

UPPSC-AE

2023

Uttar Pradesh Public Service Commission

Combined State Engineering Services Examination
Assistant Engineer

Civil Engineering

Engineering Hydrology

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



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Engineering Hydrology

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1.1 Introduction

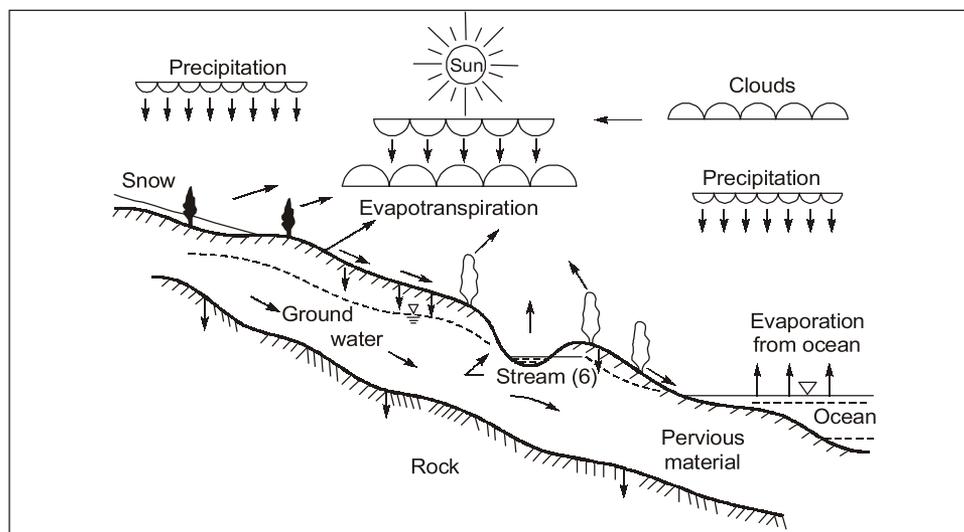
Hydrology is an earth science involving the study of water on earth. It deals with the occurrence, circulation and distribution of water on the earth and atmosphere.

1.2 Hydrology Cycle

- The hydrological cycle is a global sun driven process in which water is transported from oceans to the atmosphere than to the land and then back to the sea.
- It is a continuous process with no definite starting point. A convenient starting point to describe the cycle is taken as oceans.

Extent: 1 km below the earth surface and 15 km above the surface.

- Due to solar radiation falling on ocean surface water evaporates and mixes with the dry air above making it moist. Moist air being lighter than dry air rises and in the process cools down thereby increasing its relative humidity.
- Relative humidity subsequently reaches 100% full saturation, any further rise in elevation of moist air causes condensation followed by precipitation.
- The hydrological cycle is usually described in terms of six major components: Precipitation (P), Infiltration (I), Evaporation (E), Transpiration (T), surface Runoff (R) and Ground water flow (G).
- For computational purpose, evaporation and transpiration are sometimes lumped together as evapotranspiration (ET). Figure below shows these components and illustrates the paths they define in hydrological cycle.

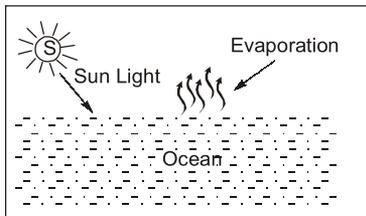


The Hydrologic cycle

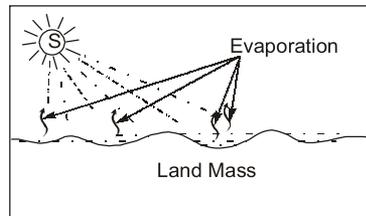
1.2.1 Components of Hydrologic Cycle

(i) **Evaporation:** When the water come into contact with heat radiation, it turns into vapour. It is called evaporation.

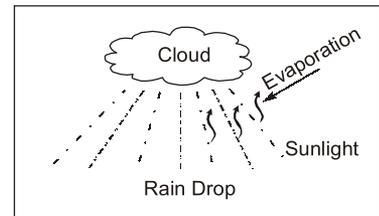
- In hydrologic cycle, evaporation mainly occur from ocean. Ocean evaporation contributes in large part and the real evaporation occur from land mass and raindrop evaporation.
- When rain drop comes to the earth surface, and come in contact with sunlight than they also get evaporated in air.



Evaporation from Ocean



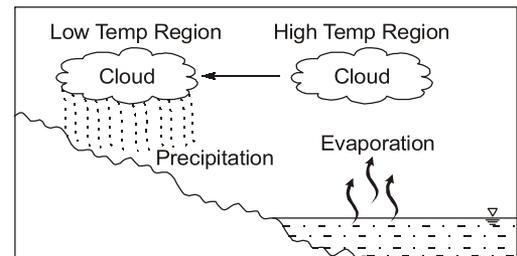
Evaporation from land mass



Rain drop evaporation

(ii) **Precipitation:** As the evaporation continues, the amount of vapour in atmosphere goes on increasing, after reaching a certain amount, the vapour condense and come to earth's surface in solid or liquid form, this is called precipitation.

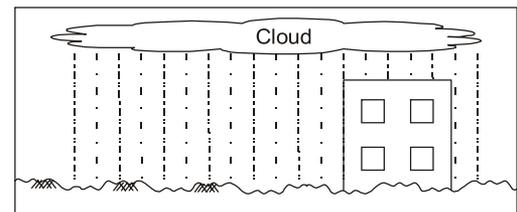
- As the air temperature decrease, its moisture holding capacity decreases.



Precipitation

(iii) **Interception:** Some amount of precipitation is evaporated back to the atmosphere and another part of precipitation is intercepted by vegetation, structure etc. from where it may be either evaporated back to atmosphere or move down to ground surface.

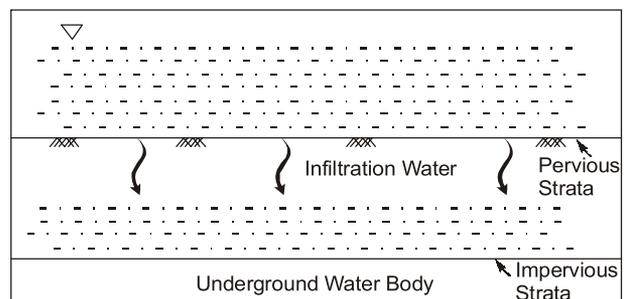
- Amount of rainfall on the roof building is intercepted rainfall or simply interception.



Interception

(iv) **Infiltration:** When the water come in to the earth surface. Some portion of it penetrate the ground and increase the moisture capacity of soil beneath the surface.

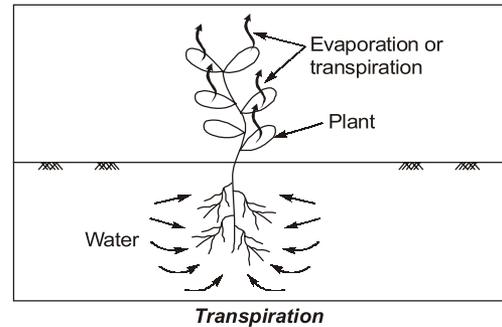
- This water is called infiltrated water and this process is called infiltration.
- Through infiltration the water level of underground water bodies increases.
- Infiltration is important for underground water movement, by increasing in its volume.
- Infiltration will be more in a village in comparison to town, because the town have pacca road which is treated as impervious strata.
- Infiltration will be more in forest area in comparison to dessert land because the tree make the surface pervious and increase the infiltration.



Infiltration Beneath a Water Body

(v) **Transpiration:** Vegetation use the ground water or soil moisture for their growth. This moisture again convert in evaporation through vegetation. This is called transpiration.

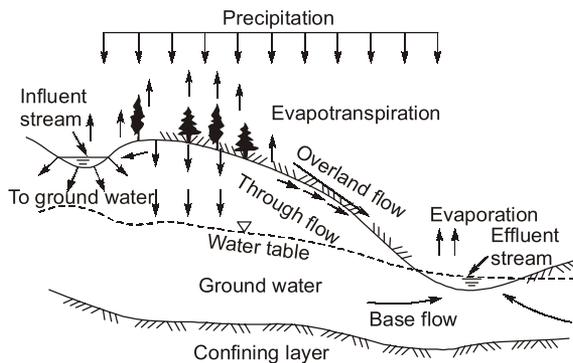
- Water extracted by plant's roots, transported upward through its stem and diffused into the atmosphere through tiny openings in the leaves is called transpiration water and process is called transpiration.



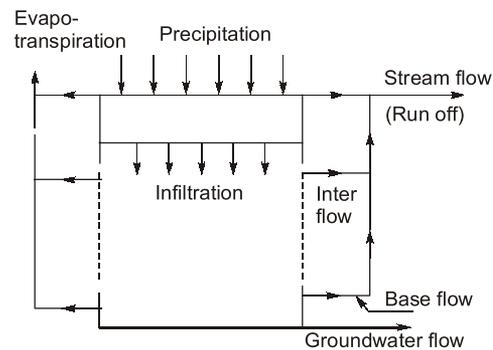
Transpiration

(vi) **Runoff:** The portion of precipitation which come on the surface and reach the stream channel by above and below the surface of earth is called runoff.

- The portion of precipitation that reach the stream after reaching on surface, only from above the surface is called surface runoff.
- The runoff reach in stream channel is called *stream flow*.
- Runoff means the draining or flowing off of precipitation from a catchment area through a surface channel.



Different routes of runoff



Transportation Components of the Hydrologic Cycle



NOTE

- **Evaporation:** Change of water from liquid to gaseous phase.
- **Precipitation:** The deposition of water on earth surface as rain, snow, hail etc.
- **Interception:** Short term retention of rainwater by vegetation, roof tops, pavement etc.
- **Infiltration:** Movement of water into the soil at the surface.
- **Percolation:** Movement of water from one soil zone to a lower soil zone.
- **Transpiration:** It is the water absorbed from the ground and evaporated into the atmosphere through leaves.
- **Interflow:** It is the groundwater flowing horizontally above the GWT. It is also known as subsurface flow.
- **Depression storage:** Rainwater accumulated in small depressions and ditches above the surface.
- **Surface Runoff:** It is the part of rain which reaches the stream immediately after the rainfall flowing over the surface.

1.3 Water Budget Equation

The quantity of water going through various individual paths of the hydrological cycle in a given system can be described by the continuity principle known as *Water Budget Equation* or *Hydrologic Equations*. The *Conservation of Mass* is the most useful physical principle in hydrologic analysis and is required in almost all applied problem.

For a given catchment area in an interval of time Δt , the continuity equation for water is

Mass of water inflow – Mass of water outflow = Change in mass of water storage

If the density of water in inflow, outflow and storage water are same, then

Vol. of inflow water – Vol. of outflow water = Change in storage vol. of water

$$V_i - V_o = \Delta S$$

For solving the problem of water budget equation we should be clear in mind, what factor recharges the water discharged in the water body.

- (i) Water Budget Equation for a Catchment

For a particular time Δt ,

$$P - R - G - E - T = \Delta S$$

- (ii) Water Budget Equation for Water Bodies

$$I + P - G - E - O = \Delta S$$

- (iii) Water Budget Equation for Surface Flow

$$P + I + I_G - O - E - T - I_n = \Delta S$$

- (iv) Water Budget Equation for Underground Flow

$$I_G + I_n - O_G - O_S - T = \Delta S$$

Where, P = Precipitation; R = Surface runoff; G = Net ground water flow out of the catchment

E = Evaporation; T = Transpiration; ΔS = Change in storage = $S_s + S_{sm} + S_g$

S_s = Surface water storage; S_{sm} = Water in storage as soil moisture

S_g = water in storage as groundwater; I = Inflow; O = Outflow

I_G = Ground water come to the surface; I_n = Infiltration

O_G = Ground water outflow; O_S = Ground water come to the surface

Water budget equation in terms of rainfall runoff relationship can be represented as

$$R = P - L$$

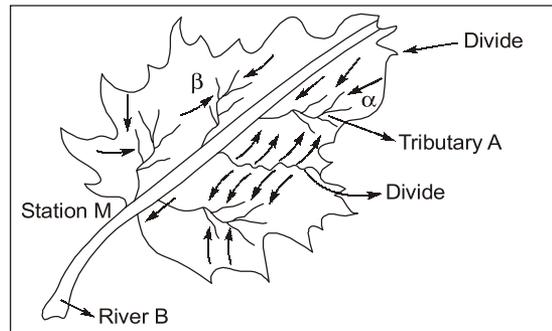
R = Runoff, P = Precipitation and L = Losses (infiltration, evaporation, transpiration and surface storage)

- For large catchment area, ground water inflow and outflow are almost equal.
- In general, after a long period the storage in catchment be same as prior.

1.4 Catchment Area

- The area of land from which the runoff comes into a stream is called the catchment area of that stream.
- It is also called as *drainage basin* or *drainage area* or *water shed*.
- The area of land draining into a stream or water course at a given location is known as catchment area.

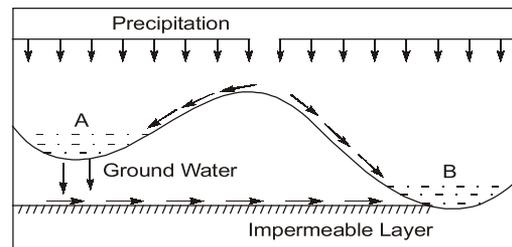
- A catchment area is separated from its neighbouring areas by a ridge called *divide* or *watershed*.
- The catchment area of tributary river A is α and $(\alpha + \beta)$ is the catchment area of river B.
- If the catchment has no outlet point than it is called a *closed catchment*. In closed catchment water converges to a single point inside the basin known as *sink*, which may be a permanent lake, or a point where surface water is lost underground.



Schematic Sketch of Catchment of River B at station M

1.5 Catchment Leakage

- We measure the runoff at the outlet of catchment area, sometimes, it happens that runoff from nearby catchment also come so due to this the error will come in result. This generally occur due to subsurface water. Thus, the catchment leakage is said to occur.
- Catchment leakage also occur when the topographic divide are not coincident with the ground water divide.



Leakage of Catchment



Example-1.1 A small catchment of area 150 Ha received 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 and experienced a runoff lasting for 10 hours with an average discharge of 1.5 m³/s. The stream was again dry after the runoff event. (a) What is the amount of water which was not available to runoff due to combined effect of infiltration, evaporation and transpiration? What is the ratio of runoff to precipitation?

Solution:

The water budget equation for the catchment in a time Δt is

$$R = P - L$$

Where, L = losses = water not available to runoff due to infiltration (causing addition to soil moisture and groundwater storage), evaporation, transpiration and surface storage.

In the present case Δt = duration of the runoff = 10 hours.

Note that the rainfall occurred in the first 90 minutes and the rest 8.5 hours the precipitation was zero.

(a) P = Inflow due to precipitation in 10 hours
 $= 150 \times 10^4 \times (10.5/100) = 157,500 \text{ m}^3$

R = Runoff volume = outflow volume at the catchment outlet in 10 hours
 $= 1.5 \times 10 \times 60 \times 60 = 54,000 \text{ m}^3$

Hence losses $L = 157,500 - 54,000 = 103,500 \text{ m}^3$

(b) Runoff/rainfall = $54,000/157,500 = 0.343$



Example - 1.2 The plan area of a reservoir is 1 km^2 . The water level in the reservoir is observed to decline by 20 cm in a certain period. During this period the reservoir receives a surface inflow of 10 hectare-meters, and 20 hectare-meters are abstracted from the reservoir for irrigation and power. The pan evaporation and rainfall recorded during the same period at a nearby meteorological station are 12 cm and 3 cm respectively. The calibrated pan factor is 0.7. The seepage loss from the reservoir during this period in hectare-meters is

- (a) 0.0 (b) 1.0
(c) 2.4 (d) 4.6

Solution: (d)

Inflow to reservoir, $I = 10 \text{ ha-m}$

Outflow from reservoir, $Q = 20 \text{ ha-m}$

Evaporation loss, $E = 1 \times 10^6 \times \frac{12}{100} \times 0.7 = 8.4 \text{ ha-m}$

Rainfall, $P = 1 \times 10^6 \times \frac{3}{100} = 3 \text{ ha-m}$

Change in storage, $\Delta S = 1 \times 10^6 \times \frac{20}{100} = -20 \text{ ha-m}$

We know that

$$\begin{aligned} (I + P) - (E + Q + \text{seepage}) &= \Delta S \\ \Rightarrow (10 + 3) - (8.4 + 20 + \text{seepage}) &= -20 \\ \Rightarrow 13 - 28.4 - \text{seepage} &= -20 \\ \Rightarrow \text{seepage} &= 4.6 \text{ ha-m} \end{aligned}$$



Example - 1.3 A reservoir has average water spread over 4 km^2 . During two months period of study, surface inflow = 240 ha-m, surface outflow = 192 ha-m; rainfall = 28 cm; change in storage = (+)72 ha-m. By the hydrologic equation, the estimated reservoir losses are

- (a) 160 ha-m (b) 120 ha-m
(c) 88 ha-m (d) 232 ha-m

Solution: (c)

Area = 4 km^2

Surface inflow = 240 ha-m

Surface outflow = 192 ha-m

Rainfall = 28 cm

Change in storage = +72 ha-m

Total mass inflow

$$\begin{aligned} &= 240 \text{ ha-m} + \text{rainfall} \\ &= 240 \text{ ha-m} + 0.28 \times 400 = 352 \text{ ha-m} \end{aligned}$$

Let losses are Δ_L ,

Using hydrologic equation,
mass inflow – mass out flow

$$\begin{aligned} &= \text{Change in storage} \\ 352 - (192 + \Delta_L) &= 72 \\ \Delta_L &= 352 - 192 - 72 = 88 \text{ ha-m} \end{aligned}$$

Hence option (c) is correct.

1.6 Residence Time

- The residence time is the average duration for a water molecule to pass through a subsystem of hydrological cycle.
- Average time taken by the water molecule to pass through a particular part of hydrological cycle is known as residence time of that part of hydrological cycle.

Residence time is calculated by

$$T_r = \frac{S}{Q}$$

S = Storage of water in that particular subsystem or part

Q = Flow of water through that particular subsystem or part



Example - 1.4 The volume of atmosphere moisture is 12900 km³ and the flow rate of precipitation is 577000 km³/yr. Find the residence time of moisture.

Solution:

Storage of water in form of moisture

$$S = 12900 \text{ km}^3$$

Flow of water as precipitation, $Q = 577000 \text{ km}^3/\text{yr}$

So the residence time is

$$T_r = \frac{S}{Q} = \frac{12900 \text{ km}^3}{577000 \text{ km}^3/\text{yr}} = 0.022 \text{ year} = 8.2 \text{ days}$$



NOTE

- Evaporation from ocean contributes 90% of the atmospheric moisture.
- Runoff/rainfall = 46% (long term estimate) for India.
- Average annual rainfall over whole of India is 119 cm.
- In the ocean about 9% more water evaporates than that falls back as precipitation.
- Phytometer measures transpiration.
- Lysimeter is used to measure evapotranspiration.
- Atmometer is used to measure evaporation.
- Speed of wind is measured using anemometer.
- Humidity is measured using hygrometer or Psychrometer.



Student's Assignment

- Q.1** What is hydrological cycle?
- processes involved in transfer of moisture from sea to land
 - processes involved in transfer of moisture from sea back to sea again
 - process involved in transfer of water from snowmelt in mountains to sea
 - process involved in transfer of water from sea to land and back to sea again.
- Q.2** The percentage of earth is covered by oceans is about
- 31%
 - 51%
 - 71%
 - 97%
- Q.3** The percentage of total quantity of water in the World that is saline about
- 71%
 - 33%
 - 67%
 - 97%
- Q.4** The percentage of total quantity of fresh water in World available in liquid form is about
- 30%
 - 70%
 - 11%
 - 51%
- Q.5** In a hydrological cycle, the average residence time of water in the global
- atmospheric moisture is larger than that in global rivers
 - ocean is smaller than that of global ground water
 - rivers is larger than that of global ground water
 - ocean is larger than that of the global ground water.
- Q.6** By which simple equation the hydrologic cycle can be expressed?
- Precipitation = Evaporation – Run-off
 - Evaporation = Precipitation + Run-off
 - Run-off = Precipitation + Evaporation
 - Precipitation = Evaporation + Run-off
- Q.7** The quantitative statement of balance between water gains and losses in a certain basin during a specified period of time is known as which of the following.
- Water budget
 - Hydraulic budget
 - Ground water budge
 - None
- Q.8** Which of the following are pertinent to the realization of hydrological cycle?
- Latitudinal difference in solar heating of earth surface.
 - Inclination of earth's axis.
 - Uneven distribution of land and water.
 - Coriolis effect.
- 1 only
 - 2 only
 - 3 only
 - all of the above
- Q.9** Catchment of area 120 km² has three distinct zones as below:
- | Zone | Area (km ²) | Annual run - off (cm) |
|------|-------------------------|-----------------------|
| A | 61 | 52 |
| B | 39 | 42 |
| C | 20 | 32 |
- The annual run-off from catchment is
- 126 cm
 - 42 cm
 - 45.4 cm
 - 47.3 cm
- Q.10** The hydrologic equation states that :
- Σ Inflow – Σ outflow = constant
 - Sub-surface inflow = sub-surface outflow
 - Inflow into the basin = outflow from the basin
 - Inflow – outflow = change in storage
- Q.11** Hydrology deals with
- process of depletion of water resources of land
 - process of natural science of water
 - process of various water phases
 - all of the above

- Q.12** In the hydrological cycle the average residence time of water in the global
- (a) atmospheric moisture is larger than that in the global rivers.
 - (b) oceans is smaller than that of the global groundwater
 - (c) rivers is larger than that of the global groundwater
 - (d) oceans is larger than that of the global groundwater

$$= \frac{5450}{120} = 45.4 \text{ cm}$$

- Q.13** A watershed has an area of 300 ha. Due to a 10 cm rainfall event over the watershed a streamflow is generated and at the outlet of the watershed it last for 10 hrs. Assuming runoff/rainfall ratio of 0.2 for this event, the average stream flow rate at the outlet in this period of 10 hrs is
- (a) 1.33 m³/s
 - (b) 16.7 m³/s
 - (c) 100 m³/min
 - (b) 60000 m³/hr

- Q.14** Rainfall of intensity of 20 mm/hr occurred over a watershed of area 100 ha for a duration of 6 hr measured runoff volume in the stream draining the watershed was found to be 30000 m³. The precipitation not available to runoff in this case is
- (a) 9 cm
 - (b) 3 cm
 - (c) 17.5 mm
 - (b) 5 mm

10. (d)

The hydrologic equation is based on the law of conservation of mass and it state that
Mass inflow – mass outflow = Change in storage

$$I - O = \Delta_{\text{storage}}$$

Hence option (d) is correct.

11. (d)

Hydrology is the science which deals with the occurrence, circulation and distribution of water on earth and its atmosphere. The movement of water from one phase (i.e., liquid or gaseous) to another phase is known as hydrological cycle. Hence option (d) is correct.

13. (c)

Given, Precipitation = 10 cm
At outlet
∴ Runoff = 0.2 × 10 = 2 cm
∴ Stream flow rate at outlet

$$= \frac{2 \text{ cm} \times 300 \text{ ha}}{10 \text{ hr}} = \frac{2 \times 10^{-2} \times 300 \times 10^4}{10 \times 60} = 100 \text{ m}^3/\text{min}$$

14. (a)

Area of watershed = 100 ha
Total ppt (P) = 20 × 6 = 120 mm = 12 cm

$$\text{Total Runoff (R)} = \frac{30,000}{100 \times 10^4} = \frac{3}{100} \text{ m} = 3 \text{ cm}$$

The precipitation not available to runoff
i.e. losses = P – R
(L) = 12 – 3 = 9 cm



ANSWER KEY // **STUDENT'S ASSIGNMENT**

- | | | | | |
|---------|---------|---------|---------|---------|
| 1. (d) | 2. (c) | 3. (b) | 4. (a) | 5. (d) |
| 6. (d) | 7. (a) | 8. (d) | 9. (c) | 10. (d) |
| 11. (d) | 12. (d) | 13. (c) | 14. (a) | |

HINTS & SOLUTIONS // **STUDENT'S ASSIGNMENT**

9. (c)

$$\begin{aligned} \text{Annual run-off} &= \frac{R_1 A_1 + R_2 A_2 + R_3 A_3}{A_1 + A_2 + A_3} \\ &= \frac{61 \times 52 + 39 \times 42 + 20 \times 32}{61 + 39 + 32} \end{aligned}$$