Chapter 3
Water Losses

The hydrologic equation states that
Rainfall–Losses = Runoff ...(3.1)
In the previous chapter we studied precipitation and its measurement. The various water losses that occur in nature are enumerated below. If these losses are deducted from the rainfall, the surface runoff can be obtained.

WATER LOSSES

(*i*) Interception loss-due to surface vegetation, *i.e.,* held by plant leaves.
(*ii*) Evaporation:
(*a*) from water surface, *i.e.*, reservoirs, lakes, ponds, river channels, etc.
(*b*) from soil surface, appreciably when the ground water table is very near the soil surface.
(*iii*) Transpiration—from plant leaves.
(*iv*) Evapotranspiration for consumptive use—from irrigated or cropped land.
(*v*) Infiltration—into the soil at the ground surface.
(*vi*) Watershed leakage—ground water movement from one basin to another or into the sea.

1- Evaporation

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.
The rate of evaporation is depended on the following:

(i)Vapor Pressure
$E_L = C\,(e_w - e_a)$
Where E_L = rate of evaporation (mm/day)
C = a constant
e_w = the saturation vapor pressure at the water temperature in mm of mercury
e_a = the actual vapor pressure in the air in mm of mercury
This equation is known as **Dalton's law** of evaporation after John Dalton (1802)
Who first recognized this law. Evaporation continuous till $e_w = e_a$. If $e_w > e_a$
Condensation takes place

(ii) Temperature
The rate of evaporation increases with an increase in the water temperature.
(iii) Wind
The rate of evaporation increases with the wind speed up to a critical speed beyond which any further increase in the wind speed has no influence on the evaporation rate.
(iv) Atmospheric Pressure
A decrease in the barometric pressure, as in high altitudes, increases evaporation.
(v) Soluble Salts
When a solute is dissolved in water, the vapor pressure of the solution is less than that of pure water and hence causes reduction in the rate of evaporation. For example, under identical condition evaporation from sea water is about 2 – 3% less than the fresh water.

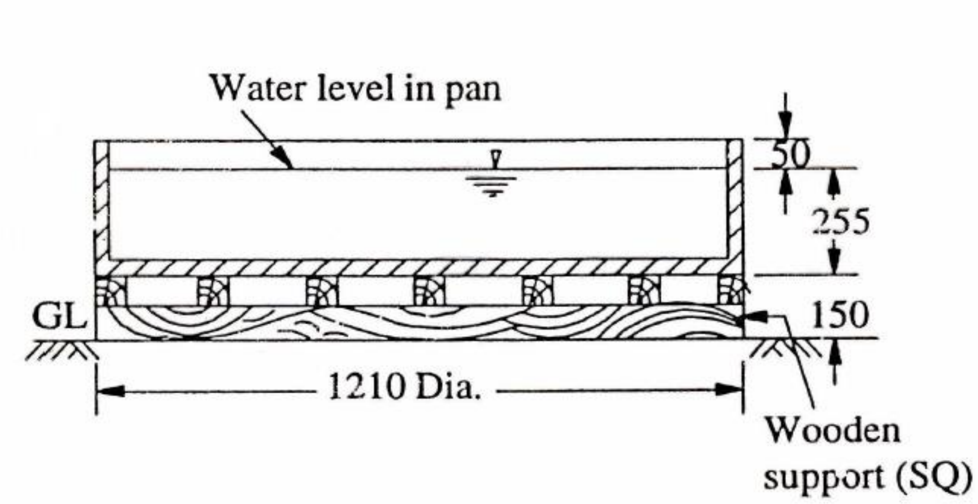
(vi) Heat Storage in Water Bodies
Deep water bodies have more heat storage than shallow ones.

Evaporimeters

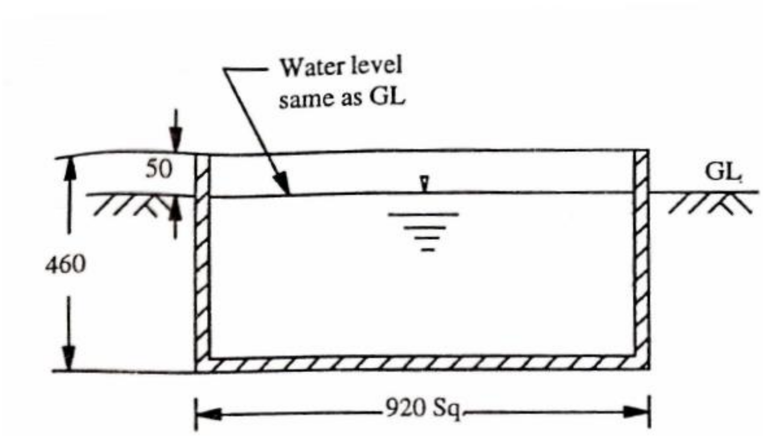
The amount of water evaporated from a water Surface is estimated by the Following methods :
(i) Using evaporimeter
(ii) Empirical evaporation equations and
(iii) Analytical methods

Types of Evaporimeters

Class A Evaporation Pan



Colorado Sunken Pan



US Geological Survey Floating Pan
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 a float in a lake. The water level in the pan is kept at the same level as the lake leaving a rim of 75 mm.

Pan Coefficient Cp
Evaporation pan are not exact models of large reservoirs and have the following principle drawbacks (عيوب):
1. They differ in the heat storing capacity and heat transfer from the sides and bottom. The sunken pan (المغمورة) and floating pan aim to reduce this deficiency. As a result of this factor the evaporation from a pan depends to a certain extent on its size.

2. The height of the rim (حافة) in an evaporation pan affects the wind action over the surface.

3. The heat transfer characteristics of the pan material is different from that of the reservoir.

Thus a coefficient is introduced as
Lake evaporation = Cp x pan evaporation
In which Cp = pan coefficient. The values of Cp in use for different pans are given in the following Table

VALUES OF PAN COEFFICIENT C_P

Sl. No.	Types of pan	Average value	Range
1.	Class A Land Pan	0.70	0.60-0.80
2.	Colorado Sunken Pan	0.78	0.75-0.86
3.	USGS Floating Pan	0.80	0.70-0.82

Evaporation Stations
The WMO recommends the minimum network of evaporimeter stations as Below.
1. Arid zones – one station for every 30,000 Km^2

2. Humid temperate climates – one station for every 50,000 Km^2, and

3. Cold regions – one station for every 100,000 Km^2.

Example:

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.

Example 3.1 *The following are the monthly pan evaporation data (Jan.-Dec.) at Krishnarajasagara in a certain year in cm.*

16.7, 14.3, 17.8, 25.0, 28.6, 21.4

16.7, 16.7, 16.7, 21.4, 16.7, 16.7

The water spread area in a lake nearby in the beginning of January in that year was 2.80 km² and at the end of December it was measured as 2.55 km². Calculate the loss of water due to evaporation in that year. Assume a pan coefficient of 0.7.

Solution Mean water spread area of lake

$$A_{ave} = \frac{1}{3}(A_1 + A_2 + \sqrt{A_1 A_2}), \qquad \text{cone formula}$$

$$= \frac{1}{3}(2.80 + 2.55 + \sqrt{2.80 \times 2.55})$$

$$= 2.673 \text{ km}^2$$

Annual loss of water due to evaporation (adding up the monthly values)

$$= 228.7 \text{ cm}$$

Annual volume of water lost due to evaporation

$$= (2.673 \times 10^6) \times \frac{228.7}{100} \times 0.7$$

$$= 4.29 \times 10^6 \text{ m}^3 \text{ or } \mathbf{4.29 \ Mm^3}$$

Example: *Compute the daily evaporation from a Class A pan if the amounts of water added to bring the level to the fixed point are as follows:*

Day:	*1*	*2*	*3*	*4*	*5*	*6*	*7*
Rainfall (mm):	*14*	*6*	*12*	*8*	*0*	*5*	*6*
Water added (mm):	*–5 (removed)*	*3*	*0*	*0*	*7*	*4*	*3*

What is the evaporation loss of water in this week from a lake (surface area = 640 ha) in the vicinity, assuming a pan coefficient of 0.75?

Solution Pan evaporation, E_p, mm = Rainfall $\begin{matrix} + \text{water added} \\ \text{or} \\ - \text{water removed} \end{matrix}$

Day:	1	2	3	4	5	6	7
E_p: (mm):	14 – 5 = 9	6 + 3 = 9	12	8	7	5 + 4 = 9	6 + 3 = 9

Pan evaporation in the week $= \sum_{1}^{7} E_p = 63$ mm

Pan coefficient $0.75 = \frac{E_L}{E_p}$

∴ Lake evaporation during the week E_L

$= 63 \times 0.75 = 47.25$ mm

Water lost from the lake $= A \cdot E_L = 640 \times \frac{47.25}{1000} = 30.24$ ha.m $\simeq$ **0.3 Mm³**

Empirical evaporation Equations

Meyer's Formula (1915)

$E_L = K_M (e_w - e_a) (1 + u_9/16)$

In which, u_9 = 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 and 0.50 for small shallow waters.

Rohwer's Formula (1931)

$E_L = 0.771(1.465 - 0.000732\ Pa) (0.44 + 0.0733\ u_o) (e_w - e_a)$

Pa = mean barometric reading in mm of mercury

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

The wind velocity can be assumed to follow the 1/7 power law

$U_h = C\ h^{1/7}$

Where, U_h = wind velocity at a height h above the ground and

C = constant.

This equation can be used to determine the velocity at any desired level.

Example : A reservoir with a surface area of 250hectares had the following average values of parameters during a week : water temperature = 20° C, relative humidity = 40% wind velocity at 1.0 m above ground = 16km/h. Estimate the average daily evaporation from the lake and volume of water Evaporated from the lake during that one week.

Solution :

e_w = 17.54 mm of Hg

e_a = 0.40 x 17.54 = 7.02 mm of Hg

u_9 = wind velocity at a height of 9.0 m above ground

u_1 = 16 km/h u_9 = ?

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

$u_h = C\,(1)^{1/7}$ = 16 km/h

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

$u_9 = u_1\,(9)^{1/7}$
$= 16\,(9)^{1/7}$
= 21.9 km/h

By Meyer's formula

E = 0.36 (17.54 – 7.02) (1 + 21.9/16)
= 8.97 mm/day

Evaporated volume in 7 days
= 7 x 8.97/1000 x 250 x10000
= 157,000 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, and
3. Mass – transfer method

Water Budget Equation:-

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

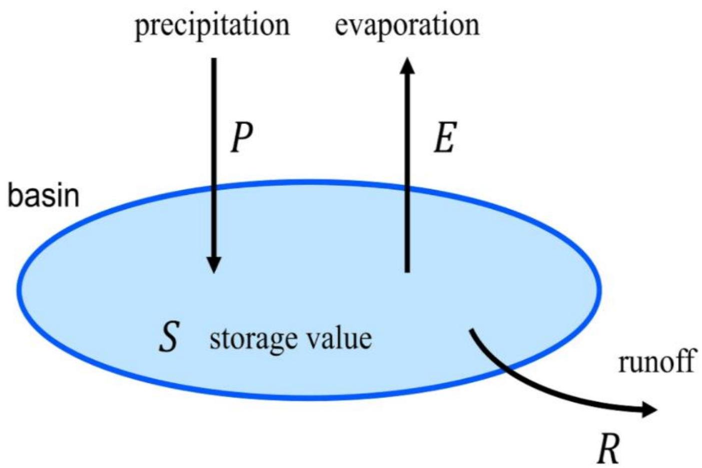
E= (S1–S2) +I-Q

E=Evaporation.

S1 & S2 are initial & final storage.

I=Inflow volume.

Q=Out flow volume



Example:

The following observation were taken for a reservoir over a period of 24 hours. Spread of reservoir = 5 km², Average inflow = 1 m³/s, Average outflow = 11 m³/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:-

$E = (S_1 - S_2) + I - Q$

$(S_1 - S_2) = (5000000 \times 0.02)\ m^3 = 1000000\ m^3$

$I = (1 \times 3600 \times 24)\ m^3 = 86400\ m^3$

$Q = (11 \times 3600 \times 24)\ m^3 = 950400\ m^3$

$E = (1000000) + 86400 - 950400$

$E = 136000\ m^3 / day$

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

Energy – Budget Method

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

Where, H_n = net heat energy received by the water surface

$= H_c (1- r) - H_b$

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

H_b = back radiation (long wave) from water body

H_a = sensible heat transfer from water surface to air

H_e = heat energy used up in evaporation

$= \rho L E_L$ where ρ = density of water ,

L = latent heat of evaporation and

E_L = evaporation in mm

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 (advected energy)