SYLLABUS

UNIT - II

Abstractions from precipitation: Evaporation process, evaporimeters, analytical methods of evaporation estimation, reservoir evaporation and methods for its reduction, evapotranspiration, measurement of evapotranspiration, evapotranspiration equations: Penman and Blaney & Criddle Methods, potential evapotranspiration over India, actual evapotranspiration, interception, depression storage, infiltration, infiltration capacity, measurement of infiltration, modelling infiltration capacity, classification of infiltration capacities, infiltration indices.

Run off: Components of Runoff, Factors affecting runoff, Basin yield, SCS-CN method of estimating runoff, Flow duration curves, Mass curve of runoff – Analysis, concepts of watershed management.

UNIT – II - ABSTRACTIONS AND PRECIPITATION

EVAPORATION

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

It is a continuous natural process by which substance changes from liquid to gaseous state.

Factors Affecting Evaporation

1. Temperature

- Higher temperature increases the kinetic energy of water molecules, which speeds up evaporation.
- Warm climates or summer seasons generally show higher evaporation rates.

2. Vapour Pressure

The rate of evaporation is proportional to the difference between the saturated vapour pressure at the water temperature, (e_w) and the actual vapour pressure in the air, (e_a). Thus where

EL = rate of evaporation (mm/day) and e_w and e_a are in mm of mercury. The equation is known as Dalton's Law of Evaporation after John Dalton (1802) who first recognised this law. Evaporation continues till $e_w = e_a$. If $e_w > e_a$ condensation takes place.

$$EL \; \alpha \; [e_W - e_a]$$

3. 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, any further increase in wind velocity does not influence the evaporation.

4. Soluble Salt

When a salt is dissolved in water, the vapour pressure of a solution is less than that of pure water and hence causes reduction in the rate of evaporation. The percentage reduction in evaporation approximately corresponds to the percentage increase in the specific gravity. Thus, for example, under identical conditions evaporation from sea water is about 2-3% less than that from fresh water.

5. Humidity

- Lower relative humidity increases evaporation.
- If the surrounding air is already humid, evaporation slows down.

6. Surface Area

- A larger exposed surface allows more water molecules to escape into the air.
- Shallow, wide lakes evaporate faster than deep, narrow ones.
- Area increases evaporation increases

7. 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 evaporation in winter compared to a shallow lake exposed to a similar situation. However, the effect of heat storage is essentially to change the seasonal evaporation rates and the annual evaporation rate is seldom affected.

MEASUREMENTS OF EVAPORATION

Evaporation is typically measured to understand water losses from lakes, reservoirs, and soil surfaces. Here are the most common methods/instruments used to measure evaporation.

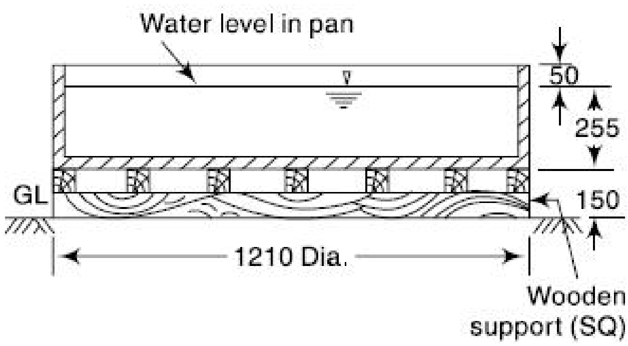
The amount of water evaporated from a water surface is estimated by the following methods: (i) Using Evaporimeter Data, (ii) Empirical Equations, and (iii) Analytical Methods.

Evaporimeter are water-containing pans which are exposed to the atmosphere and the loss of water by evaporation measured in them at regular intervals. Meteorological data, such as humidity, wind movement, air and water temperatures and precipitation are also noted along with evaporation measurement.

Many types of evaporimeters are in use and a few commonly used pans are described here.

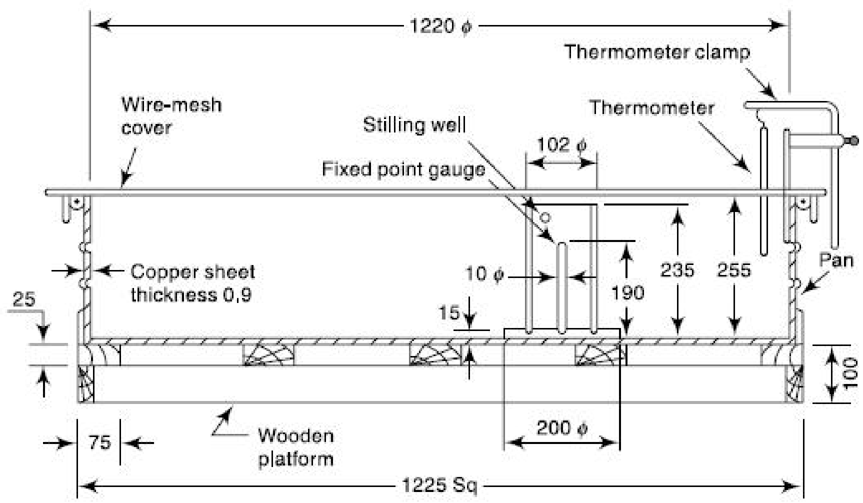
1. CLASS A EVAPORATION PAN

It is standard pan of 1210 mm diameter and 255 mm 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 galvanised iron sheet. Monel metal is used where corrosion is a problem. The pan is placed on a wooden platform of 15 cm height above the ground to allow free circulation of air below the pan. Evaporation measurements are made by measuring the depth of water with a hook gauge in a stilling well.



2. ISI STANDARD PAN

- The ISI Standard Pan, also known as the modified Class A Pan, is defined by IS: 5973–1970. It is a type of pan evaporimeter used to measure evaporation. The pan is **1220 mm in diameter** and **255 mm deep**, constructed from a **0.9 mm thick copper sheet**, tinned on the inside and painted white on the outside.
- To measure evaporation accurately, a **fixed point gauge** is used to indicate the water level, and a **calibrated cylindrical measure** is used to either add or remove water to maintain the level at a fixed point.
- The **top of the pan is completely covered with hexagonal wire netting** made of galvanized iron, which helps protect the water from birds. Additionally, a **wire mesh** is placed over the pan to keep the water temperature more uniform between day and night.
- Due to this covering, the evaporation measured from this pan is found to be about **14% less** than that from an unscreened pan.
- To facilitate air circulation below the pan, it is placed on a **square wooden platform** that is **1225 mm wide and 100 mm high**.

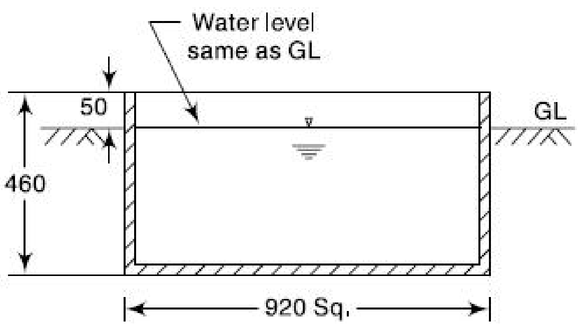


3. COLORADO SUNKEN PAN

This pan, 920 mm square and 460 mm deep is made up unpainted galvanised iron sheet and buried into the ground within 100 mm of the top. The chief advantage of the sunken pan is that radiation and aerodynamic characteristics are similar to those of the lake. However, it has the following disadvantages: (i) difficult to detect leaks, (ii) extra care is needed to keep the surrounding area free from tall grass, dust, etc., and (iii) expensive to instal.

4. US GEOLOGICAL SURVEY FLOATING PAN

With a view to simulate the characteristics of a large body of water, this square pan (900 mm side and 450 mm depth) supported by drum floats in the middle of a raft (4.25 m x 4.87 m) is set afloat in a lake. The water level in the pan is kept at the same level as the lake leaving a rim of 75 mm. Diagonal baffles provided in the pan reduce the surging in the pan due to wave action. Its high cost of installation and maintenance together with the difficulty involved in performing measurements are its main disadvantages.



PAN COEFFICIENT (C_p)

Evaporation pans are **not exact models** of large water bodies like lakes or reservoirs, and they come with some **drawbacks**, as listed below:

1. **Heat-Storing Capacity and Heat Transfer**: Pans differ from natural reservoirs in terms of how they store and transfer heat through the sides and bottom.
    - **Sunken** and **floating pans** are used to reduce this issue.
    - The evaporation rate from a pan also depends on its **size**. For example:
        - A **3-meter** diameter pan gives values close to those of nearby lakes.
        - A **1-meter** diameter pan shows about **20% more evaporation** than the 3-meter one.
2. **Effect of Pan Rim Height**
    - The **rim height** affects how wind acts over the water surface.
    - It also casts **shadows**, which can vary in size and reduce solar radiation reaching the water.
3. **Material Differences**
    - The **pan material** (usually metal) has different heat-transfer properties than natural reservoirs, affecting evaporation.

Why Use a Pan Coefficient?

Because of the above limitations, the **evaporation observed from a pan** is corrected to estimate the **actual evaporation from a lake or reservoir** under similar weather conditions.

This is done using the **Pan Coefficient (C_p)**, defined as:

$$\boxed{\text{Lake Evaporation} = C_p \times \text{Pan Evaporation}}$$

Values of Pan Coefficient C_p

S.No.	Types of pan	Average value	Range
1.	Class A Land Pan	0.70	0.60–0.80
2.	ISI Pan (modified Class A)	0.80	0.65–1.10
3.	Colorado Sunken Pan	0.78	0.75–0.86
4.	USGS Floating Pan	0.80	0.70–0.82

EVAPORATION STATIONS

It is usual to install evaporation pans in such locations where other meteorological data are also simultaneously collected. The WMO recommends the minimum network of evaporimeter stations as below:

1. Arid Zones – One station for every 30,000 km^2
2. Humid temperature climates – One station for every 50,000 km^2, and
3. Cold regions – one station for every 100,000 km^2

1. **A class A pan was set up 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 the specified 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 lake evaporation in that week.**

   Given:

   Initial depth of water in pan = 195 mm

   Rainfall = 45 mm

   Removal of water = 15 mm

   Depth of water in pan at the end of week = 190 mm

   Cp for Class A pan = 0.7

   Solution:

   Total water in pan = 195 + 45

   = 240 mm

   Water remaining after removal = 240 – 15

   = 225 mm

   Water evaporated = 225 – 190

   = 35 mm

Lake Evaporation = Cp x Pan Evaporation

= 0.7 x 35

= 24.50 mm

2. **A Class A pan was set up adjacent to a lake. The depth of water in the pan at the beginning of a certain week was 200 mm. During that week, there was a rainfall of 50 mm, and 20 mm of water was removed from the pan to maintain the water level within the specified range. If the depth of water in the pan at the end of the week was 193 mm, calculate the pan evaporation. Using a suitable pan coefficient, estimate lake evaporation during that week.**

Given:

Initial depth of water in pan = 200 mm

Rainfall = 50 mm

Removal of water = 20 mm

Depth of water in pan at the end of week = 193 mm

Cp for Class A pan = 0.7

Solution:

Total water in pan = 200 + 50

= 250 mm

Water remaining after removal = 250 – 20

= 230 mm

Water evaporated = 230 – 193

= 37 mm

Lake Evaporation = Cp x Pan Evaporation

= 0.7 x 37

= 25.90 mm

3. **An ISI Standard Pan was set up near a reservoir. The depth of water in the pan at the beginning of a certain week was 210 mm. During the week, there was a rainfall of 40 mm, and 10 mm of water was removed from the pan to maintain the permissible level. If the depth of water in the pan at the end of the week was 202 mm, calculate the pan evaporation. Using a suitable pan coefficient, estimate the evaporation from the reservoir for that week.**

Given:

Initial depth of water in pan = 210 mm

Rainfall = 40 mm

Removal of water = 10 mm

Depth of water in pan at the end of week = 202 mm

Cp for ISI Standard pan = 0.8

Solution:

Total water in pan = 210 + 40

= 250 mm

Water remaining after removal = 250 – 10

= 240 mm

Water evaporated = 240 – 202

= 38 mm

Lake Evaporation = Cp x Pan Evaporation

= 0.8 x 38

= 30.40 mm

EMPIRICAL EVAPORATION EQUATIONS

A large number of empirical equations are available to estimate lake evaporation using commonly available meteorological data. Most formulae are based on the Dalton type equation and can be expressed in the general form

$$E_L = Kf(u)(e_w - e_a) \qquad \text{---------------------------- (1)}$$

Where,

E_L = Lake evaporation (in mm/day)

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

e_a = Actual vapour pressure of overlying air at a specified height in mm of mercury

f_u = Wind speed correction function

K = Coefficient

Two commonly used empirical evaporation formulae are:

1. Meyer's Formula (1915)

$$E_L = K_M(e_w - e_a)\left(1 + \frac{u_9}{16}\right) \qquad \text{---------------------------- (2)}$$

in which E_L, e_w, e_a are as defined in Eq. (1), u_0 = monthly mean wind velocity in km/h at about 9 m above ground and K_M = coefficient accounting for various other factors with a value of 0.36 for large deep waters and 0.50 for small, shallow waters.

2. Rohwer's Formula (1931)

Rohwer's formula considers a correction for the effect of pressure in addition to the wind-speed effect and is given by:

$$E_L = 0.771(1.465 - 0.000732\, p_a)(0.44 + 0.0733\, u_0)(e_w - e_a) \quad \text{--- (3)}$$

in which E_L, e_w, e_a are as defined in Eq. (1),

p_a= mean barometric reading in mm of mercury

u_0 = mean wind velocity in km/h at ground level, which can be taken to be the velocity at 0.6 m height above ground.

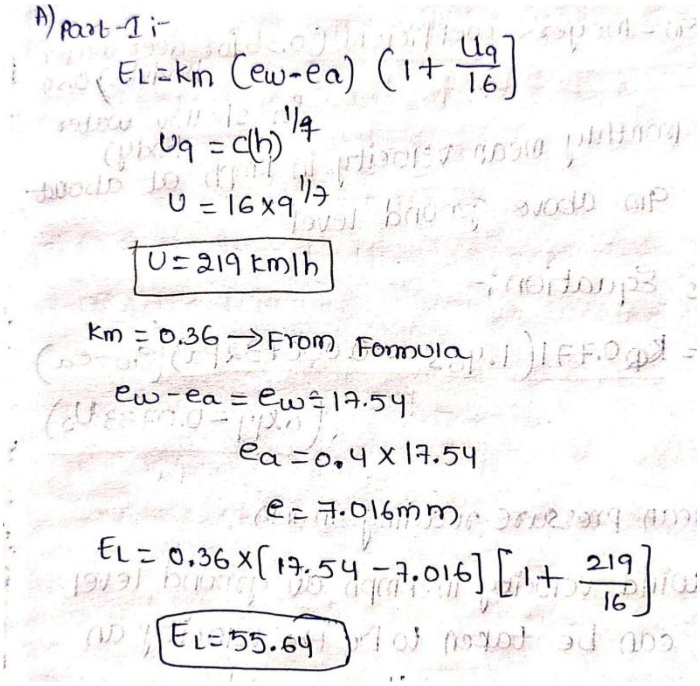
<u>**Difference between Meyer's and Rohwer's Formula**</u>

Aspect	Meyer's Formula (1915)	Rohwer's Formula (1931)
Formula	$E_L = K_M(e_w - e_a)\left(1 + \frac{u_9}{16}\right)$	$E_L = 0.771(1.465 - 0.000732\,p_a)(0.44 + 0.0733\,u_0)(e_w - e_a)$
Primary Factors	Difference between saturated and actual vapour pressures, wind speed	Same as Meyer's but also includes barometric pressure correction
Wind Speed Term	$\left(1 + \frac{u_9}{16}\right)$	$(0.44 + 0.0733\,u_0)$
Pressure Correction	Not included	$(1.465 - 0.000732\,p_a)$
Coefficient	K_M depends on water body size: 0.36 for large deep waters, 0.50 for small shallow waters	Fixed coefficient: 0.771
Wind Speed Measurement Height	Measured at ~9 m above ground	Measured at ground level (~0.6 m height)
Ease of Use	Simpler (fewer parameters)	Slightly more complex due to pressure term
Accuracy	Less accurate in areas with significant pressure variation	More accurate where pressure effects are significant
Units	E_L in mm/day, e_w, e_a in mm of Hg, u_0 in km/h	Same units as Meyer's formula
Purpose	Estimates evaporation with emphasis on wind speed influence	Estimates evaporation with both wind speed and pressure influence

1. (a) A reservoir with a surface area of 250 hectares had the following average values of parameters during a week:

- **Water temperature = 20°C**
- **Relative humidity = 40%**
- **Wind velocity at 1 m above ground = 16 km/h**

Estimate the average daily evaporation from the lake and the volume of water evaporated from the lake during that one week.



A) Part-I :-

$E_L = k_m (e_w - e_a) \left(1 + \frac{u_9}{16}\right)$

$u_9 = c(h)^{1/4}$

$U = 16 \times 9^{1/7}$

$U = 219$ km/h

$k_m = 0.36 \rightarrow$ From Formula

$e_w - e_a = e_w \doteq 17.54$

$e_a = 0.4 \times 17.54$

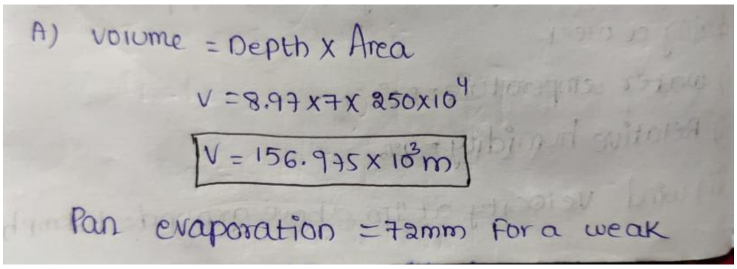
$e = 7.016$ mm

$E_L = 0.36 \times [17.54 - 7.016]\left[1 + \frac{219}{16}\right]$

$E_L = 55.64$

(b) An ISI pan at the site of Cp = 0.80, If pan indicates evaporation of 72 mm in a week:

1. **Estimate the accuracy of Meyer's method relative to the pan evaporation measurements.**
2. **Estimate the volume of water evaporated from the lake in that last week.**



A) volume = Depth x Area

$V = 8.97 \times 7 \times 250 \times 10^4$

$V = 156.975 \times 10^3 m$

Pan evaporation = 72mm for a weak

$\frac{72}{7}$ Per day = 10.28 mm per day

lake evaporation = 0.8 X 10.28

= 8.224 mm/day

ii) volume = 8.224 X 7 X 250 X 10^4

= 144.025 X 10^3 m

= 144025 m

Table 3.3 Saturation Vapour Pressure of Water

Temperature (°C)	Saturation vapour pressure e_w (mm of 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	27.54	1.61
30.0	31.82	1.85
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 of Hg, where t = temperature in °C.

2. At the beginning of a certain week, the depth of water in an evaporation pan, 1.2 m dia, was 7.75 cm. During a week, the rainfall was 2.8 cm and 2.5 cm of water was removed from the pan to keep the depth of water in it within a fixed range. At the end of the week, the gauge indicated a depth of 8.32 cm of water in the Class A pan.

Estimate the evaporation during the week from the surface of a reservoir under similar atmospheric conditions.

Given:

Initial depth of water in pan = 7.75 cm

Rainfall = 3.8 cm

Removal of water = 2.5 cm

Depth of water in pan at the end of week = 8.32 cm

Cp for Class A pan = 0.7

Solution:

Total water in pan = 7.75 + 3.8

= 11.55 cm

Water remaining after removal = 11.55 – 2.5

= 9.05 cm

Water evaporated = 9.05 – 8.32

= 0.73 cm

Lake Evaporation = Cp x Pan Evaporation

= 0.7 x 0.73

= 0.511 cm, = 5.11 mm

3. A reservoir with a surface area of 300 hectares has the following average meteorological value during a given week:

- **Water temp = 30°C**
- **Relative humidity = 50%**

- **Wind velocity at 1 m above ground = 12 km/h**
- **Mean barometric reading = 750 mm of mercury**

Estimate the average daily evaporation from the lake reservoir & volume of water evaporated from the lake during this week.

Compare results of Meyer's & Rohwer's formula.

A) Given data:-

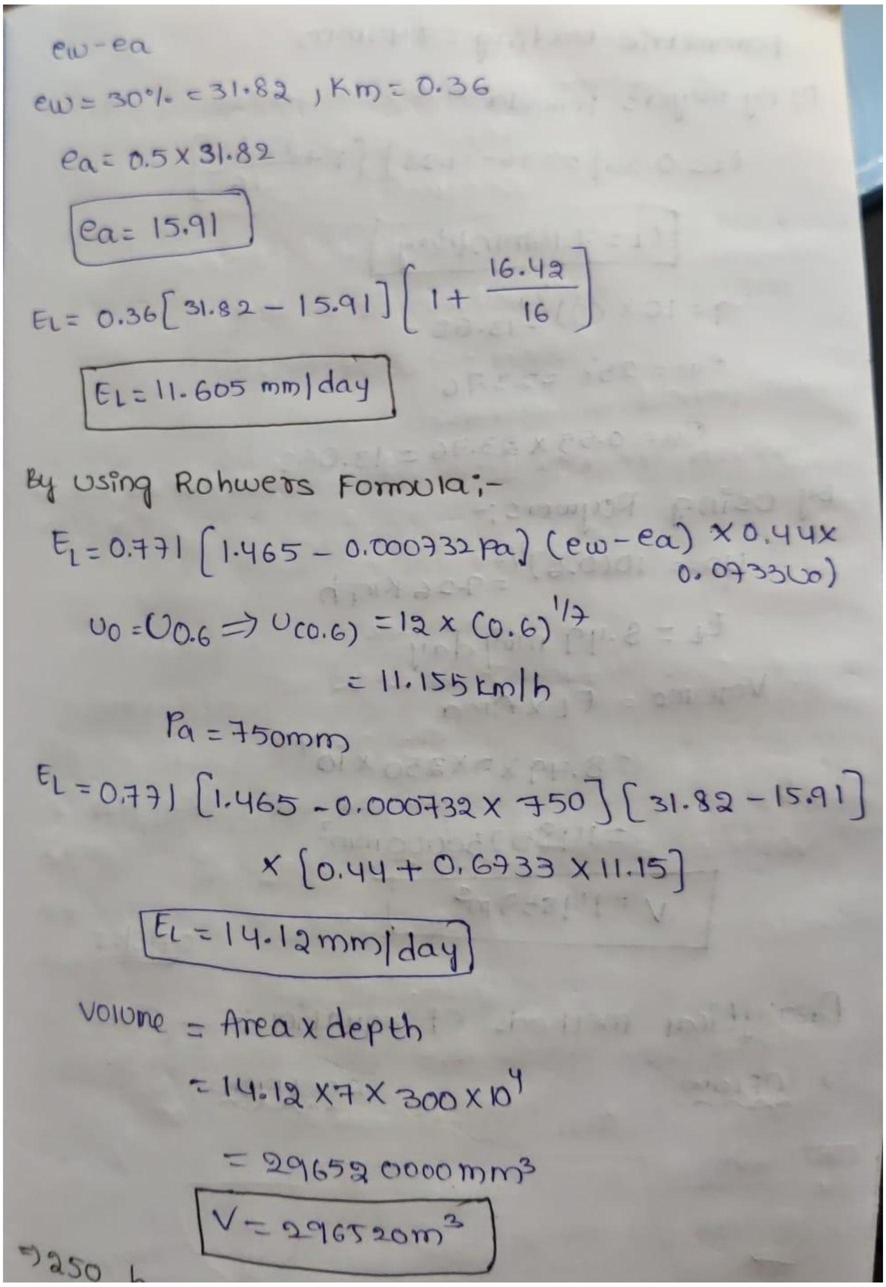
Area = 300 hectres

Using meyer's Formula:-

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

$$u_9 = C(h)^{1/7} = 12 \times 9^{1/7}$$

$$u_9 = 16.42 \text{ km/h}$$



$e_w - e_a$

$e_w = 30\% = 31.82$, $K_m = 0.36$

$e_a = 0.5 \times 31.82$

$e_a = 15.91$

$E_L = 0.36[31.82 - 15.91]\left[1 + \frac{16.42}{16}\right]$

$E_L = 11.605$ mm/day

By using Rohwers Formula:-

$E_L = 0.771\,[1.465 - 0.000732\,p_a]\,(e_w - e_a) \times 0.44 \times 0.0733 u_0)$

$u_0 = u_{0.6} \Rightarrow u_{(0.6)} = 12 \times (0.6)^{1/7}$

$= 11.155$ km/h

$p_a = 750$ mm

$E_L = 0.771\,[1.465 - 0.000732 \times 750]\,[31.82 - 15.91]$

$\times\,[0.44 + 0.6733 \times 11.15]$

$E_L = 14.12$ mm/day

Volume = Area × depth

$= 14.12 \times 7 \times 300 \times 10^4$

$= 296520000\ mm^3$

$V = 296520\ m^3$

⇒ 250 h

4. A reservoir with a surface area of 250 hectares has the following average meteorological data recorded during a certain week:

- **Water temperature = 25°C**
- **Relative humidity = 55%**
- **Wind velocity at 1 m above ground = 10 km/h**
- **Mean barometric pressure = 745 mm of mercury**

Tasks:

1. **Estimate the average daily evaporation from the lake reservoir.**
2. **Calculate the volume of water evaporated from the lake over the week.**
3. **Compare the results obtained using Meyer's formula and Rohwer's formula.**

⇒ 250 hecters = Area

water temperature = 25°c

Relative humidity = 55%

velocity = 10kmpH

barometric reading = 745mm

A) By meyer's formula

$E_L = 0.36[23.76 - 11.88]\left[1 + \frac{13.65}{16}\right]$

$E_L = 7.16 mm/day$

$U_9 = 10 \times (9)^{1/7} = 13.68$

$e_w = 25°c = 23.76$

$e_a = 0.55 \times 23.76 = 13.068$

By using Roywers;-

$U_{as} = 10(0.6)^{1/7} = 9.26 \text{ Kmph}$

$E_L = 8.49 \text{ mm/day}$

Volume = $E_L \times$ Area

$= 8.49 \times 7 \times 250 \times 10^4$

$= 14857750000 mm^3$

$V = 14857 m^3$

ANALYTICAL METHODS OF EVAPORATION ESTIMATION

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

1. Water – budget method
2. Energy – balance method
3. 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 writing the hydrological continuity equation for the lake and determining the evaporation from a knowledge or estimation of other variables. Thus considering the daily average values for a lake, the continuity equation is written as

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

Where,

P = daily precipitation

V_{is} = daily surface inflow into the lake
V_{ig} = daily groundwater inflow
V_{os} = daily surface outflow from the lake
V_{og} = daily seepage outflow
E_L = daily lake evaporation
ΔS = increase in lake storage in a day
T_L = daily transpiration loss

All quantities are in units of volume (m3) or depth (mm) over a reference area.

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

1. **A lake had a water surface elevation of 103.2 m above datum at the beginning of a certain month.**

   During that month:

- **The lake received an average inflow of 6 m^3/s from surface runoff sources.**
- **The outflow from the lake sources had an average value of 6.5 m^3/s.**
- **The lake also received rainfall of 145 mm.**
- **The evaporation from the lake surface was estimated as 6.1 cm.**

The task is to calculate the water surface elevation of the lake at the end of the month.

Additional data:

- **Lake surface area = 5000 hectares.**
- **Assume no contribution to or from groundwater storage.**

Given data:-

water surface elevation = 103.2cm

INFLOW = $6 m^3/sec$

OUTFLOW = $6.5 m^3/sec$

Precipitation P = 145mm

Evaporation "EL" = 6.1cm

Area = 5000 hectres

Time period in seconds:-

1 month how many seconds = 24 hrs x 60min x 60 sec x 30day

$= 24 \times 60 \times 60 \times 30$

$= 2.592 \times 10^6$ sec

Volume of Inflow :- $6 \times 2.592 \times 10^6$

$= 15.552 \times 10^6$

$= 15.552 \, Mm^3$ (Mm = million meter)

Volume of outflow :- $6.5 \times 2.592 \times 10^6$

$= 16.848 \times 10^6$

$= 16.848 \, Mm^3$

Volume of water due to precipitation:-

$= \frac{145}{1000} \times 5000 \times 10^4$

$= 7.25 \times 10^6$

$= 7.25 \, Mm^3$

Volume of water due to Evaporation

$= \frac{6.1}{100} \times 5000 \times 10^4$

$= 3.05 \times 10^6$

$= 3.05 \, Mm^3$

INFLOW − INFLOW = ΔS

$\Delta S = [15.552 + 7.25] - [16.848 + 3.05]$

$\boxed{\Delta S = 2.904\ Mm^3}$

$$\text{change in depth} = \frac{\text{change in Volume } (\Delta S)}{\text{Area}}$$

$$= \frac{2.904 \times 10^6}{5000 \times 10^4}$$

$$= 0.058m$$

Elevation at the end of the month = water surface elevation + change in depth

$= 103.2 + 0.058$

$= 103.258\ m$

08/8/25

2. **A small catchment of area 150 hectares receives a rainfall of 10.5 cm in 90 minutes due to a storm.**

At the outlet of the catchment:

- **The stream draining the catchment was dry before the storm.**
- **The stream experienced a runoff lasting for 10 hours with an average discharge value of 2 m^3/s.**
- **After the runoff event, the stream again became dry.**

Answer the following:

(a) What is the amount of water which is not available for runoff?

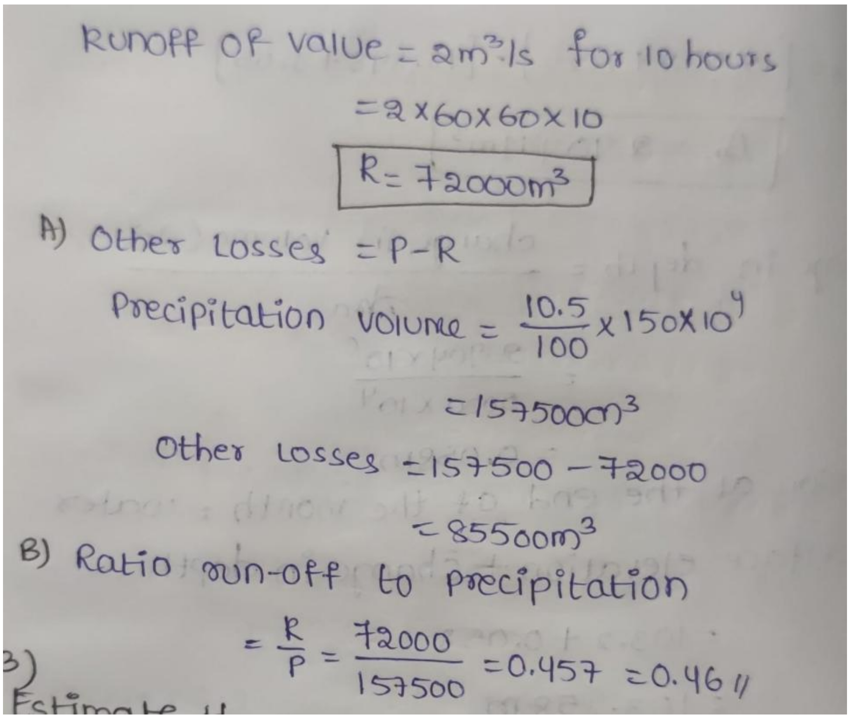
(b) What is the ratio of runoff to precipitation?

Given

Area = 150 hectors = 150 x 10^4 m^2

Rainfall = 10.5 cm

Solution



Runoff of value = $2 m^3/s$ for 10 hours

$= 2 \times 60 \times 60 \times 10$

$R = 72000 m^3$

A) Other Losses = P − R

Precipitation volume $= \frac{10.5}{100} \times 150 \times 10^4$

$= 157500 m^3$

Other losses = 157500 − 72000

$= 85500 m^3$

B) Ratio run-off to precipitation

$= \frac{R}{P} = \frac{72000}{157500} = 0.457 = 0.46$

3. **Estimate the constant rate of withdrawal from a reservoir with a surface area of 1375 hectares over a month of 30 days. During this month, the reservoir water level dropped by 0.75 meters, despite an average inflow into the reservoir of 0.5 Mm^3. During the same month, the average seepage loss from the reservoir was 2.5 cm, the total precipitation over the reservoir surface was 18.5 cm, and the total evaporation from the reservoir surface was 9.5 cm.**

Given

Area = 1375 hectors

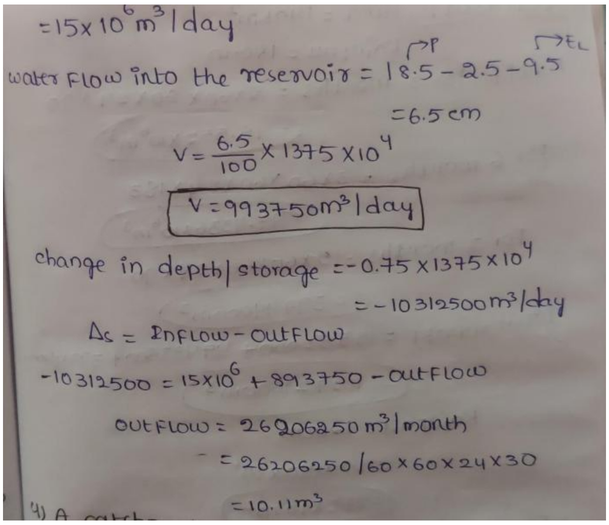
Precipitation loss = 18.5 cm

Seepage loss = 2.5 cm

Evaporation loss = 9.5 cm

Inflow = 0.5 Mm^3/day x 30

= 15 x 10^6 m^3/day



$=15 \times 10^6 \, m^3/day$

P, EL

water flow into the reservoir = 18.5 − 2.5 − 9.5

= 6.5 cm

$V = \frac{6.5}{100} \times 1375 \times 10^4$

$V = 993750 \, m^3/day$

change in depth/storage = $-0.75 \times 1375 \times 10^4$

$= -10312500 \, m^3/day$

Δs = Inflow − outflow

$-10312500 = 15 \times 10^6 + 893750 - \text{outflow}$

outflow = 26206250 m^3/month

= 26206250/60 x 60 x 24 x 30

= 10.11 m^3

4) A catch...

4. A catchment area of 140 km² received 120 cm of rainfall in a year. At the outlet of the catchment, the flow in a stream draining the catchment was found to have an average discharge of:

- **2 m^3/s for 3 months,**
- **3 m^3/s for 6 months, and**
- **5 m^3/s for 3 months.**

Tasks:

1. Find the runoff–rainfall ratio.

2. **If the runoff to rainfall ratio reduces to 0.5, determine the increase in abstraction from precipitation (due to infiltration, evaporation, and transpiration) for the same rainfall of 120 cm.**

A) Given data:- Area = 140 km^2

Rainfall = 120 cm

Runoff for 3 months = $2 \times 60 \times 60 \times 24 \times 90$

$= 15.552 \times 10^6 \, m^3$

For 6 months = $3 \times 60 \times 60 \times 24 \times 183$

$= 47.4336 \times 10^6 \, m^3$

For 3 months = $5 \times 60 \times 60 \times 24 \times 90$

$= 39744000 \, m^3$

Total runoff = $15552000 + 47433600 + 39744000$

$= 102729600 \, m^3$

Rainfall = 120 cm

$= 1.2 \times 140 \times 10^6$

$= 168 \times 10^6 \, m^3$

i) Run-off ratio:-

$= \frac{\text{Runoff}}{\text{Rainfall}} = \frac{102729600}{168 \times 10^6}$

$= 0.611$

ii) Rainfall reduce to 0.5 $= 168 \times 10^6 \times 0.5$

$= 84 \times 10^6 \, m^3$

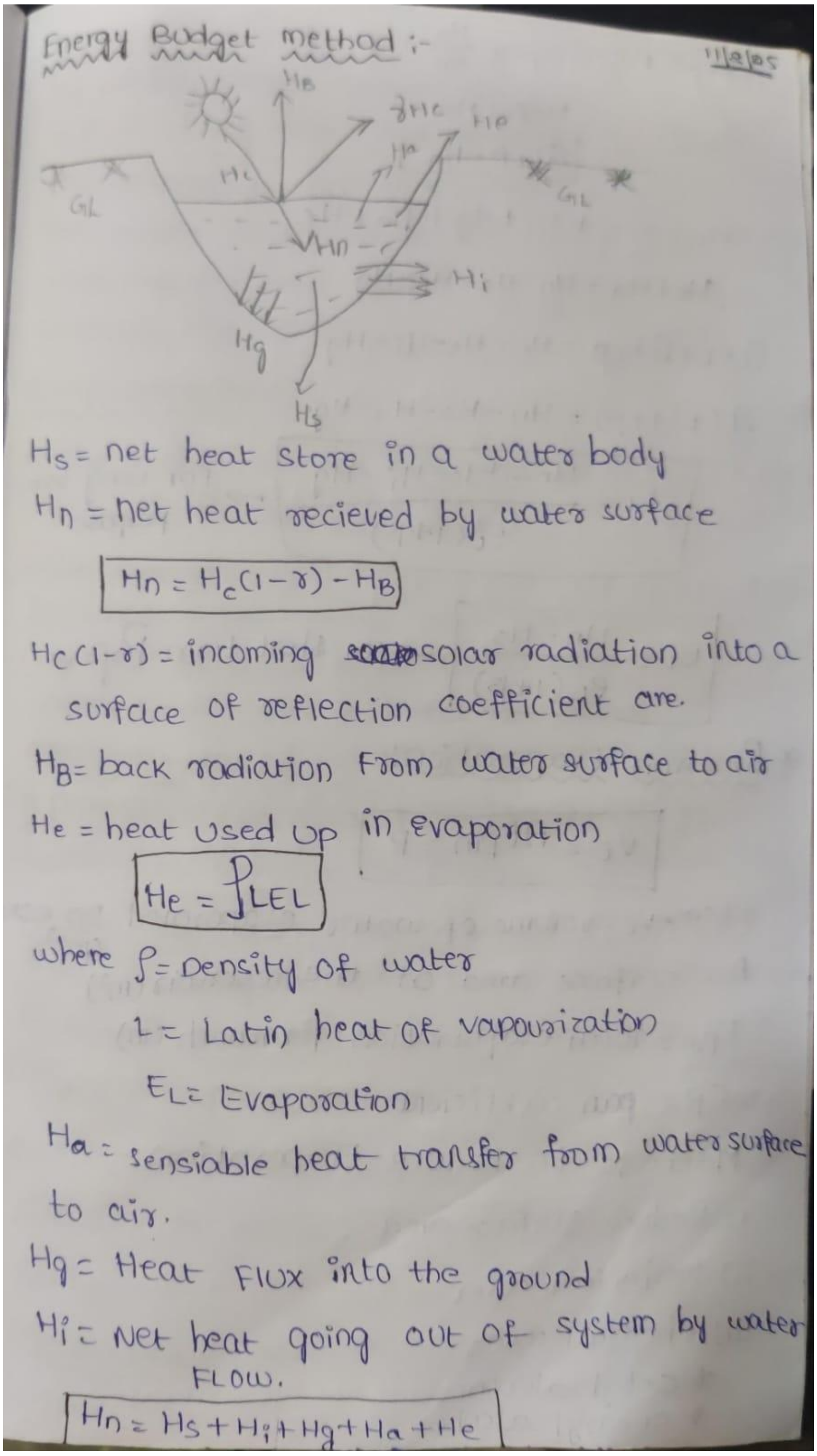
Abstraction from precipitation

$= 102729600 - 84000000$

$= 18.729 \, Mm^3$

ENERGY BALANCE METHOD

The energy – budget method is an application of the law 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 time interval.


Energy Budget method :-

H_s = net heat store in a water body

H_n = net heat recieved by water surface

$$H_n = H_c(1-r) - H_B$$

$H_c(1-r)$ = incoming solar radiation into a surface of reflection coefficient are.

H_B = back radiation from water surface to air

H_e = heat used up in evaporation

$$H_e = \rho L E_L$$

where ρ = Density of water

L = Latin heat of vapourization

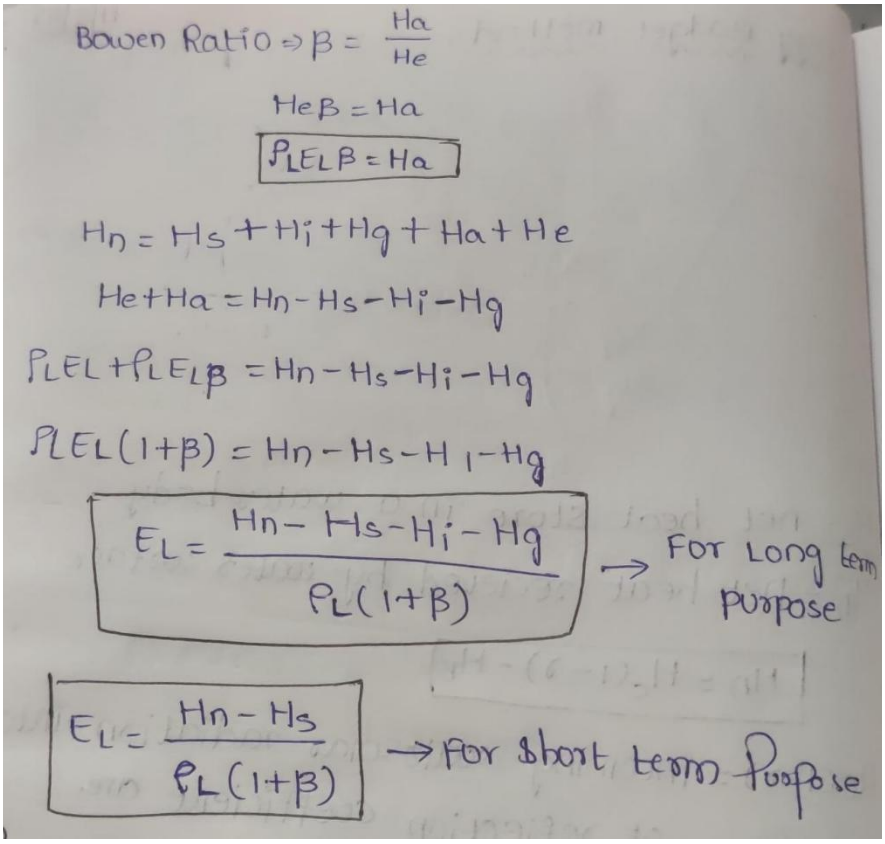
E_L = Evaporation

H_a = sensiable heat transfer from water surface to air.

H_g = Heat flux into the ground

H_i = Net heat going out of system by water flow.

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



Bowen Ratio ⇒ $\beta = \frac{H_a}{H_e}$

$$H_e \beta = H_a$$

$$\boxed{\rho_L E_L \beta = H_a}$$

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

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

$$\rho_L E_L + \rho_L E_L \beta = H_n - H_s - H_i - H_g$$

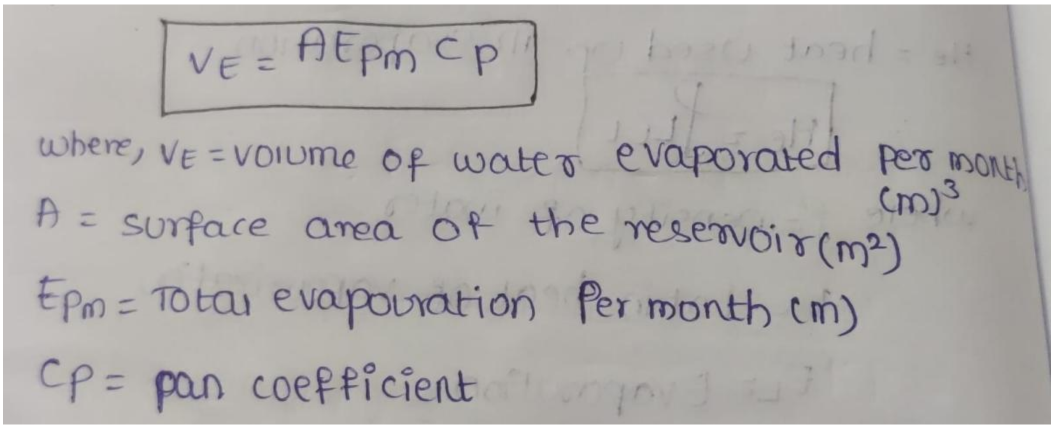
$$\rho_L E_L (1+\beta) = H_n - H_s - H_i - H_g$$

$$\boxed{E_L = \frac{H_n - H_s - H_i - H_g}{\rho_L (1+\beta)}}$$ → For Long term purpose

$$\boxed{E_L = \frac{H_n - H_s}{\rho_L (1+\beta)}}$$ → For short term Purpose

RESERVOIR EVAPORATION AND METHODS FOR ITS REDUCTION

Any of the methods mentioned above may be used for the estimation of reservoir evaporation. Although analytical methods provide better results, they involve parameters that are difficult to assess or expensive to obtain. Empirical equations can at best give approximate values of the correct order of magnitude. Therefore, the pan measurement finds general acceptance for practical application. Mean montly and annual evaporation data collected by IMD are very valuable in field estimations. The water volume lost due to evaporation from a reservoir in a month is calculated as



$$\boxed{V_E = A E_{pm} C_p}$$

where, V_E = volume of water evaporated per month $(m)^3$

A = surface area of the reservoir (m^2)

E_{pm} = Total evapouration per month (m)

C_p = pan coefficient

METHODS TO REDUCE EVAPORATION LOSSES

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

(i) Reduction of Surface Area

The amount of water lost due to evaporation is directly related to the surface area of the water body. Therefore, reducing the surface area wherever possible will reduce evaporation losses. Examples include constructing deep reservoirs instead of wide shallow ones, and eliminating shallow areas of reservoirs.

(ii) Mechanical Covers

Evaporation can also be reduced by using covers. These may include permanent roofs over reservoirs, temporary covers, floating roofs such as rafts, or even lightweight floating materials. However, these methods are practical only for small water bodies, like ponds, since they are not feasible for very large reservoirs.

(iii) Chemical Cover

- Thin chemical films (e.g., **cetyl alcohol** and **stearyl alcohol**) form a **monomolecular layer** on the water surface.
- They reduce evaporation by preventing water molecules from escaping.

Desirable features of the film:

1. Strong and flexible, resistant to wave action.
2. Self-healing if punctured by rain, birds, or insects.
3. Allows oxygen and carbon dioxide exchange → water quality unaffected.
4. Colourless, odourless, non-toxic.

Cetyl Alcohol (best choice):

- White, waxy solid; available as lumps, flakes, or powder.
- Applied as powder/emulsion/solution; requires ~ **3.5 N/hectare/day**.
- Needs replenishment (loss by oxidation, wind, insects, etc.).
- Can reduce evaporation up to **60%** in experiments; **20–50%** in field.
- Works well even in small lakes (<1000 ha).
- **Limitation** → less effective under strong winds/heavy waves.

TRANSPIRATION

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

EVAPOTRANSPIRATION

This combination of evaporation and transpiration is called as "Evapotranspiration".

While transpiration takes place, the land area in which plant stand also lose moisture by the evaporation of water from soil and water bodies, hence these two terms are combine called as "evapotranspiration"

POTENTIAL EVAPOTRANSPIRATION (PET)

If sufficient moisture is always available to completely meet the need of vegetation fully covering the area, the resulting evaporation is called "Potential Evapotranspiration."

ACTUAL EVAPOTRANSPIRATION (AET)

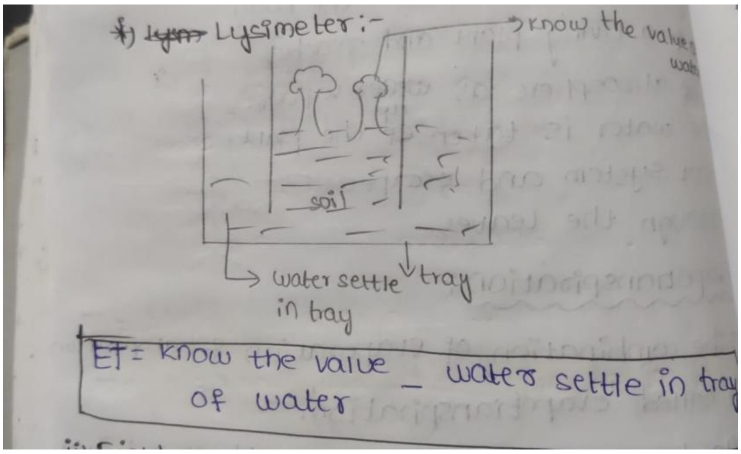
The real evapotranspiration occurring in a specific situation is called “Actual Evapotranspiration.”

MEASUREMENT OF EVAPOTRANSPIRATION

The measurement of evapotranspiration for a given vegetation type can be carried out in two ways: either by using lysimeters or by the use of field plots

LYSIMETERS

A lysimeter is a special watertight 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 surrounding field. Evapotranspiration is estimated in terms of the amount of water required to maintain constant moisture conditions within the tank, measured either volumetrically or gravimetrically through an arrangement made in the lysimeter. Lysimeters should be designed to accurately reproduce the soil conditions, moisture content, type and size of the vegetation of the surrounding area. They should be so buried that the soil is at the same level inside and outside the container. Lysimeter studies are time-consuming and expensive.

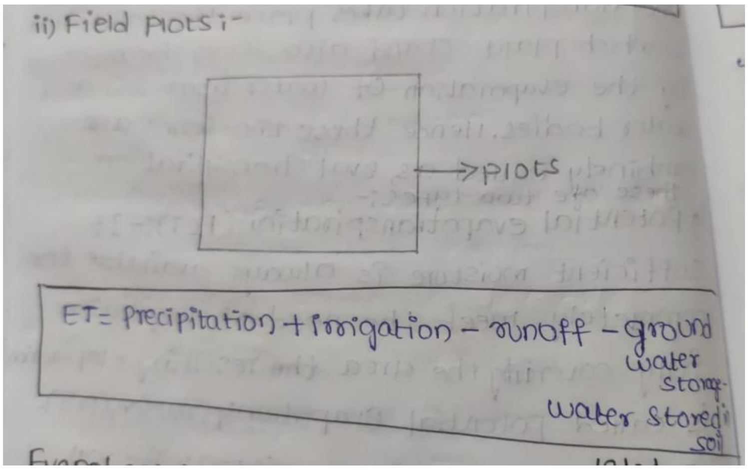


FIELD PLOTS

In special plots, all the elements of the water budget in a known interval of time are measured and the evapotranspiration is determined as:

Evapotranspiration = [precipitation + irrigation input – runoff – increase in soil storage – groundwater loss]

Measurements are usually confined to precipitation, irrigation input, surface runoff, and soil moisture. Groundwater loss due to deep percolation is difficult to measure and can be minimized by keeping the moisture condition of the plot at field capacity. This method provides fairly reliable results.



<u>EVAPOTRANSPIRATION EQUATION</u>

The lack of reliable field data and the difficulties of obtaining reliable evapotranspiration data have given rise to a number of methods to predict PET by using climatological data. Large number of formulae are available. They range fro purely empirical ones to those backed by theoretical concepts. Two useful equations are given below.

PENMAN’s EQUATION

Penman’s equation is based on sound theoretical reasoning and is obtained by a combination of the energy-balanced and mass-transfer approach. Penman’s equation, incorporation some of the modifications suggested by other investigation is

$$\text{PET} = \frac{AH_n + E_a \gamma}{A + \gamma}$$

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 of mercury per °C (Table 3.3)

H_n = net radiation in mm of evaporable water per day

E_a = parameter including wind velocity and saturation deficit

γ = psychrometric constant = 0.49 mm of mercury/°C

$$H_n = H_a (1 - r)\left(a + b\frac{n}{N}\right) - \sigma T_a^4 (0.56 - 0.092\sqrt{e_a})\left(0.10 + 0.90\frac{n}{N}\right)$$

where H_a = incident solar radiation outside the atmosphere on a horizontal surface, expressed in mm of evaporable water per day (it is a function of the latitude and period of the year as indicated in Table 3.4)

a = a constant depending upon the latitude ϕ and is given by $a = 0.29 \cos \phi$

b = a constant with an average value of 0.52

n = actual duration of bright sunshine in hours

N = maximum possible hours of bright sunshine (it is a function of latitude as indicated in Table 3.5)

r = reflection coefficient (albedo). Usual ranges of values of r are given below.

Surface	Range of *r* values
Close ground corps	0.15–0.25
Bare lands	0.05–0.45
Water surface	0.05
Snow	0.45–0.95

σ = Stefan-Boltzman constant = 2.01×10^{-9} mm/day

T_a = mean air temperature in degrees kelvin = 273 + °C

e_a = actual mean vapour pressure in the air in mm of mercury

The parameter E_a is estimated as

$$E_a = 0.35\left(1+\frac{u_2}{160}\right)(e_w - e_a)$$

in which

u_2 = mean wind speed at 2 m above ground in km/day

e_w = saturation vapour pressure at mean air temperature in mm of mercury (Table 3.3)

e_a = actual vapour pressure, defined earlier

Table 3.4 Mean Monthly Solar Radiation at Top of Atmosphere, H_a in mm of Evaporable Water/Day

North latitude	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0°	14.5	15.0	15.2	14.7	13.9	13.4	13.5	14.2	14.9	15.0	14.6	14.3
10°	12.8	13.9	14.8	15.2	15.0	14.8	14.8	15.0	14.9	14.1	13.1	12.4
20°	10.8	12.3	13.9	15.2	15.7	15.8	15.7	15.3	14.4	12.9	11.2	10.3
30°	8.5	10.5	12.7	14.8	16.0	16.5	16.2	15.3	13.5	11.3	9.1	7.9
40°	6.0	8.3	11.0	13.9	15.9	16.7	16.3	14.8	12.2	9.3	6.7	5.4
50°	3.6	5.9	9.1	12.7	15.4	16.7	16.1	13.9	10.5	7.1	4.3	3.0

Table 3.5 Mean Monthly Values of Possible Sunshine Hours, *N*

North latitude	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0°	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1
10°	11.6	11.8	12.1	12.4	12.6	12.7	12.6	12.4	12.9	11.9	11.7	11.5
20°	11.1	11.5	12.0	12.6	13.1	13.3	13.2	12.8	12.3	11.7	11.2	10.9
30°	10.4	11.1	12.0	12.9	13.7	14.1	13.9	13.2	12.4	11.5	10.6	10.2
40°	9.6	10.7	11.9	13.2	14.4	15.0	14.7	13.8	12.5	11.2	10.0	9.4
50°	8.6	10.1	11.8	13.8	15.4	16.4	16.0	14.5	12.7	10.8	9.1	8.1

1. **Calculate the potential evapotranspiration from an area near New Delhi in the month of November by Penman's Formula. The following data are available**

Latitude	**28^0 4' N**
Elevation	**230 mm**
Mean Monthly temperature	**19^0C**

Mean relative humidity	**75%**
Mean observed sunshine hours	**9 h**
Wind velocity at 2m height	**85 km/day**
Nature of surface cover	**Close ground green crop**

Given

Month = November

Latitude ϕ = 28°4'N

Elevation = 230 m

Temperature = 19°c

= °c to Kelvin

= 273 + 19

= 292

n = 9 hours

u_2 = 85 km/hr

Nature of Cover Surface, r = Close ground Green Crop = (0.15-0.25)

= 0.25

$\gamma = 0.49$ (constant)

Solution

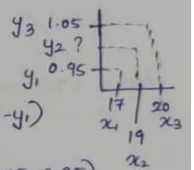
$$PET = \frac{A H_n + E_a \gamma}{A + \gamma}$$

$A = 1\,mm/°C$ for 19°c (table 3.3) $\Rightarrow \because$ Interpolation

$$y_2 = y_1 + \frac{(x_2 - x_1)}{(x_3 - x_1)}(y_3 - y_1)$$

$$= 0.95 + \frac{(19-17)}{(20-17)}(1.05 - 0.95)$$

$$= 1.01$$



e_w = 16.50 mm of Hg (table 3.3) (Same as Interpolation)

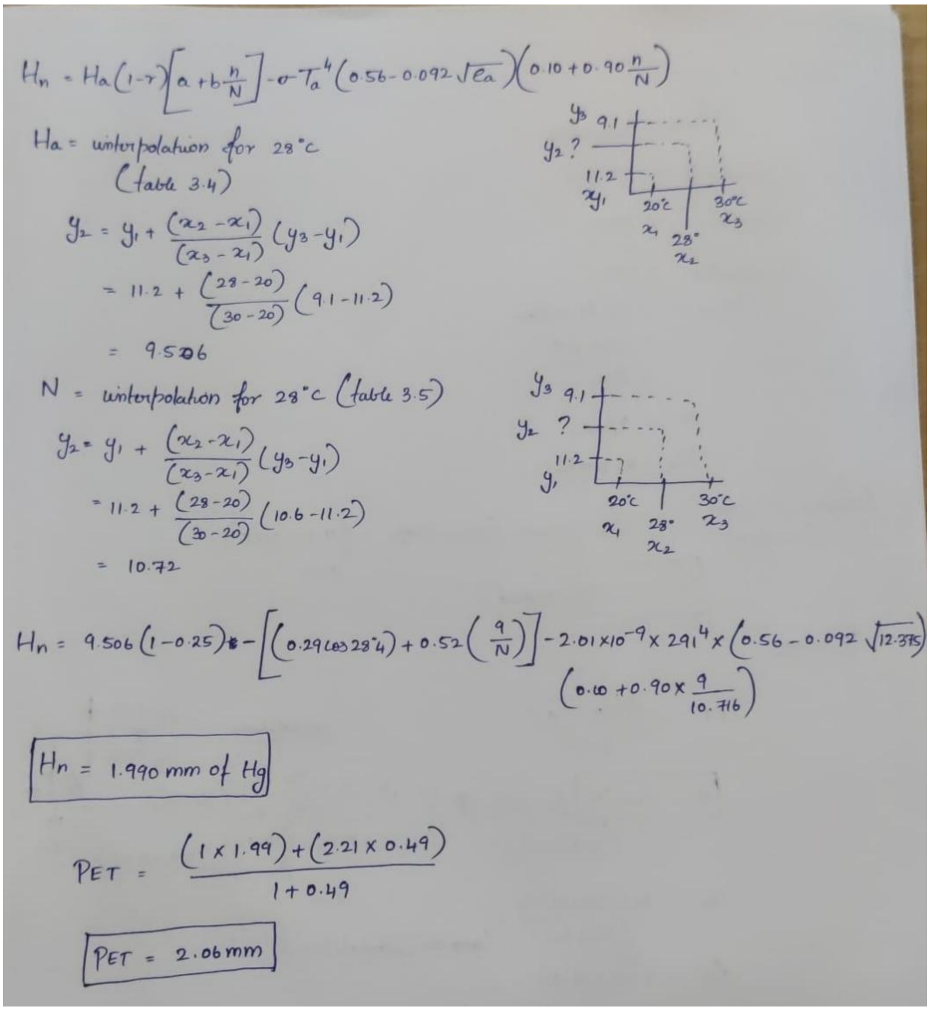
e_a = 0.75 × 16.50 (75%)

= 12.375 mm of Hg

$$E_a = 0.35\left[1 + \frac{u_2}{160}\right](e_w - e_a)$$

$$= 0.35\left[1 + \frac{85}{160}\right](16.50 - 12.375)$$

E_a = 2.21 mm/day



$$H_n = H_a(1-r)\left[a + b\frac{n}{N}\right] - \sigma T_a^4 (0.56 - 0.092\sqrt{e_a})\left(0.10 + 0.90\frac{n}{N}\right)$$

H_a = interpolation for 28°c (table 3.4)

$$y_2 = y_1 + \frac{(x_2 - x_1)}{(x_3 - x_1)}(y_3 - y_1)$$

$$= 11.2 + \frac{(28-20)}{(30-20)}(9.1 - 11.2)$$

$$= 9.506$$

N = interpolation for 28°c (table 3.5)

$$y_2 = y_1 + \frac{(x_2 - x_1)}{(x_3 - x_1)}(y_3 - y_1)$$

$$= 11.2 + \frac{(28-20)}{(30-20)}(10.6 - 11.2)$$

$$= 10.72$$

$$H_n = 9.506(1 - 0.25) - \left[(0.29\cos 28°4) + 0.52\left(\frac{9}{N}\right)\right] - 2.01\times10^{-9} \times 291^4 \times (0.56 - 0.092\sqrt{12.375})\left(0.10 + 0.90 \times \frac{9}{10.716}\right)$$

$$H_n = 1.990 \text{ mm of Hg}$$

$$PET = \frac{(1 \times 1.99) + (2.21 \times 0.49)}{1 + 0.49}$$

$$PET = 2.06 \text{ mm}$$

EMPIRICAL FORMULAE

A large number of empirical formulae are available for estimation of PET based on climatological data. These are not universally applicable to all climatic areas. They should be used with caution in area different from those for which they were derived.

BLANEY – CRIDDLE FORMULA

This purely empirical formula based on data from arid western United States. This formula assumes that the PET is related to hours of sunshine and temperature, which are taken as measures of solar radiation of an area. The Potential evapotranspiration in a crop-growing season is given by

$$E_T = 2.54\ KF$$

and $$F = \Sigma P_h \overline{T}_f / 100$$

where E_T = PET in a crop season in cm

K = an empirical coefficient, depends on the type of the crop and stage of growth

F = sum of monthly consumptive use factors for the period

P_h = monthly percent of annual day-time hours, depends on the latitude of the place (Table 3.6)

and $\overline{T}_f$ = mean monthly temperature in °F

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

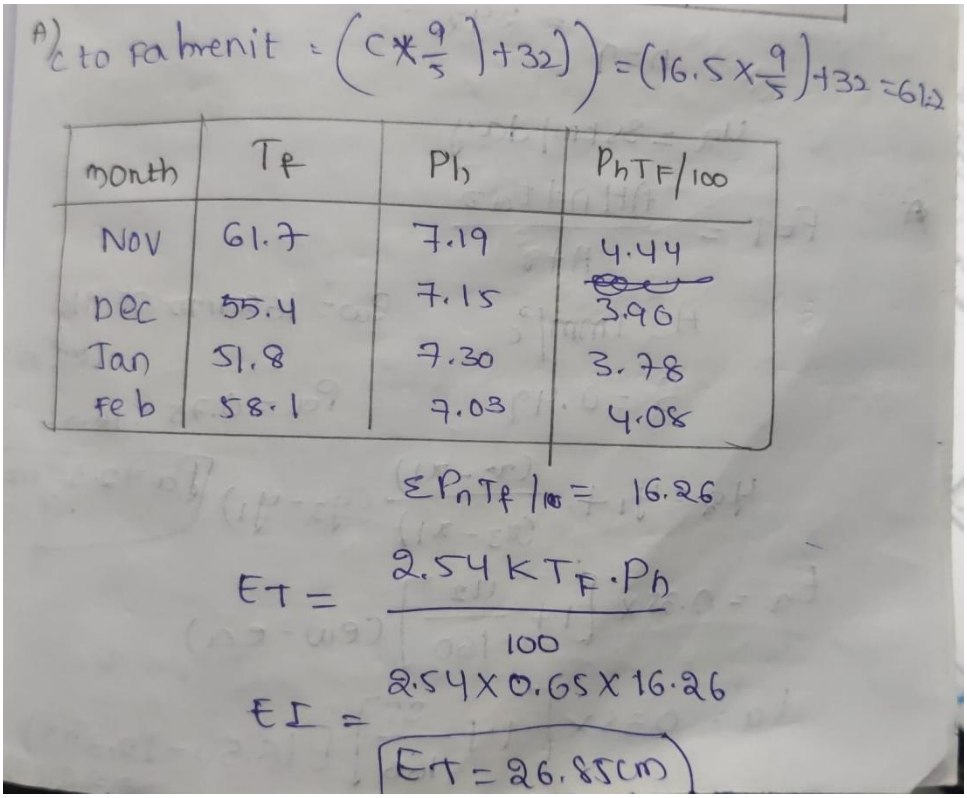
Table 3.7 Values of K for Selected Crops

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	

2. **Estimate the PET of an area for the season November to February in which wheat is grown. The area is in North India at a latitude of 30^0N with mean monthly temperature as below**

Month	Nov.	Dec.	Jan.	Feb.
Temp. (°C)	16.5	13.0	11.0	14.5

Use the Blaney-Criddle formula



A) °C to Fahrenit = $((C * \frac{9}{5}) + 32)) = (16.5 \times \frac{9}{5}) + 32 = 61.2$

month	T_f	P_h	$P_h T_F / 100$
Nov	61.7	7.19	4.44
Dec	55.4	7.15	3.96
Jan	51.8	7.30	3.78
Feb	58.1	7.03	4.08

$\Sigma P_n T_f / 100 = 16.26$

$$ET = \frac{2.54\, K T_F \cdot P_h}{100}$$

$$ET = 2.54 \times 0.65 \times 16.26$$

$ET = 26.85 cm$

<u>**INTERCEPTION**</u>

1. When it rains over a catchment, not all the precipitation falls directly onto the ground. Before it reaches the ground, a part of it may be caught by the vegetation and subsequently evaporated. The volume of water so caught is called interception.
2. The interception precipitation may follow one of the three possible routes.
    - It may be retained by the vegetation as surface storage and returned to the atmosphere by evaporation; a process termed interception loss.
    - It can drip off the plant leaves to join the ground surface or the surface flow; this is known as throughfall.
    - The rainwater may run along the leaves and branches and down the stem to reach the ground surface. This part is called stemflow

3. It is estimated that of the total rainfall in an area during a plant-growing season the interception loss is about 10 – 20%. For forest it will be greater than the 25% of the annual precipitation.
4. It is difficult to measure and is rarely significant in hydrological studies dealing floods so a lump sum value as initial loss to be deducted from initial period of storm.

DEPRESSION STORAGE

1. When the precipitation reaches the ground surface it must fill up the depression before it can flow over surface. The volume of water trapped in these depression is called as depression storage.
2. Rainfall held in these storage doesn't contribute to surface runoff unless these are filled to capacity
3. The amount is eventually lost through evaporation and infiltration
4. Depression storage depends on a vast number of factors the chief of which are
    - The type of soil
    - The condition of the surface reflecting the amount and nature of depression
    - The slope of the catchment
    - The antecedent precipitation
5. From the experiment on different soil we are able to take some values for depression storage loss during intensive storms.

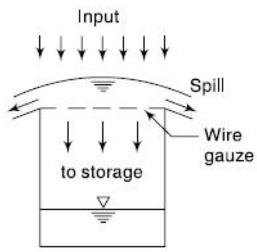
    Sand – 0.5 cm

    Loam – 0.4 cm

    Clay – 0.25 cm

INFILTRATION AND INFILTRATION CAPACITY

Infiltration is the flow of water into the ground through the soil surface. The infiltration process can be easily understood through a simple analogy. Consider a small container covered with wire gauze as shown in Figure.



When water is poured into a **container**, part of it goes inside and part of it **overflows**. The container can hold only a fixed quantity, and once it is full, no more water can enter.

RAINFALL = INTERCEPTION LOSS + DEPRESSION STORAGE + INFILTRATION + RUNOFF

Therefore, INTERCEPTION LOSS and DEPRESSION STORAGE = INITIAL LOSS

This example helps us understand two important points about soil:

1. **Infiltration capacity** → The maximum rate at which soil can absorb water.

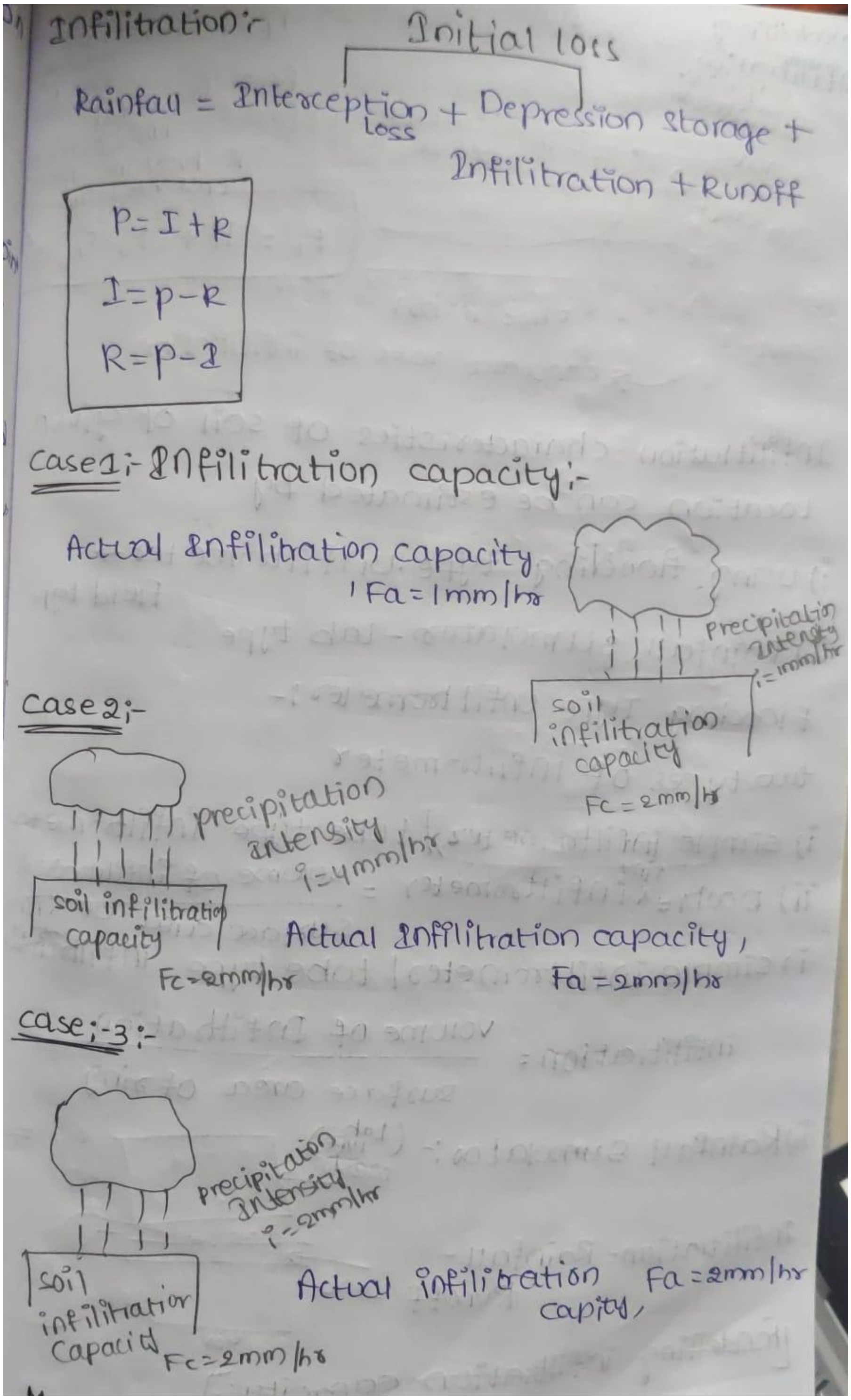
   Definition: The maximum rate at which a given soil at a given time can absorb water is defined as the infiltration capacity

2. **Field capacity** → The total amount of water the soil can hold.

If more water falls than the soil can absorb, the extra water will flow away as **runoff**, while the absorbed water increases soil moisture and may recharge **groundwater**.

This process can be shown for two situations:

- **Low intensity rainfall** → All water may infiltrate (no runoff).
- **High intensity rainfall** → Infiltration capacity is exceeded, so runoff occurs.



EFFECTS OF INFILTRATION

- It reduces the magnitude of the flood.
- It delays the time of arrival of water to the channel
- It recharges the ground water reservoir
- It reduces soil corrosion
- It fills the soil pores to its field capacity thus making available to plants
- It sustains green vegetation cover on the ground surface thus helps in reducing dust storms.

FACTORS EFFECTING INFILTRATION

- Condition of entry surface (Vegetation cover for bare land)
- Permeability (or) percolation characteristics of soil formation
- Moisture conditions in soil
- Temperature
- Intensity and duration of rainfall
- Movement of man and animals
- Change due to human activities
- Quality of water
- Presence of ground water table
- Size and characteristics of soil particles
- Catchment parameters

MEASUREMENT OF INFILTRATION

Infiltration characteristics of a soil at a given location can be estimated by

- Using flooding type infiltrometer

- Rainfall simulator

FLOODING – TYPE INFILTROMETER

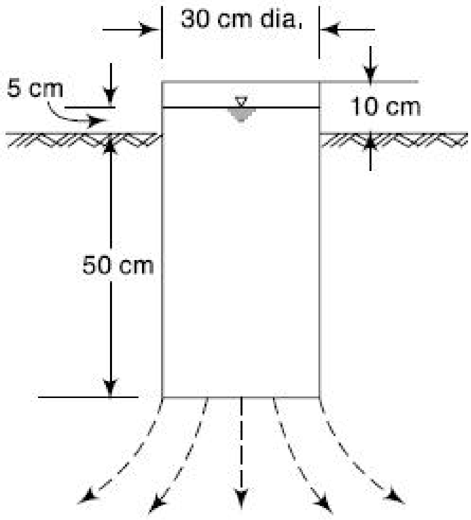
Flooding – type infiltrometer are experimental devices used to obtain data relating to variation of infiltration capacity with time. Two types of flooding type infiltrometers are in common use. Tney are (a) Tube-Type (or Simple) infiltrometer and (b) Double-ring infiltrometer.

SIMPLE (TUBE TYPE) INFILTROMETER

This is a simple instrument consisting essentially of a metal cylinder, 30 cm in diameter and 60 cm long, open at both ends. The cylinder is driven into the ground to a depth of 50 cm. Water is poured into the top part to a depth of 5 cm and a pointer is set to mark the water level.

As infiltration proceeds, the volume is maintained by adding water from a burette to keep the water level at the tip of the pointer. By knowing the volume of water added during different time intervals, a plot of infiltration capacity versus time is obtained.

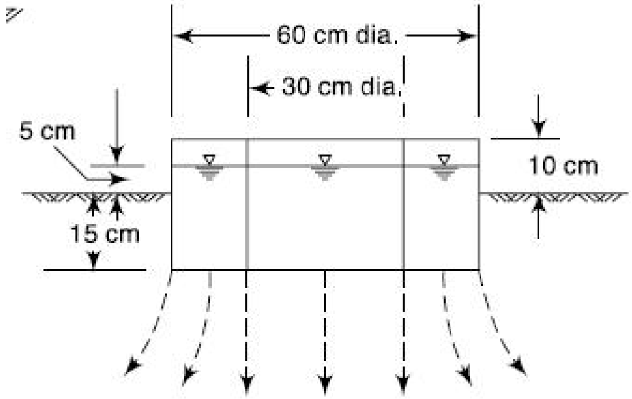
The experiments are continued until a uniform rate of infiltration is obtained, which may take 2–3 hours. The surface of the soil is usually protected by a perforated disc to prevent the formation of turbidity and settling of soil particles on the surface.



INFILTRATION (mm or cm) = VOLUME INFILTRATED/SURFACE AREA OF RING

DOUBLE – RING INFILTROMETER

This most commonly used infiltrometer is designed to overcome the basic objection of the tube infiltrometer, namely that the tube area is not representative of the infiltrating area. In this method, two sets of concentric rings with diameters of 30 cm and 60 cm and of a minimum length of 25 cm are used. The two rings are inserted into the ground, and water is applied into both the rings to maintain a constant depth of about 5.0 cm.



INFILTRATION (mm or cm) = VOLUME INFILTRATED/SURFACE AREA OF INNER RING

The outer ring provides a water jacket to the infiltrating water from the inner ring and hence prevents the spreading out of the infiltrating water of the inner ring. The water depths in the inner and outer rings are kept the same during the observation period. The measurement of water volume is done on the inner ring only.

The experiment is carried out until a constant infiltration rate is obtained. A perforated disc to prevent the formation of turbidity and settling of fines on the soil surface is provided on the surface of the soil in both the inner ring and the annular space.

As the flooding-type infiltrometer measures the infiltration characteristics at a spot only, a large number of pre-planned experiments are necessary to obtain representative infiltration characteristics for an entire watershed.

Some of the chief disadvantages of flooding-type infiltrometers are:

1. The raindrop impact effect is not simulated.
2. The driving of the tube or rings disturbs the soil structure.
3. The results of the infiltrometers depend to some extent on their size, with the larger meters giving less rates than the smaller ones; this is due to the border effect.

RAINFALL SIMULATOR

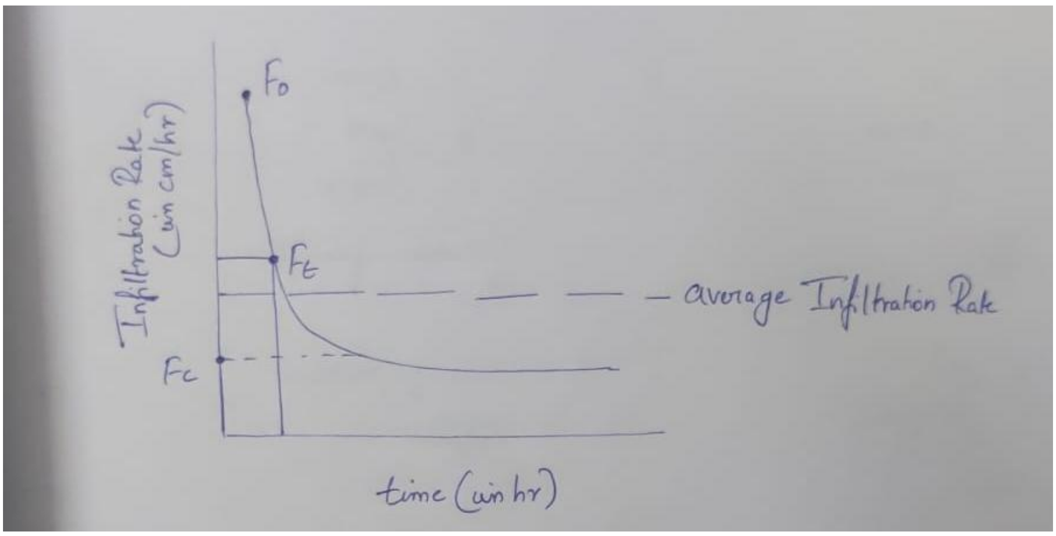
In this small plot of land, of about 2 m × 4 m size, a series of nozzles are provided on the longer side with arrangements to collect and measure the surface runoff rate. The specially designed nozzles produce raindrops falling from a height of 2 m and are capable of producing various intensities of rainfall.

Experiments are conducted under controlled conditions with different combinations of rainfall intensities and durations, and the surface runoff rates and volumes are measured in each case.

Using the water budget equation involving the volume of rainfall, infiltration, and runoff, the infiltration rate and its variation with time are estimated. If the rainfall intensity is higher than the infiltration rate, the infiltration capacity values are obtained.

Rainfall simulator type infiltrometers give lower values than flooding type infiltrometers. This is due to the effect of the rainfall impact and turbidity of the surface water present in the former.

MODELING INFILTRATION CAPACITY



$$F_t = F_c + (F_o - F_c)e^{-kt}$$

where,

F_t = infiltration time at Any time t (cm/hr)

F_c = Constant Rate of Infiltration

F_o = Initial Infiltration

k = Hortons decay Constant

t = time (in hr)

INFILTRATION INDICES

In hydrological calculations involving floods it is found convenient to use a constant value of infiltration rate for the duration of the storm. The defined average infiltration rate is called infiltration index and two types of indices are in common use.

ϕ – Index

It is average rainfall which the rainfall volume is equal to runoff volume

- Initial loss is considered as infiltration loss

$$\boxed{\phi \text{ (average infiltration)} = (P - R)/Te}$$

where,

Te = Effective time of runoff

w – Index

It is refining form of ϕ – Index in which initial losses are separated from the total abstraction and an average value of infiltration rate called the w-index

w index = [P – (R + Initial Loss)]/Te

1. **A storm with 10 cm of precipitation produced a direct runoff of 5.8 cm. the duration of the rainfall was 8 hours and its time distribution is given below. Estimate the ϕ – Index of the storm:**

Time (in hr)	1	2	3	4	5	6	7	8
Rainfall (in cm)	0.4	0.9	1.5	2.3	1.8	1.6	1.0	0.5

A) Given, P=10cm, R=5.8cm

trail-I

$$\phi = \frac{P-R}{Te}$$

$$\phi = \frac{10-5.8}{8}$$

$$\phi = 0.525\ cm/hr$$

Trail-2:-

$$\phi = \frac{P-R}{Te}$$

$$\phi = \frac{9.1-5.8}{6}$$

$$\phi = 0.55\ cm/hr$$

RUNOFF

Runoff is that portion of rain which ultimately join the water bodies. Such as streams, rivers, lakes, etc. Runoff is also known as effective rainfall or excess rainfall or rainfall excess or net runoff. It is an output produced by the catchment for a given input rainfall.

Based on the time delay between the precipitation and the runoff, the runoff is classified into two categories; as

1. Direct Runoff

The portion of precipitation that flows into a stream or other water bodies almost immediately after the rainfall event. In the case of snow – melts, the resulting flow entering the stream is also a direct runoff.

2. Base Flow

The portion of streamflow that is sustained between precipitation events, primarily fed by groundwater discharge.

COMPONENTS OF RUNOFF

1. **Surface runoff**

   This is the water that flows over the land surface, typically in the form of sheet flow, rills, and gullies, before reaching a stream. It's the most visible and rapid form of runoff.

2. **Subsurface runoff (Interflow)**

   This refers to water that infiltrates the soil but then moves laterally through the upper soil layers, eventually reaching a stream. It's faster than groundwater flow but slower than surface runoff.

3. **Groundwater runoff**

This is the water that infiltrates deep into the soil and rock layers, eventually discharging into a stream or other water body. It's the slowest component of runoff and contributes to the baseflow of rivers, especially during dry periods.

FACTORS AFFECTING RUNOFF

The principal factors affecting the flow from a catchment area are:

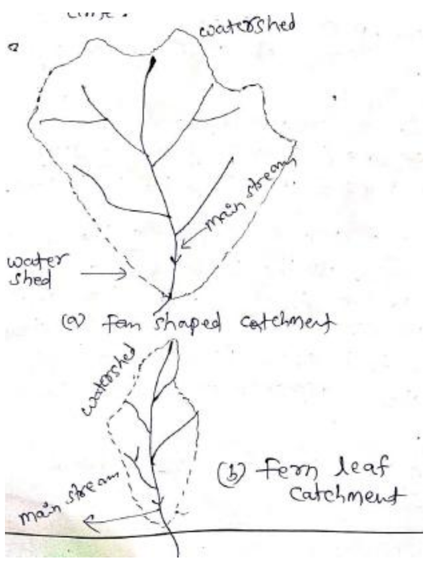
- Precipitation characteristics
- Shape and size of the catchment
- Topography
- Geological characteristics
- Meteorological characteristics
- Character of the catchment surface
- Storage characteristics

1) Precipitation characteristics:

- This is the most important factor which is depends upon the runoff.
- Important precipitation characteristics are:
    - Intensity
    - Duration
    - Areal distribution
    - Direction of storm movement
    - Form of precipitation
    - Evapotranspiration
- The runoff depends upon the type of storm causing precipitation & duration. Runoff also increases with the intensity of rainfall.

2) **Shape and Size of the Catchment:**

- The runoff from a catchment area also depends upon the size, shape, and location of the catchment. More intense rainfalls are generally distributed over a relatively smaller area.
- A stream collecting water from a small catchment area is likely to give greater runoff intensity per unit area.
- In the case of **fan (or sector shaped) catchment**, all the tributaries are approximately of the same size, such that the catchment gives greater runoff since the peak flood from the tributaries is likely to reach the main stream approximately at the same time.
- In the case of a **fern leaf catchment**, the tributaries are generally of different lengths, and meet the main stream at regular intervals. In such a narrow catchment, the peak flood intensity is reduced since discharges are likely to be distributed over a long period of time.



3) Topography of catchment:

- The runoff depends upon the surface of the catchment, whether it is smooth or rugged.
- If the surface slope is steep, water will flow quickly; absorption and evaporation losses will be less, resulting in greater runoff.

- If the catchment is mountainous and on the windward side of the mountains, the intensity of rainfall will be more, and runoff will also be more.

4) Geological characteristics:

- This is an important factor affecting the runoff. These include the type of surface soil and subsoil, type of rock, and their permeability characteristics.
- If the soil and subsoil are pervious, seepage will be more, and this reduces the peak flood.
- If the surface is rocky and absorption is practically nil, then the runoff will be more.

5) Meteorological characteristics:

- Temperature, wind, and humidity also affect the runoff.
- If the temperature is low and the ground is saturated and frozen, it gives rise to greater runoff.
- However, if the whole of the stream freezes, the peak floods will be reduced.
- On the other hand, high temperature and greater wind velocity give rise to greater evaporation loss and reduce the runoff.
- The peak flood depends upon the direction of movement of the storm causing rainfall with relation to the direction of the stream.

6) Character of the catchment surface:

- The runoff also depends upon the surface conditions — whether the surface is drained or undrained, natural or cultivated, and if it is bare or covered with vegetation, etc.
- If the surface has no natural drainage, absorption loss will be more.
- If more area of a catchment is cultivated, surface run-off will be less.

7) Storage Characteristics:

- The artificial storage such as dams, weirs, etc., and natural storage such as lakes, ponds, etc., tend to reduce the peak flow.
- They also give rise to greater evaporation losses.

FLOW DURATION CURVE

What it is:

A graph that plots the daily, weekly, or monthly discharge rates against the percentage of time those flows were equaled or exceeded.

What it shows:

It represents the flow characteristics of a stream across a range of discharges, irrespective of the time of occurrence. A steep curve indicates high flows for short periods (like floods), while a flat curve indicates low flows for longer periods.

Applications:

Waterpower and water-supply studies: Helps in predicting future flow distributions for design purposes.

Stream and catchment assessment: The shape of the curve can reveal characteristics of the watershed and its geological features.

Environmental flow assessment: Used to determine minimum flow requirements to sustain ecosystems or for pollution control.

MASS CURVE OF RUNOFF

What it is:

A graph of the cumulative runoff volume (total amount of water) against time, ordered chronologically. It's the integral of the runoff hydrograph.

What it shows:

The cumulative volume of water that has passed a specific point in a river over time.

How to interpret it:

The slope of the mass curve at any given point represents the instantaneous discharge (flow rate) at that time.

Applications:

Reservoir design: Used to determine the required storage capacity for a reservoir by analyzing water inflow and potential withdrawal rates.

Water resource management: Helps in planning water supply and managing water infrastructure by providing a visual of total water availability over time.

WHAT IS A WATERSHED?

A watershed, also known as a drainage basin or catchment area, is a land area where surface water from rain and snowmelt converges to flow towards a single point, such as a river, lake, or ocean. The boundaries of a watershed are determined by the topography of the land, with higher elevations acting as divides separating different drainage areas.

SCS-CN METHOD OF ESTIMATING RUNOFF

The SCS CN (Soil Conservation Service Curve Number) method is a widely used empirical model that estimates surface runoff volume from rainfall by considering watershed characteristics like soil type, land use, and antecedent soil moisture conditions

HOW THE SCS-CN METHOD WORKS

1. Water Balance and Assumptions:

The method relies on a water balance equation and two key hypotheses:

Initial Abstraction: Runoff begins only after an initial abstraction (Ia) – a combination of interception, surface storage, and initial infiltration – is satisfied.

Equal Proportions: The ratio of direct runoff (Q) to rainfall minus initial abstraction (P - Ia) is equal to the ratio of potential maximum retention (S) to total infiltration (F).

2. Curve Number (CN):

A dimensionless parameter ranging from 0 to 100, the CN represents a specific soil-vegetation-land use complex's water retention. Higher CN values indicate greater runoff potential.

3. Potential Maximum Retention (S):

The CN is used to calculate S, which is the total retention after runoff begins:

$S = (1000 / CN) - 10$: (when S and CN are in inches)

4. Initial Abstraction (Ia):

The SCS assumes that Ia is 20% of the potential maximum retention, so $Ia = 0.2S$.

5. The Runoff Equation:

With the above parameters, the direct runoff (Q) is calculated using the following equation:

$$Q = (P - 0.2S)^2 / (P + 0.8S)$$

Key Factors Affecting CN

The Curve Number is determined by several watershed properties:

Hydrologic Soil Group: Soils are classified (A, B, C, or D) based on their infiltration characteristics.

Land Use and Land Cover: Different vegetation types and land use practices influence runoff.

Antecedent Moisture Condition (AMC): The level of soil moisture at the start of a rainfall event, categorized into three levels (I, II, III), affects the runoff.

Land Treatment: Agricultural practices and other land treatments are also considered.