Hydrology and Irrigation Engineering (18CV63)

Module – 2: Evaporation, Evapo - Transpiration, Infiltration

Evaporation Introduction:

- **Evaporation** is the process by which surface water transfer into vapor state, which diffuses into the atmosphere.
- The water molecules both in the air and in the water are in rapid motion.
- Evaporation occurs when the number of moving molecules that break from the water surface escape into the air as vapor.

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Module – 2: Evaporation, Evapo - Transpiration, Infiltration

Evaporation Introduction:

- Evaporation, which may occur from water surfaces, wet leaf surfaces or from water on the soil particles, is important in water management and conservation.
- Evaporation of water from reservoirs, rivers and agricultural fields results in major losses of critical water resources, especially in arid reasons.
- In arid regions, evaporation can account for as much as 25 to 30% of the total consumptive use of surface water.

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Module – 2: Evaporation, Evapo - Transpiration, Infiltration

Evaporation Process:

- When external thermal energy is supplied to the water surface, the kinetic energy of the water molecules increases.
- When the water molecules at the surface reach sufficient kinetic energy they escape from the water body overcoming the intermolecular forces and eject themselves into the atmosphere.

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Module – 2: Evaporation, Evapo - Transpiration, Infiltration

Evaporation Process:

- When external thermal energy is not made available, heat energy is removed from the water body during the process of evaporation and hence lowering the water temperature.
- Therefore, evaporation is indirectly a process of cooling.
- The partial pressure or vapor pressure is the differential value of atmosphere pressure and the vapor molecule pressure.

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Evaporation Process:

- Continued supply of heat energy causes accumulation of more and more vapor molecules and a stage may came when the gaseous medium can no longer accommodate any more and rejects the vapor molecules in the form of condensation at the same rate of vaporization, this represents the saturation of air.
- At saturation, the partial pressure exerted by the water vapor is termed as saturation vapor pressure e_s.

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Module – 2: Evaporation, Evapo - Transpiration, Infiltration

Evaporation Process:

- As saturation vapor pressure increases with increase in temperature.
- Equilibrium is said to occur when the vapor pressure of air above the surface of water is already equal to the saturation vapor pressure e_s.

Hence it is clear that for evaporation to occur it is necessary to have:

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Module – 2: Evaporation, Evapo - Transpiration, Infiltration

Evaporation Process:

- Supply of water
- Source of heat energy
- Vapor pressure depict a difference between the saturated vapor pressure of water e_s and the actual vapor pressure of air above the free surface e_a.
- According to Dalton vapor pressure E can be expressed as

$$E = c\,(e_s - e_a)$$

C = a coefficient which accounts for other factors

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Module – 2: Evaporation, Evapo - Transpiration, Infiltration

Definition of Evaporation:

- It is the process under which a portion of water near its surface is changed from liquid state to a gaseous state below the boiling point through the transfer of heat energy.

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Factors affecting Evaporation:

- **Vapor Pressure Difference:** evaporation depends upon the difference between saturated vapor pressure of the air at the temperature of water and of dew point.
- **Temperature of Air and Water:** the rate of evaporation increases with the increase in temperature of water.
- **Relative Humidity:** evaporation is inversely proportional to humidity.

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Module – 2: Evaporation, Evapo - Transpiration, Infiltration

Factors affecting Evaporation:

- **Atmospheric Pressure and Altitude:** evaporation decreases with increase in atmosphere pressure. At higher altitudes the atmosphere pressure decreases thereby increasing the rate of evaporation.
- **Wind Velocity:** when the wind velocity is more, the rate of evaporation will be more.
- **Water Depth:** has nothing to do with the surface evaporation, however evaporation will be more from shallow water depths.

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Module – 2: Evaporation, Evapo - Transpiration, Infiltration

Factors affecting Evaporation:

- **Water Surface Area:** rate of evaporation is directly proportional to water surface area, longer the area more is the evaporation and vice versa.
- **Water Quality:** turbidity of water decreases the rate of evaporation.
- **Meteorological Factors:** the rate of evaporation is influenced by solar radiation, latitude, season, time of the day and sky conditions.

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Module – 2: Evaporation, Evapo - Transpiration, Infiltration

Measurement of Evaporation:

- The class A pan as suggested by IS 5973 – 1970, 1220mm diameter and 255mm in depth.
- This pan is made of 0.9mm thick copper sheet, tinned inside and painted white outside as shown in figure.
- A point gauge is used to measure the depths of water.
- A calibrated cylindrical measuring jar is used to add or remove water maintaining the level in the pan to a fixed mark.

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Module – 2: Evaporation, Evapo - Transpiration, Infiltration

Measurement of Evaporation:

- The top of the pan is covered with a galvanized iron net to protect the water from birds and animals and also this mesh makes the water temperature more uniform during day and night.
- The evaporation from this pan is found to be about 14% less, compared to that from the unscreened pan.
- The entire pan is mounted on a square wooden platform of 225mm width and 100mm height to enable circulation of air underneath the pan.

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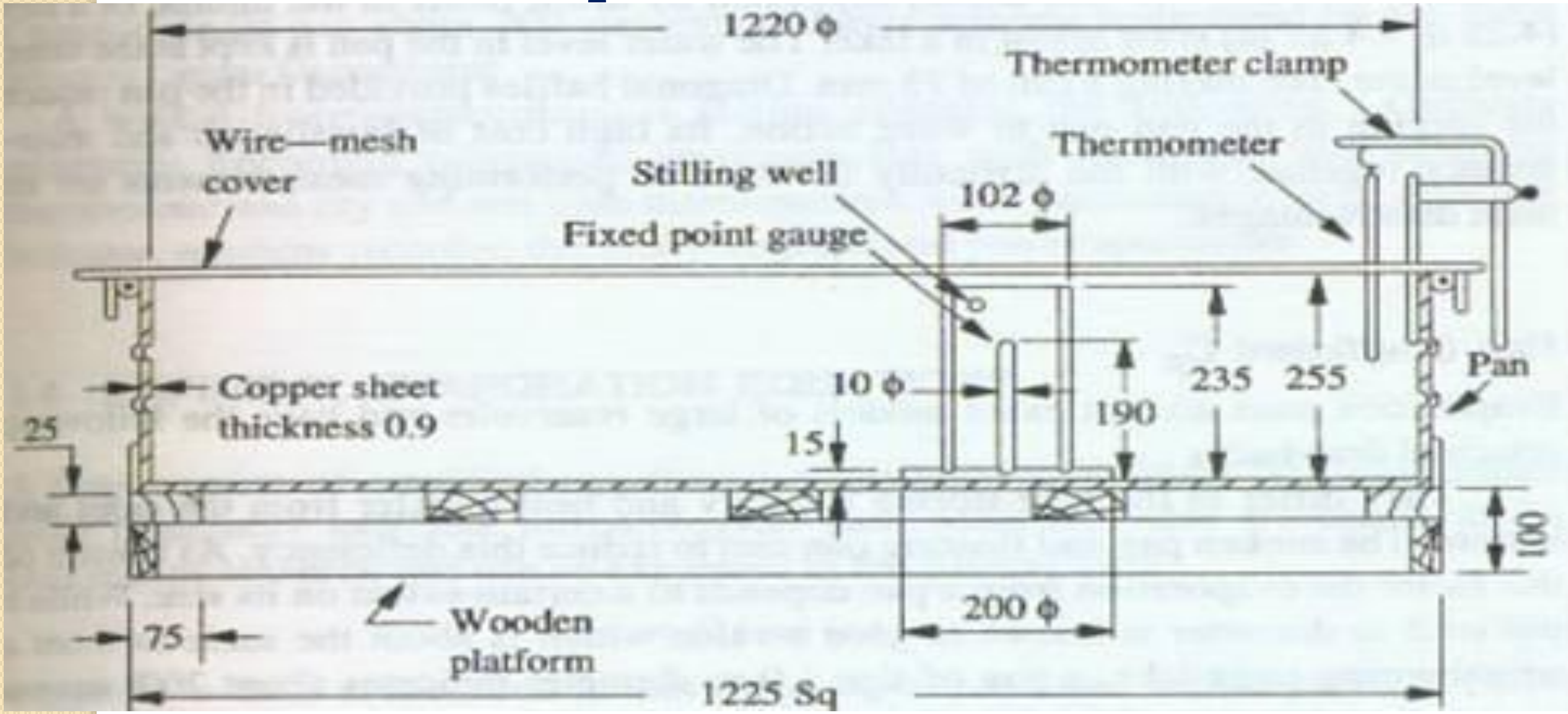
Measurement of Evaporation:



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Module – 2: Evaporation, Evapo - Transpiration, Infiltration

Measurement of Evaporation:

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Estimation of Lake Evaporation:

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

- Storage equation or Water budget method
- Energy budget method
- Mass transfer method
- Meyer’s equation
- Rohwer’s equation

Module – 2: Evaporation, Evapo - Transpiration, Infiltration

Storage Equation or Water Budget Method:

$$I - O = \Delta S$$

or

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

Where, I = Inflow, O = Outflow and ΔS = Change in storage.

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Energy Budget Method:

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

Value of E, the evaporation in cm can be calculated from the equation:

Module – 2: Evaporation, Evapo - Transpiration, Infiltration

Energy Budget Method:

$$E = \frac{Qs - Qr - Qb + Qv - Q\Phi}{\rho\ Hv\ (1+R)}$$

Where

ρ = density of water, Hv = latent heat of evaporation, R = bowen ratio = {heat lost by conduction / heat lost by evaporation}, Qs = sun and sky radiation incident at the water surface, Qr = reflected radiation, Qb = net energy lost by the water body through exchange of long wave radiation, Qv = net energy adverted into the water body, QΦ = increase in the energy stored in the water body.

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Mass Transfer Method:

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

Meyer's Equation:

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

Where

E = evaporation in mm/month, e_s = saturation vapour pressure in mm of mercury corresponding to mean monthly temperature of air, e_a = actual vapour pressure in air based on mean monthly temperature and relative humidity, V = monthly mean wind velocity in km/hr at 10m above ground, C = 15 small shallow ponds.

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Rohwer's Equation:

$$E = 0.771\,(1.465 - 0.000732\,Pa)\,(0.44 + 0.07334\,V)\,(e_s - e_a)$$

Where

E = evaporation in mm/day, Pa = men barometric reading in mm of mercury and e_s , e_a and V have the same meaning as mentioned in Meyer's Equation.

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Reduction of Evaporation:

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

- The reservoir should be of larger depth and lesser surface area.
- By growing tall trees on the windward side of the reservoir, wind velocity can be reduced and hence the evaporation loss can be reduced.

Module – 2: Evaporation, Evapo - Transpiration, Infiltration

Reduction of Evaporation:

- By allowing flow of water, temperature can be reduced and in turn evaporation can be reduced.
- By removing the water loving weeds and plants from the periphery of the reservoir, evaporation can be reduced.
- By spreading certain chemicals a film is formed on the water surface and thereby it is suited for small and medium reservoirs, also when the velocity is small.

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Reduction of Evaporation:

- By straightening the streams, channels, the exposed area of the water surface is reduced and hence evaporation can be reduced.
- By covering the reservoir surface with polythene sheets, evaporation can be reduced. But this method is suited for small reservoir.
- By developing underground reservoir, evaporation can be reduced.

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Reservoir Evaporation:

- Very large quantities of water is generally lost from a storage reservoir due to evaporation and such a loss depends upon various factors like: water surface area, water depth, humidity, wind velocity, temperature, atmospheric pressure and quality of water.
- The evaporation loss from a reservoir can be effectively estimated by measuring the standard pan evaporation and multiplying it by the pan coefficient.

Module – 2: Evaporation, Evapo - Transpiration, Infiltration

Reservoir Evaporation:

- The evaporation losses become very significant particularly in a hot and humid country like India.
- Therefore, realistic estimation of this loss is very essential.
- Evaporation loss can vary from place to place and season to season.
- On the basis of review conducted on 130 reservoir the central water commission (CWC) in 1990 has estimated the average annual evaporation loss around 225 cm.

Module – 2: Evaporation, Evapo - Transpiration, Infiltration

Evapo – Transpiration:

- Evapo – Transpiration is a combination of the words evaporation and transpiration.
- It refers to the process of water (moisture) moving from the soil and the plant and entering the earth's atmosphere.

Module – 2: Evaporation, Evapo - Transpiration, Infiltration

Factors Affecting Evapo – Transpiration:

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

Module – 2: Evaporation, Evapo - Transpiration, Infiltration

Factors Affecting Evapo – Transpiration:

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

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Module – 2: Evaporation, Evapo - Transpiration, Infiltration

Factors Affecting Evapo – Transpiration:

- Orientation of row crops would also influence the evapo – transpiration for the reason that interception of solar energy is a function of orientation.
- Pressure or absence of crops in the surrounding lands may also influence evapo – transpiration.
- Evapo – transpiration tends to be more when air masses pass over a cooler cropped and irrigated filed when compared to that coming from a bare ground.

Module – 2: Evaporation, Evapo - Transpiration, Infiltration

Factors Affecting Evapo – Transpiration:

- AET is influenced by the soil and plant factors also.
- AET is found to be a function of density of vegetation cover.
- Evapo – transpiration reduces with reduction in density of vegetation cover.
- AET varies with stages of plant growth or development.

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Module – 2: Evaporation, Evapo - Transpiration, Infiltration

Measurement of Evapo – Transpiration:

- Usually evapo – transpiration is measured with the help of LYSIMETER or Evapo – transpirometer.
- It is usually a circular tank of about 60 to 90 cm in diameter and 180 cm deep.
- It required larger diameters up to 3m and depth 3m are being used.
- The lysimeter is filled with soil with the crop under study in it.

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Module – 2: Evaporation, Evapo - Transpiration, Infiltration

Measurement of Evapo – Transpiration:

- The entire meter is buried with its top in flush with the surrounding ground surface.
- The sides of the meter would be impervious but the bottom being pervious.
- The upper surface is watered of known volume and the water passing out of the tank bottom is measured by volumetric or gravimetric method.
- The soil moisture is measured by moisture sampling.

Module – 2: Evaporation, Evapo - Transpiration, Infiltration

Measurement of Evapo – Transpiration:

- Evapo – transpiration is then determined from the measurement of amount of water added outflow at the tank bottom and changes in the soil moisture.
- It is advisable that the meter is guarded at least by four hectares around it.

Module – 2: Evaporation, Evapo - Transpiration, Infiltration

Measurement of Evapo – Transpiration:

Limitation of Lysimeter:

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

Module – 2: Evaporation, Evapo - Transpiration, Infiltration

Estimation of Evapo – Transpiration:

Penman's Method:

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

$$PET = \frac{AHn + Ea\gamma}{A + \gamma}$$

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Module – 2: Evaporation, Evapo - Transpiration, Infiltration

Estimation of Evapo – Transpiration:

Penman's Method:

Where

A = slope of the saturation vapor pressure versus temperature curve at the mean air temperature in mm of mercury per degree centigrade, Hn = net radiation in mm of evaporable water per day, Ea = parameter including wind velocity and saturation deficit, Ɣ = psychrometric constant = 0.49 mm of mercury/°C.

Module – 2: Evaporation, Evapo - Transpiration, Infiltration

Estimation of Evapo – Transpiration:

Blaney Criddle Method:

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

$$Cu = \frac{K\,p}{40}\,(1.8t + 32)\text{in MKS system}$$

Where Cu = monthly consumptive use in cm, K = crop factor, determined by experiments for each crop, t = mean monthly temperature, P = monthly percent of annual day light hours that occur during the period.

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Module – 2: Evaporation, Evapo - Transpiration, Infiltration

Estimation of Evapo – Transpiration:

Blaney Criddle Method:

- The above formula involves the use of crop factor K, the value of which is to be determined for each crop and different places.
- At present, this information is not available in India.
- Also, this formula does not consider many important factor such as humidity, wind velocity, elevation etc. on which consumptive use is dependent.

Module – 2: Evaporation, Evapo - Transpiration, Infiltration

Methods of reducing the Evapo – Transpiration:

Evapo – transpiration can be reduced in the following ways:

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

Module – 2: Evaporation, Evapo - Transpiration, Infiltration

Infiltration Introduction:

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

Module – 2: Evaporation, Evapo - Transpiration, Infiltration

Definition of Infiltration:

- Infiltration is defined as the process by which water enters the soil through pores or interstices or in other words it is the movement of water through the soil surface.

Module – 2: Evaporation, Evapo - Transpiration, Infiltration

Factors Affecting Infiltration:

- **Soil Porosity:** infiltration increases with increase in porosity.
- **Freezing of Soil:** when the soil is frozen infiltration reduces.
- **In wash of Fine Material:** fine material forms a relatively impervious layer, thereby infiltration reduces.
- **Initial Moisture Content:** initially when the soil is dry, infiltration will be high, but reduces as the water content >.

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Module – 2: Evaporation, Evapo - Transpiration, Infiltration

Factors Affecting Infiltration:

- **Microstructure of the Soil:** when the soil has more openings due to various reasons, infiltration would be more.
- **Compaction due to Men and Animals:** higher the compaction, lesser will be infiltration.
- **Vegetal Cover:** vegetation greatly promotes infiltration.
- **Compaction due to Rain:** when soil compacted due to rain, infiltration reduces.

Module – 2: Evaporation, Evapo - Transpiration, Infiltration

Factors Affecting Infiltration:

- **Drop Size and Rainfall Intensity:** when soil is compacted due to rain, infiltration reduces.
- **Temperature:** high temperature and less viscosity results in higher infiltration capacity.
- **Season:** seasonal variation in infiltration is influenced by temperature, evaporation, vegetation etc.
- **Land Slope:** Land slope is observed to have little effect on infiltration rate.

Module – 2: Evaporation, Evapo - Transpiration, Infiltration

Measurement of Infiltration:

The various methods for determining infiltration are:

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

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Module – 2: Evaporation, Evapo - Transpiration, Infiltration

Measurement of Infiltration:

- Infiltrometer are of two types; Double ring infiltrometer and Tube infiltrometer.
- In the second method, infiltration can be determined by noting the water levels in the pits and ponds and deducting the loss due to evaporation.
- In the third method, a catch basin (Lysimeter) is placed under a laboratory sample or at some depth below the land surface, the infiltration water can be measured.

Module – 2: Evaporation, Evapo - Transpiration, Infiltration

Measurement of Infiltration:

- In the fourth method, on a small area of 0.1 to 50 square meter water is applied by artificial shower at a uniform rate. The resulting surface measured, from which the infiltration capacity of the soil can be determined.
- In the hydrograph analysis method, by knowing accurately the varying intensities of rainfall during a storm and the continuous record of the resulting runoff, the infiltration capacity can be determined.

Module – 2: Evaporation, Evapo - Transpiration, Infiltration

Double Ring Infiltrometer:

- A double ring infiltrometer will be shown in figure.
- It is essentially consists of two hallow concentric metallic rings, driven into the soil uniformly to a depth of about 15cm.
- Once it is driven, soil adjacent to it is tamped.
- Point gauges for recording the water levels are fixed in the center of the rings and in the annular space between the two rings.

Module – 2: Evaporation, Evapo - Transpiration, Infiltration

Double Ring Infiltrometer:

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

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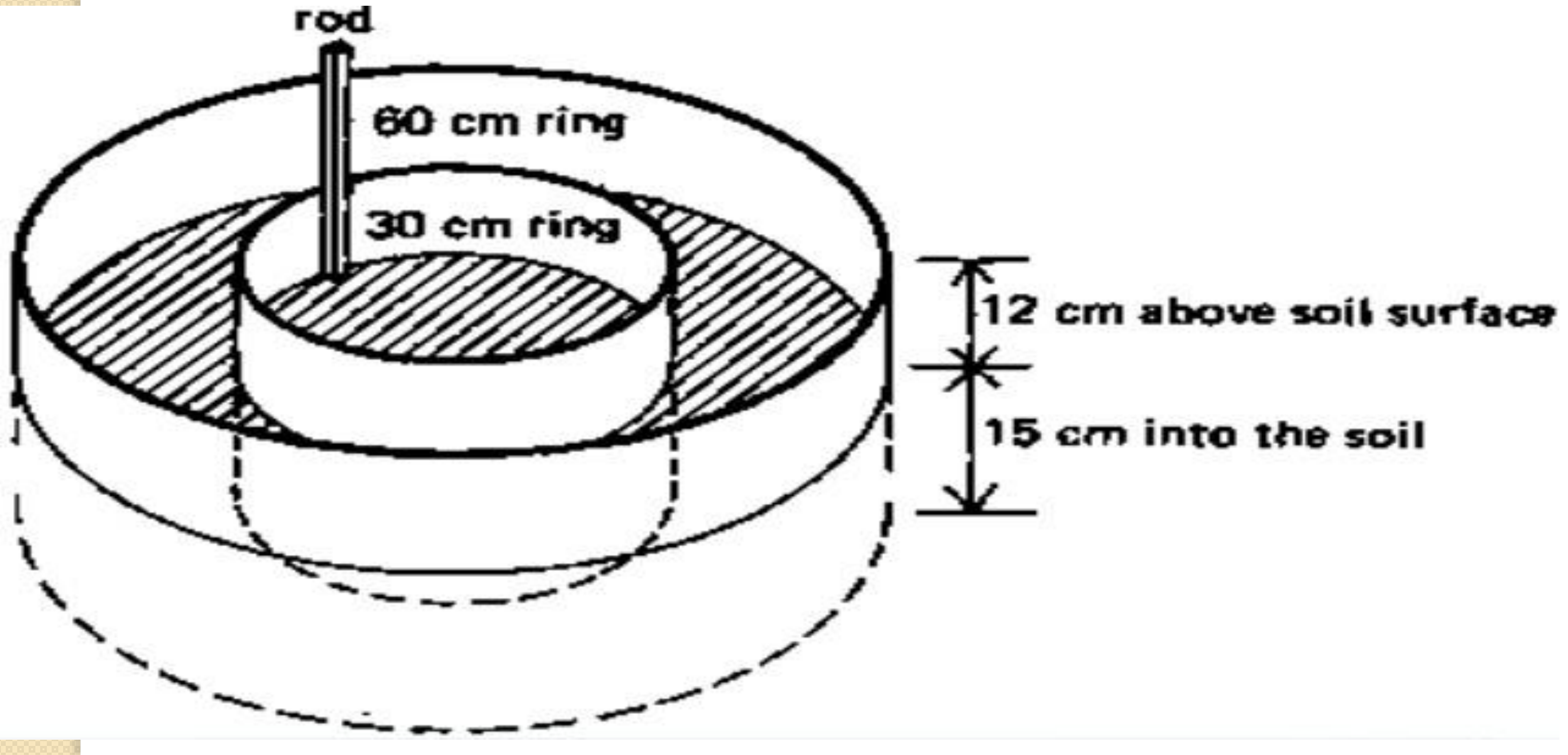
Module – 2: Evaporation, Evapo - Transpiration, Infiltration

Double Ring Infiltrometer:



Module – 2: Evaporation, Evapo - Transpiration, Infiltration

Tube Infiltrometer:

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

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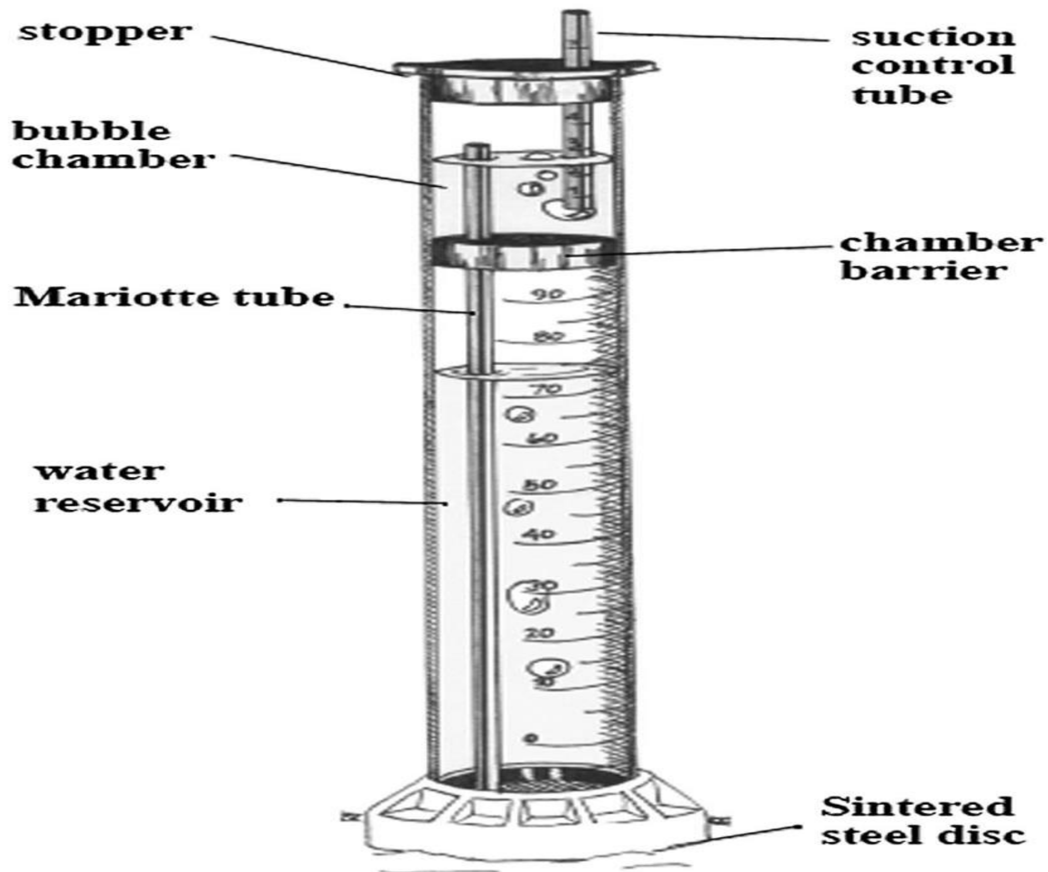
Module – 2: Evaporation, Evapo - Transpiration, Infiltration

Tube Infiltrometer:



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Module – 2: Evaporation, Evapo - Transpiration, Infiltration

Infiltration Indices:

- **Supra – Rain:** the rainfall in excess of a particular value of Φ index for the entire pattern of storm rainfall is known as supra – rain.
- **Φ Index:** is the average rainfall above which the rainfall volume is equal to the runoff volume.

  Φ Index = (Basin recharge / Duration of rainfall)
- **W Index:** it is defined as the difference of Φ index with the initial losses.

Module – 2: Evaporation, Evapo - Transpiration, Infiltration

Infiltration Indices:

$$W\ Index = (\Phi\ Index - Losses)$$

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

Where

P = total precipitation in cm, R = total runoff in cm, I = initial losses, t = duration of rainfall excess (hours) i.e., the time in which the rainfall intensity is greater than initial capacity, W Index = average rate of infiltration cm/hour.

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Horton’s Equation for Finding the Infiltration Rate:

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

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Module – 2: Evaporation, Evapo - Transpiration, Infiltration

Horton's Equation for Finding the Infiltration Rate:

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

Where f_o = initial rate of infiltration capacity, f_c = final constant rate of infiltration at saturation, K = constant depending primarily upon soil and vegetation, e = base of the Napierian logarithm, Fc = shaded area in figure, t = time from the beginning of the storm.

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