EVAPOTRANSPIRATION

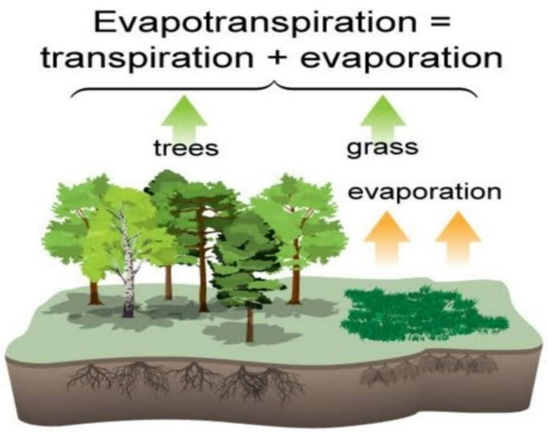
Introduction

Transpiration

- Process by which water leaves the body of living plant and reaches atmosphere as water vapour.
- Water leaves the plant from its leaves and stomata.

Evapotranspiration

- When transpiration takes place, land area in which plants stand also lose moisture by evaporation of water.
- Since in process of vegetation growth it is generally not possible to separate transpiration and evaporation .
- So evaporation and transpiration are considered under same head which is known as evapotranspiration.



Evaporation and evapotranspiration

When precipitation comes to the earth surface , it produces runoff . The runoff is important for study to design the hydraulic structure, estimating flood , etc. All the precipitation that comes to the earth surface does not contribute to runoff , some part of it disappeared. The lose of it occurs due to evaporation, transpiration , interception, depression storage and infiltration. This are also called as abstraction from precipitation.

Evaporation is the process in which a liquid changes to the gaseous state at the free surface, below the boiling point through the transfer of heat energy.

- Evaporation is a cooling process but boiling is a heating process.
- Latent heat of vaporization of water is 585 cal/gm .
- In evaporation liquid provide heat it self to evaporate in evaporation (latent heat).

Difference between evaporation and transpiration

Transpiration	Evaporation
Transpiration is physiological process.	Evaporation is physical process.
It is loss of water from the free surface of cells.	It is loss of water from the free surface of water.
Regulated process	Non regulated process.
It is comparatively slow process.	It is faster process.
Influence by anatomy of plants.	There is no such influence.

Types of evapotranspiration

There are two types of evapotranspiration :

- Potential evapotranspiration (PET)
- Actual evapotranspiration (AET)

Potential evapotranspiration

- When sufficient moisture is freely available to completely meets the need of vegetation fully covering the area, resulting evapotranspiration is called potential evapotranspiration.
- The lose of water due evaporation lose and plant transpiration.

Actual evapotranspiration

- Real evapotranspiration occuring in a specific situation in the field.

Factors affecting evapotranspiration

- Temperature
- Vapour pressure
- Wind
- Soluble salt
- Humidity
- Surface area
- Heat storage in water bodies

- **Temperature** : Rate of evaporation increases with increase in water temperature.

- **Vapour pressure** : The rate of evaporation is proportional to the difference between the saturated vapour pressure(e_w) and the actual vapour pressure(e_a)

$$E_L \alpha \ (e_w - e_a)$$

  Where, E_L = Rate of evaporation (mm/day)

- **Wind** : Wind helps in removing the evaporated water vapour from the zone of evaporation and subsequently creates greater scope for evaporation. If the wind velocity is large enough to remove all the evaporated water vapour , anyfurther increase in wind velocity doesnot influence the evaporation.

- **Soluble salt** : When a solute is dissolved in water, the vapour pressure of a solution is less than that of pore water and hence causes reduction in the rate of evaporation under identical conditions evaporation from sea water is about 2.3 percent less than that from fresh water.

- Humidity : More humidity less evaporation.
- Surface area : Area increases evaporation increases.
- Heat storage in water bodies : Deep water bodies have more heat storage than shallow ones.

A deep lake may store radiation energy received in summer and release it in winter causing less evaporation in summer and more in winter as compare to shallow lake expresses to a simillar situation.

Effect of heat storage is essential to change the seasonal evaporation rate and the annual rate is seldom effected.

Methods for measuring of evaporation

There are three methods for measuring the evaporation-

- Evaporimeter
- Empirical formula
- Analytical method

Evaporimeter

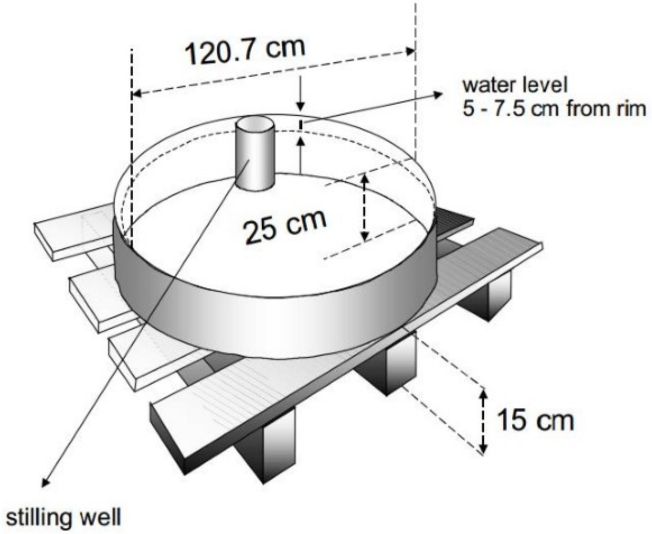
•These is a water containing pans which are exposed to the atmosphere and the loss of water measured at regular interval of time

Types of evaporimeter

- Class A pan
- ISI Standard Pan
- Colorado Sunken Pan
- US Geological Survey Floating Pan

• Class A Evaporation Pan

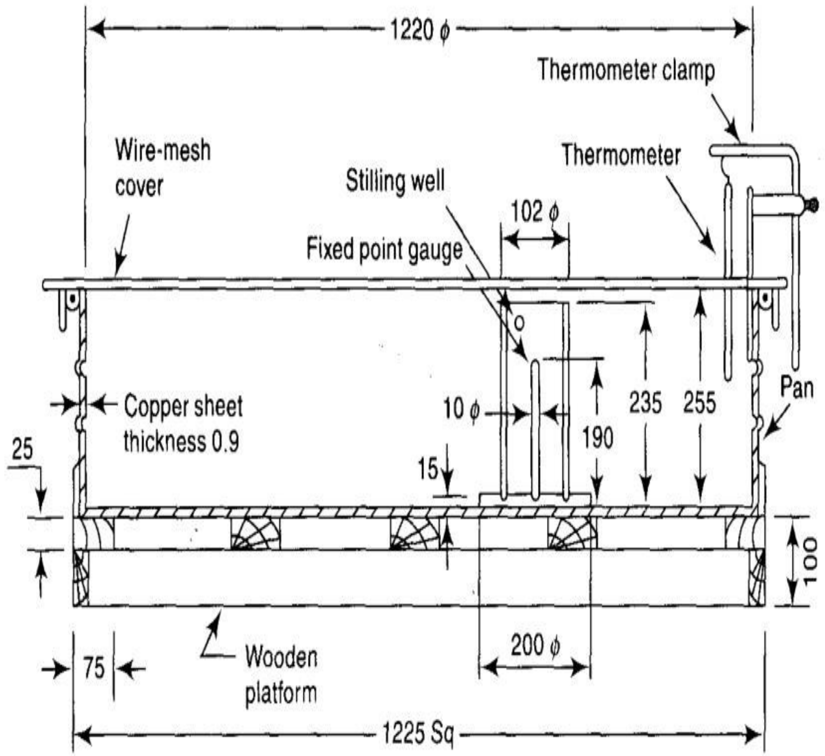
- A pan of diameter 1210mm and depth 255mm
- Depth of water is measured between 18 and 20 cm
- The pan is made of unpainted GI sheet
- The pan is placed on a wooden platform of height 15cm above ground level to allow free air circulation below the pan



ISI Standard Pan

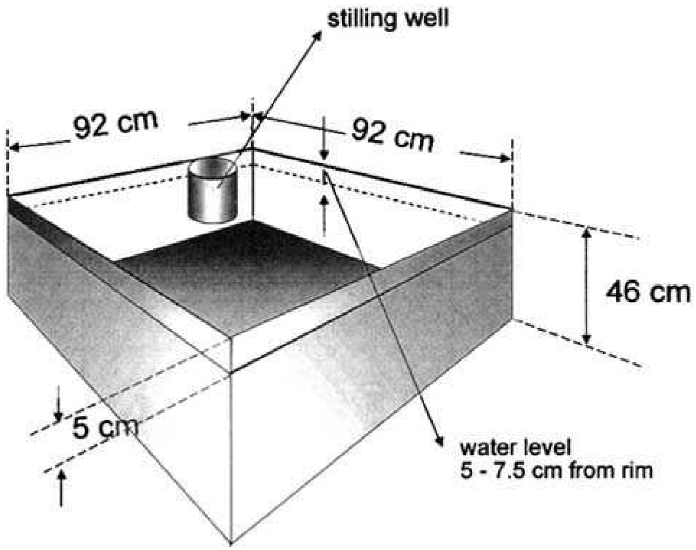
- Specified by IS: 5973 and known as the modified Class A Pan
- A pan of diameter 1220mm and depth 225mm
- The pan is made of copper sheet of 0.9mm thick, tinned inside and painted white outside
- The pan is placed on a square wooden platform of width 1225mm and height 100mm above ground level to allow free air circulation below the pan
- A fixed point gauge indicates the level
- Water id added to or removal from the pan to maintain the water level at a fixed mark using a calibrated measure
- The top of the pan is covered with a hexagonal wire net of GI to protect water in the pan from birds

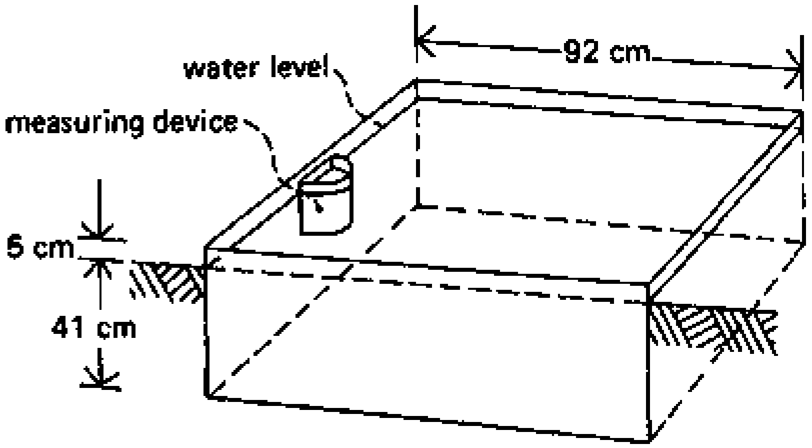
ISI Standard Pan (Modified class A Pan) IS:5973-1970:



Colorado Sunken Pan

- 920mm square pan made of unpainted GI sheet, 460mm deep, and buried into the ground within 100mm of the top
- Main advantage of this pan is that its aerodynamic and radiation characteristics are similar to that of a lake
- Disadvantages of this pan is it is difficult to detect leakage, expansive to install, extra care is needed to keep the surrounding area free from tall grass, dust etc





US Geological Survey Floating Pan

- A square pan of 900mm sides and 450mm deep
- supported by drum float in the middle of a raft of size 4.25m x 4.87m
- Water level in the pan is maintained at the same level as that in the lake, leaving a rim of 75mm
- Diagonal baffles are provided in the pan to reduce surging in the pan due to wave action
- Disadvantages of this pan is its coast of installation and maintenance is high

Pan Coefficient

• Pan coefficient is the ratio of the amount of evaporation from a large body of water to that measured in an evaporation pan evaporation pan

Pan Coefficient (Cp)

For accurate measurements from evaporation pan a coefficient is introduce, known as pan coefficient (**Cp**). Lake evaporation = **Cp** x pan evaporation

Type of pan	Range of **Cp**	Average value **Cp**
Class A land pan	0.60-0.80	0.70
ISI pan	0.65-1.10	0.80
Colorado sunken pan	0.75-0.86	0.78
USGS Floating pan	0.70-0.82	0.80

Empirical Evaporation Equation

- Most of the available empirical equations for estimate lake evaporation are a Dalton type equation.
- The general form of this equation is-

$$E_L = Kf(u)(e_w - e_a)$$

Where,

E_L = Lake evaporation (mm/day)

e_w = Saturated vapour pressure at the water surface temperature(mm of mercury)

e_a =Actual vapour pressure of over laying air at a specified height (mm of mercury)

$f(u)$ = wind speed correction function

K = co-efficient

e is measured as the same height at which wind speed(u) is measured

Mayer's Formula

$$E_L = K_M (e_w - e_a)[1 + \frac{u_9}{16}]$$

E_L = lake evaporation(mm/day)

e_w = saturation vapour pressure at the water surface temperature(mm/day)

= actual vapour pressure at the overlying air at a specified height(mm/day)

e_a

= monthly mean wind velocity (km ph) at a height of 9m above the ground

u_9

= coefficient accounting for other factors (0.36 for large deep waters and 0.50 for small shallow waters.

K_M

Rohwer's Formula

$$E_L = 0.771(1.465 - 0.000732 p_a)(0.44 + 0.733 u_0)(e_w - e_a)$$

p_a = mean barometric pressure (mm of mercury)

u_0 = mean wind velocity in kmph at ground level(taken as the wind velocity at 0.6m height above the ground)

E_L e_w and e_a are as mentioned earlier

Analytical Method

The analytical methods for the determination of lake evaporation can be broadly classified into three categories as-

1. Water budget method
2. Energy budget method
3. Mass-transfer method

Analytical methods for the determination of lake evaporation

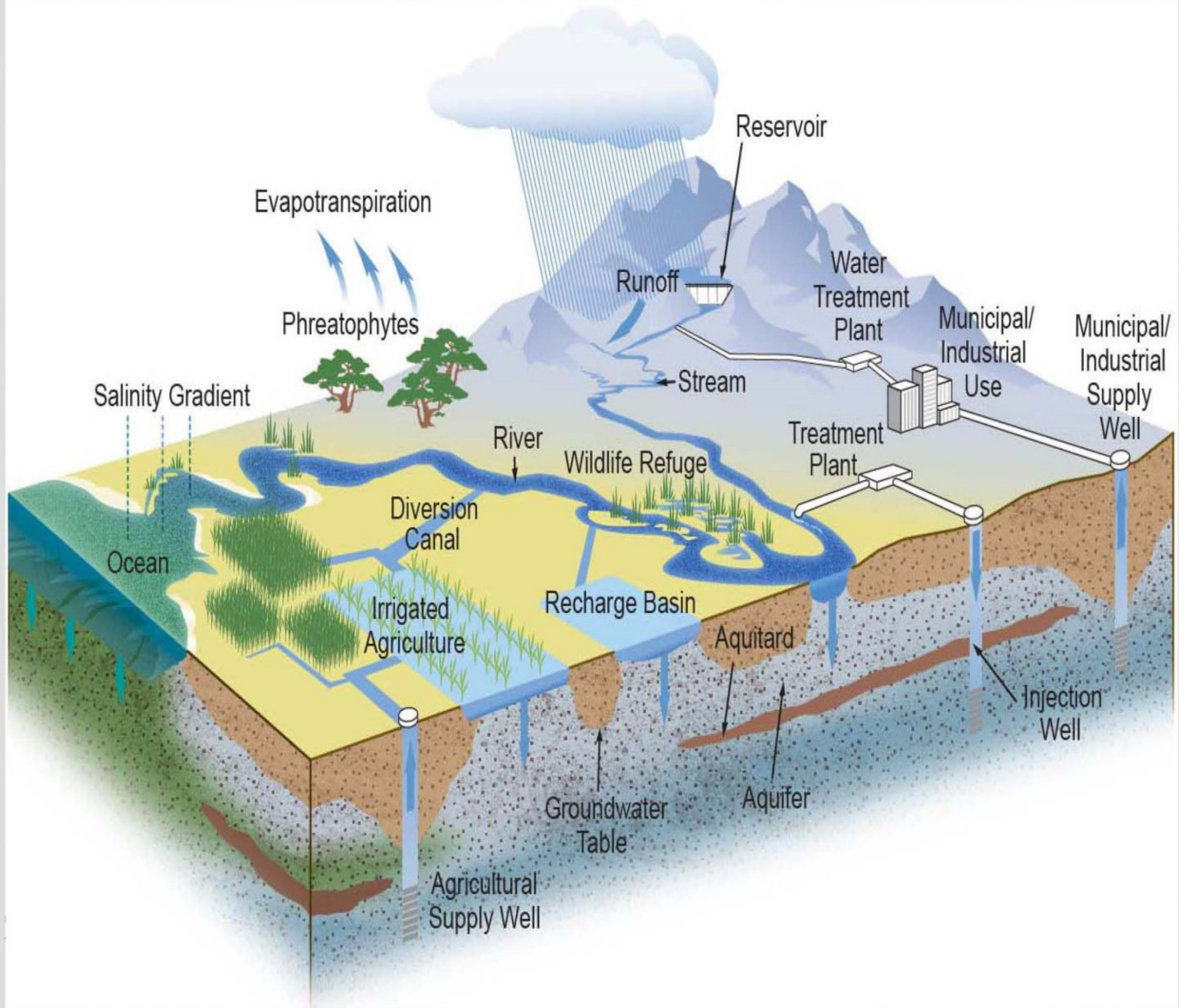
The analytical methods can be broadly classified into three –

- Water-Budget Method
- Energy-Budget Method
- Mass-transfer Method

Water-Budget Method

The water-budget method is the simplest of the three analytical methods and is also the least reliable . It involves in writing the hydrological continuity equation for the lake and determining the evaporation from a knowledge or estimation of other variables .

A water budget is an essential element in water resources management.



Calculation

Considering the daily average value for a lake , the continuity equation can be written as:

$$P + V_{is} + V_{ig} = V_{os} + V_{og} + E_L + \Delta S + T_L \quad \text{(equation i)}$$

where P = daily precipitation

V_{is} = daily surface inflow

V_{ig} = daily groundwater inflow

V_{os} = daily surface outflow

V_{og} = daily seepage outflow

E_L = daily evaporation

T_L = daily transpiration loss

ΔS = increase in lake storage

The equation 'i' can be written as:

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

- In this terms P, V_{is}, V_{os}, and ΔS can be measured.
- The terms V_{ig}, V_{og} and T_L can only be estimated.
- If the unit of time is kept large, better accuracy in the measurement of E_L is possible.

Energy-Budget Equation

The energy-budget method is an application of the low of conservation of energy . The energy available for evaporation is determined by considering the incoming energy , outgoing energy and energy stored in the water body over a known interval of time.

Calculation

Consider the water body as in fig.3.4, the energy balance to the evaporating surface in a period of one day is given by:

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

where H_n = net heat energy received by the water surface

$$= H_c(1 - r) - H_b$$

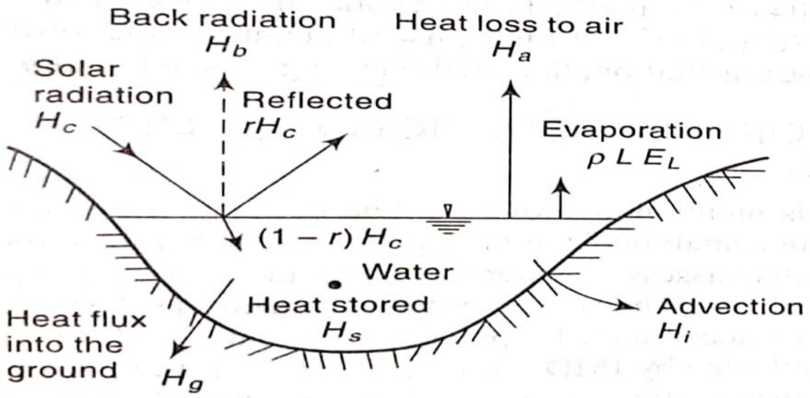


Fig. 3.4 Energy Balance in a Water Body

in which $H_c(1 - r)$ = incoming solar radiation into a surface of reflection coefficient (albedo) r

H_b=back radiation from water body

H_a=sensible heat transfer from water surface to air

H_e=heat energy used in evaporation

H_g=heat flux into the ground

H_s=heat stored in water body

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

The sensible heat term H_a which cannot be readily measured is estimation using Bowen's ratio ß given by the expression.

$ß = Ha/\mathrm{pLE_L}$

The evaporation can be evaluated as:

$$E_L = H_n - Hg - Hs - Hi/\mathrm{pL}(1+ß)$$

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.

With the use of quantity measured by sophisticated instrumentations, this method can give satisfactory results.

Ques : Following observations were made for conducting the water budget of reservoir over a period of 30 days

Average surface area = 10 km^2	Rainfall = 10 cm
Mean surface inflow rate = 10 m^3/s	Mean surface outflow rate = 15 m^3/s
Fall in reservoir level = 1.50 m	Pan evaporation = 20 cm
Assume pan evaporation coefficient = 0.70	

Estimate the average seepage discharge during that month.

Solution

Area of reservoir $= 10 \times 10^6\ m^2$

Inflow		Outflow	
Item	**Volume (m^3)**	**Item**	**Volume (m^3)**
Surface inflow $= 15 \times 3600 \times 24 \times 30$	25,920,000	Surface outflow = $15 \times 3600 \times 24 \times 30$	38,880,000
Rainfall $= 10 \times 10^6 \times 10/100$	1,000,000	Evaporation $= 0.7 \times 10 \times 10^6 \times 20/100$	1,400,000
		Seepage volume $= S_e$	S_e
Total inflow volume	26,920,000	Total outflow	$40{,}280{,}000 + S_e$
Reduction in storage $= 10 \times 10^6 \times 1.5$	15,000,000		

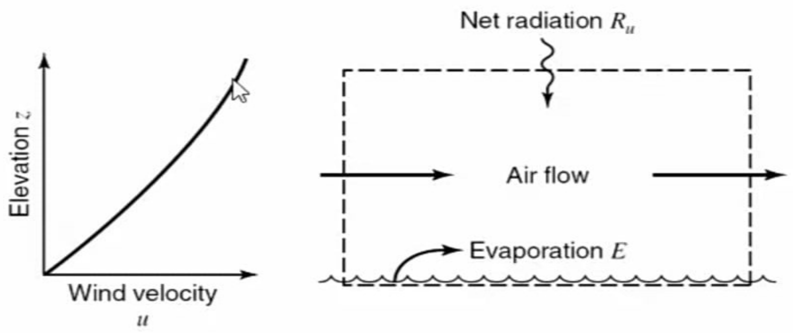
Total outflow volume – Total inflow volume = Reduction in storage

$$(40{,}280{,}000 + S_e) - (26{,}920{,}000) = 15{,}000{,}000$$

$$S_e = 1{,}640{,}000 = 1.64\ Mm^3$$

AERODYNAMIC METHOD

- *How quickly can water vapor be transported away from the water surface*



- ***Driving force***: *gradient (difference) in amount of water in the air*
- *More wind = greater rate of vapor transport (provides unsaturated air)*

Aerodynamic Method, *cont…*

$$E_a = B(e_{as} - e_a)$$

$$B = \frac{0.102u_2}{[\ln(z_2 / z_0)]^2}$$

$$e_{as} = 611\exp\left(\frac{17.27T_a}{237.3 + T_a}\right)$$

$$e_a = R_h e_{as}$$

E_a = evaporation rate (aerodynamic)
B = vapor transfer coefficient (mm/d·Pa)
e_{as} = saturation vapor pressure (Pa)
e_a = ambient vapor pressure (Pa)
R_h = relative humidity
u_2 = wind velocity (m/s) at height z_2 (cm)
z_0 = water surface roughness height (cm), typically 0.01 – 0.06 cm
T_a = air temp (°C)

FACTORS AFFECTING EVAPORATION

A. **Water Surface Area:** Evaporation is a surface phenomenon and the quantity lost through evaporation from water stored, therefore, depends directly on the extent of its surface exposed to the atmosphere.

B. **Temperature:** The temperature of water and the air above it affect the rate of evaporation. The rate of emission of molecules from liquid water is a function of temperature. The higher the temperature, greater is the rate of evaporation.

C. **Vapor Pressure Difference:** The rate of evaporation therefore depends on the difference between saturation vapor pressure at the water temperature and at the dew point of the air. Higher the difference, more the evaporation.

D. **Wind Effect:** The greater the movement of air above the water, greater is the loss of water vapor. Experimental studies on the relationship between wind speed and evaporation show direct relationship up-to a certain value of wind velocity beyond which perhaps the relationship does not hold good.

E. **Atmospheric Pressure:** Atmospheric pressure is very much related to other factors affecting evaporation. The number of air molecules per unit volume increases with pressure.

F. **Quality of Water:** The salt content in water affects the rate of evaporation. Experimental studies show that the rate of evaporation decreases with increase in salt content in water. In the case of sea water, the evaporation is 2 to 3% less as compared to fresh water, when other conditions are same.

METHODS TO REDUCE EVAPORATION

Covering the Water Surface:

- By Covering the surface of water bodies with fixed or floating covers considerably retards evaporation loss. These covers reflect energy inputs from atmosphere, as a result of which evaporation loss is reduced.
- The covers literally trap the air and prevent transfer of water vapor to outer atmosphere.

- It is reported that floating spheres of a polystyrol reduced evaporation to 80% in small experimental tanks.

Wind Breakers:

- Wind is one of the most important factors which affect rate of evaporation loss from water surface. The greater the movement of air over the water surface, greater is the evaporation loss.
- Plants to act as wind breakers are usually arranged in rows, with tallest plants in the middle and the smallest along the end rows, so that more or less conical formation is formed.
- Plants selected as wind breakers should be capable of resisting these stresses.

Reduction of Exposed Water Surface:

- In this method shallow portions of the reservoirs are isolated or curtailed by construction of dykes or bunds at suitable locations.
- Water accumulated during the monsoon season in such shallow portions is diverted or pumped to appropriate deeper pocket in summer months, so that the shallow water surface area exposed to evaporation is effectively reduced.

Underground storages of water:

- The water can be stored underground in cavities and aquifers, where available, which do not entail higher lateral dispersion losses.
- This method has the advantage of saving valuable lands on the ground, since there is no surface submergence involved.
- The disadvantage is that the water needs to be pumped for use, which entails additional pumping costs and energy consumption.
- This method may therefore be suitable only when the economics of valuable land saved compares well with additional expenditure on pumping and energy is generally available.

Treatment with Chemical Water Evapo-Retarders (WER):

- Chemicals capable of forming a thin mono-molecular film have been found to be effective for reducing evaporation loss from water surface. The film so formed reflects energy inputs from atmosphere, as a result of which evaporation loss is reduced.
- The film allows enough passage of air through it and hence, aquatic life is not affected. The film developed by using fatty alcohols of different grades has been found most useful for control of evaporation

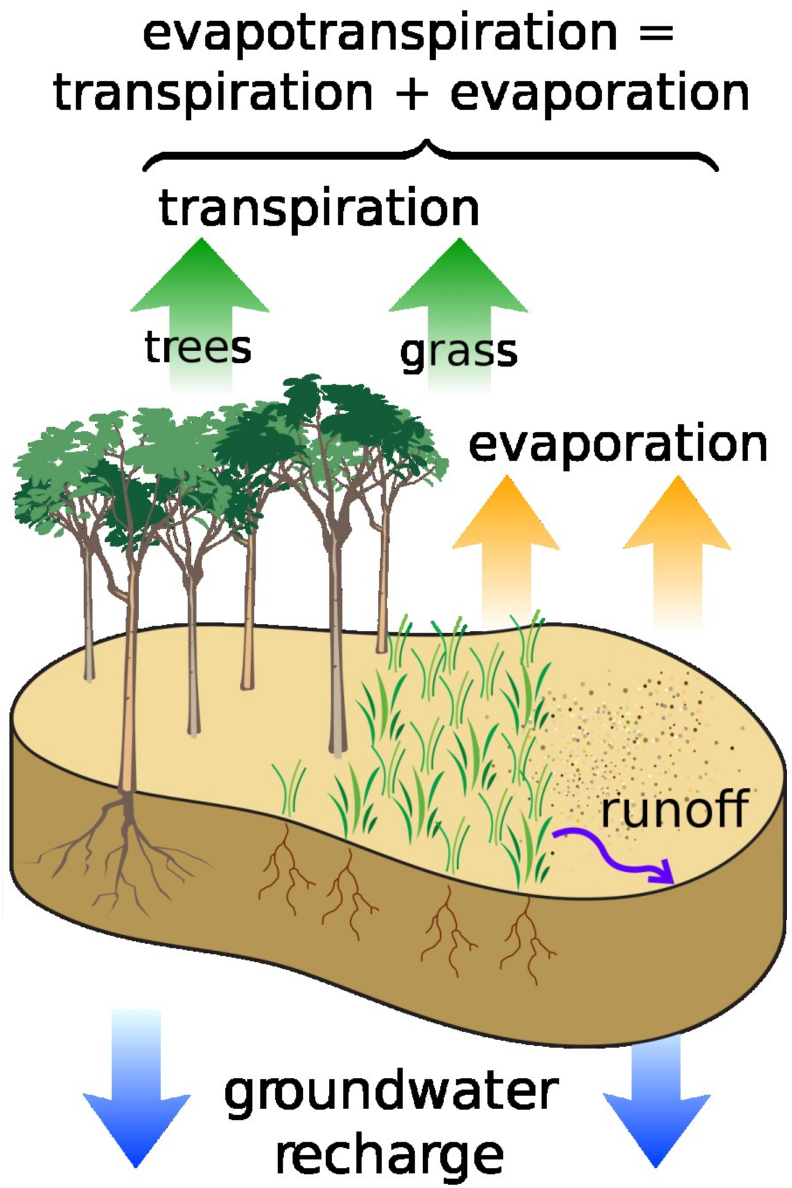
Following chemicals are generally used for water evaporation retardation:

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

What is Evapotranspiration?

Evaporation:- Evaporation is the process in which a liquid changes to the gaseous state due to increase in temperature or pressure.

Transpiration:- Transpiration is the process by which the water leaves the body of a living plant and reaches the atmosphere as water vapour. The water leaves the plant through its leaves and stomata.

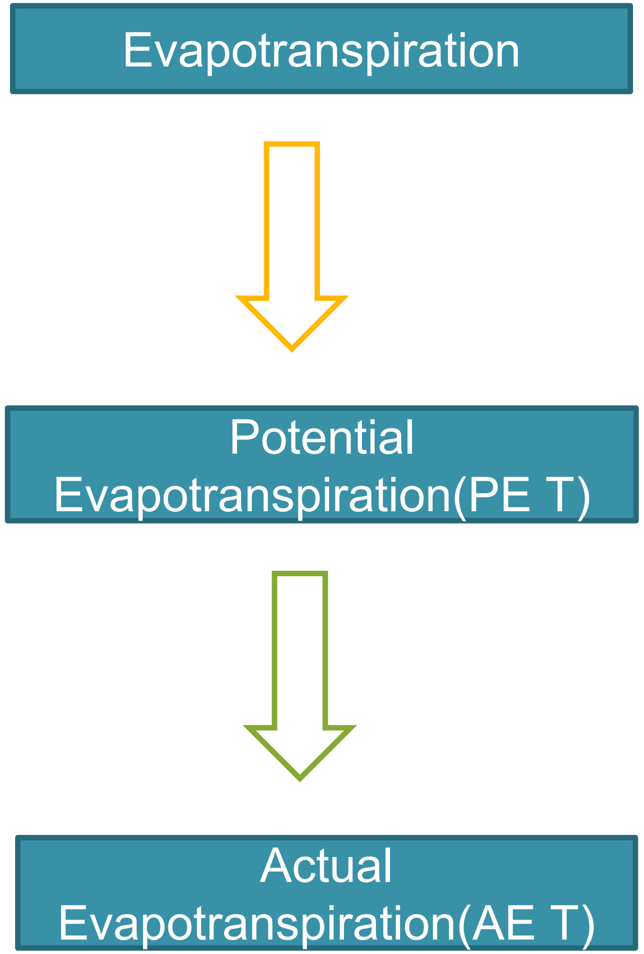


Evapotranspiration (ET): -

- When the transpiration takes place the land area in which the plants stand also loose moisture by evaporation of water. Since in process of vegetation growth it is not possible to separate the transpiration and connected evaporation from the plants surrounding .So the evaporation and transpiration are considered under one head called evapotranspiration.

Evapotranspiration can be classified as:-

- Types of Evapotranspiration:-



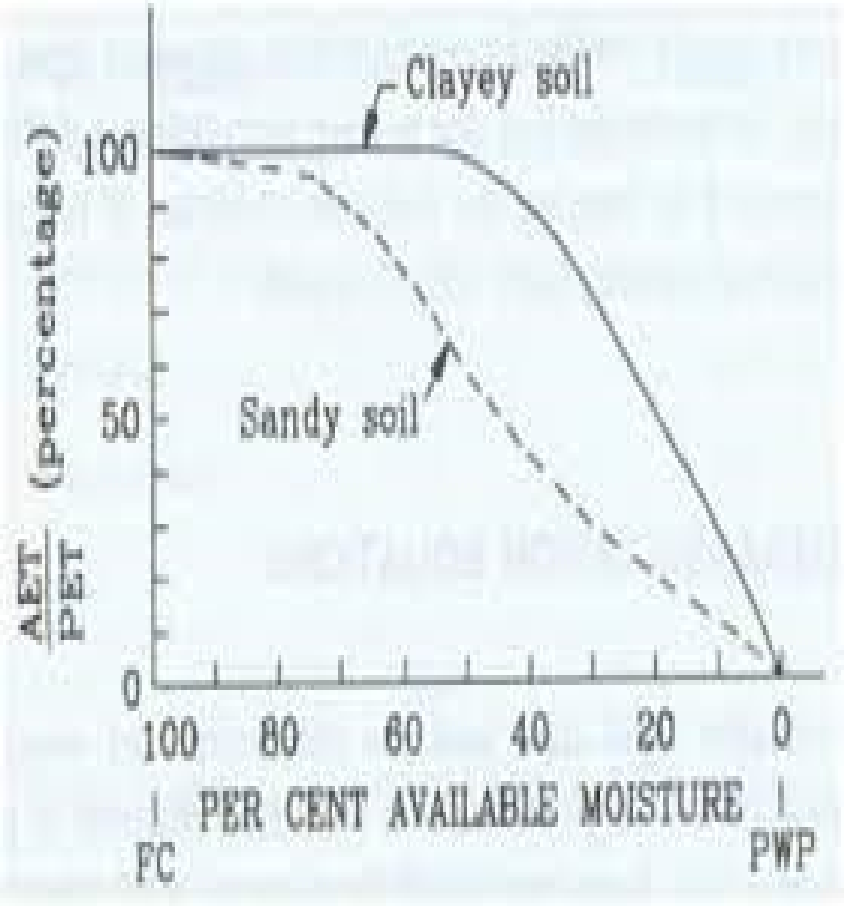
- **Potential Evapotranspiration(PET**) :-

When sufficient moisture is freely available to completely meet the needs of the vegetation fully covering the area ,the result in evapotranspiration is called Potential Evapotranspiration (PET)

- **Actual Evapotranspiration's (AET):-**
- It is the actual Evapotranspiration of a crop at particular locality and at particular time. It depends upon crop, soil ,climate and moisture condition.
- **Field Capacity**:- Field capacity 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 the soil at which the moisture is no longer available in sufficient quantity to sustain the plant .

Graph of Variation of AET :-



- If the water supply is adequate soil moisture will be at field capacity and AET/PET =1
- If water supply is less than PET the soil dries out and the ratio AET/PET will be less than unity
- For clayey soil AET/PET =1

Measurement of Evapotranspiration

- Using lysimeter
- Evapotranspiration equation
- Empirical equations

- **Using Lysimeter:-**

A lysimeter is a special water tight tank containing a block of soil and set in a field of growing plants. The plant grows in the lysimeter or same as surrounding field. The evaporation is estimated in terms of the amount of water required to maintain constant moisture condition within the tank and is measured by an arrangement made in lysimeter.

Lysimeter studies are time consuming and expensive suppose,

W_{Si} = *weight of initial setup*
W_{ad} = *initial applied water*
W_C = *Water collected at the bottom*
w_{sf} = *Weight of final setup*

Then,
$(W_{si} + W_{ad}) - (W_C + W_{sf})$ = total evaporation loses

Evapotranspiration Equation:-

- **Penman's Equation:**

This equation is based on sound theoretical reason and is obtained by the combination of energy balance equation and mass transfer method.

$$P.E.T = \frac{A_{Hn} + E_{a.\gamma}}{A+\gamma}$$

Where, PET = daily potential evapotranspiration in mm per day

A= slope of the saturation vapour pressure vs temperature curve at the mean air temperature,in mm Hg per° C

Hn= net radiation in mm of evaporable water per day

Ea= parameter including wind velocity and saturation deficit where Ea = $0.35\left(1+\frac{U_2}{160}\right)(e_W - e_a)$

γ = psychormetric constant = 0.49 mm Hg/ °C

Thornthwaite Formula :-

This formula was developed from data of eastern USA and uses only the mean monthly temperature together with the adjustment for day length. The equation is $Er = 1.6\, L_a (\, 10\, T \div It\,)^{a}$

Where,

- Er= monthly PET in cm
- La= adjustment for the number of hours of daylight and days in months related to latitude table
- T= mean monthly temperature
- It= the total of 12 monthly value of heat index and I = (T/5)1.51
- a = empirical constant

Pennman's table to find value of A and ew

able elsewhere.[2,5,7] Tables 3.3, 3.4 and 3.5 are helpful in the use of Penman's equation.

Table 3.3 Saturation Vapour Pressure of Water

Temperature (°C)	Saturation Vapour Pressure e_w (mm Hg)	A (mm/°C)
0	4.58	0.30
5.0	6.54	0.45
7.5	7.78	0.54
10.0	9.21	0.60
12.5	10.87	0.71
15.0	12.79	0.80
17.5	15.00	0.95
20.0	17.54	1.05
22.5	20.44	1.24
25.0	23.76	1.40
27.5	[illegible]	[illegible]
32.5	36.68	2.07
35.0	42.81	2.35
37.5	48.36	2.62
40.0	55.32	2.95
45.0	71.20	3.66

$$e_w = 4.584 \exp\left(\frac{17.27t}{237.3 + t}\right)$$ mm Hg, where t = temperature in °C.

- **Table for Blaney criddle and thornwaite formula for finding Ph, K, La**

Table 3.6 Monthly Daytime Hours Percentages, P_h, for use in Blaney–Criddle Formula (Eq. 3.17)

North Latitude (deg)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0	8.50	7.66	8.49	8.21	8.50	8.22	8.50	8.49	8.21	8.50	8.22	8.50
10	8.13	7.47	8.45	8.37	8.81	8.60	8.86	8.71	8.25	8.34	7.91	8.10
15	7.94	7.36	8.43	8.44	8.98	8.80	9.05	8.83	8.28	8.26	7.75	7.88
20	7.74	7.25	8.41	8.52	9.15	9.00	9.25	8.96	8.30	8.18	7.58	7.66
25	7.53	7.14	8.39	8.61	9.33	9.23	9.45	9.09	8.32	8.09	7.40	7.42
30	7.30	7.03	8.38	8.72	9.53	9.49	9.67	9.22	8.33	7.99	7.19	7.15
35	7.05	6.88	8.35	8.83	9.76	9.77	9.93	9.37	8.36	7.87	6.97	6.86
40	6.76	6.72	8.33	8.95	10.02	10.08	10.22	9.54	8.39	7.75	6.72	6.52

Table 3.7 Values of *K* for Selected Crops

Crop	Average Value of *K*	Range of Monthly Values
Rice	1.10	0.85–1.30
Wheat	0.65	0.50–0.75
Maize	0.65	0.50–0.80
Sugarcane	0.90	0.75–1.00
Cotton	0.65	0.50–0.90
Potatoes	0.70	0.65–0.75
Natural Vegetation		
(a) Very dense	1.30	
(b) Dense	1.20	
(c) Medium	1.00	
(d) Light	0.80	

Table 3.8 Adjustment Factor L_a for Use in Thornthwaite Formula (Eq. 3.18)

North Latitude (deg)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0	1.04	0.94	1.04	1.01	1.04	1.01	1.04	1.04	1.01	1.04	1.01	1.04
10	1.00	0.91	1.03	1.03	1.08	1.06	1.08	1.07	1.02	1.02	0.98	0.99
15	0.97	0.91	1.03	1.04	1.11	1.08	1.12	1.08	1.02	1.01	0.95	0.97
20	0.95	0.90	1.03	1.05	1.13	1.11	1.14	1.11	1.02	1.00	0.93	0.94
25	0.93	0.89	1.03	1.06	1.15	1.14	1.17	1.12	1.02	0.99	0.91	0.91
30	0.90	0.87	1.03	1.08	1.18	1.17	1.20	1.14	1.03	0.98	0.89	0.88
40	0.84	0.83	1.03	1.11	1.24	1.25	1.27	1.18	1.04	0.96	0.83	0.81