Unit-II

Abstractions from precipitation

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Losses from the precipitation :-

Total loss = Interception + Evaporation + Transpiration + Infiltration + watershed leakage.

Evaporation :- It is the process in which the liquid changes to the gaseous state at the free surface, below the boiling point through the transfer of heat energy. The main source of evaporation is the solar radiation.

The rate of evaporation depends on the following factors :-

(1) Vapour pressure at the water surface and air above
(2) Air and water temperatures.
(3) solar radiation.
(4) Wind speed
(5) Atmospheric pressure
(6) Nature and size of evaporating surface.
(7) Quality of water.

Dalton's law of evaporation :-

$$E = k(P_s - P_a)$$
$$= (a + bv)(P_s - P_a)$$

Where, E = Evaporation loss (mm/day)

P_s = Saturation vapour pressure at water surface temperature in millibar

P_a = Actual vapour pressure of the air above.

k = a constant whose value depends upon various factors such as barometric pressure, wind, velocity etc..

$k = a + bv$

where a, b = constants

v = wind speed in km/hr.

if $P_a \leq P_s$ evaporation.

$P_a > P_s$ condensation.

Factors Affecting evaporation losses :-

1) Nature of Evaporating surface :-

Different evaporating surface like soil, barren land, forest area, houses and lakes affect evaporation to the extent they have the potential. Black cotton soils help to evaporate the soil water faster than red soil, because such soils have the potential to absorb incoming radiation more effectively.

2) Area of Water surface :-

The evaporation loss directly depends upon the area of the water surface - greater the area greater will be the water loss due to evaporation.

3) Depth of water in water body :-

Deep water bodies evaporate slower than shallow water bodies in summer while in winter season, they evaporate faster.

4) Humidity :-

Evaporation is inversely proportional to humidity. If the humidity in the atmosphere is more, evaporation will be less.

5) Wind velocity :- Wind removes the overlaying vapour from an evaporating body there by increasing the rate of the evaporation.

temperature of air :-

Increase in air temperature increases the evaporation rate through not always proportionately. For the same temperature, colder months have less evaporation than summer months due to the combined effect of other environmental parameters.

(7) Atmospheric pressure :-

As per Dalton's law, evaporation will be less if the atmospheric pressure (ea) is more. Thus at higher altitudes, evaporation loss is more. while in deep valleys, evaporation is less.

(8) Quality of Water :-

The presence of dissolved salts in water reduces the saturation vapour pressure (es) of water which consequently reduces the rate of evaporation.

* Measurement of Evaporation :-

(1) Measurement using evaporation pans.

(2) Use of empirical equations.

(3) Water budget method.

(4) Energy budget method.

Measurement using evaporation pans :- The following are the different type of evaporation pans.

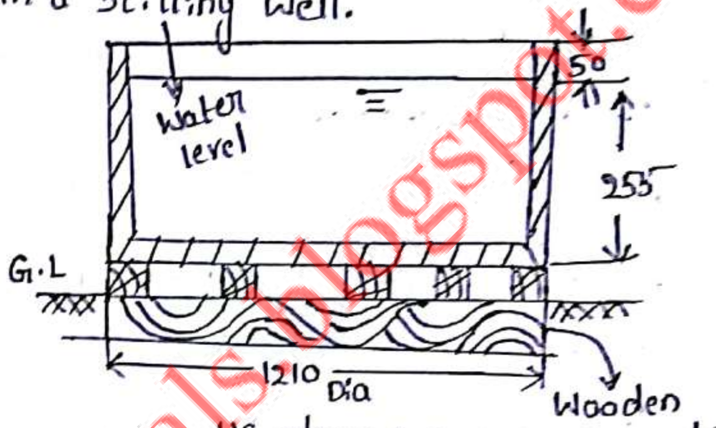
1. US class A-pan.
2. ISA standard pan.
3. Colorada sunkan pan.
4. US Geological survey floating pan.

US class A-pan :- It is a standard pan of 1210mm diameter and 255m depth used by the US Weather Bureau and is known as

Class A Land pan. The depth of water is maintained between 18 cm and 20 cm. The pan is normally made of unpainted galavanised iron sheet. Monel metal is used where corrosion is a the major problem.

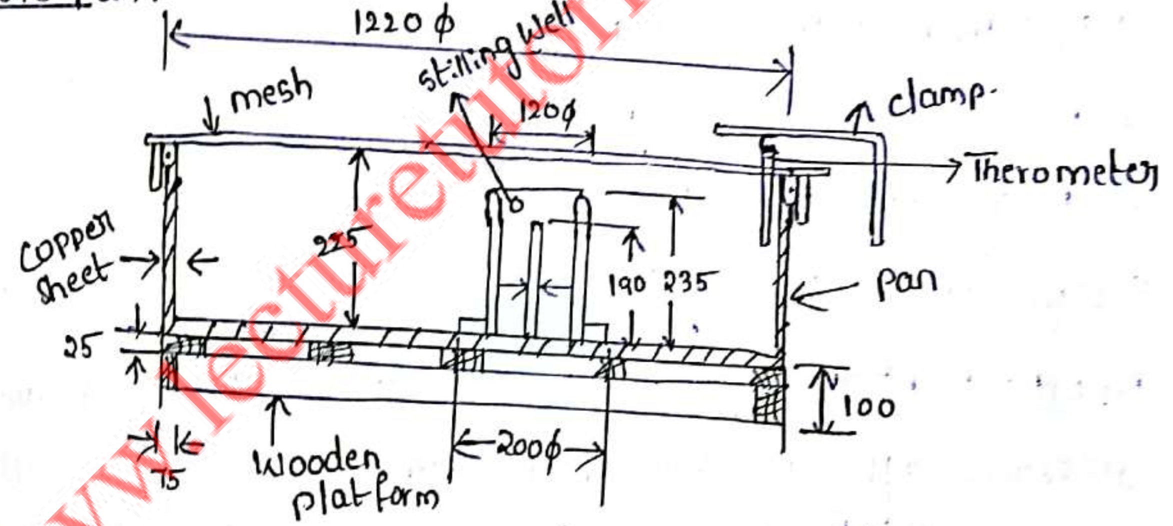
The pan is placed on the wooden platform of a 15cm height above the ground to allow free circulation of air below the pan.

Evaporation measurements are made by measuring depth of water with a hook gauge in a stilling well.



US. class A pan

Standard pan:-



* This pan evaporimeter specified by IS : 5973-1970 also known as modified class A pan.
* It consists of a pan dia 1220mm and 255m depth.
* The pan is made of copper sheet 0.9mm thickness, tinned inside and painted white on out side.

A fixed point gauge indicates the level of water. And a calibrated cylindrical measure is used to add or remove the water maintaining the water level in the pan to a fixed mark.

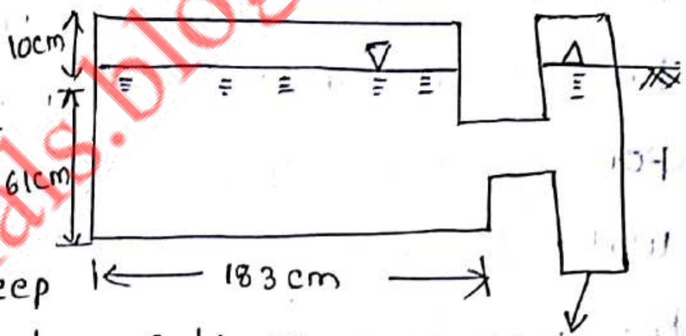
* And the top of pan is protected by wire neetting of galvanized iron to protect the water in the pan from birds.

* The evaporation from this pan is found to be less by about 14% compared to that from unscreened pan.

* It is placed 100mm height to enable circulation of air under the pan and place it over square wooden platform of 1225 mm width.

<u>Colorado sunken pan</u>:-

* This type of pan is used by United States Bureau of plant industry (USBPI).



* Its dia is 183cm and 61cm deep burried in the ground such that top of the rim is 10cm above the ground level.

* The water surface in the pan is maintained 15mm of the ground level.

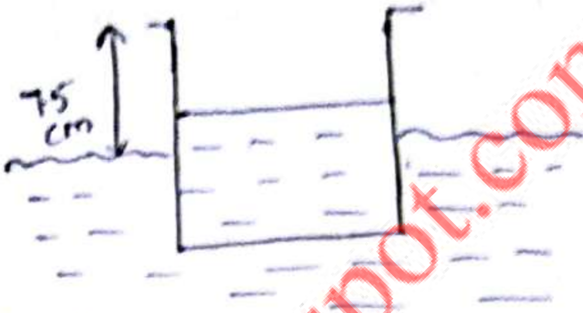
* Evaporation is measured by means of pointer gauge in a stilling well outside the pan.

<u>Advantage</u>:- The sunken pan has certain boundary effects as well as such direct solar radiation on side wall & heat is less because walls are coated with white paint & placed in the ground.

Disadvantage:-

* difficult to detect leaks.
* Expensive to instal.
* Extra care is needed to keep the sourrounding area free from tall grass, dust etc.,

5 Geological survey floating pan:-



he apparatus is kept in the loating water about 7.5 cm above e water level. The pan coefficient of this oating pan is 0.7 to 0.82. The main disadvantage of this in is that due to heavy wind flow, the water in the provided nd may be splashed in to the pan. Hence the volume of ater inside the pan may either increase (or) decrease, it changes e amount of evaporation.

Factors responsible for the evaporation changes takes place y the following reasons:-

* Depth of exposure of pan above ground.
* colour of the pan.
* Height of the rim.
* Diameter of pan and cross section area of pan.
* Variation in wind speed, vapour pressure, water and emperature.

of empirical equations:-

i) Meyer's Formula:- $E = k(P_s - P_a)\left[1 + \frac{V_9}{16}\right]$

$= k(P_s - P_a)[1 + 0.0625 V_9]$

Where, E: Evaporation from the water body, in mm/day.

P_s: saturation vapour pressure.

P_a: actual vapour pressure.

V_9: mean wind velocity in km/h at a height of 9m above the ground.

k: coefficient accounting for various other factor
= 0.36 for large deep water.
= 0.50 for small shallow water.

(ii) Rohwer's formula:-

$E = 0.771(1.465 - 0.000732 P_a)(0.44 + 0.0733)(V_{0.6})(e_s - e_a)$

Where, E: Evaporation from the water body in mm/day

P_a: mean barometric reading in mm of Hg.

$V_{0.6}$: Velocity in km/h at 0.6m above the ground level.

e_s: Saturation vapour pressure.

e_a: actual vapour pressure.

* It is known that in the lower part of the atmosphere up to a height of about 500m above the ground less, the velocity is assumed to follow "1/7 power"

$V_h = ch^{1/7}$ (OR) $\frac{V_{h_1}}{V_{h_2}} = \left(\frac{h_1}{h_2}\right)^{1/7}$

"V_h": the velocity at height 'h' above the ground.

Water budget (or) Water balance method :- This method balances all incoming, outgoing and stored water in a lake (or) reservoir over a period of time, using the following equation.

Σ Inflow - Σ out flow = change in storage + Evaporation loss.

$\{R+P\} - \{O+E+S\} = \Delta S$

where; R = Runoff joing the water body.

P = Rainfall.

O = out flow from the water body.

E = Evaporation losses.

S = seepage into ground.

$E = \Delta S + R + P - O - S$

ΔS" may be "+ve" (or) "-ve" ; ΔS = change in storage.

$+\Delta S$ is increased in water quantity.

$-\Delta S$ is decreased in water quantity.

Energy-Budget method:- This method uses the conservation of energy by incorporating all the incoming, outgoing and stored energy of a lake / reservoir in the following from.

$\{Energy\}_{in} - \{Energy\}_{out} = 0$

$\{Energy\}_{in} = \{Energy\}_{out}$

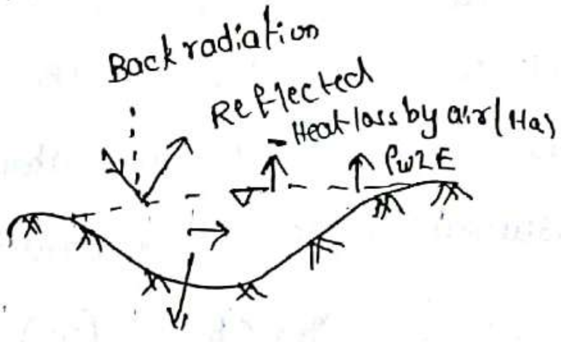
$k = H_a + H_g + H_e + H_s + H_i$

$H_e = R - [H_a + H_g]$

$H_e = \rho_w L E$

$H_e = R - [H_a + H_g]$

$\rho_w L E = R - [H_a + H_g]$



Hg-Heat ground flux

$$E = \frac{R - [H_a + H_g]}{\rho_w L}$$

$$\boxed{E = \frac{R}{\rho_w L}}$$ [Neglecting H_a, H_g, H_s, H_i]

Where, H_a = Sensible heat transfer from water surface to air.

H_g = heat flux in to the ground.

H_e = Heat energy used up in evaporation.

$H_e = \rho_w L E$

ρ_w = density of water

L = Latent heat

H_s = heat stored in water body.

H_i = Net heat conducted out of the system by water flow.

Methods to reduce Evaporation loss :-

Various methods are available for reduction of evaporation losses can be considered in three categories :-

(1) Reduction of Surface Area :- The volume of water lost by the evaporation is directly proportional to the surface area of the water body, the reduction of surface area where ever feasible reduces evaporation losses.

Measures like having deep reservoirs in place of wider ones and elimination of shallow areas can be considered under this type of category.

(2) mechanical covers :- Temporary roofs and floating roofs such as rafts and light-weight floating particles can be adopted wherever feasiable. obviously these measures are limited to very small water bodies such as ponds, reservoirs etc.,

Evapotranspiration :- Evapotranspiration is the sum of plants evaporation and as well as land evaporation surrounding the plants.

Potential evapotranspiration :- If sufficient moisture is always available to completely meet the needs of vegetation fully covering the area, the resulting evaporation is called potential evapotranspiration.

P.E.T. no longer critically depends on the soil and plant factors but depends essentially on the climatic factors.

Actual evapotranspiration (AET) :-

The real evapotranspiration occuring in a specific situation is called as Actual evapotranspiration.

Field capacity (Fc) :-

Fc is the maximum quantity of water that the soil can retain against the force of gravity.

permanent wilting point :-

permanent wilting point is the moisture content of a soil at which the moisture is no longer available in sufficient quantity to sustain the plant. Some moisture, it will be so held by the soil gains that the roots of the plants are not able to extract it in sufficient quantities to sustain the plants and consequently the plants gets dried.

* If moisture content of soil = Fc then AET = PET

$$\frac{AET}{PET} = 1$$

the and f moisture content of soil < Fc, then AET < PET

$$\frac{AET}{PET} < 1$$

* If moisture content of soil = Permanent wilting point (PWP), then

$$AET = 0 \quad ; \quad \frac{AET}{PET} = 0.$$

<u>Note:-</u> For clay soil $\frac{AET}{PET} = 1$ up to moisture content of soil $\geq 50\%$ Fc

<u>Measurement of Evapotranspiration</u> :- The following methods are used to measure the evapotranspiration and they are :-

1. Lysimeters.
2. Penman's equation.
3. Blaney-criddle formula.
4. Analytical method.

1. <u>Lysimeters</u> :-

* A lysimeter is a special water tight tank containing a block of soil and set in a field of growing plants.

* The plants grown in the lysimeter are the same as in the sourrounding field.

* Evapotranspiration is estimated in terms of the amount of water ab required to maintain in terms of the amount maintain constant moisture conditions with in the tank measured eitherly volumetrically (or) gravitationally through an arrangement made in the lysimeters.

ET = Vol. of water added - Vol. of water drained out - Δ_{mc}

Δ_{mc} = change in the moisture content of soil.

Penman's equation:-

Based on sound theoretical reasoning and is obtained by a combination of energy balance and mass transfer approch.

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

Where PET = Daily potential evapotranspiration in mm.

A = Slope of saturation vapour pressure Vs temperature curve at the mean air temperature in mm of Hg °c

H_n = net radiation in mm of evaporable water per day.

E = parameter including wind velocity and saturation deficit.

γ = psychrometric constant = 0.49mm of Hg/°c

Blaney - criddle formula:-

$$PET = \frac{k p T_m}{100}$$

Where k = crop factor (or) consumptive use factor.

$$k = \frac{\text{consumptive use}}{\text{Pan evaporation}}$$

Rice k = 1.1

Sugarcane - 0.9

cotton - 0.65

Maize - 0.6

wheat

P = Percentage day - light hours in a month.

T_m = mean monthly temperature in F°.

Consumptive use = Evapotranspiration {if water consume by the plant is neglected}

(or)

$\boxed{Cu = kf}$ $f = (0.0457 t_m + 0.8128\, p)$

Cu = monthly consumptive use in cm

k = monthly crop coefficient to be determined from imentally.

∴ monthly consumptive use factor

$f = (0.0457\, t_m + 0.8128)\, p$

Where t_m = mean monthly temperature in degree centigrade (°c)

p = monthly % of hours of bright sun in the year

Rice (k) = 1.1

Wheat (k) = 0.65

Sugar cane (k) = 0.9

cotton (k) = 0.65.

Hargreaves class A pan Evaporation method :- This method is used in Israel, U.S.A.

$\boxed{E_t \text{ (or) } C_u = k \cdot E_p}$

$E_p = 0.459\, R_A \cdot C_t \cdot C_w \cdot C_s \cdot C_e \cdot C_h$

E_p = class A-pan evaporation.

C_t = coefficient of temperature.

C_s = coefficient of sunshine.

C_w = Coefficient of wind velocity.

C_h = Coefficient of humidity.

C_e = Coefficient of elevation.

R_A = Extra terrestrial radiation

Integrated method :- Factors to be consider like additional cultivation, moisture content and water bodies and find the evapotranspiration.

Inflow-out flow :- $U = (I+P) - (G_a - G_e) - R$

Where U = Valley consumptive use

I = total inflow during one year.

P = yearly precipitation.

G_s : Ground storeage at begining of year.

G_e : Ground storeage at the end of year.

R = yearly out flow.

Factors Affecting Evapotranspiration are as follows :-

* Atomospheric vapour pressure
* Temperature
* wind.
* Light intensity.
* characteristics of the plant, such as the roots and leaf systems.

Transpiration :-

Transpiration is the process by which water leaves the body of a living plants and reaches the atmosphere as water vapour. The water is take up by the plant-root system and escapes through the leaves.

Evaporation continues all through the day and night although the rate are different.

Transpiration loss is measured by "phytometer".

K = monthly crop coefficient ...

Transpiration ratio = $\dfrac{\text{Weight of water transpired by the plant during its growth}}{\text{Weight of dry matter produced by the plant \& roots.}}$

Transpiration ratio for, wheat – 560.
rice – 690.

Infiltration :-

Infiltration is the flow of water into ground through the soil surface, to meet soil moisture deficiency. The excess water will move in vertically deep below the ground water table.

Percolation :-

The process of transmission of water in the soil.

Infiltration capacity :- The capacity of any soil to absorb the water from rain falling continuously at an excessive rate goes on decreases with time. The infiltration rate at any instant is the rate at which water actually enters into the soil during strom time and it is equal to infiltration capacity

Effects of infiltration :-

* It reduces magnitude of flood.
* It delay the time arrival of water to the channel.
* It recharges ground water reserviors.
* It reduces soil erosion.
* It fills the soil pores up to its field capacity that is making the availability of moisture content to the plants.

Factors effecting Infiltration :-

1. Condition of entry surface :- Vegetation cover versus barren land. If the area is covered by grass, vegetation and bushes, plants infiltration capacity will be more. The vegetation cover also provides a layer of decaying organic matter and which promotes activities of burrowing insects etc, which in turn produce spong permeable soil structure resulting in increased infiltration.

If the soil surface is barren, the impact of rain drops falling on the surface will cause in-washing of finer particles of the soil and will log the surface, thus resulting in the retardation of infiltration.

2. Quality of water :- Silts and other important impurities present in incoming water results in retardation of infiltration rate due to clogging of soil pores. The salts present in water effect the viscosity of water and may react with soil to form complexes that produce the porosity of soil.

3. Size and characteristics of soil particles :- Infiltration rate is directly proportional to the grain size/diameter, for the granular soils. However if the soil has swelling minerals like illite and montmorillonite, the infiltration rate will reduce drastically.

4. more of man and animals :-

When there is heavy movement of man and animals soils get compacted resulting in the reduction of infiltration rate.

5. moisture conditions in the soil :- Infiltration rate will depend on initial moisture conditions of soil. When the soil moisture is high, the infiltration rate (f_t) will be low.

When water falls on a dry surface, the upper surface becomes wet while the lower parts of the soil remain comparatively dry initially, this results in a large difference of capillary potential due to which a downward force will act on the water, in addition to the normal force of gravity.

6. Temperature :- The viscosity of water changes with the temperature. The flow of water with in the body of the soil is laminar and the flow is directly related to viscosity. In summer infiltration rate will be high due to less viscous water, in comparison to winter.

7. Intensity and duration of rain fall :- when the percipitation 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 the rainfall of lesser intensity result in higher infiltration rate. The rainfall with higher duration will result in lower infiltration in comparison to the same quantity of rainfall as and number of isolated storms.

Infiltration capacity curve:

It is a curve drawn between infiltration rate and time. Infiltration rate is the maximum at the beinging of the rainfall and there after infiltration decreases expotentially with time. Horton's gives the equation for the calculation of infiltration.

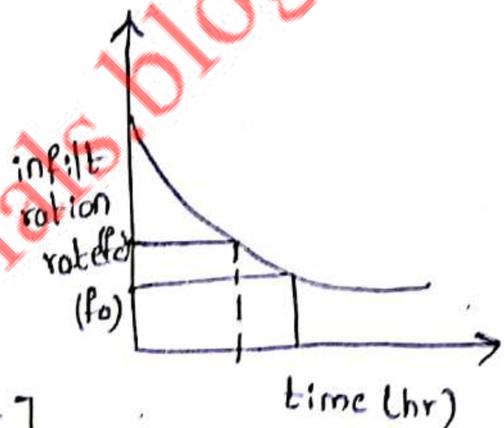
Let f_c = constant rate of infiltration at particular time.

f_o = infiltration rate at the begining

f_t = infiltration rate at any time 't'

k = constant which depends on soil and vegetation conditions.

$$\therefore \boxed{f_t = f_c + (f_o - f_c)\, e^{-kt}}$$



$$f_t - f_c = (f_o - f_c)\, e^{-kt}$$

Apply 'log' on bothsides

$$\log_{10}(f_t - f_c) = \log_{10}[(f_o - f_c)\, e^{-kt}]$$

$$\log_{10}(f_t - f_c) = \log_{10}(f_o - f_c) - kt \cdot \log_{10} e.$$

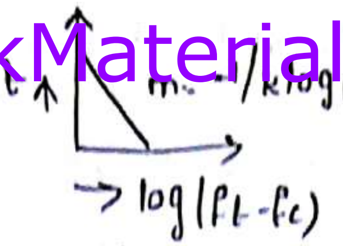
$$kt \log_{10} e = -[\log_{10}(f_t - f_c) - \log_{10}(f_o - f_c)]$$

$$t = \frac{-1}{k \log_{10} e} \log_{10}(f_t - f_c) + \frac{1}{k \cdot \log_{10} e} [\log_{10}(f_o - f_c)]$$

Compare straight line equation $y = mx + c$

$y = t$, $m = -1 / k \log_{10} e$, $x = \log(f_t - f_c)$

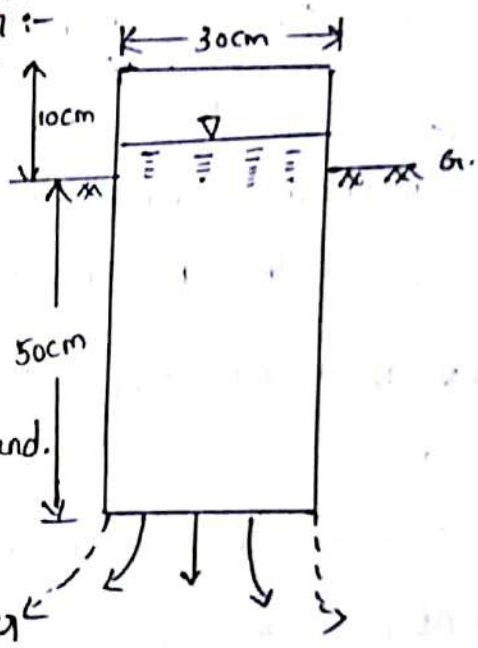
$= \frac{1}{k \log_{10}}$



* Measurement of infiltration rate

1. Field measurement using infiltrometers
   (i) single cylindrical infiltrometers.
   (ii) Double cylindrical infiltrometers.
2. Rainfall simulator.
3. Horton's equation.
4. Infiltration indices.

(i) Single cylindrical (or) tube infiltrometer :-



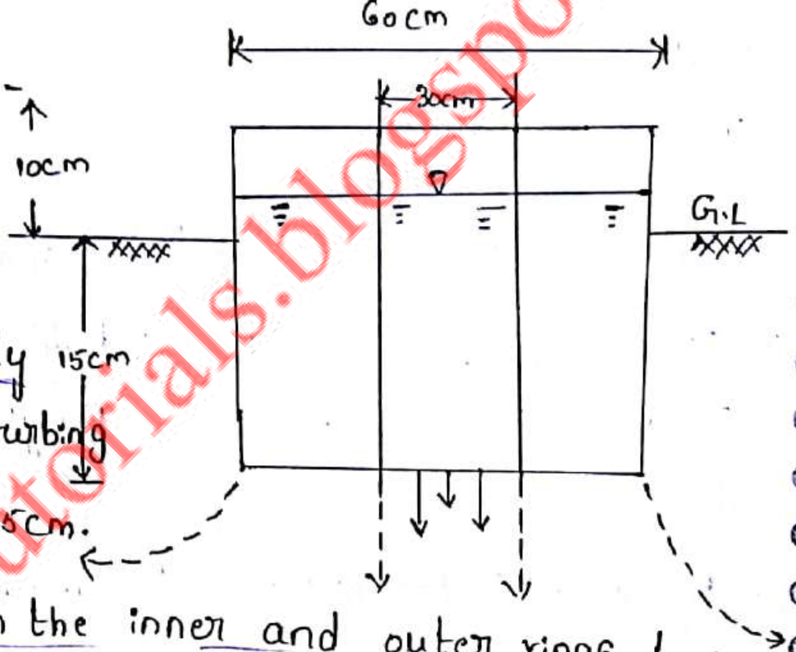
* It consists of a hallow metal cylinder of 30 cm diameter and 60 cm length with both ends open.
* The cylinder is driven in the ground such that 10 cm of its projects above the ground. The cylinder is filled with water up to some head the water level in the cylinder will go on decreasing.
* The volume of water added over a predetermined time interval gives the infiltration rate for that time interval.
* The observations are continued still almost uniform infiltration rate is obtained, which may take about 3 to 6 hours, depending upon type of soil.

Depth of water infiltrated = Volume of infiltrated / area

$$\text{Rate of infiltration} = \frac{\text{depth of water infiltrated}}{\text{duration of observation}}$$

Drawback:- The infiltrated water percolates laterally at the bottom of the ring as shown in figure. Hence it does not truly represents the area through which infiltration takes place.

ii) Doube tube infiltrometer:-



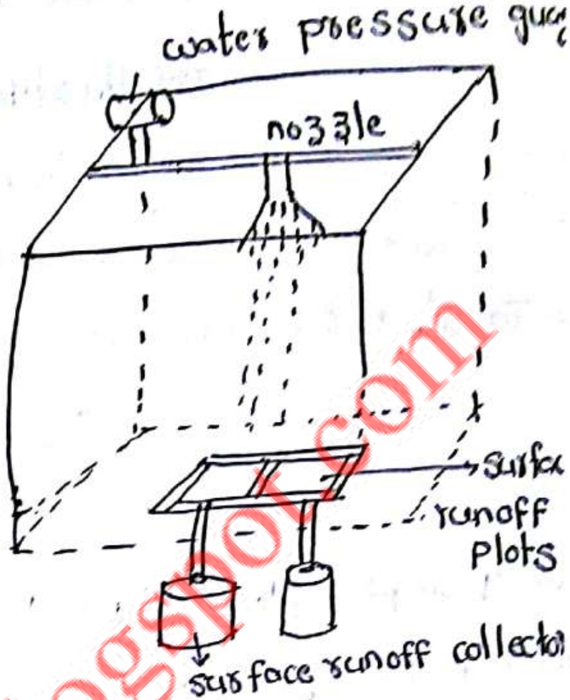
It consists of two concentric hallow rings driven into the soil uniformly without any tilt and disturbing soil, to least depth of 15cm.

Water is applied in both the inner and outer rings to maintain a constant depth of above 5cm. The measurement of volume of water added into the inner comprtment, to maintain the constant water level and the corresponding time.

As the purpose of outer ring is to supress the lateral percolation of water from inner ring, the water added to it need not be measured through water is added to it to maintain the same depth as the inner ring. Observations are continued till constant rate is obtained.

he graph between rate of infiltration (fc) in cm/hr as y-axis and time in (minutes) as x-axis.

(2) Rainfall simulator :-



* In a small plot of land of about 2m x 4m size is provided with a series of nozzles on the longer side arrangements to collect and measure the surface runoff rate. Experiments are conducted under controlled conditions with various combination of intensities and durations and the surface runoff rates and volumes are measured in each case.

* Rainfall simulator type infiltrometer gives lower values than flooding type infiltrometers.

* This effect due to the rainfall impact and turbidity of the surface water present in the formation.

Infiltration Rate = Rainfall - Runoff. = P - R

(3) Horton's Equation :-

Infiltration capacity at the begining (or) initial stage is very high and exponentially decreases with time and attains a constant rate of infiltration.

Horton's gave the following equation for finding infiltration rate (ft) at any time period.

$$\boxed{f_t = f_c + (f_0 - f_c)e^{-kt}}$$

Where f_t = infiltration rate at any time 't'

f_c = constant infiltration rate a time 't'

f_o = Infiltration rate in the begining $(t=0)$

k = a constant which depends on the soil and the soil and vegetation.

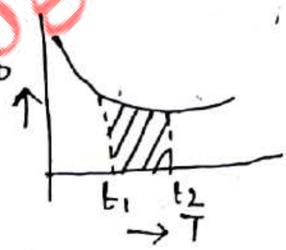
Total infiltration rate @ time $(0-t)$

$$F_t = \int_0^t f_t \cdot dt$$

For example; If we have to find out infiltration rate at shaded portion area

Infiltration rate between t_1 to t_2 = Area shaded under the infiltration capacity curve

$$= \int_{t_1}^{t_2} f_t \cdot dt$$

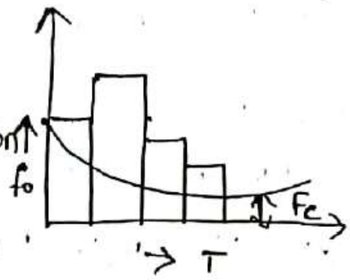


Presentation of infiltration capacity curve over hydrograph method

The shaded portion above infiltration capacity curve represent Runoff.

$\therefore$ Runoff = Rainfall - total infiltration

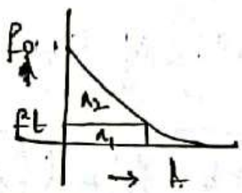
$$= \Sigma i_i t_i - \int_0^t f_t \cdot dt$$



* If $f_t = f_c$, then the soil attains constant infiltration rate.

Total infiltration $= \int_0^t f_t \cdot dt$

$$F_T = \int_0^t f_c + (f_o - f_c)\, e^{-kt}$$



$$F_T = F_c[t]_0^t + (f_0 - f_c)\int_0^t e^{-kt}\,dt$$

$$F_T = f_c t + \frac{f_0 - f_c}{k}$$

$$\left\{ \text{if } t \to \infty \int_0^\infty e^{-kt}\,dt \Rightarrow \frac{1}{k} \right\}$$

* If $f_t > f_c$ yet to attain constant rate of infiltration.

(4) Infiltration Indices :-

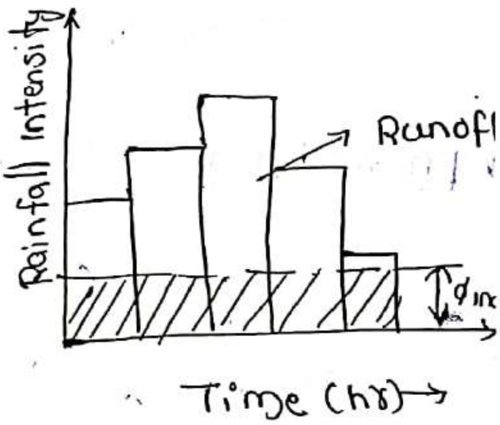
Average infiltration rate there are two types of infiltratic indices.

(i) Average infiltrate rate (or) w-index.

(ii) ϕ - index.

(i) W- index is calculated from the expression.

$$w_i = \frac{P - R - I_a}{t}$$



Where P = total strom precipitation (cm).

$= \Sigma i_i t_i$

R = total strom runoff (cm).

I_a = Initial losses (cm).

t = duration of rainfall in hours.

W_i = defined average rate of infiltration (cm)

(ii) ϕ - index :-

The average rate of rainfall above which the rainfall volume equal to the run-off volume.

The runoff volume, above ϕ - index is usually known as rainfall excess (or) effective rainfall.

ϕ_i Average rate of rainfall anything above which is runoff.

$$\phi_i = \frac{P_e - R}{t_e}$$

<u>Where</u> P_e = the portion of the rainfall which produce runoff

R = Runoff

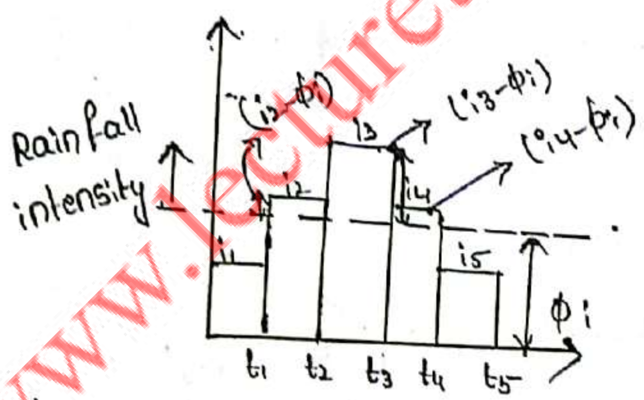
t_e = the duration of the rain during the period of runoff.

$$\phi_i = \frac{\text{Total infiltration during period of rainfall excess}}{\text{Total period of rainfall excess.}}$$

<u>Note:-</u> (i) $W_i < \phi_i$ for Non-uniform rain

(ii) $\phi_i = W_i$ for uniform intensity rain

<u>presentation of ϕ_i (or) ϕ index line over rainfall hydrograph:-</u>



$P_e = i_2 t_2 + i_3 t_3 + i_4 t_4$.

$P = i_1 t_1 + i_2 t_2 + i_3 t_3 + i_4 t_4 + i_5 t_5$.

$t = t_1 + t_2 + t_3 + t_4\ t_5$.

$t_e = t_2 + t_3 + t_4$.

<u>Note:-</u> ϕ index widely used in the calculation of runoff

W index is used for calculation of infiltration