Losses from Precipitation

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Overview

Losses from Precipitation

In engineering hydrology, runoff is the main important area of study. Hence, in the hydrologic cycle, any process that does not contribute to the runoff process, is known as Losses from Precipitation. Based on this definition of loss, following processes can be termed as losses.

- Evaporation
- Transpiration
- Interception
- Depression storage
- Infiltration

It is to noted that from runoff point of view, *infiltration* is a loss. But, from groundwater viewpoint, infiltration is a gain.

Evaporation

Definition

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

Evaporation is a cooling process in that the latent heat of vapourization ($585 cal/g$ of evaporated water) must be provided by the water body.

Latent Heat

The amount of energy expanded by a unit mass of water while passing from liquid state to gaseous state at constant temperature is called the *latent heat of vapourization*.

Factors Affecting Evaporation

The factors those affect the rate of quantity of evaporation are:

1. Vapour Pressure
2. Temperature
3. Wind
4. Atmospheric Pressure
5. Soluble Salts
6. Heat Storage in Water Bodies

Vapour Pressure

Dalton's Law of Evaporation

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

$$E_L = C(e_w - e_a)$$

where E_L = rate of evaporation in mm/day, and C = a constant

Evaporation continues till $E_w = e_a$.

Temperature

Relationship

The movement of water molecules increases with temperature. The kinetic energy of water molecules increases as temperature rises and this increased energy permits molecules to escape from water to air more rapidly than otherwise.

For this reason, the warmer the water, the more active are the molecules and the greater is the transfer of molecules from water to air. Experiments have shown that evaporation increases as water is warmed.

Temperature, Latent Heat and Saturation Vapour Pressure

Latent Heat, L

$L = 2501 - 2.37T$ kJ/kg

Vapour Pressure, e_w

$e_w = 4.584\ \exp[\,(17.27\,T)/(237.3 + T)]$ mm of Hg

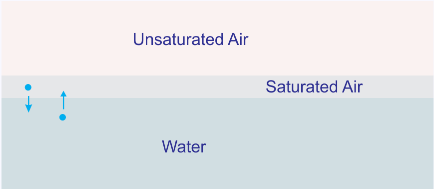
where T = temperature in ^oC

Of course, temperature and other factors are interrelated and it is not possible to isolate the effect of each factor on evaporation. As such, a high correlation between evaporation rate and air temperature *does not* exist.

Wind

Effect

A thin film of saturated vapour would exist over the water surface. It slows down the rate of evaporation. Wind removes this layer and re-expose the water surface to unsaturated air. Evaporation process continues.



However, if the wind velocity is large enough to remove all evaporated water vapor, any further increase in wind velocity does not influence evaporation. Thus the rate of evaporation increases with the wind speed up to a critical speed, above which the speed has no influence.

Atmospheric Pressure

In lower atmospheric pressure, air is less dense and fewer air molecules are present. Hence, there is less likelihood of escaping water molecules colliding with air molecules. Consequently, evaporation is greater at low atmospheric pressure than at high atmospheric pressure.

Atmospheric pressure decreases with altitude and therefore, evaporation is higher at higher altitudes.

Soluble Salts

Water Quality

The vapour pressure of water is reduced when solids are dissolved in water. Pure water has a higher vapour pressure than salt water. Hence presence of soluble salts causesreductioninn evaporation. A salt content of 1% slows the evaporation rate by about 1%. Since the ocean has generally a salt content of little over 3%, sea-water evaporation is 3% less than freshwater evaporation.

Heat Storage in Water Bodies

Deep and shallow water bodies

Deep water bodies have more heat storage than shallow ones. A deep lake may store radiation energy received in summer and release in winter, causing less evaporation in summer and more evaporation in winter, compared to a shallow lake. However, the annual evaporation rate is seldom affected.

Water Vapour

Existence

Atmospheric water mostly exists as a gas or vapour. Locally it becomes a liquid in rainfall and as water droplets in clouds, or it becomes a solid in snowfall, in hail. The amount of water vapour in the atmosphere is less than 1 part in 10^5 of all the waters of the earth, but it plays a vital role in the hydrologic cycle.

Vapour Pressure

Dalton's Law

Dalton's law of partial pressure states that *the pressure exerted by a gas (its vapor pressure) is independent of the presence of other gases*. The vapour pressure e of the water vapor is given by the *ideal gas law* as

$$e = \rho_v R_v T$$

where ρ_v is the density of water vapour, R_v is the gas constant for water vapor and T is the absolute temperature in K.

If the total pressure exerted by the moist air is p, then $p - e$ is the partial pressure due to the dry air, and

$$p - e = \rho_d R_d T$$

where ρ_d is the density of dry air and R_d is the gas constant for dry air.

Humidity

Specific Humidity

The mass of water per unit mass of moist air is called the specific humidity, q_v and equals to the ratio of densities of water vapour ρ_v and moist air ρ_a:

$$q_v = \frac{\rho_v}{\rho_a}$$

It can be shown that

$$q_v = 0.622\frac{e}{p}$$

Humidity

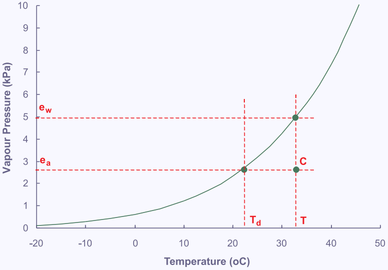
Relative Humidity

For a given air temperature, there is a maximum moisture content that air can hold and the corresponding vapour pressure is called saturation vapour pressure, e_w. At this vapour pressure, the rates of evaporation and condensation are equal.

Saturation vapour pressure vs Temperature

$$e_w = 611 \ \exp \frac{17.27T}{237.3 + T}$$

where e_w is in N/m^2 and T is in ^oC. For point C, actual vapour pressure is e_a and saturated vapour pressure is e_w at temperature T. The relative humidity is $R_h = e_a/e_w$.



Saturated Vapour Pressure

Dew Point Temperature

The temperature at which the air is saturated for vapour pressure $= e_a$ is the dew point temperature T_d.

Example

At a climate station, air pressure is measured as 100kPa, air temperature at $20^o C$, and the wet-bulb or dew point temperature as $16^o C$. Calculate the corresponding vapour pressure, relative humidity, and specific humidity.

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The specific humidity for $p = 100kPa$ and $e_a = 1819Pa$ is

$$q_v = 0.622\frac{e_a}{p} = 0.622\frac{1819}{100 \times 10^3} = 0.0113$$

Introduction

Estimation of evaporation is very important in planning and operation of reservoirs and irrigation systems, particularly in arid zones where scarce water is available. However, the exact measurement of water from a large body is a difficult task.

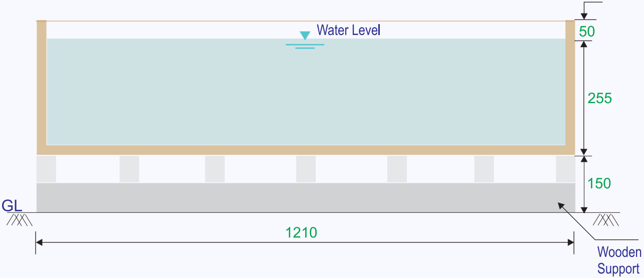
The amount of water evaporated from a water surface can be measured by an *evaporimeter*. Alternatively, it can be estimated by using *empirical equations* and *analytical methods*.

Evaporimeters

Evaporimeters or *Evaporation Pan*s are most widely used for measuring evaporation. These are usually water containing cylindrical pans exposed to the atmosphere. The measuring process is as follows:-

1. Water is poured in the pan
2. Initial water level is measured by a hook gauge
3. Water is added daily to keep the water level within a specified limit
4. Evaporation is calculated from the change in the water level and the depth of water added.
5. Pan evaporation thus obtained is converted to lake evaporation multiplying by a pan coefficient

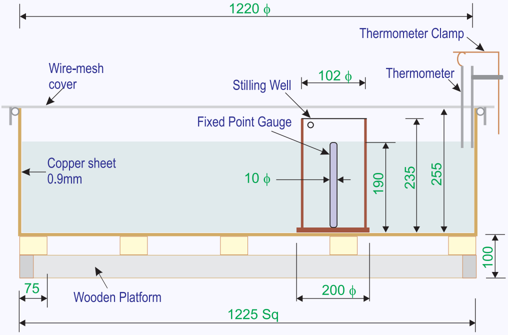
Class A Pan



U. S. Class A Evaporation Pan

This pan is used by the US Weather Bureau and is known as Class A Land Pan. The depth of water is maintained between 18cm to 20cm. The pan is normally made of unpainted galvanized iron sheet. Measurements of the depth of water are taken by a hook gauge in a stilling well.

ISI Pan



ISI Evaporation Pan

This pan evaporimeter specified by IS: 5973-1970, is also known as modified Class A Land Pan. It is made of copper sheet, tinned inside and painted white outside. A fixed point gauge indicates the level of water. A calibrated cylindrical measure is used to add or remove water to maintain the level to a fixed mark.The top of the pan is covered fully with a hexagonal wire net of galvanized iron to protect water from birds. This net also makes the water temperature uniform in day and night.

Lake Evaporation

Evaporation from lake or reservoir is a serious problem. Each year, large amount water is lost due to evaporation, which otherwise could have been utilized for other beneficial purposes. To have an estimate of this loss, measurement of evaporation from lakes is essentially required.

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An evaporimeter usually indicates 20% to 30% more evaporation than the neighbouring lake or reservoir.

Pan Coefficient

A conversion coefficient, known as pan coefficient, C_p is used to estimate lake evaporation from the data obtained from an evaporimeter placed nearby the lake. The conversion is as follows

Lake Evaportaion $= C_p \times$ Pan Evaporation

Values of pan coefficient

Types of Pan	Average Value	Range
Class A Land Pan	0.70	0.60 - 0.80
ISI Pan	0.80	0.65 - 1.10
Colorado Sunken Pan	0.78	0.75 - 0.86
USGS Floating Pan	0.80	0.70 - 0.82

Evaporation Stations

WMO recommendation

1. Arid zones - One station for every $30,000$ km^2
2. Humid temperate climate - One station for every $50,000$ km^2
3. Cold regions - One station for every $100,000$ km^2

Currently India has more than 200 pan evaporimeter.

Example 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. 15 mm of water was removed from the pan to keep the water level within the specified depth range. If the depth of the water in the pan at the end of the week was 190 mm, calculate the pan evaporation. Using a pan coefficient $C_p = 0.7$, estimate the evaporation from the lake in that week.

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Hence, evaporation during the week = 195 + 45 - 15 - 190 = 35 mm.
Evaporation from the lake = $C_p \times$ pan evaporation = $0.7 \times 35 = 24.5$ mm.

Example 2

A class A pan was set up adjacent to a lake of surface area 500 hectare. The daily rainfall and the amount of water added to bring the water level in the pan to the fixed point are given below. Assuming a pan coefficient, C_p=0.8, calculate the volume of 6-day evalporation from the lake.

Day	1	2	3	4	5	6
Rainfall (cm)	0	0.5	0.1	0	0	0.4
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Total 6-day evaporation from the lake = 6.32 cm

Total 6-day volume of evaporation from the lake = $(6.32/100) \times 500 \times 10^4$ m^3 = 316000 m^3.

Example 3

Calculate the mean daily evaporation loss in hectare-metre for the month of July from a stream reach 100 km long and 50 m wide, on the average. The mean daily evaporation measured by a Class A pan for July is 0.6 cm. Assume the pan coefficient as 0.8.

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Surface area of the entire stream reach $= 100 \times 1000 \times 50$ m^2 $=$

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Solution:
Mean daily evaporation from the river $=0.8 \times 0.6$ cm $= 0.48$ cm.
Surface area of the entire stream reach $= 100 \times 1000 \times 50$ m^2 $= 500 \times 10^4$ m^2 $=$ 500 ha.

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So, volume of daily evaporation from the river reach $= 500 \times 0.48 / 100$ ha-m $= 2.4$ ha-m.

This loss of water due to evaporation *must be considered* in managing water of this river reach.

Estimation of Evaporation

Estimation of evaporation is essentially needed for planning and design of water resourses projects.

- Multipurpose Reservoir: Due consideration should be given to volume loss due to evaporation, while fixing the storage capacity.
- Canal Network: Loss of water due to evaporation should be estimated while calculating the design discharge, particularly for a long canal.

Loss of water due to evaporation can be estimated using

- Empirical Methods
  - Meyer's Formula
  - Rohwer's Formula
- Analytical Methods
  - Water Budget Methods
  - Energy Balance Method
  - Mass Transfer Method

Empirical Methods

Most empirical formulae are based on the Dalton-type equation

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

where
E_L = evaporation in mm/day,
e_w = saturated vapour pressure at the water surface in mm of Hg,
e_a = actual vapour pressure at the water surface in mm of Hg,
$f(u)$ = wind-speed correction function and
K = a coefficient

Empirical Formula

Meyer's Formula

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

where
E_L = evaporation in mm/day,
e_w = saturated vapour pressure at the water surface in mm of Hg,
e_a = actual vapour pressure at the water surface in mm of Hg,
u_9 = monthly mean wind veleocity in km/h at 9m above ground
K_M = a coefficient = 0.36 for large deep reservoir and 0.5 for small, shallow reservoir

In the lower part of the atmosphere, upto a height of about 500m above ground level, wind velocity can be expressed as

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

where u_h = wind velocity at a height h above the ground and C = constant.

Meyer's Formula

Example

Following daily meteorological data were obtained for a large reservoir of surface area 15 km^2.

Air temperature : 26^oC
Atmospheric pressure : 752 mm of Hg
Wind speed at 0.5 m above GL : 25.3 km/h
Relative humidity : 46%

Estimate the average daily evaporation from the reservoir and also the evaporation losses from the reservoir for a period of one week using *Meyer's formula*.

Solution

$$\begin{aligned}\text{Saturation vapour, } e_w \text{ at } 26^oC &= 4.584 \text{ exp } (17.27 \text{ T})/(237.3 + \text{T}) \\ &= 4.584 \text{ exp } (17.27 \times 26)/(237.3 + 26) \\ &= 25.227 \text{ mm of Hg.}\end{aligned}$$

Relative humidity, $R_h = e_a/e_w = 46\% = 0.46$.
Therefore, $e_a = 0.46 \times 25.227\text{mm} = 11.604$ mm of Hg.

Wind speed at a height of 0.5m = 25.3 km/h. Now,

$$\frac{u_2}{u_1} = \left[\frac{C\ h_2}{C\ h_1}\right]^{1/7}$$

So, $u_9 = u_2 = u_1 \times [h_2/\ h_1]^{1/7} = 25.3 \times (9/0.5)^{1/7} = 38.234$ km/h

From Meyer's formula with $K_M = 0.36$
$E_L = K_M(e_w - e_a)\left(1 + \frac{u_9}{16}\right) = 0.36 \times (25.227 - 11.604) \times [1 + (38.234/16)] = 16.624$ mm of Hg.

Water Budget Method

This method is based hydrological continuity equation applied to a lake.

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

Where
P = Daily precipitation
V_{is} = Daily surface water inflow into the lake
V_{ig} = Daily groundwater inflow into the lake
V_{os} = Daily surface water outflow from the lake
V_{og} = Daily seepage outflow from the lake
E_L = Daily lake evaporation
ΔS = Increase in lake storage in a day
T_L = Daily transpiration loss
All quantities are in m^3 or in mm.

From the above,

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

P, V_{is}, V_{os} and ΔS can be measured, but other terms are to be estimated.