OPSC-AEE 2020

Odisha Public Service Commission

Assistant Executive Engineer

Civil Engineering

Engineering Hydrology

Well Illustrated **Theory** *with*
Solved Examples and **Practice Questions**

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Engineering Hydrology

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CHAPTER 3

Abstraction from Precipitation

3.1 Introduction

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

3.2 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 molecule of water in a water body are in constant motion with a wide range of instantaneous velocities. If heat is given to a water molecule it increases kinetic energy of the water molecule. As the kinetic energy of the water particle increases, they tend to leave the surface of water body. And some water particles tend to come in water body from air (if present). If the net particle is going outward of body then it is called evaporation and if the net particle is going inward of water body then it is called condensation.

NOTE: Evaporation is a cooling process in which the latent heat of vaporization (about 585 cal/gm of evaporated water) must be provided by the water body.

3.3 Factors Affecting Evaporation

- The vapour pressure at the water surface and air above it
- Air and water temperature
- Atmospheric pressure
- Quality of water
- Size of the water body
- Wind Speed
- Humidity

Vapour Pressure

- Rate of evaporation 'E' is proportional to the difference between the saturation vapour pressure 'e_s' at the water temperature and the actual vapour pressure in the air 'e_a'

  Thus, $E_L \propto (e_s - e_a)$

  $\Rightarrow$ $E_L = C(e_s - e_a)$
- E can be taken in mm/day. Evaporation will continue till $e_s = e_a$. If $e_s > e_a$ condensation takes place.

Temperature

The rate of evaporation increases with an increase in the water temperature.

Wind

Evaporation is increased due to higher wind speed, but if the wind speed is large enough to remove all the evaporated water vapour, any further increase in wind speed does not influence the evaporation.

Atmosphere Pressure

Decrease in barometric pressure (as in high altitudes) increases evaporation.

Soluble Salts

- When a solute is dissolved in water, the vapour pressure of the solution is less than that of pure water and hence causes reduction in the rate of evaporation.
- Under same conditions evaporation from sea water is about 2-3% less than that from fresh water.

Depth of Water body

- In Summer, the temperature of water body of the shallow lake will rise and hence normal evaporation will take place, but in a deep lake the temperature of water will remain much less than that of the air above, which will reduce the evaporation from deep lakes
- In winter, the temperature of air falls, but temperature of deep lakes does not fall so easily and thus water remains warmer, hence increase in depth, increases the rate of evaporation.

Humidity

If the humidity of the atmosphere is more, the evaporation will be less. Because during the process of evaporation, water vapour move from the point of higher moisture content to the point of lower moisture content and the rate of this movement is governed by the difference of their moisture contents. So if the humidity is more than evaporation will be less.

NOTE

- **Humidity:** The term humidity is used in order to obtain an idea of the amount of moisture present in the air. The amount of moisture present in the air, when expressed as mass per unit volume is known as *absolute humidity*.
- **Relative Humidity:** It is defined as the ratio of the *actual vapour pressure* to the *saturation vapour pressure* at the same temperature. It tells us of the extent to which the air is saturated. Humidity is measured by the psychrometer or *hygrometer*.

3.4 Measurement of Evaporation

3.1.1 Evaporation Data: The commonly used evaporators are:

3.4.1.1 Class 'A' Evaporation Pan

It is standard pan of 1210 mm diameter and 255 mm depth. The depth of water is maintained between 18 cm to 20 cm. The pan is normally made of unpainted galvanized iron sheet. Monel metal is used where corrosion is a problem.

3.4.1.2 ISI Standard Pan

- This is also known as modified class A pan. This is 1220 mm in diameter with 255 mm of depth. This pan is made of copper sheet of 0.9 mm thickness. The top of the pan is covered fully with a hexagonal wire netting of galvanized iron to protect the water form birds. This wire mesh also helps to make the temperature uniform during day and night.
  Evaporation from this pan is about 14% less than as compared to the evaporation from unscreened pan.
- Lake evaporation = $C_p \times$ pan evaporation
  C_p = pan coefficient = 0.8 for ISI pan = 0.7 for class -A pan.
- 1. Arid zones-One station for every 30,000 km^2.
  2. Humid temperate climates-One station for every 50,000 km^2.

NOTE

- The world Metrological Organization 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.
- Currently India has about 220 pan- evaporimeter stations maintained by IMD.

3.4.2 Empirical Evaporation Equations

Most of the equations are based on Dalton's law.

Meyer's formula

$$E = K_m(e_s - e_a)\left[1 + \frac{V_9}{16}\right]$$

Where,
E = Evaporation in mm/day
e_s = Saturated vapour pressure in mm at water temperature
e_a = Actual vapour pressure of overlying air in mm of Hg at specified height of 8 m
V_9 = Monthly mean wind velocity in km/hr at about 9 m above the ground
K_m = Coefficient = 0.36 (for large deep water)
= 0.50 (for small and shallow waters)

If 'V_{z1}' is the velocity of wind at height 'Z_1' and 'V_{z2}' is the velocity of wind at height 'Z_2' from ground level then,

$$\frac{V_{z1}}{V_{z2}} = \left(\frac{Z_1}{Z_2}\right)^{1/7}$$

Example - 3.1

(a) A reservoir with a surface area of 250 hectares had the following average values of climate parameters during a week; water temperature = 20°C, Relative humidity = 40%, wind velocity at 1.0 m above ground surface = 16 km/h and e_w = 17.54 mm (Hg).
Estimate the average daily evaporation from the lake by using Meyer's formula.

(b) An ISI Standard evaporation pan at the site indicated a pan coefficient of 0.80 on the basis of calibration against controlled water budgeting method. If this pan indicated an evaporation of 72 mm in the week under question, (i) estimate the accuracy if Meyer's method relative to the pan evaporation measurements. (ii) Also, estimate the volume of water evaporated from the lake in that week.

Solution:

(a) e_w = 17.54 mm of Hg, e_a = 0.4 × 17.54 = 7.02 mm of Hg

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

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

By Meyer's formula $$E_L = 0.36(17.54 - 7.02)\left(1 + \frac{21.9}{16}\right) = 8.97 \text{ mm/day}$$

(b) (i) Daily evaporation as per Pan evaporimeter $= \left(\frac{72.00}{7}\right) \times 0.8 = 8.23 \text{ mm}$

Error by Meyer's formula = (8.23 – 8.97) = –0.74 mm. Hence, Meyer's method overestimates the evaporation relative to the pan.

(ii) Considering the Pan measurements as the basis, volume of water evaporated from the lake in 7 days = 7 × (8.23/1000) × 250 × 10^4 = 144025 m^3

[The lake area is assumed to be constant at 250 ha throughout the week]

Example - 3.2 At the beginning of a certain week, the depth of water in an evaporation pan, 1.2 metre diameter, was 7.75 cm. During the week, the rainfall was 3.8 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 pan. Using a suitable evaporation pan coefficient, estimate the evaporation during the week from the surface of a reservoir under similar atmospheric condition.

Solution:

Initial depth of water in the pan = 7.75 cm

Rainfall = 3.8 cm

Water removed = 2.5 cm

Net addition of water in the pan = 3.8 – 2.5 = 1.3 cm

Depth at the end of week, if there is no loss = 7.75 + 1.3 = 9.05 cm

Actual depth at the end of week = 8.32 cm

Evaporation lost from the pan = 9.05 – 8.32 = 0.73 cm

Evaporation loss from the reservoir = 0.7 × 0.73 = 0.511 cm (Assume a pan coefficient = 0.7)

Hence, the evaporation during the week from the surface of reservoir under similar atmospheric conditions is 5.11 mm.

3.4.3 Analytical Methods

Analytical method for determination of lake evaporation can be broadly classified as

(i) Water budget method (ii) Energy balance method (iii) Mass transfer method

(i) Water budget method: This method is simplest in all three method. In this by the hydrological continuity equation, we find out the evaporation from the lake.

The continuity is written down as:

$$P + V_{iS} + V_{iG} = V_{oS} + V_{oG} + E_L + \Delta S + T_L$$

Where, P = precipitation, V_{iS} = surface inflow

V_{iG} = ground water inflow, V_{oS} = surface outflow

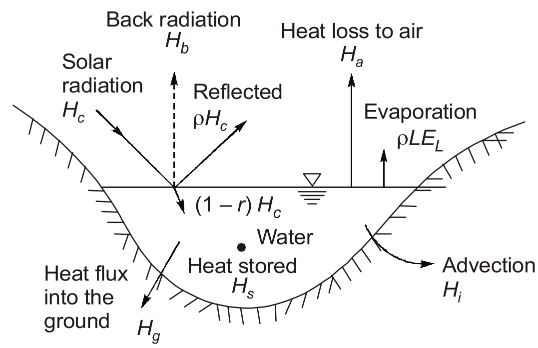
V_{oG} = Seepage outflow, E_L = evaporation

ΔS = change in storage, T_L = daily transpiration loss

P, V_{iS}, V_{oS} and ΔS can be measured, but it is not possible to measure V_{iG}, V_{oG} and T_L and these quantities can only be estimated. Due to this reason, the result from this E_L is not accurate.

If time period is kept large for estimation of E_L, better accuracy is possible.

(ii) **Energy budget 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 water body over a known time interval.



Consider the water body, the energy balance to the evaporating surface in a period of one day is given by

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

r = reflection coefficient

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 r (albedo)

H_a = sensible heat transfer from water surface to air,

H_e = heat energy used in evaporation = ρLE_L

ρ = density, L = latent heat of evaporation

E_L = evaporation in mm, H_g = heat flux into the ground

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

All the energy term are in calories/sq.mm/day

If the time period are short, the term H_s and H_i can be neglected as they are negligibly small. Then

$$E_L = \frac{H_n - H_g - H_s - H_i}{\rho L(1+\beta)} \quad \text{where,} \quad \beta = \text{Bowen's ratio} = \frac{H_a}{H_e}$$

Estimated of evaporation in a lake by the energy balance method has been found to give satisfactory result, when applied for a short period less than a week.

(iii) **Mass-Transfer Method:** This method is based on theories of turbulent mass transfer in boundary layer to calculate the mass of water vapour transfer from the surface to the surrounding atmosphere.

The volume of water lost due to evaporation from a water body is calculated as

$$V_E = AE_{pm}C_p$$

V_E = Volume of water lost in evaporation, A = Average reservoir surface area

E_{pm} = Pan evaporation, C_p = relevant pan coefficient

Typically, under Indian condition, evaporation loss from a water body is about 160 cm in a year. Value will increase in arid.

3.5 Reduction of Evaporation

- By providing mechanical surface covers.
- By opting for deep reservoirs as against shallow reservoir for storing same volume of water.
- By adding chemicals like cetyl alcohol (hexadecanol) or stearyl alcohol (octadecanol)

Properties of chemicals to be added:

- Density should be less than that of water.
- Rate of evaporation should be less than that of water.
- Not toxic.

3.6 Transpiration and Evapotranspiration

3.6.1 Transpiration:

- Transpiration is the process by which water leaves the body of a living plant and reaches the atmosphere as water vapour.
- Essentially takes place during daylight hours, whereas evaporation takes place throughout day and night.
- The important factor which effect the transpiration are:
  - (i) Atmospheric vapour pressure
  - (ii) Temperature
  - (iii) Wind
  - (iv) Light intensity
  - (v) Characteristics of plant
- Measured by 'Phytometer'

3.6.2 Evapotranspiration:

Evaporation when studied in conjugation with transpiration is called evapotranspiration or consumptive use.

3.6.2.1 Potential evapotranspiration (PET):

When sufficient moisture is always available to completely meets the need of vegetation fully covering the area is called potential evapotranspiration.

3.6.2.2 Actual evapotranspiration (AET):

Evapotranspiration taking place at existing or prevailing conditions is called actual evapotranspiration.

3.6.2.3 Measurement of Actual evapotranspiration:

The measurement of evapotranspiration for a given vegetation type can be carried out in two ways:

(i) By using Lysimeter (ii) By use of field plots

3.6.2.4 Measurement of Potential evapotranspiration:

Potential evapotranspiration is found by using penmann's equation and some empirical formulae.

(i) **Penman's equation:** It is based on combination of energy balance method and mass transfer method.

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

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.

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

E_a =Parameter including wind velocity and saturation deficit.

γ = Psychometric constant = 0.49 mm of Hg/°C.

(i) **Blaney Criddle formula:** This is purely empirical formula based on data from arid western united states. This formula assume that the PET is related to the hours of sunshine and temperature, which are taken as a measure of solar radiation on a given area. The potential evapotranspiration in a crop growing season is given by

$$E_r = 2.54k\Sigma\frac{P_h \times T_f}{100}$$

E_r = PET in a crop season in cm

k = An empirical coefficient depending on the type of crop month and locality.

T_f = Monthly mean temperature (in °F)

$$°F = 1.8t + 32$$

$$t = \text{Temperature (in °C)}$$

P_h = Monthly percentage of annual daytime hour.

NOTE: Isopleth: The lines on a map through places having equal depth of evapotranspiration.

3.7 Interception

- When a rain falls, it is firstly intercepted by trees, plants, buildings etc., when they become completely wet, the water comes down to the earth surface.
- The initial water intercepted by trees, plants and buildings etc., is required to wet them and after that the water intercepted by them equals evaporation rate. So this complete amount of water is called interception loss. It is denoted by

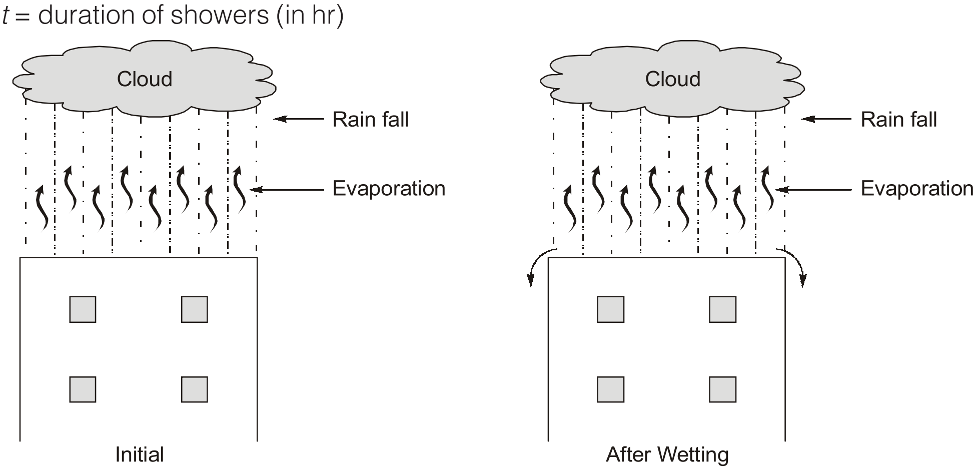
$$x = a + bt$$

x = total interception (in cm)

a = water required for wetting (or interception storage capacity (in cm)

b = evaporation rate from the intercepting surface (in cm/hr)

t = duration of showers (in hr)



Interception loss