# CIVIL ENGINEERING

# Engineering Hydrology

Comprehensive Theory
*with* Solved Examples *and* Practice Questions

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# Engineering Hydrology





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# Engineering Hydrology

CHAPTER

1

# Introduction

## 1.1 INTRODUCTION

Hydrology means the science of water. Hydrology deals with the occurrence, circulation and distribution of water on the earth and earth's atmosphere. Hydrology may be defined as the science that deals with the charging and discharging of our water resource. Practical application of hydrology is required in the design and operation of hydraulic structure, water supply, irrigation, hydro power generation, flood control, etc.

The study of hydrology which is concerned mainly with academic aspects (such as geology, chemistry and physics etc.) is known as **Scientific hydrology**. Whereas, **Engineering Hydrology** or **Applied Hydrology** is the study of hydrology concerned mainly with engineering applications.

In this chapter, we will study about hydrologic cycle, its component and continuity equations used in hydrology known as water budget equations.

## 1.2 THE HYDROLOGIC CYCLE

Water occurs on the Earth and Earth's atmosphere in all its three states (liquid, gas, solid). There is endless circulation of water between the earth and its atmosphere. This circulation is called hydrologic cycle. This cycle has no beginning or end and its many process occurs simultaneously. Water on the earth exists in a space called hydrosphere and it has boundary 15 km up into atmosphere and 1 km down into lithosphere. Hydrologic cycle also moves within this boundary. Sun imparts energy for the movement of this cycle. Sun and Coriolis force (due to this force, wind moves in different direction) plays important role in completion of hydrologic cycle. Sun evaporates water and Coriolis force (by controlling wind) circulate the water vapour, where precipitation occurs.

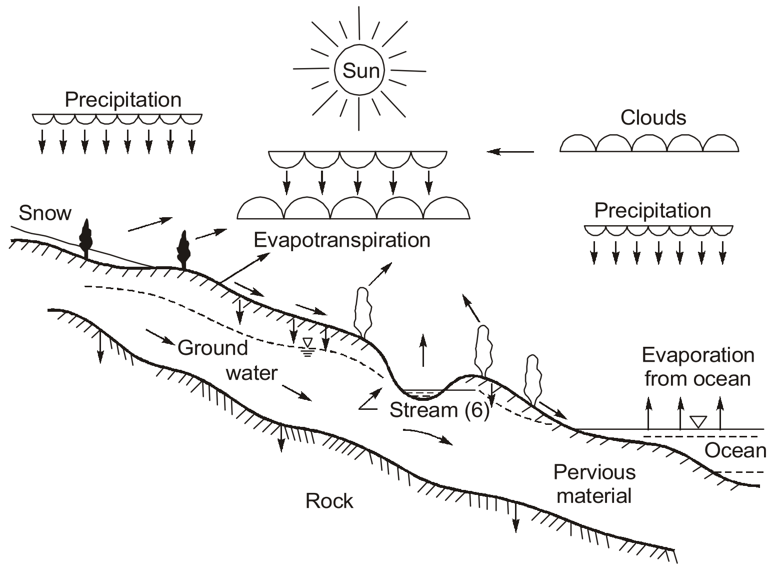


**Fig.** The global hydrologic cycle represented as a system

### 1.2.1 Components of Hydrologic Cycle

Various components of hydrologic cycle are as follows:

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

- In hydrologic cycle, evaporation mainly occurs 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, they also get evaporated in atmosphere.

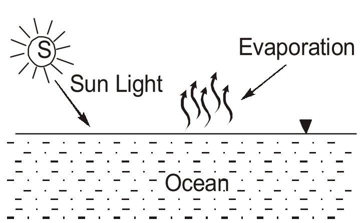


**Fig.** Evaporation from Ocean

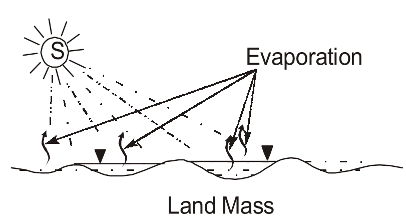


**Fig.** Evaporation from land mass

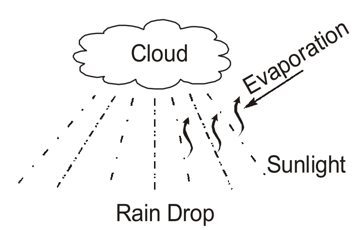


**Fig.** Rain drop evaporation

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

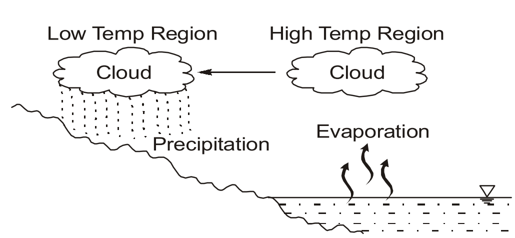


**Fig.** Precipitation

(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.

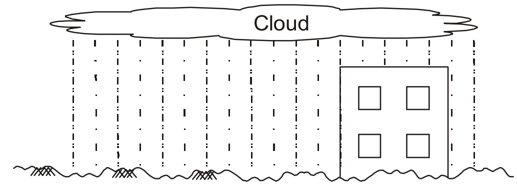


**Fig.** Interception

(iv) **Infiltration:** When the water comes in to the earth surface, some portion of it penetrate into the ground and increases 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.
- It is important for underground water movement.
- It will be more in a village in comparison to town, because the town have pacca road which is treated as impervious strata.
- It will be more in forest area in comparison to dessert land because the tree make the surface pervious and increases the infiltration.

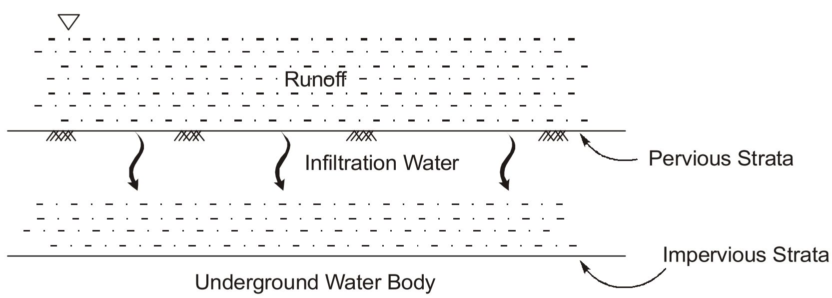


**Fig.** Infiltration Beneath a Water Body

(v) **Transpiration:** Vegetation use the ground water or soil moisture for their growth. This moisture again convert into vapour through the process known as 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 the process is called transpiration.

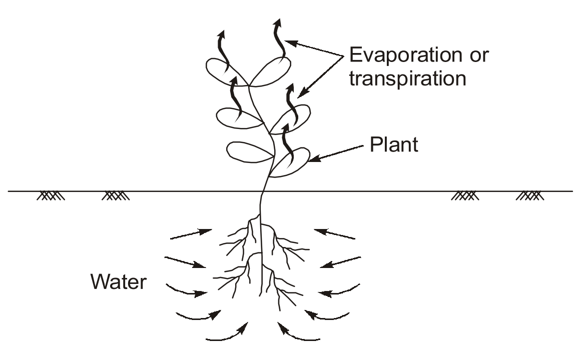


**Fig.** Transpiration

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

Thus, it means, the draining or flowing off of precipitation from a catchment area through a surface channel.

- The portion of precipitation that reaches 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*.

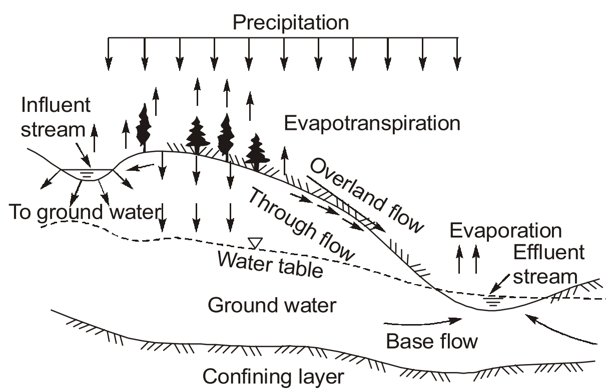


**Fig.** Different routes of runoff

**NOTE**

- 96.5 percent of water on the earth's surface is in the ocean. Remaining 1.7 percent is in the polar ice, 1.7 percent in ground water and 0.1 percent in the surface and atmospheric water system.
- If we assume that the 100 parts of water come to the land area through precipitation then 61 parts of this precipitation goes to the atmosphere through evaporation and 39 parts of it form runoff to the ocean.
- Average annual depth of precipitation over the world is 0.752 m, but 0.428 m depth of water gets evaporated. Only 0.342 m water is available for runoff.
- Average annual precipitation in India is 120 cm in a highly uneven portion.
- The per capita water availability for the Indian people is less in comparison to world's. As we have 4% of world's average annual water supply and 16% of world's population.
- Due to unevenness in precipitation at different places of world, a large quantity of available river runoff is wasted as they join the ocean. We use water around 20% of available water.
- The Amazon river carries about 17% of total flow of world.
- Per capita average annual runoff of India is about 1700 $m^3$.
- The percentage of total quantity of **fresh water** in the world is only 0.3% available in liquid form.
- Most of the water that evaporate from the ocean gets back to the ocean in the form of precipitation. About 9% more water evaporates from the ocean than what falls back on them as precipitation.

## 1.3 CATCHMENT AREA

- The area of land from which the runoff comes into a stream is called the catchment area of that stream.

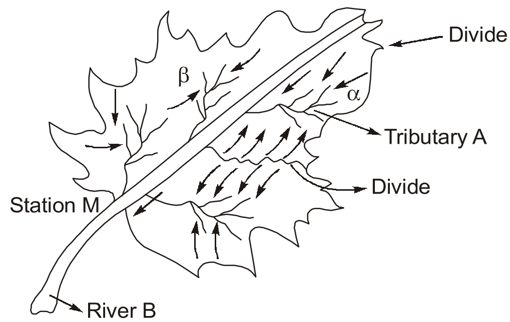


**Fig.** Schematic Sketch of Catchment of River B at station M

- It is also called as *drainage basin* or *drainage area* or watershed.
- 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 $\alpha$ and $(\alpha + \beta)$ is the catchment area of river B.
- If the catchment has no outlet point then it is called as *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.

### 1.3.1 Leakage of Catchment

- 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.

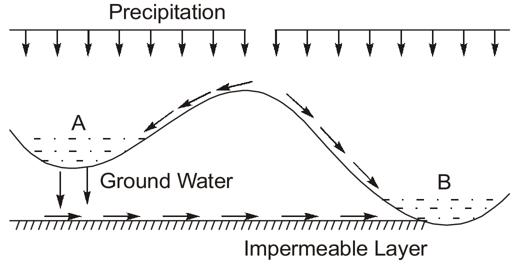


**Fig.** Leakage of Catchment

## 1.4 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 equation 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 stored water

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

Volume of inflow water – Volume of outflow water = Change in storage volume of water

$$V_i - V_o = \Delta S$$

(i) Water Budget Equation for a Catchment

In a particular time interval $\Delta t$,

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

(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

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

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

$$R = P - L$$

Where, $P$ = Precipitation; $R$ = Surface runoff; $G$ = Net ground water flow out of the catchment
$E$ = Evaporation; $T$ = Transpiration; $\Delta S$ = 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
$L$ = Losses (infiltration, evaporation, transpiration and surface storage)

**Example 1.1** A lake had a water surface elevation of 103.200 m above datum at the beginning of a certain month. In that month the lake received an average inflow of 6.0 m$^3$/s from surface runoff sources. In the same period the outflow from the lake had an average value of 6.5 m$^3$/s. Further, in that month, the lake received a rainfall of 145 mm and the evaporation from the lake surface was estimated as 6.10 cm. Write the water budget equation for the lake and calculate the water surface elevation of the lake at the end of the month. The average lake surface area can be taken as 5000 Ha. Assume that there is no contribution to or from the groundwater storage.

**Solution:** In a time interval $\Delta t$ the water budget for the lake can be written as

Inflow volume – Outflow volume = Change in water storage of the lake

$$(\bar{I}\Delta t + PA) - (\bar{Q}\Delta t + EA) = \Delta S$$

Where, $\bar{I}$ = Average rate of inflow of water into the lake
$\bar{Q}$ = Average rate of outflow from the lake
$P$ = Precipitation
$E$ = Evaporation
$A$ = Average surface area of the lake and
$\Delta S$ = Change in storage volume of the lake

Here, $\Delta t$ = 1 month = 30 × 24 × 60 × 60
= 2.592 × $10^6$ sec = 2.592 M sec

In one month:

Inflow volume $\bar{I}\Delta t$ = 6.0 × 2.592 = 15.552 M $m^3$

Outflow volume $\bar{Q}\Delta t$ = 6.5 × 2.592 = 16.848 M $m^3$

Inflow due to precipitation $PA = \frac{145 \times 5000 \times 10^4}{1000 \times 10^6}$ M $m^3$ = 7.25 M $m^3$ (∵ 1 Ha = $10^4$ $m^2$)

Outflow due to evaporation $EA = \frac{6.10}{100} \times \frac{5000 \times 10^4}{10^6} = 3.05$ M $m^3$

Hence, $\Delta S$ = 15.552 + 7.25 – 16.848 – 3.05 = 2.904 M $m^3$

Change in elevation, $\Delta z = \frac{\Delta S}{A} = \frac{2.904 \times 10^6}{5000 \times 10^4} = 0.058$ m

New water surface elevation at the end of the month = 103.200 + 0.058
= 103.258 m above the datum.

**Example 1.2** 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 $m^3$/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 $\Delta t$ 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 $\Delta t$ = 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 × $10^4$ × (10.5/100) = 157,500 $m^3$

$R$ = Runoff volume = outflow volume at the catchment outlet in 10 hours
= 1.5 × 10 × 60 × 60 = 54,000 $m^3$

Hence losses $L$ = 157,500 – 54,000 = 103,500 $m^3$

(b) Runoff/rainfall = 54,000/157500 = 0.343

**Example 1.3** 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

**And. (d)**

Inflow to reservoir, $I$ = 10 ha-m

Outflow from reservoir, $Q$ = 20 ha-m

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

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

Change in storage,

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

We know that

$$(I + P) - (E + Q + \text{seepage}) = \Delta S$$

$$\Rightarrow (10 + 3) - (8.4 + 20 + \text{seepage}) = -20$$

$$\Rightarrow 13 - 28.4 - \text{seepage} = -20$$

$$\Rightarrow \text{seepage} = 4.6 \text{ ha-m}$$

## 1.5 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

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

where, $S$ = 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 $km^3$ and the flow rate of precipitation is 577000 $km^3$/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 $T_r = \frac{S}{Q} = \frac{12900 \text{ km}^3}{577000 \text{ km}^3/\text{yr}} = 0.022 \text{ year} = 8.2 \text{ days}$

**Example 1.5** Which of the following are pertinent to the realization of hydrological cycle?

1. Latitudinal difference in solar heating of the Earth's surface
2. Inclination of the Earth's axis
3. Uneven distribution of land and water
4. Coriolis effect

(a) 1, 2 and 3 (b) 1, 2 and 4
(c) 2, 3 and 4 (d) 1, 2, 3 and 4

**Ans. (d)**

**Example 1.6** The percentage of total quantity of water in the world available in the liquid form is about

(a) 30% (b) 70%
(c) 11% (d) 51%

**Ans. (a)**

## OBJECTIVE BRAIN TEASERS

**Q.1** The hydrologic happenings from the time a heavy rainfall occurs, and up to the time the movement of the fallen rain water is completed, is called :
(a) hydrologic cycle
(b) runoff cycle
(c) precipitation cycle
(d) all of the above

**Q.2** Hydrology is the science which deals with:
(a) surface water
(b) ground water
(c) surface as well as ground water
(d) flood water

**Q.3** The National water policy (2002), of India, gives the top priority to:
(a) drinking water (b) hydro power
(c) irrigation water (d) None of the above

**Q.4** All India forecasts of rainfall are prepared at :
(a) Bombay (b) New Delhi
(c) Calcutta (d) Pune

**Q.5** The circulation of water from the earth's surface to the atmosphere, and vice versa, is called:
(a) hydrologic cycle
(b) runoff cycle
(c) precipitation cycle
(d) all of the above

### ANSWER KEY

| | | | | |
|---|---|---|---|---|
| 1. (b) | 2. (c) | 3. (a) | 4. (b) | 5. (a) |

■■■■