ENGINEERING HYDROLOGY

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UNIT-I

1) **Introduction:** Engineering hydrology, hydrological cycle, hydrological equation, Importance of temperature, wind and humidity in hydrological studies.

2) **Precipitation:** Definition, types and forms of precipitation, factors affecting precipitation, measurement of precipitation (using rainguages & analytical methods), optimum number of rain gauge stations, radar measurement of rainfall, mass curves, data missing records. Intensity-Duration-Frequency and Depth-Area-Duration analysis.

UNIT-II

1) **Infiltration:** Definition, mechanism, factors affecting Infiltration & Infiltration indices.

2) **Evaporation:** Definition, mechanism, factors affecting evaporation, estimation of evaporation (instrumental & analytical) & evaporation control.

3) **Transpiration:** Definition, mechanism, factors affecting transpiration, its measurement and control.

4) **Evapotranspiration** & Its measurement.

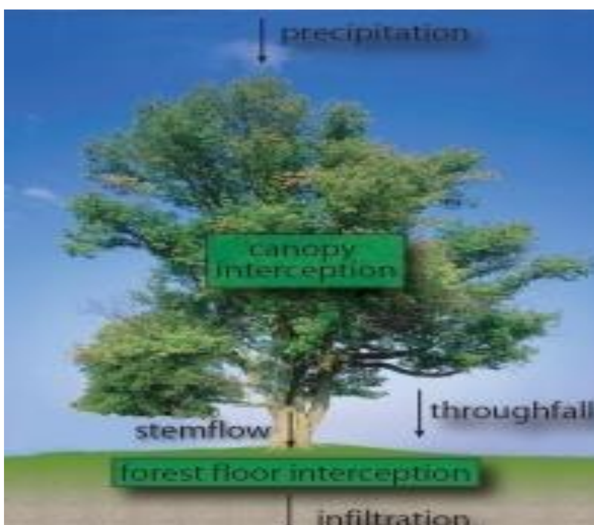
5) **Interception** and its measurement.

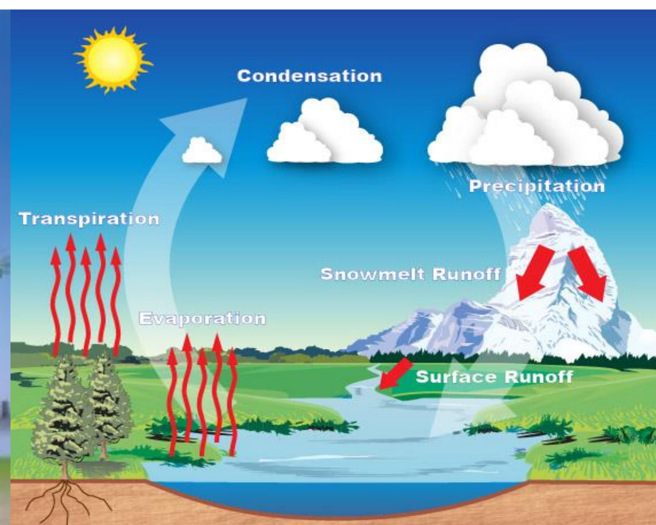
Text Books & Reference Books

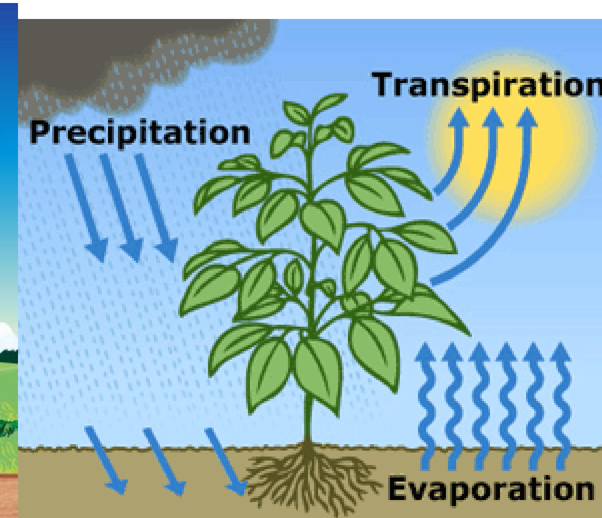
1) Ojha, C.S.P., Berndtsson, R., & Bhunya, P., Engineering Hydrology, Oxford University Press.
2) Raghunath H.M., Hydrology, New Age International Publishers.
3) Reddy R., Hydrology, Tata McGraw-Hill New Delhi.
4) Linsley, R.K.,Kohler, M.A. and Paulhas, Hydrology for Engineers, Tata McGraw-Hill Publishing Company Limited.
5) Todd, D.K., Ground Water Hydrology, John Wiley & Sons.
6) Subramnaya, K., Engineering Hydrology, Tata McGraw-Hill Publishing Company Limited.
7) Sharma R.K. & Sharma T.K., Hydrology & Water Resources Engineering, Dhanpat Rai Publications.

Abstraction from Precipitation

1) In Engg. Hydrology, **runoff** is the prime subject of study.
2) Rainfall is lost through various processes such as **Evaporation, Transpiration, Interception, Depression Storage & infiltration.**
3) **Interception** is the process of interrupting the movement of water. It can take place by vegetal cover or depression storage in puddles and in land formations such as rills and furrows.
4) **Transpiration** is evaporation of water from plant leaves & branches.
5) **Evapo-transpiration** is the sum of evaporation and transpiration.

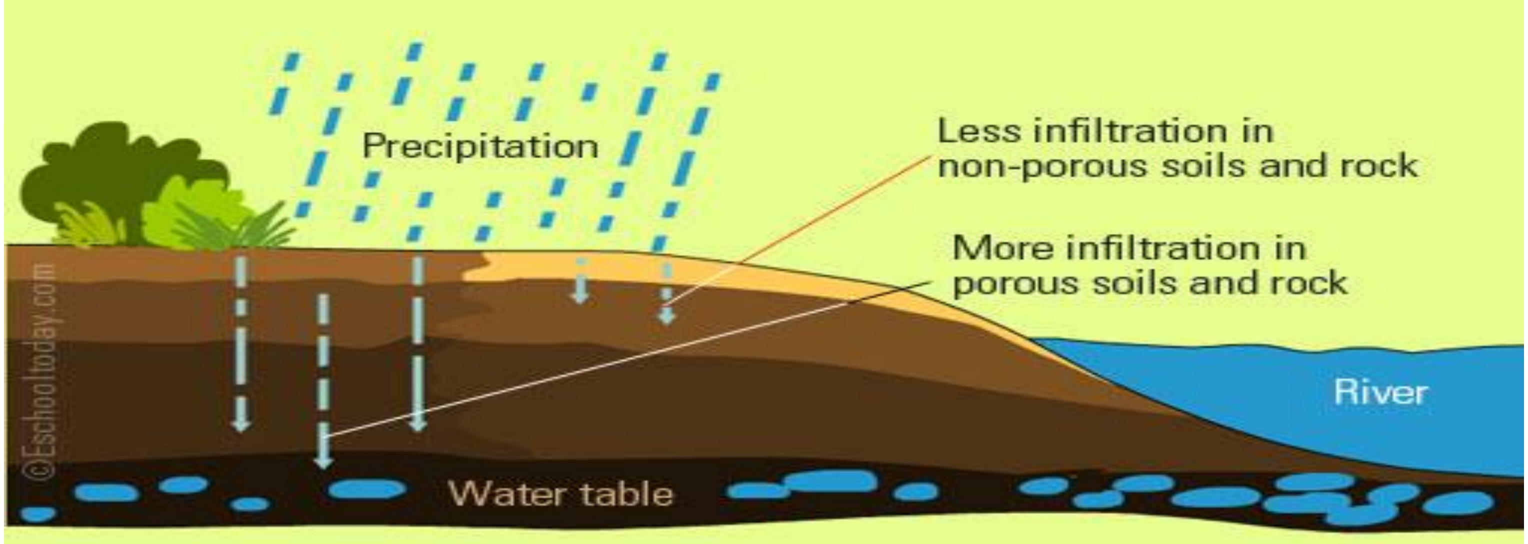






Infiltration:-

1) **Infiltration is** the process by which precipitation (water) moves downward through the surface of the earth & replenish soil moisture, recharge aquifer & ultimately support stream flow during dry season.
2) Rainfall – Infiltration – Interception – Evaporation – Depression Storage = **Runoff**
3) During major storm, losses are negligible Hence we can say, Rainfall = Runoff
4) **Infiltration** is the physical process involving movement of water through the boundary area where the atmosphere interfaces with the soil. (upper layer)
5) **Percolation** is the movement of water though the soil, and it's layers, by gravity and capillary forces. (from one layer to other layer of soil)



Factors Affecting Infiltration:-

1) **Moisture content of soil:** if the soil moisture contained in the soil is greater, the rate of infiltration is less.
2) Resistance to flow is proportional to the thickness of saturated layer, as thickness of saturated layer increases, resistances also increase & thereby infiltration decreases.
3) As **rainfall intensity** increase, infiltration is also increases till infiltration capacity but If rainfall intensity is more than infiltration capacity then infiltration reduces due to compaction of soil by drops.
4) **Soil Porosity:-** Infiltration rate increases with porosity.
5) **Surface cover :-** vegetation cover over the soil surface increases infiltration rate.
6) **Temperature:-** at high temp., viscosity is low, therefore infiltration rate is high.
7) **Entrapped air:-** presence of entrapped air in the soil pores increases the resistance to flow, therefore reduces the infiltration rate.
8) Characteristics of Soil or types of soil.

1) **Infiltration capacity:-** maximum rate at which rain can be absorbed by a soil in a given condition.

2) Infiltration Rate:- it is the actual rate of infiltration, which is smaller than or equal to infiltration capacity.

3) Infiltration rate is equal to the infiltration capacity only when the rainfall intensity equals or exceeds the infiltration capacity.

4) Infiltration capacity or amount of infiltration depends on Soil type, Surface of entry & Fluid characteristics.

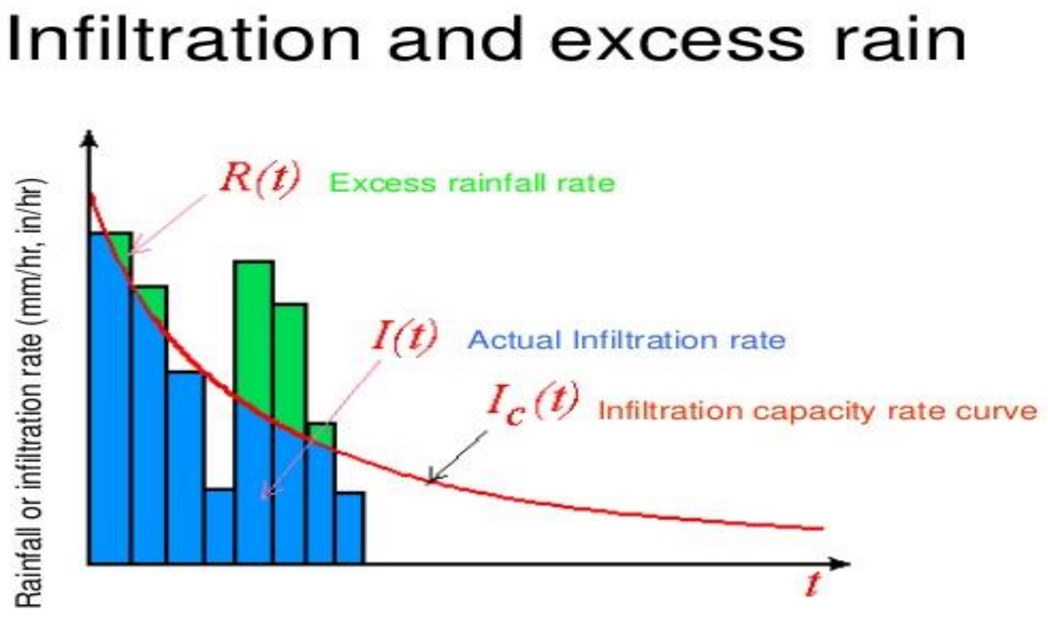
5) $f \leq fc$ when $i \geq fc$

6) $f < fc$ when $i < fc$

fc = infiltration capacity (cm/hr

i = intensity of rainfall (cm/hr)

f = rate of infiltration (cm/hr) M

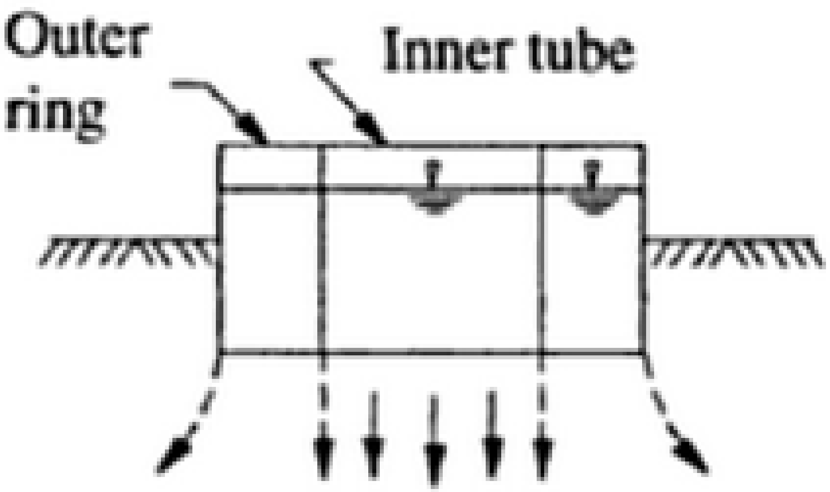


Measurement of Infiltration:-

1) Infiltration characteristics of a soil, at a given location, can be obtained by conducting controlled experiments on small areas.
2) The experimental setup is called as infiltrometer & they are two types (Flooding Type Infiltrometer & Rainfall Infiltrometer)
3) Infiltrometer is a device by which rate Of infiltration into soil is determined.

Flooding Type Infiltrometer:-

1) Water is applied by flooding the soil surface without disturbing the soil structure.
2) It gives comparatively higher infiltration rate.
3) Metal cylinder is driven into the ground to a depth of 50 cm in single & 15-25cm in Double ring.
4) Water is poured into the top part to a depth of 5 cm & pointer is set to mark the water level.
5) As infiltration proceeds, the volume is made up by adding water from a burette to keep the water level at the tip of pointer.
6) Knowing the water volume added at different time intervals, the plot of infiltration capacity vs time is obtained.



Single Ring

Double Ring

Sprinkling Type Infiltrometer or Rainfall Simulator:-

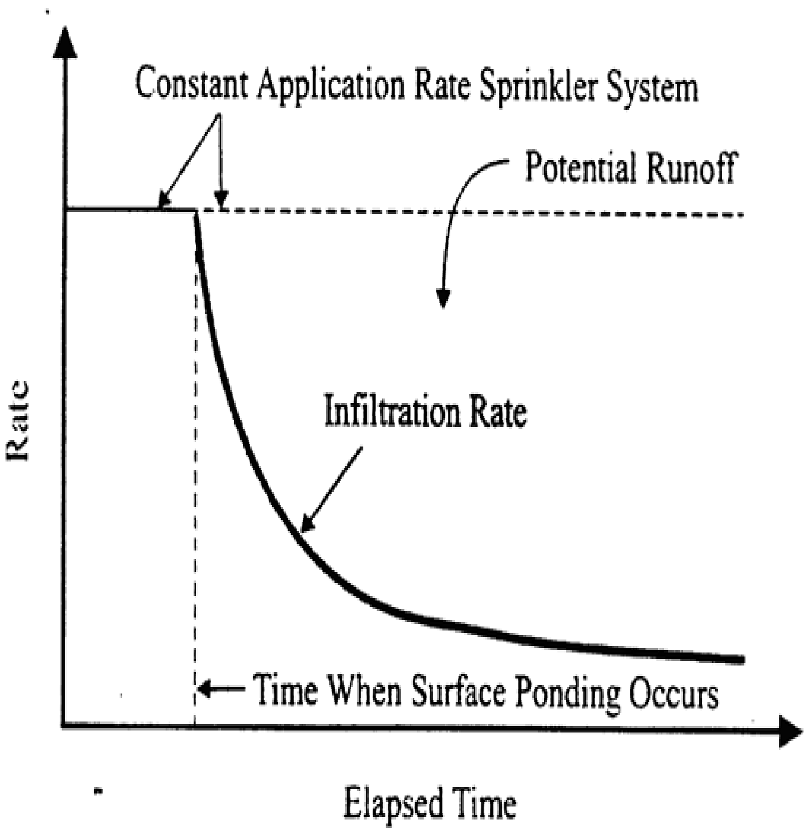
1) To eliminates the drawbacks of flooding type infiltrometer, this infiltrometer is used.
2) Small plot of land about 2 x 2m size is used & water is applied by sprinkling at a uniform rate that is generally in excess of infiltration capacity.
3) Specially design nozzles produce raindrops falling from a height of 2m.
4) Using water budget equation, infiltration is estimated.
5) This gives lower value than flooding type infiltrometer due to the effect of rainfall impact & turbid water.
6) This is of two types type F & type $F_{A.}$ (F is used for greater accuracy)

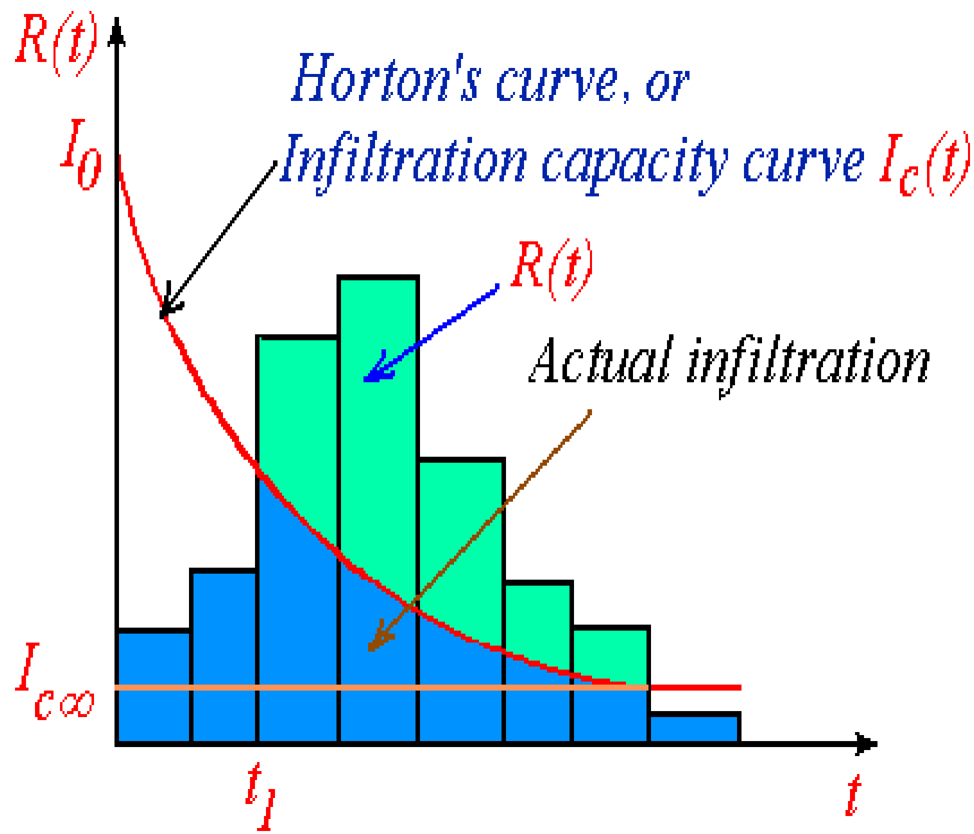
Horton Infiltration Equation:-

$f = fc + (f_0 - fc)\, e^{-\alpha t}$

Where, f_0, fc & α (constant) are parameter to be estimated from the given data.

t is time from the beginning of rainfall. α





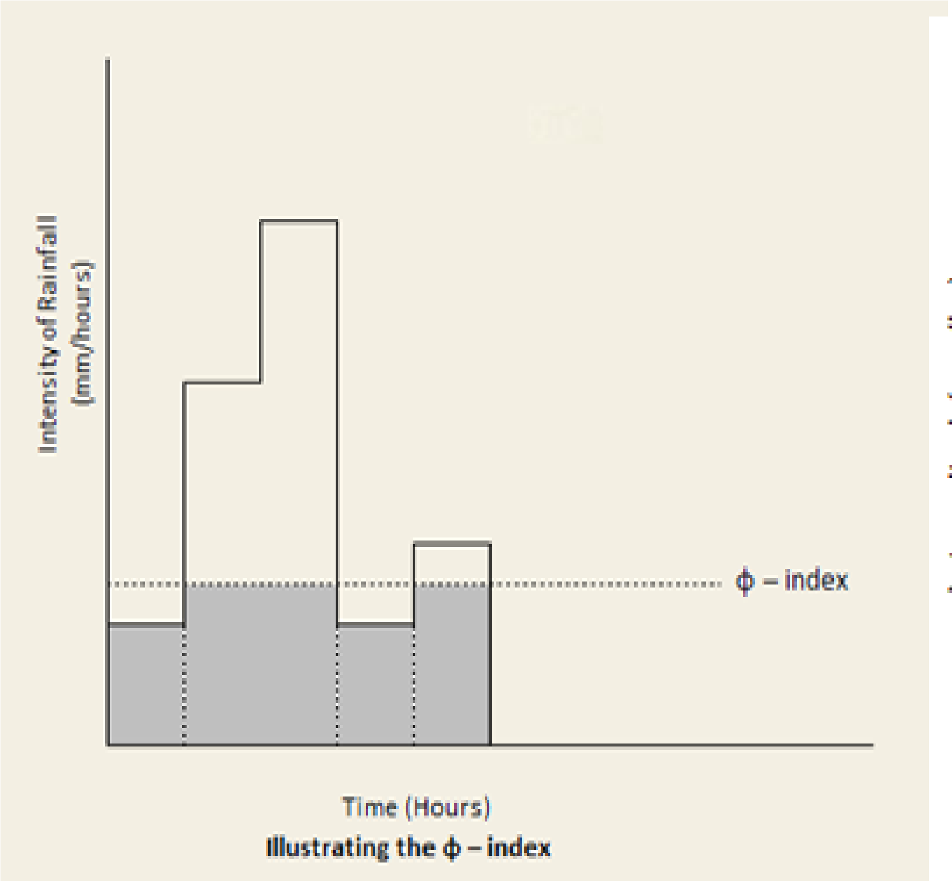
Infiltration Indices:-

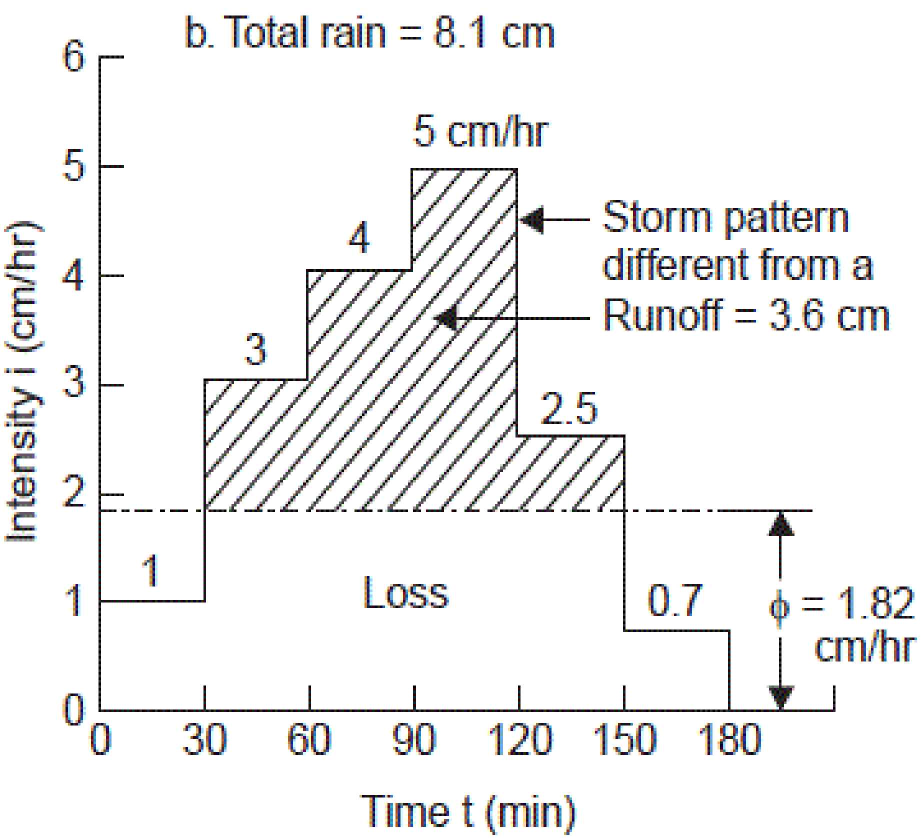
1) The average infiltration rate is called infiltration index & there are two types of indices.

Φ- Index:-

- The Φ-index is the average rainfall above which the rainfall volume is equal to the runoff volume.
- It is average infiltration rate during the period of rainfall excess.
- Rainfall excess is the rainfall contribution to runoff and the period during which such a rainfall takes place is called period of rainfall excess.
- Φ-index is derived from the rainfall hyetograph with the knowledge of the resulting runoff volume. The initial loss is also considered as part of infiltration
- If $i < \Phi$-index then $f = i$ and if $i > \Phi$-index then $f = \Phi$ (i is rainfall intensity & f is infiltration rate)
- In estimating max. flood in design purpose, Φ-index value 0.10 cm/hr can be assumed.

Rainfall intensity – Φ index = Effective rainfall intensity





Infiltration Indices:-

W- Index:-

- The W-index is a redefined version of Φ-index .
- It exclude the depression storage & interception from the total losses.
- It is the average infiltration rate during the time rainfall intensity exceeds the capacity rate.
- **W = (F / t) = (P – Q – S) / t**

F is total infiltration.

t is time during which rainfall intensity exceeds infiltration capacity.

P is total precipitation corresponding to t.

Q is the total storm runoff.

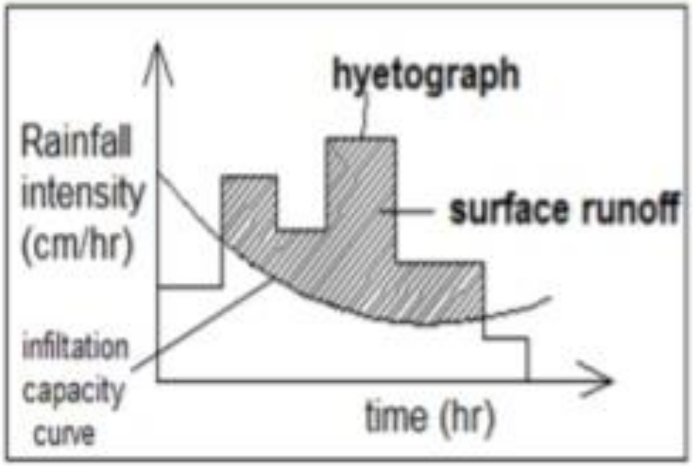
S is the volume of depression storage.

- W-index ≤ Φ-index.

Measurement of infiltration

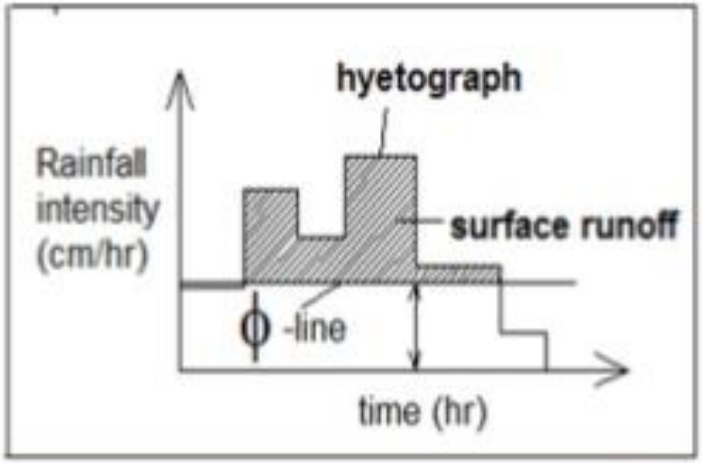
Infiltration indices

The average value of infiltration is called infiltration index.



Two types of infiltration indices

- ϕ - index
- w –index



Que. 1. The rainfall on three successive 6 hr periods are 1.3, 4.6 & 3.1 cm. If the surface runoff resulting from this storm is 3 cm what is the value of Φ-index for this storm?

Sol:-

The resulting runoff is 3 cm.

By trail & error if Φ-index is chosen to be 4.1 cm/hr.

Runoff volume above Φ-index line = Rainfall intensity – Φ index value

$$= (1.3- 4.1)x6 + (4.6-4.1)x6 + (3.1-4.1)x6$$

$$= 0 + (4.6-4.1)x6 + 0 = 3cm$$

Therefore Φ-index = 4.1 cm/hr.

Que. 2. The total observed runoff volume during a 6 hr storm with a uniform intensity of 1.5 cm/hr is 21.6x 10^6 m^3. if the area of the basin is 300 km^2, find the average infiltration rate for the basin.

Sol:-

Total Rainfall = Intensity of rainfall x Duration of rainfall = 1.5 x 6 = 9 cm.

Volume of runoff = 21.6x 10^6 m^3

Area of basin = 300 km^2 = 300 x 10^6 m^2

Depth of runoff = (21.6x 10^6) / (300 x 10^6) = 0.072 m = 7.20 cm

Depth of infiltration = depth of rainfall – depth of runoff = 9 – 7.2 = 1.8 cm

Average infiltration rate = 1.8 / 6 = 0.30 cm/hr.

Que. 3. A storm over a catchment area of 72 km^2 was observed as 2 cm / hr for 2 hr & 3 cm/hr for next 3 hr. the surface runoff was plotted on a graph paper with the scale On x-axis: 1 cm = 0.5 hr & On y-axis: 1cm = 10 m^3/s. The area under the surface runoff hydrograph was measured to be 80 cm^2. find the Φ index of infiltration.

Sol:-

For 1 cm^2 area of graph, runoff volume = 10 x 0.5 x 3600 = 18000 m^3

For 80 cm^2 = 18000 x 80 m^3

Depth of runoff = (18000 x 80) / (72 x 10^6) = 0.02 m = 2 cm.

By trail & error if Φ index is 2.33 cm / hr then runoff above Φ line :-

0 + (3-2.33) x 3 = 2 cm (observed runoff)

Hence Φ index is 2.33 cm/hr.

Que. 6. Determine the net runoff, total rainfall for the following data:-

Time of rainfall in minute	Total rainfall in cm/hr
45	3
45	3.5
45	13
45	9
45	3

Φ index = 4.0 cm/hr.

Sol:- Φ index = 4.0 cm/hr.

Net runoff = 0 + 0+ ((13 – 4) x (45/60)) + ((9-4) x (45/ 60)) + 0 = 10.5 cm

Total rainfall = (3 x (45/60)) + (3.5 x (45/60)) + (13 x (45/60)) + (9 x (45/60)) + (3 x (45/60))

= 23.625 cm

Evaporation:-

1) The process of transformation of liquid water into gaseous form is called evaporation.
2) The rate of evaporation depends on:-
    1) The vapor pressure at the water surface and air above (2.3 kPa)
    2) Air & water temperature
    3) Radiation
    4) Wind speed
    5) Atmospheric pressure (Barometric Pressure= pressure by atmosphere on water = 101.32 kPa)
    6) Quality of water
    7) Depth of water
    8) Shape & size of water body
    9) Surface area
    10) Relative Humidity.

Methods to Control Evaporation loss from Soil:-

1) Vegetation cover
2) Slope of ground surface
3) Artificial cover

Methods to Control Evaporation loss from Reservoir:-

1) Reduction in surface area
2) Mechanical cover (floating block, box, rafts, etc.)
3) Use of evaporation films (chemicals-acetyl alcohol, etc.)

Evaporation Measurement:-

1) The amount of water evaporated from a water surface is estimated by the following methods:-
    1) Using Evaporimeter data
    2) Using Empirical Evaporation Equation
    3) Analytical Methods
2) Evaporimeter are water containing pans which are exposed to the atmosphere and the loss of water by evaporation in them is measured at regular interval.

Types of Evaporimeter:-

1) Class ‘A’ Evaporation Pan (US Weather Bureau)
2) ISI Standard Pan (Used in India)
3) Colorado Sunken Pan (Pan is sunk below ground such that water level in Pan is at Ground level)
4) US Geological Survey Floating Pan.(Evaporimeter is kept floating in lake)




Evaporation Measurement:-

1) Methods of estimation of evaporation may be grouped into two categories:
   1) Empirical Formulae (Meyer's formula, Lake mead, Horton's, Rohwer's, Fitzgeralds equation)
   2) Analytical Methods(water budget method, energy balance method, mass transfer method,etc.)

Meyer's Equation:-

$$\mathbf{E_L = K_M (e_w - e_a) (1 + (u_9 / 16))}$$

E_L = Evaporation in mm / day.

K_M = 0.36 for large deep and 0.5 for shallow small water bodies.

e_w = saturated vapour pressure at the water surface in mm of mercury.

e_a= actual vapour pressure of overlaying air at a specified height in mm of mercury.

u_9 = monthly mean wind velocity in km/hr at about 9m above the ground.

$$\mathbf{u_h = C \cdot (h)^{1/7}}$$

u_h = wind velocity at a height h in meter above the ground in km/hr.

C = constant

A reservoir with surface area of 250 hectares has saturation vapour pressure at water surface = 17.24 mm of Hg and actual vapour pressure of air = 7.02 mm of Hg. Wind velocity at 1m above ground surface = 16 km/hr. Estimates the average daily evaporation from the lake using meyers formula.

Meyer's Equation:-

$$\mathbf{E_L = K_M (e_w - e_a) (1 + (u_9 / 16))}$$

E_L = Evaporation in mm / day.

K_M = 0.36 for large deep water bodies.

e_w = 17.54 = saturated vapour pressure at the water surface in mm of mercury.

e_a= 7.02 = actual vapour pressure of overlaying air at a specified height in mm of mercury.

u_9 = ? = monthly mean wind velocity in km/hr at about 9m above the ground.

$$\mathbf{u_h = C\ (h)^{1/7}}$$

u_h = wind velocity at a height h in meter above the ground in km/hr = u_1 = 16 km/hr

C = constant

$$\mathbf{(u_1 / u_9) = (C\ (1)^{1/7}) / (C\ (9)^{1/7})}$$

$$\mathbf{u_9 = 21.9\ km/hr}$$

$$\mathbf{E_L = 0.36 (17.54 - 7.02) (1 + (21.6 / 16))}$$

$$\mathbf{E_L = 8.97\ mm /day}$$

Evaporation Measurement:-

1) Methods of estimation of evaporation may be grouped into two categories:
    1) Empirical Formulae (Meyer's formula, Lake mead, Horton's, Rohwer's, Fitzgeralds equation)
    2) Analytical Methods(water budget method, energy balance method, mass transfer method,etc.)

Water Budget Equation:-

Outflow, inflow & storage are determined & mass balance equation is applied.

$$\mathbf{E = (S_1 - S_2) + I - Q}$$

E = Evaporation.

S_1 & S_2 are initial & final storage.

I = Inflow volume.

Q = Outflow volume.

The following observation were taken for a reservoir over a period of 24 hours. Spread of reservoir = 5 km^2, Average inflow = 1 m^3/s, Average outflow = 11 m^3/s, Reduction in water level of the reservoir = 20 mm, Neglecting the seepage losses from the reservoir, find the evaporation rate in cm/day/m2.

Water Budget Equation:-

$E = (S_1 – S_2) + I - Q$

$(S_1 – S_2) = (5000000 \text{ x } 0.02) \text{ m}^3 = 1000000 \text{ m}^3$

$I = (1 \text{ x } 3600 \text{ x } 24) \text{ m}^3 = 86400 \text{ m}^3$

$Q = (11 \text{ x } 3600 \text{ x } 24) \text{ m}^3 = 950400 \text{ m}^3$

$E = (1000000) + 86400 – 950400$

$E = 136000 \text{ m}^3 / \text{day}$

$E = (136000 / 5000000)\ 100 \text{ cm / day / m}^2 = 2.72 \text{ cm / day / m}^2$

A class ‘A’ pan was setup adjacent to a lake. The depth of water in the pan at the beginning of a certain week was 195 mm. In that week there was a rainfall of 45 mm and 15 mm of water was removed from the pan to keep the water level within specified depth range. If the depth of water in the pan at the end of the week was 190 mm, calculate the pan evaporation. Using a suitable pan coefficient, estimate the lake evaporation in that week.

Pan evaporation = Difference in depth of water in the pan + Depth of water removed

= (195 – 190) + 45 – 15 = 35 mm

Assuming pan coefficient = 0.80 = (Lake evaporation / Pan evaporation)

The lake evaporation in that week = 0.80 x 35 = 28 mm.

A canal is 80km long and has an average surface width of 15 m. If the evaporation measured in a class 'A' pan is 0.5 cm/day, what is the volume in cubic meters of water evaporated in a month of 30 days.

Monthly pan evaporation = 0.5 x 30 = 15 cm

Pan coefficient in class A pan = 0.8 (assume)

Monthly lake evaporation = 0.8 x 15 = 12 cm

Volume of water evaporated =

(Area of water body in m^2) x Monthly Lake Evaporation in m

= (80 x 1000 x 15) x 12 $x10^{-2}$ = 14000 m^3

Evapo-transpiration:-

1) It is a combined natural process by which water is evaporated from moist surface and transpired by plants.
2) It is also denoted as consumptive use.
3) The moisture content at which permanent wilting of plants occurs & does not recover in humid condition is called wilting point.
4) The range of soil moisture from field capacity to wilting point is called available water.
5) In a area covered with vegetation, it is difficult and also unnecessary from practical view point to separately evaluate evaporation and transpiration.
6) More convenient to estimate the evapo-transpiration directly, only those area of earths surface where no vegetation is present will purely evaporation occur.

Evapo-transpiration:-

1) If sufficient moisture is always available to completely meet the needs of vegetation fully covering area, the resulting evapo-transpiration is called Potential Evapo-Transpiration (PET).
2) The real evapo-transpiration occurring in prevailing actual condition is called actual evapo-transpiration (AET).
3) If the soil moisture capacity is at the field capacity AET = PET.
4) If he water supply is less than PET, the soil dries out & ratio AET / PET will be less than unity.
5) Ratio depends on types of soil & rate of drying.

Measurement of Evapo-transpiration:-

1) It is measured by two ways:

   1)Lysimeter (Evapo-transpirometeter(

   2)Field Experimental Plot

Thornthwaite Equation:-

$E_T = 1.6 \text{ x } La \left((10 \text{ x } T) / I_t \right)^a$

E_T = Monthly PET in cm.

La = Adjustment for the number of hours of daylight days in the month related to the latitude of place

T = Mean monthly air temperature, ^{O}C

I_t= Total of 12 monthly value of head index

$I_t = \sum I$

a = empirical constant

$= (6.75 \text{ x } 10^{-7}) I_t^3 – (7.71 \text{ x } 10^{-5}) I_t^2 + (1.792 \text{ x } 10^{-2}) I_t + 0.49239$

The mean monthly temperature in ^{O}C from January to Decmber in a year are 16.6, 18.5, 23.3, 27.6, <u>28.4</u>, 25.8, 24.4, 23.8, 23.5, 23.6, <u>20.2</u> & 17.1. Calculate the PET for the months of May & November using the Thornthwaite Equation. Day light hours for these two months as percent of the day light hours of the year are 9.3 & 7 respectively.

Monthly PET in cm, $E_T = 1.6 \times La \left((10 \times T) / I_t \right)^{a}$

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Day light hours in May = (9.3 /100) x 365 = 33.945

La = Adjustment for the number of hours of daylight days in the month related to the latitude of place = (sunshine hours in the month) / 30 = (33.945) / (30) = 1.13

The mean monthly temperature in ^{O}C from January to Decmber in a year are 16.6, 18.5, 23.3, 27.6, 28.4, 25.8, 24.4, 23.8, 23.5, 23.6, 20.2 & 17.1. Calculate the PET for the months of May & November using the Thornthwaite Equation. Day light hours for these two months as percent of the day light hours of the year are 9.3 & 7 respectively.

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Month	Mean Monthly Temp. ^{O}C	Monthly Heat Index of Jan. , $i = (t_m / 5)^{1.514}$
Jan	16.6	6.152
Feb	18.5	7.249
March	23.30	10.279
April	27.60	13.283
May	28.4	13.870
June	25.8	11.994
July	24.4	11.022
Aug	23.8	10.614
Sept	23.5	10.413
Oct	23.6	10.480
Nov	2020	8.281
Dec	17.10	6.435
		I_t = 120.072

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La = 1.13

$I_t = 120.072$

T = Mean monthly air temperature of May, ^{O}C = 28.40 ^{O}C

a= empirical constant = $(6.75 \times 10^{-7})\, I_t^3 - (7.71 \times 10^{-5})\, I_t^2 + (1.792 \times 10^{-2})\, I_t + 0.49239$

$= (6.75 \times 10^{-7}) 120.072^3 - (7.71 \times 10^{-5})\, 120.072^2 + (1.792 \times 10^{-2})\, 120.072 + 0.49239$

a = 2.7

Monthly PET in cm, $E_T = 1.6 \times La \left((10 \times T) / I_t \right)^a$

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$= (6.75 \times 10^{-7}) 120.072^3 - (7.71 \times 10^{-5})\, 120.072^2 + (1.792 \times 10^{-2})\, 120.072 + 0.49239$

a = 2.7

Monthly PET in May in cm, $E_T = 1.6 \times La\, ((10 \times T) / I_t)^{a}$

$= 1.6 \times 1.13\, ((10 \times 28.40) / 120.72)^{2.70}$

$\mathbf{E_T = 18.48\ cm}$

The mean monthly temperature in ^{O}C from January to Decmber in a year are 16.6, 18.5, 23.3, 27.6, <u>28.4</u>, 25.8, 24.4, 23.8, 23.5, 23.6, <u>20.2</u> & 17.1. Calculate the PET for the months of May & November using the Thornthwaite Equation. Day light hours for these two months as percent of the day light hours of the year are 9.3 & 7 respectively.

Similarly for November:-

T = Mean monthly air temperature of November, ^{O}C = **20.2 ^{O}C**

a= 2.7

I_t = 120.072

Day light hours in November = **(7.0** /100) x 365 = **25.55**

La = Adjustment for the number of hours of daylight days in the month related to the latitude of place = (sunshine hours in the month) / 30 = **(25.55)** / (30) = **0.852**

The mean monthly temperature in ^{O}C from January to Decmber in a year are 16.6, 18.5, 23.3, 27.6, <u>28.4</u>, 25.8, 24.4, 23.8, 23.5, 23.6, <u>20.2</u> & 17.1. Calculate the PET for the months of May & November using the Thornthwaite Equation. Day light hours for these two months as percent of the day light hours of the year are 9.3 & 7 respectively.

Similarly for November:-

T = Mean monthly air temperature of November, ^{O}C = **20.2 ^{O}C**

a= 2.7

I_t = 120.072

Day light hours in November = **(7.0** /100) x 365 x 12 = **306.6**

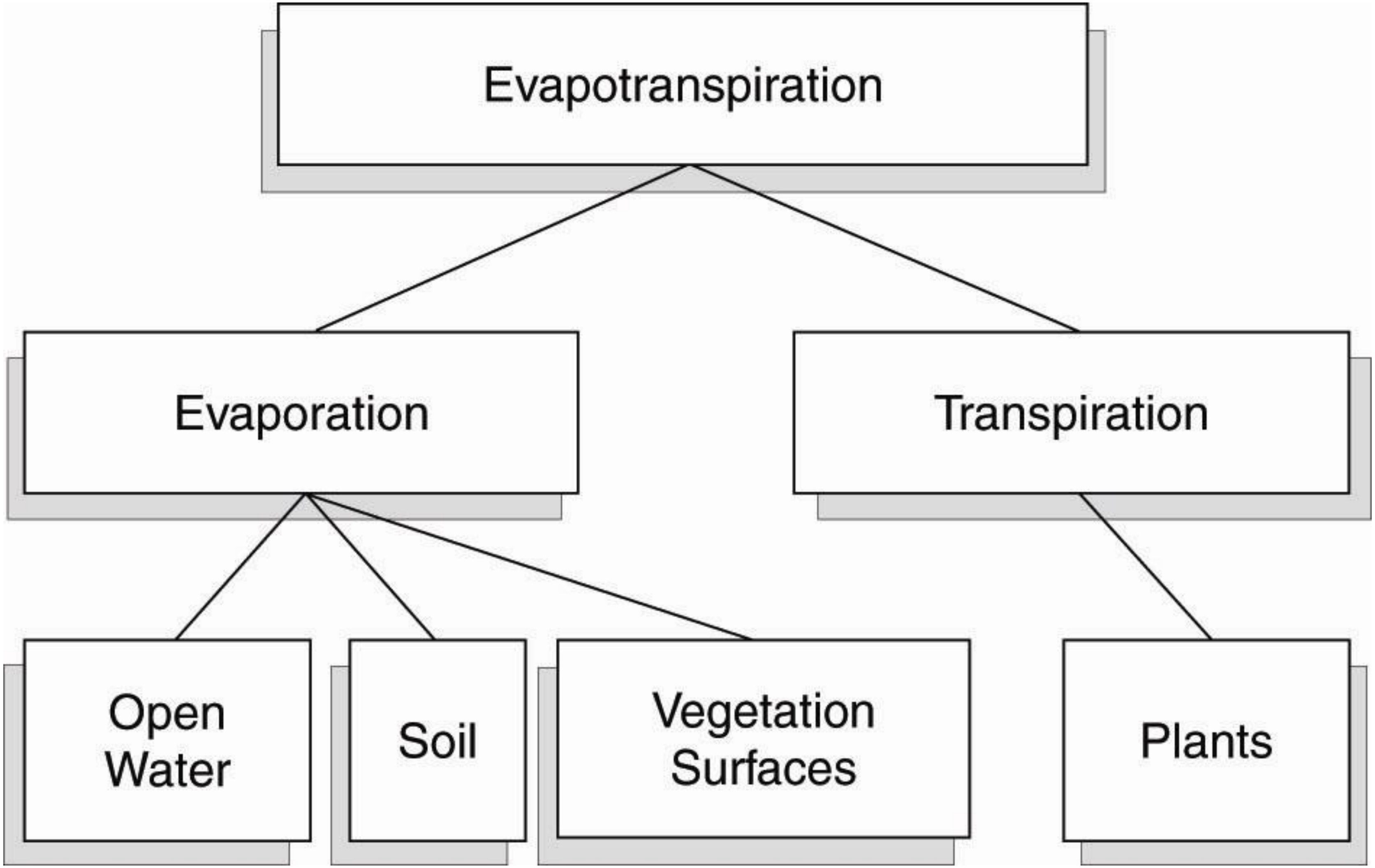
La = Adjustment for the number of hours of daylight days in the month related to the latitude of place = (sunshine hours in the month) / 12 x 30 = **(306.6)** / (12 x 30) = **0.852**

Monthly PET in cm, $E_T = 1.6 \times La\ ((10 \times T) / I_t)^{a}$

$$= 1.6 \times 0.852\ ((10 \times 20.2) / 120.72)^{2.70}$$

$$\mathbf{E_T = 5.55\ cm}$$

Evaporation & Transpiration



Evaporating playa lake with salts around margin, eastern Washington

References

1) Ojha, C.S.P., Berndtsson, R., & Bhunya, P., Engineering Hydrology, Oxford University Press
2) Raghunath H.M., Hydrology, New Age International Publishers.
3) Reddy R., Hydrology, Tata McGraw-Hill New Delhi.
4) Linsley, R.K.,Kohler, M.A. and Paulhas, Hydrology for Engineers, Tata McGraw-Hill Publishing Company Limited.
5) Todd, D.K., Ground Water Hydrology, John Wiley & Sons.
6) Subramnaya, K., Engineering Hydrology, Tata McGraw-Hill Publishing Company Limited
.
7) .Sharma R.K., Sharma T.K., Hydrology & Water Resources Engineering, Dhanpat Rai Publications.
8) https://www.geography.wikispaces.com
9) http://www.thegeographeronline.net/
10) http://www.eschooltoday.com/water-cycle/what-is-runoff-in-water-cycle.html