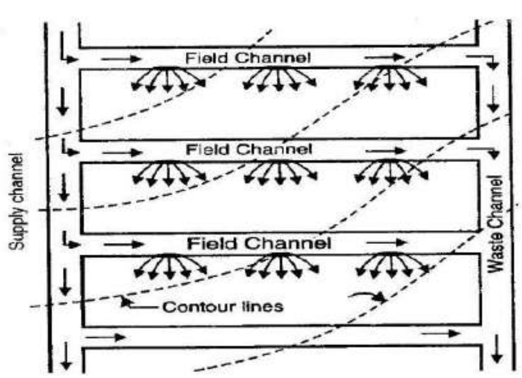
Various surface irrigation methods that are practiced are listed as follows.

**1. Wild flooding**: In this method water is applied by spreading water over the land to be irrigated without any preparation. There is no restriction for the movement of water. It follows the natural slope of the land. The water may be applied to the land directly from a natural stream during season of high flow as in inundation irrigation. This method is suitable for flat and smooth land but involves wastage of water and hence it can be practiced where water is abundant and inexpensive.

**2. Controlled flooding**: In this method water is applied by spreading it over the land to be irrigated with proper control over the flow of water and as well as the quantity of water to be applied. In such methods prior land preparation is essential.

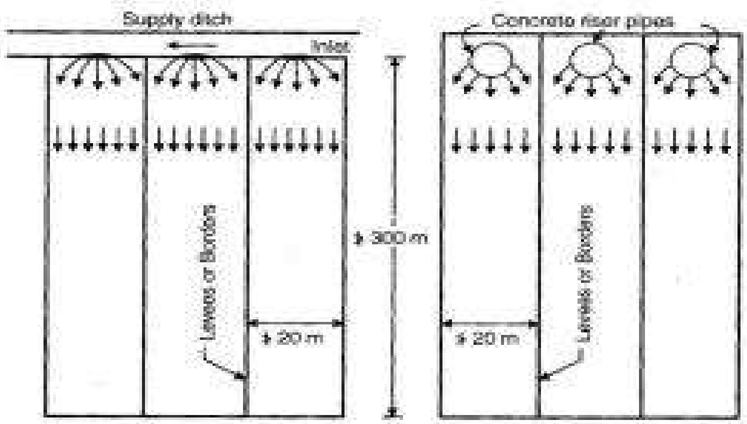
Various controlled flooding methods are as follows.

**i) Free flooding**: This method is also known as irrigation by plots. Here the field is divided into a number of small sized plots which are practically level. Water is admitted at the higher end of the plots and the water supply is cut off as soon as the water reaches the lower end of the plots.




(a) Field channels at right angles to the sides of the field

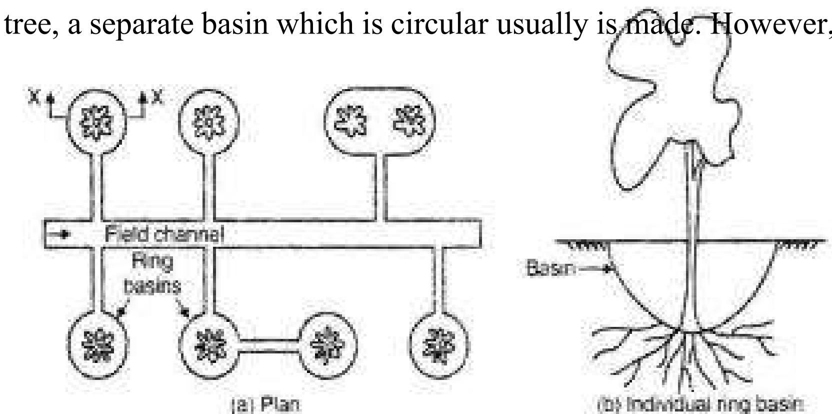
**ii) Border strip method**: In this method the land to be irrigated is divided into a series of long narrow strips separated from each other by levees (Earthen bunds) or borders. The width of the strips varies between 10 to 20 m and the length of the strip varies between 60 to 300 m depending upon the nature of the soil and rate of water supply.




The strip of the land has no cross slope and has uniform gentle slope in the longitudinal direction. This method is suitable for forage crops requiring least labour. Mechanized farming can be adopted in this method.

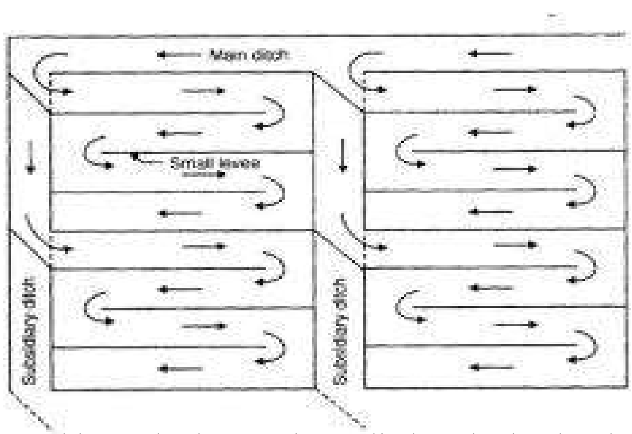
**iii) Checks or Levees**: In this method a comparatively large stream of water discharged into a relatively level plot surrounded by check or levees or low rise bunds. The checks are usually 30 cm high. The checks may be temporary for a single crop season or semi permanent for repeated used as in case of paddy fields. The size of the plots depends upon the discharge of water and porosity of the soil. The usual size of the plot varies between 0.04 hectares to 0.05 hectares.

**iv) Basin flooding**: This method of irrigation is adopted for irrigating orchards (enclosures of fruit trees). For each tree, a separate basin which is circular usually is made. However, in some cases

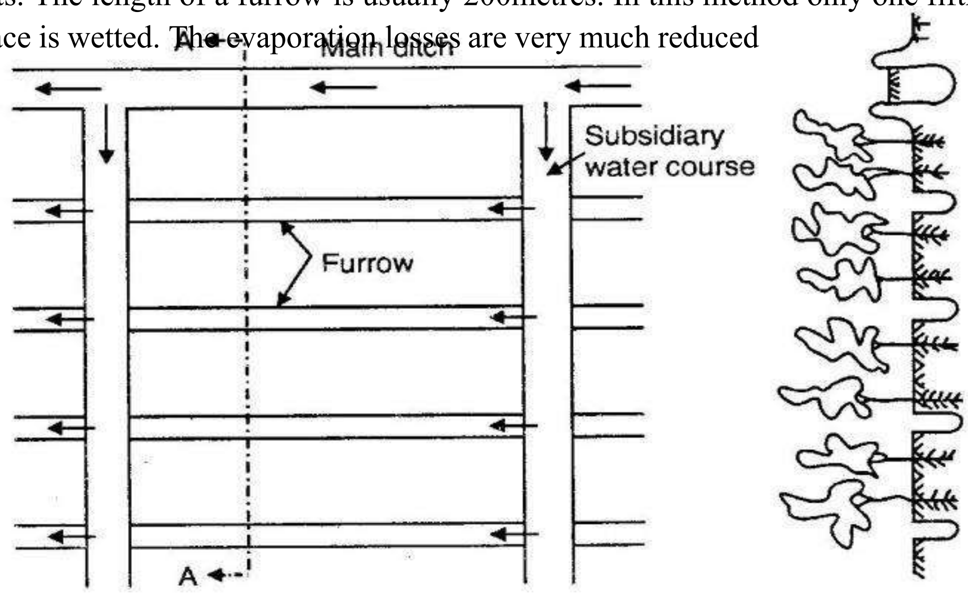


basins are made large to include two or more trees in each basin. Water is supplied through a separate field channel, but in some cases the basins are inter connected.

**v) Zigzag flooding**: This is a special method of flooding where the water takes a circuitous route before reaching the dead end of each plot. Each plot is subdivided with help of low bunds. This method is adopted in loose soils to prevent erosion at the higher ends.

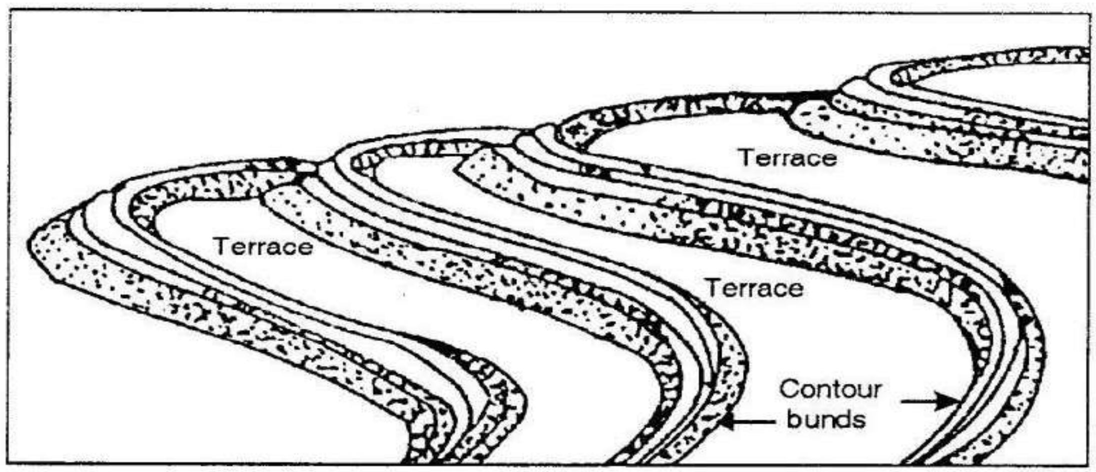



**vi) Furrow method:** In this method water is applied to the land to be irrigated by a series of long narrow field channels called furrows. A furrow is a narrow ditch 75 to 125 mm deep excavated between rows of plants to carry irrigation water. The spacing of furrows depends upon the spacing of the plants. The length of a furrow is usually 200metres. In this method only one fifth to one half of the surface is wetted. The evaporation losses are very much reduced

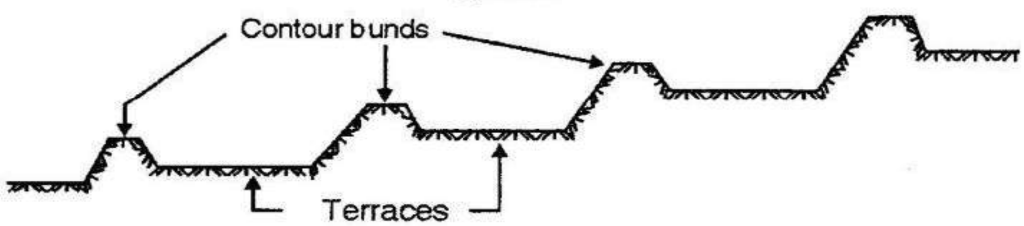


**vii) Contour farming**:

Contour farming is practiced in hilly regions where, the land to be irrigated has a steep slope. Here the land is divided into a series of strips usually known as terraces or benches which are aligned to follow the contour of the sloping area. This method also helps in controlling soil erosion




(a) Plan




(b) Section

**b. Sub Surface Irrigation**: This method consists of supplying water directly to the route zone through ditches at a slow rate which are 0.5 m to 1 m deep and 25 to 50 cm wide. The ditches are spaced 50 to 100 m apart. Water seeps into the ground and is available to the crop in the form of a capillary fringe. Proper drainage of excess water is permitted either naturally or providing suitable drainage works, thereby preventing water logging in fields. The favourable conditions to practice subsurface conditions are,

1. Availability of imperious subsoil at a reasonable depth (2 to 3m).
2. Water table is present at shallow depth.
3. Availability of moderate slope.
4. Availability of good quality irrigation water.

With the above favourable conditions and necessary precautions it is possible to achieve higher yields at low cost.

**C. Sprinkler Irrigation**: This method consists of applying water in the form of a fine spray as similar to rain fall. Stationary over head perforated pipes or fixed nozzle pipes installations were earlier used. However, with the introduction of light weight pipes and quick couplers, portable sprinkler systems with rotating nozzle have been developed and hence these have become popular. A pump usually lifts water from the source and supplies it through the distribution system and then through the sprinkler nozzle or sprinkler head mounted on the riser pipes. About, 80 % irrigation efficiency is possible with sprinkler irrigation, particularly in semi arid and humid regions. The efficiency of this system decreases by 5 % for every 7.5 km/hour of increase in wind velocity.

Note: Irrigation efficiency ($\eta$) is given as,

$$\eta = \left(\frac{w_s}{w_p} \times 100\right)\%$$

Where

$w_s$ - represents amount of irrigation water stored in root zone

$w_p$ - Amount of water pumped or supplied into the system.

Sprinkler irrigation method is adopted in regions where, surface irrigation methods cannot be used due to the following reasons.

1. The soil is too pervious or impervious.
2. The nature of the soil is too erosive.
3. The topography is not uniform or very steep.
4. The land is not suitable for surface irrigation method.

Advantages:

1. Soil erosion is well controlled by adjusting the discharge through the nozzle.
2. Uniform water application is possible.
3. In case of seedlings and young plants, light irrigation is possible easily.
4. Much land preparation is not essential and hence labour cost is reduced.
5. More land for cropping is available since borders and ditches are not required.
6. Small amounts of irrigation water in water scarcity regions can be effectively utilized.

Disadvantages:

1. Wind will distort the sprinkling pattern.
2. Constant water supply under pressure is required for economic use of equipment.
3. Irrigation water must be free from silt, sand and impurities.
4. Initial investment is high.
5. Energy requirement for pumping water is high.
6. Heavy soil with poor infiltration (clayey soil) cannot be irrigated efficiently.

**Drip or trickle irrigation**: This is the latest irrigation method, which is becoming popular in water scarcity areas and water with salt problems. In this method, small diameter plastic or PVC pipes with drip nozzles commonly called emitters or drippers are adopted to deliver water to the land surface near the base of the plant. Water can be applied at a rate varying between 2 to 10 liters per hour to keep the soil moisture within the desired range for plant growth.The main components of a drip irrigation system are a pumping unit, main pipelines, sub main pipe lines, lateral pipelines, emitters, pressure gauges etc.,

**Water logging and drainage:**

When the conditions are so created that the crop root-zone gets deprived of proper aeration due to the presence of excessive moisture or water content, the tract is said to be waterlogged. To create such conditions it is not always necessary that underground table should enter the crop root-zone.

Sometimes even if water table is below the root-zone depth the capillary water zone may extend in the root-zone depth and makes the air circulation impossible by filling the pores in the soil.

**Causes of Water logging:**

After studying the phenomenon of water logging in the light of hydrologic equation main factors which help in raising the water-table may be recognized correctly.

**They are:**

i. Inadequate drainage of over-land run-off increases the rate of percolation and in turn helps in raising the water table.

ii. The water from rivers may infiltrate into the soil.

iii. Seepage of water from earthen canals also adds significant quantity of water to the underground reservoir continuously.

iv. Sometimes subsoil does not permit free flow of subsoil water which may accentuate the process of raising the water table.

v. Irrigation water is used to flood the fields. If it is used in excess it may help appreciably in raising the water table. Good drainage facility is very essential.

**Effects of Water logging:**

**The water logging affects the land in various ways. The various after effects are the following:**

***1. Creation of Anaerobic Condition in the Crop Root-Zone:***

When the aeration of the soil is satisfactory bacteriological activities produce the required nitrates from the nitrogenous compounds present in the soil. It helps the crop growth. Excessive moisture content creates anaerobic condition in the soil. The plant roots do not get the required nourishing food or nutrients. As a result crop growth is badly affected.

***2. Growth of Water Loving Wild Plants:***

When the soil is waterlogged water loving wild plant life grows abundantly. The growth of wild plants totally prevents the growth of useful crops.

***3. Impossibility of Tillage Operations:***

Waterlogged fields cannot be tilled properly. The reason is that the soil contains excessive moisture content and it does not give proper tilt.

***4. Accumulation of Harmful Salts:***

The upward water movement brings the toxic salts in the crop root-zone. Excess accumulation of these salts may turn the soil alkaline. It may hamper the crop growth.

***5. Lowering of Soil Temperature:***

The presence of excessive moisture content lowers the temperature of the soil. In low temperature the bacteriological activities are retarded which affects the crop growth badly.

***6. Reduction in Time of Maturity:***

Untimely maturity of the cr.ops is the characteristic of waterlogged lands. Due to this shortening of crop period the crop yield is reduced considerably

**Principal crops and crop seasons**

**Crops can be classified in the following ways:**

**1. Agricultural classification**

This consists of the following types of crops.

a) Field crops: such as wheat, rice, maize, barley, oats, great millet, spiked millet, gram, pulses etc.
b) Commercial crops: such as sugar cane, cotton tobacco, hemp, sugar beet etc.
c) Oil seed crops: such as mustard, ground nut sesame, linseed, caster etc.
d) horticulture crop: consisting of various fruit crops, various vegetable crop and flower crop
e) Plantation crops: such as tea, coffee, cocoa, coconut, rubber etc.
f) Forage crop: such as fodder, grass etc.
g) miscellaneous crops: such as medicinal crops, aromatic crops, sericulture crop, condiments and spices

**2. Classification based on crop seasons**

Based on crop season, crops are classified as follows.

a) Rabi crops or winter crops: These crops are sown in autumn (or October) and are harvested in spring (or March). Various crops that fall under this category are: gram, wheat, barley, peas, mustard, tobacco, linseed, potato etc.

b) Kharif crops or monsoon crops: These crops are sown by the beginning of the southwest monsoon and are harvested in autumn. These consist of rice, maize, spiked millet, great millet, pulses, ground nut etc.

c) Perennial crops: These are the crops that require water for irrigation throughout the year. Examples of perennial crops are: sugar cane, fruits, vegetables etc.,

3. **Classification based on irrigation requirements:** Crops can be classified as

(i) dry crop :in this type do not require water for irrigation; only rain water is sufficient for their growth

(ii) Wet crops: In this type which cannot grow without irrigation

(iii) Garden crops: require irrigation throughout year

**Crop rotation:**

In a given plot of land different crops are grown one after the other in service in different seasons such a practice is known as crop rotation. Crop rotation is necessary for the following reasons.

1. By growing the same crop in the field continuously diseases and pests cannot be controlled easily. By crop rotation such a hazard can be minimized.
2. Different crops have different depths of root zones hence the nutrients at different levels can be well utilized by crop rotation.
3. By growing grams which are leguminous (they absorb more nitrogen) a plant, the nitrogen content is soil is increased and becomes beneficial for subsequent crops.

The usual crop rotations adopted in India are,

a. Wheat-Millet-gram
b. Paddy-gram
c. Cotton-wheat-gram
d. Cotton-wheat-sugarcane
e. Cotton-millet-gram

**FUNCTIONS OF IRRIGATION WATER**

The functions of soil moisture in plant growth are very important. Water and nutrients are the two most important requirements of the crop .following are the main functions of irrigation water:

1) It acts as a solvent for the nutrients. Water forms the solution of the nutrients, and this solution is absorbed by the roots. Thus, water acts as the nutrient carrier.
2) The irrigation water supplies moisture which is essential for the life of bacteria beneficial to the plant growth.
3) Irrigation water supplies moisture which essential for the chemical action within the plant leading to its growth.
4) Some salts present in soil react to produce nourishing food products only in the presence of water.
5) Water cools the soil and the atmosphere, and thus makes more favorable environment for healthy plant growth.
6) Irrigation water with controlled supplies washes out or dilutes salts in the soil.
7) It reduces the hazard of soil piping
8) It softens the tillage pans.

**QUALITY OF IRRIGATION WATER**

Good irrigation water is the one which performs the above mentioned functions without any side effects which retard the plant growth. Irrigation water may be said to be unsatisfactory for its intended use if it contains

1) Chemicals toxic to plants or the persons using plant as food,
2) Chemicals which react with the soil to produce unsatisfactory moisture characteristics
3) Bacteria injurious to persons or animals eating plants irrigated with the water.

Impurities in irrigation water:

1. Concentration of sediments in water
2. Total concentration of soluble salts
3. Proportion of sodium ions to other cations
4. Bacterial concentration

Classification of irrigation water:

1. Classification based on Total concentration of soluble salts

   $C_s = CQ/Q-(C_u-P_{eff})$

   Where
   C= concentration of salt in irrigation water
   Q = Total quantity of water
   $C_u$=Consumptive use of water

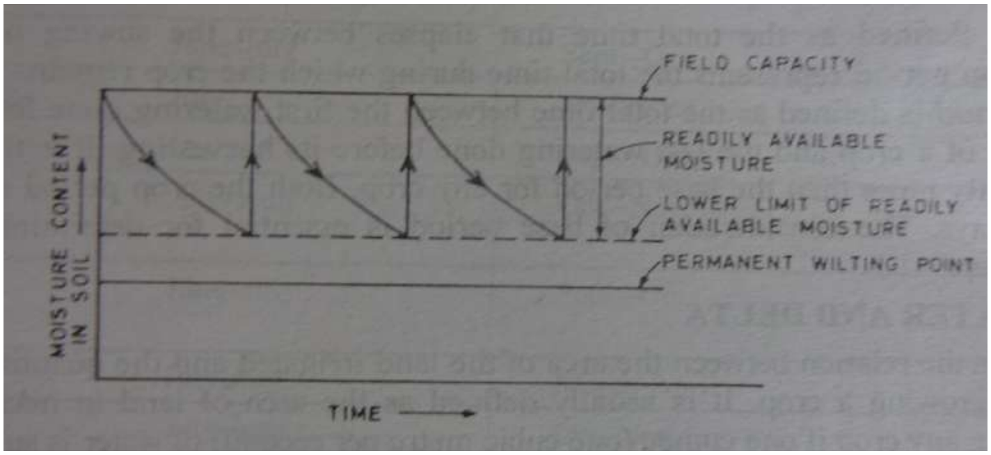
   $P_{eff}$= Useful rainfall
2. Classification based on sodium concentration

   Percentage sodium = ESP = $100Na^+/Ca^{++}+Mg^{++}+Na^++K^+$

   sodium absorption ratio (SAR) = $Na^+/(Ca^{++}+Mg^{++}/2)$
3. Classification based on electrical conductivity(EC)

**Depth and frequency of irrigation:**

The amount of irrigation water applied should be such that the moisture content is raised to the field capacity. The moisture content in soil reduces due to consumptive use by plants. However, the moisture content should not be allowed to fall below lower limit of readily available moisture. When the moisture content reaches the lower limit of readily available moisture, water should be supplied by irrigation method to raise it to the field capacity or optimum moisture content.




The minimum depth of water to be applied during irrigation to maintain field capacity is given by,

Dw= Ws/wxd(field capacity – weight of moisture content held by soil at lower limit of readily available moisture per unit weight of dry soil)

The frequency of irrigation is given by,

Fw= Dw/Cu (days)

Where Cu represents the consumptive use of water by crops expressed as depth of water in cm/day

Time required irrigating a certain area

$T = A.d_w/q$ seconds

A= area

$d_w$= depth of water

**Duty of Water:**

Duty represents the irrigating capacity of a unit of water.

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

Ex: If 5100 hectares of land can be irrigated for growing a crop with a available discharge of 3 cumec continuously for the entire crop period, then the duty of water for this crop = 5100/3 = 1700 hectares/cumec.

Different crops require different amounts of water before their harvesting and hence duty of water varies with the crops. Duty of water is said to be high, if the area of land irrigated per cumic is large.

Duty of water can be expressed in different ways as follows.

1. By the number of hectares that one cumec of water can irrigate during the base period.
2. By the total depth of water (Delta) applied
3. By the numbers of hectares can be irrigated by one million $m^3$ of stored water
4. By the number of hectare-meters of water expended (used) per hectare of land irrigated.

As in case 1, the duty expressed is called flow duty of water and commonly used in canal irrigation.

As in case 2, duty of water is suitable for tank irrigation because the area that can be irrigated is less and amount of water stored in tanks is less. It is also known as quantity duty or storage duty.

Case 3 is applicable for large storage volumes available in multi-purpose reservoirs.
The duty of water varies with the place of its measurement due to losses such as percolation; evaporation etc. The quantity of water delivered to the fields is different to the quantity of water leaving the head of the canal.

**Factors affecting duty**:

The duty water of a canal system depends on the following factors.

1. Methods and systems of irrigation: Perennial system of irrigation has more duty of water than inundation irrigation system the loss of water by deep percolation is minimum in the first case. In flow irrigation by channels the duty is less as conveyance losses are more. In lift irrigation the lands to be irrigated are very near to the source of water than any surface irrigation method.
2. Type of Crop: Different crops require varying quantities of water and therefore duty of water varies from crop to crop. Crops requiring large quantity of water have lower duty than crops requiring lesser quantity of water.
3. Climate conditions of the area: The climatic condition such as wind, temperature, humidity and rainfall affect the duty of water. At high temperature losses due to evaporation and transpiration are more and hence duty decreases. At higher wind velocity, rate of evaporation and transpiration are more thereby, duty decreased. But in

humid conditions evaporations and transpiration losses are minimum, there by duty increases.

4. Canal conditions: In earthen canals, seepage losses are high resulting low duty. If canal is lined, losses are minimum and hence duty increases. If the length of the canal is very large before it reaches the irrigation fields (as in hilly areas) the duty of water decreases.
5. Quality of Water: If water contains harmful salts and alkali contents, then more water is to be applied liberally to leach out these salts and in turn duty of water decreases.
6. Characteristics of soil and subsoil in field and canals: If the soil and subsoil of the field and canals are made of coarse grained soils the seepage and percolation losses are more and hence the duty of water decreases.
7. Topography of land: If the area to be irrigated is level, uniform water application is possible which will result in economical views and hence duty of water increases.
8. Method of Cultivation: If the land is properly tilled up to the required depth and soil is made loose before irrigation, water retaining capacity of soil increases. This reduces the number of watering or frequency of watering and hence duty increases.

**Delta:**

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

Ex: A crop require 12 watering at an interval of 10 days and depth of water required in each watering is 10cms, the delta for the crop is 12x10cms=120cms=1.2m

If the crop is grown in an area of A'hectares, then the total quantity of water required is = 1.2 x A hectares-meter in a period of 120 days.

**Some definitions:**

1. Crop Period: It is the time in days that a crop takes from the instant of its sowing to that of its harvesting.
2. Base period: It refers to the whole period of cultivation from the time when irrigation water is first applied for preparation of the ground for planting the crop to its last watering before harvesting.
3. Gross command area: It is the total area laying between the drainage boundaries which can be commanded or irrigated by a canal system.

4. Culturable command area: Gross command area may also contain villages, ponds, barrel lands, alkaline lands etc., and such areas are turned as unculturable area. The remaining area on which crops can be grown satisfactory is known as culturable command area.

**Relationship between Duty and Delta:**

Let D = Duty of water in hectares/cumec

$\Delta$ = Total depth of water required during base period in 'm'

B = Base period in days,

If we take a field of area D hectares, water supplied to the field corresponding to the water depth $\Delta$ meters will be = $\Delta$* D hectare-metres

= $D*\Delta*10^4$ cubic- metres. ……………..1

Again for the same field of D hectares, one cumec of water is required to flow during the entire base period. Hence, water supplied to this field

= $(1* B*24*60*60)\ m^3$ ………………….. 2

Eqquating equations 1 and 2 we get

$\Delta = (B*24*60*60) / (D*10^4)$

$\Delta = 8.64 B / D$

Consider a field of 'D' hectare to be irrigated and $\Delta$ be the corresponding depth of water.

The total volume of water required to be supplied for the field of 'D' hectares, if cumec is to be supplied during the entire base period 'B'