

## 2.

## EVAPORATION AND ITS MEASUREMENT

Evaporation is a cooling process in which the latent heat of evaporation of about 585 cal/gm is provided by the water body. In this process liquid changes into gaseous phase at free surface, below the boiling point through the transfer of heat energy.

### DALTON'S LAW

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

$$E = K(e_s - e_a)$$

where,  $E$  = Rate of evaporation (mm/day)  
 $e_s$  = Saturation vapour pressure of air (mm)  
 $e_a$  = Actual vapour pressure of air (mm)

$$e_s - e_a = \text{Saturation deficiency}$$

### MEASUREMENT OF EVAPORATION

#### (i) ISI Standard Pan

$$\text{Lake evaporation} = C_p \times \text{Pan evaporation}$$

where,  $C_p$  = Pan coefficient  
 = 0.8 for ISI pan  
 = 0.7 for class-A pan

#### (ii) Empirical Evaporation Equations (Meyer's Formula)

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

where  $k_m$  = Coefficients which accounts for size of water body.  
 = 0.36 (for large deep water)  
 $\simeq$  0.50 (for small and shallow waters)  
 $e_s$  = Saturation vapour pressure of air in mm of Hg.  
 $e_a$  = Actual vapour pressure of overlying air in mm at Hg at specified height of 8 m.  
 $V_9$  = Monthly mean wind velocity in km/hr at about 9 m above the ground level.

$$\frac{V_1}{V_2} = \left( \frac{H_1}{H_2} \right)^{1/7} \quad \text{where } V_1 \text{ is the wind velocity at height } H_1 \text{ and } V_2 \text{ is the wind velocity at height } H_2.$$

### WATER BUDGET METHOD

This is simplest method but it is least reliable. It is used for rough calculation. It is based on mass conservation principle.

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

where,  $P$  = Daily precipitation on the water surface.  
 $V_{is}$  = Daily surface inflow into lake.  
 $V_{os}$  = Daily surface outflow from the lake.  
 $V_{ig}$  = Daily underground inflow into the lake  
 $V_{og}$  = Daily underground outflow from the lake  
 $E$  = Daily Evaporation  
 $\Delta S$  = Change in storage of lake  
 = +ve if increase in storage  
 = -ve if decrease in storage  
 $T_L$  = Daily transpiration loss from the plants on the lake.

### 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 the water body over a known time interval.

$$E = \frac{H_n - H_g - H_s - H_i}{\delta \cdot L(1 + \beta)} \quad \text{where, } H_n = \text{Net heat energy received by the water surface}$$

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

$H_c(1 - r)$  = Incoming solar radiation into a surface of reflection coefficient,  $r$   
 $H_b$  = Back radiation from water body  
 $H_g$  = Heat flux into the ground  
 $H_s$  = Heat stored in water body  
 $H_i$  = Net heat conducted out the system by water flow (advected energy)  
 $\beta$  = Bowen's ratio.  
 $\delta$  = Density of water  
 $L$  = Latent heat of evaporation.



## EVAPO-TRANSPIRATION

While transpiration takes place, the land area in which plants stand also lose moisture by the evaporation of water from soil and water bodies. In hydrology and irrigation practice, it is found that evaporation and transpiration processes can be considered advantageously under one head as evapo-transpiration.

The real evapo-transpiration occurring in a specific situation is called actual evapo-transpiration (AET).

### • Penman's Method

Penman's equation is based on sound theoretical reasoning and is obtained by a combination of the energy balance and mass transfer approach.

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

where, PET = Daily evaporation in mm/day.

A = Slope of the saturation vapour pressure v/s Temperature curve at the mean air temperature in mm of Hg per °C.

$H_n$  = Net radiation in mm of **evaporable** water per day

$E_a$  = Parameter including wind velocity and saturation deficit.

$\gamma$  = Psychrometric constant

= 0.49 mm of Hg/°C

## TRANSPIRATION LOSS (T)

$$T = (w_1 + w) - w_2$$

where,  $w_1$  = Initial weight of the instrument

$w$  = Total weight of water added for full growth of plant.

$w_2$  = Final weight of instrument including plant and water

T = Transpiration loss.

## STREAMFLOW MEASUREMENT

Streamflow representing the runoff phase of the hydrologic cycle is the most important basic data for hydrologic studies.

Streamflow measurement techniques can be broadly classified into two categories as:

1. Direct determination and
2. Indirect determination.

Under each category there are a host of methods, the important ones are listed below:

1. Direct determination of stream discharge
  - (a) Area velocity methods
  - (b) Dilution techniques
  - (c) Electromagnetic method and
  - (d) Ultrasonic method
2. Indirect determination of streamflow
  - (a) Hydraulic structures, such as weirs, flumes and gated structures, and
  - (b) Slope-area method

## DETERMINATION OF VELOCITY

- (i) **Float Method:** Float are generally used to determine approximate velocity of the surface. These are floating devices which are passed with the water along the flow of stream.

$$V_s = \frac{L}{t}$$

Here,  $V_s$  = Surface velocity

L = Distance travelled by the float in time 't'.

- (ii) **Current Meters Method:** These consist of rotating elements which rotate due to reactions of stream currents. The number of revolution per sec are counted. This can be used to measure point velocity of any depth.

$$V = aN_s + b$$

where, V = Point velocity

$N_s$  = Number of revolution per sec. a and b are current meters constant.

## VELOCITY DISTRIBUTION

$$(i) \quad \bar{V} = (0.85 \text{ to } 0.95)V_s$$

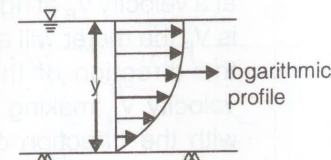
for turbulent flow

where,  $\bar{V}$  = Mean velocity

$V_s$  = Surface velocity

- (ii) **For Shallow Streams**

$$\bar{V} = V_{0.6y} \quad \text{where } V_{0.6y} = \text{Point velocity at } 0.6y \text{ from surface}$$





(iii) For Deep Streams

$$\bar{V} = \frac{V_{0.2y} + V_{0.8y}}{2}$$

- Sounding Weight

$$W = 50\bar{V}y$$

$W$  = Weight in newton

$\bar{V}$  = Average stream velocity

$y$  = Depth of flow in meters.

## STREAM FLOW (DISCHARGE MEASUREMENT)

- (i) **Area Velocity Method:** This method of discharge measurement consists essentially of measuring the area of cross-section of the river at a selected section called the gauging site and measuring the velocity of flow through the cross-sectional area. The gauging site must be selected with care to assure that the stage-discharge curve is reasonably constant over a long period of about a few years.

Total discharge,

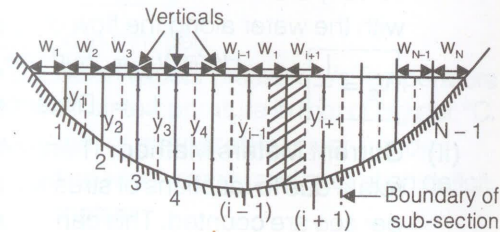
$$Q = q_1 + q_2 + \dots + q_{n-1}$$

where,  $q_1 = \bar{w}_1 \bar{y}_1 \bar{V}_1$

$q_2 = \bar{w}_2 \bar{y}_2 \bar{V}_2$  etc.

$$\bar{W}_i = \frac{W_i + W_{i+1}}{2} \text{ for } 2 \leq i \leq (n-1)$$

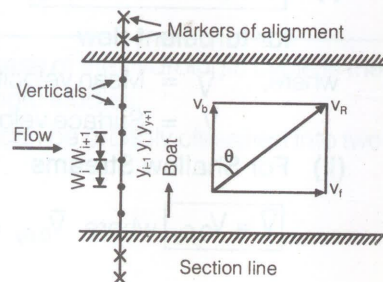
$$\bar{w}_1 = \frac{(w_1 + w_{2/2})^2}{2w_1} \quad \bar{w}_n = \frac{(w_n + w_{n-1/2})^2}{2w_n}$$



- (ii) **Moving Boat Method:** In this method a special propeller type current meter which is free to move about a vertical axis is towed in a boat at a velocity  $V_B$  at right angles to the stream flow. If the flow velocity is  $V_F$  the meter will align itself in the direction of the resultant velocity  $V_R$  making an angle  $\theta$  with the direction of the boat. Further, the meter will register the velocity  $V_R$ . If  $V_B$  is normal to  $V_F$ .

$$V_B = V_R \cos \theta$$

$$V_F = V_R \sin \theta$$



$$q_i = \left[ \frac{y_{i-1} + y_i}{2} \times w_i \right] \bar{V}_i \text{ where, } q_i = \text{Discharge through the } i^{\text{th}} \text{ segment.}$$

$$q_i = \left( \frac{y_{i-1} + y_i}{2} \right) V_R^2 \sin \theta \cos \theta t_i$$

$t_i$  = Time required to pass the boat through  $i^{\text{th}}$  segment.

- (iii) **Dilution Method:** The dilution method of flow measurement, also known as the chemical method depends upon the continuity principle applied to a tracer which is allowed to mix completely with the flow.

$$Q_0 = \frac{Q_1(C_1 - C_2)}{C_2 - C_0}$$

This technique in which  $Q_0$  is estimated by knowing  $C_1$ ,  $C_2$ ,  $C_0$  and  $Q_1$  is known as constant rate injection method or plateau gauging.

where,

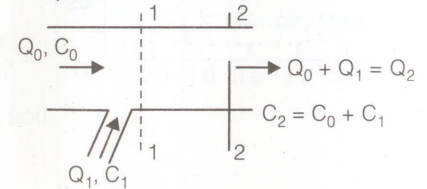
$Q_0$  = Discharge of stream

$C_0$  = Tracer intensity initially

$C_1$  = Tracer intensity at (1)

$C_2$  = Tracer intensity at (2).

$Q_1$  and  $Q_2$  are discharge at (1) and (2) respectively.



- (iv) **Slope Area Method:** It is a very versatile indirect method of discharge estimation and requires (i) the selection of a reach in which cross-sectional properties including bed elevations are known at its ends, (ii) the value of Manning's  $n$  and (iii) water-surface elevations at the two end sections.

$$(a) \quad z_1 + y_1 + \frac{V_1^2}{2g} = z_2 + y_2 + \frac{V_2^2}{2g} + H_f + H_e$$

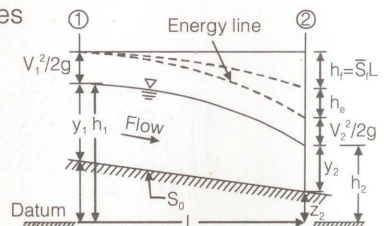
where  $H_f$  = Frictional losses

$H_e$  = Eddy losses

$$(b) \quad H_e = k_e \left[ \frac{V_1^2}{2g} - \frac{V_2^2}{2g} \right]$$

$k_e$  = Eddy loss coefficients.

$$(c) \quad h_1 + \frac{V_1^2}{2g} = h_2 + \frac{V_2^2}{2g} + H_f + H_e$$



(d) 
$$H_f = (h_1 - h_2) + \left( \frac{V_1^2}{2g} - \frac{V_2^2}{2g} \right) - k_e \left( \frac{V_1^2}{2g} - \frac{V_2^2}{2g} \right)$$

(e) 
$$Q = k \sqrt{\frac{H_F}{L}}$$
 where, Q = Stream flow (m<sup>3</sup>/sec)

(f) 
$$k = (k_1 \cdot k_2 \dots k_n)^{1/n}$$
 where, k = Conveyance

(g) 
$$k = \frac{1}{n} \cdot A \cdot R^{2/3}$$
 where, A = Area (m<sup>2</sup>)  
R = Hydraulic mean depth  

$$= \frac{\text{Area}}{\text{Wetted Perimeter}}$$

