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Engineering Hydrology

Civil Engineering

Comprehensive Theory *with* Solved Examples

Civil Services Examination

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Engineering Hydrology

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Engineering Hydrology

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CHAPTER

Introduction

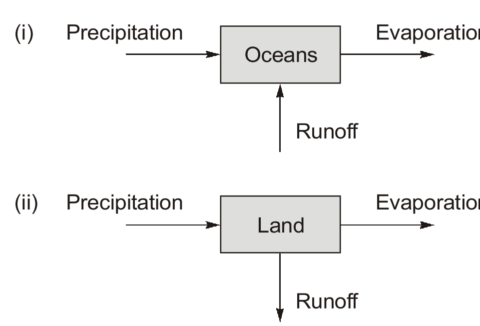
1.1 INTRODUCTION

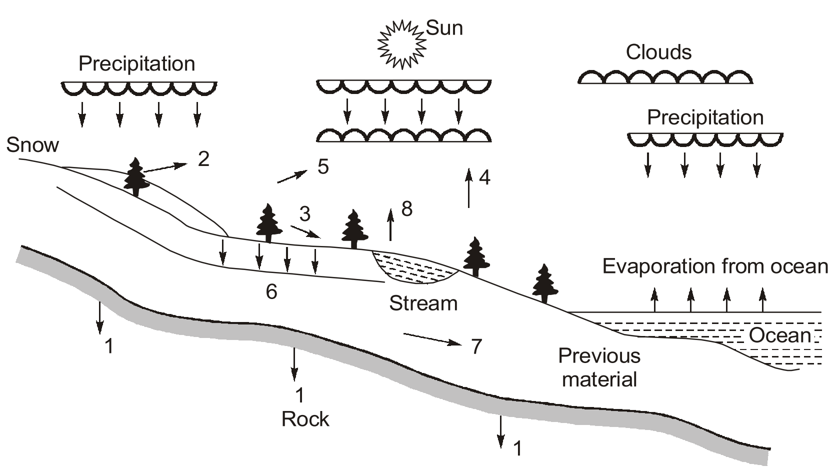
Hydrology is the branch of science which deals with the occurrence, circulation and distribution of water on the earth and atmosphere. Practical application of hydrology is required in the design and operation of hydraulic structure, water supply, irrigation, hydro power generation, flood control, etc.

The study of hydrology which is concerned mainly with academic aspects (such as geology, chemistry and physics etc.) is known as scientific hydrology. Wheareas, **Engineering hydrology** or applied hydrology is study of hydrology concerned mainly with engineering applications.

1.2 THE HYDROLOGIC CYCLE

It is a cycle in which water moves from one phase to another having different residence time. Hydrological cycle is a global sun-driven process in which water is transported from the oceans to the atmosphere, from atmosphere to the land and then back to the sea. Water on earth exists in a space called hydrosphere and it has boundary upto 15 km into atmosphere and 1 km down into lithosphere. Hydrologic cycle also moves within this boundary.





1 → deep percolation
2 → raindrop evaporation
3 → surface runoff
4 → transpiration
5 → interception
6 → infiltration
7 → ground water
8 → evaporation from water bodies

Fig. *Hydrological cycle*

Sun and Coriolis force (due to this force, wind moves in different direction) play important role in completion of hydrologic cycle. Sun evaporates water and Coriolis force, by controlling wind, circulate the water vapour, where precipitation occurs. Water evaporates due to the heat energy provided by solar radiation. The water vapour moves upwards and form clouds. A part of clouds is driven to the land area by winds, where these winds condense and precipitation occurs in various forms. A part of precipitation may evaporate back to the atmosphere, another part may be intercepted by vegetation, structures and other surface modification. A portion of water reaches the ground enters earth's surface through **infiltration**, enhance moisture content of the soil. The portion of precipitation which by a variety of paths above and below surface of earth reaches the stream channel is called **runoff**. Vegetation sends a portion of water from under the ground surface back to the atmosphere through the process of **transpiration.**

1.2.1 Components of Hydrologic Cycle

The hydrological cycle is usually described in terms of six major components:

(i) **Evaporation:** When water comes 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 then they also get evaporated in air.

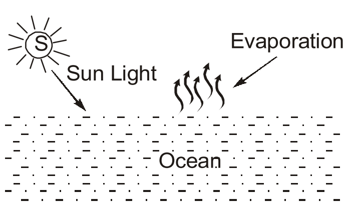


Fig. *Evaporation from Ocean*

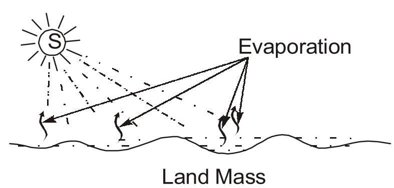


Fig. *Evaporation from land mass*

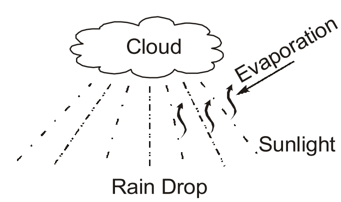


Fig. *Rain drop evaporation*

(ii) **Precipitation:** When clouds become sufficiently heavy due to condensation of water, they cannot retain the weight of water and thus comes to earth in the form of precipitation.

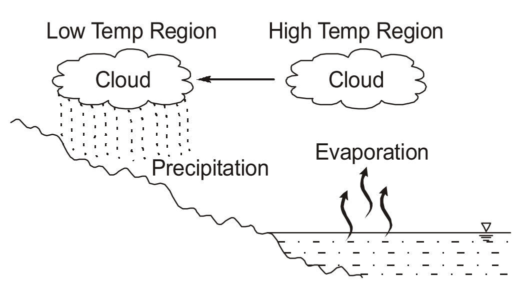


Fig. *Precipitation*

(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.

(iv) **Infiltration:** Once precipitation has started, some part of it flows on the surface called as **over land flow** which joins the streams. A part of this precipitation infiltrates through the ground and flows below ground called as **base flow.**

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 its volume. Infiltration will be more in a village in comparison to town, because the town have pucca road which is treated as impervious strata. Infiltration will be more in forest area in comparison to desert land because the trees make the surface pervious and increase the infiltration.

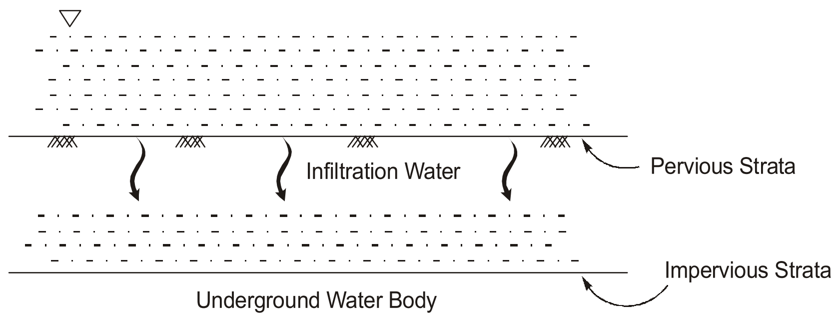


Fig. *Infiltration Beneath a Water Body*

(v) **Transpiration:** Transpiration is the process of water being lost from the leaves of the plants from their pores. For computational purpose, evaporation and transpiration are sometimes lumped together as **evapotranspiration** (ET).

During storms, evapotranspiration may be of minor consideration, but during rain free periods, it becomes a dominant feature of hydrological cycle.

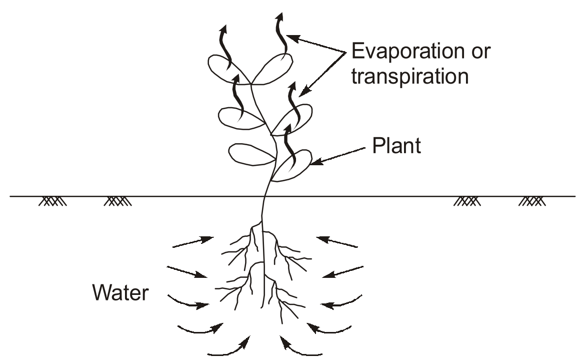


Fig. *Transpiration*

(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 reaching stream channel is called **stream flow.**

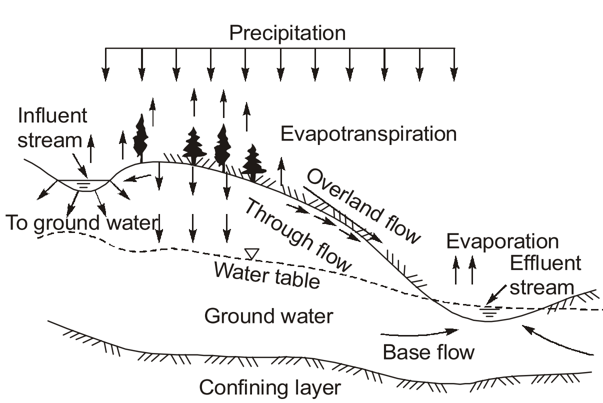


Fig. *Different routes of runoff*

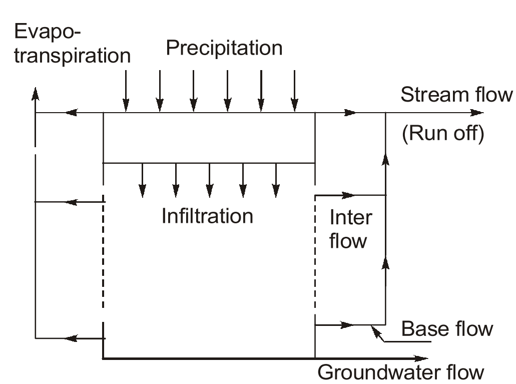


Fig. *Transportation Components of the Hydrologic Cycle*

1.2.2 Some Important Points

- 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 100 parts of water come to the land area through precipitation then 61 parts of this precipitation goes to atmosphere through evaporation and 39 parts 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.
- 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. 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. The catchment area of tributary river *A* is α and $(\alpha + \alpha)$ is the catchment area of river B. If the catchment has no outlet point than it is called a *closed catchment*. In a 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.

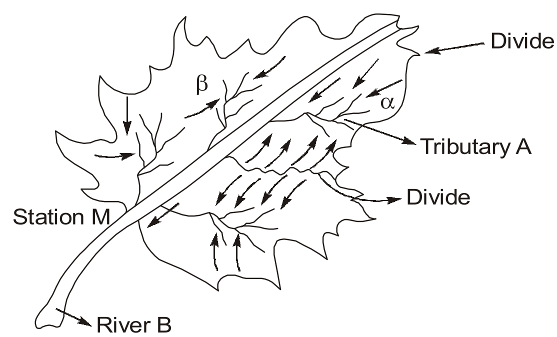


Fig. *Schematic Sketch of Catchment of River B at station M*

Each catchment area is separated topographically from adjacent catchment area by a geographical barrier such as ridge, hill or mountain. The line which divides the surface runoff between the two adjacent river basin is called the topographic water divide.

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 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

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

NOTE

For solving the problem of water budget equation, we should be clear in mind, about factors that recharges the water discharged in the water body.

Some of the examples of water budget equation are given below.

(i) Water Budget Equation for a Catchment

For a particular time Δt,

$$P - R - G - E - T = \Delta S \quad ...(i)$$

(ii) Water Budget Equation for Water Bodies

$$I + P - G - E - O = \Delta S \quad ...(ii)$$

(iii) Water Budget Equation for Surface Flow

$$P + I + I_G - O - E - T - I_n = \Delta S \quad ...(iii)$$

(iv) Water Budget Equation for Underground Flow

$$I_G + I_n - O_G - O_S - T = \Delta S \quad ...(iv)$$

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

NOTE

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.

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 Δt, 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

ΔS = change in storage volume of the lake

Here, Δt = 1 month = 30 × 24 × 60 × 60

= 2.592×10^6 sec = 2.592 M sec

In one month:

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

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

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

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

$\therefore$ $\Delta S = 15.552 + 7.25 - 16.848 - 3.05 = 2.904 \text{ M m}^3$

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

New water surface elevation at the end of the month = 103.200 + 0.058

= 103.258 m above the datum.

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 ________.

Solution:

Inflow to reservoir, I = 10 ha-m

Outflow from reservoir, Q = 20 ha-m

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

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

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

We know that

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

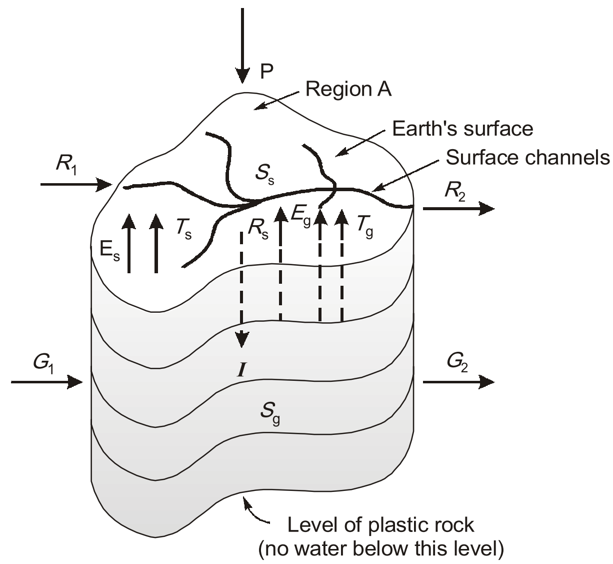
$\Rightarrow$ $(10 + 3) - (8.4 + 20 + \text{seepage}) = -20$

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

$\Rightarrow$ seepage = 4.6 ha-m

EXAMPLE : 1.3

Regional hydrological cycle is shown in the figure below:



The correct Water Budget Equation is

(a) $P + R_1 - R_2 + R_g - E_s - T_s - I = \Delta S_s$

(b) $I + G_1 - G_2 - R_g - E_g - T_g = \Delta S_g$

(c) $P - (R_2 - R_1) - (E_s + E_g) - (T_s + T_g) - (G_2 - G_1) = \Delta(S_s + S_g)$

(d) $P - R - G - E - T = \Delta S_s$

Ans. (c)

Water Budget Equation is

Inflow – Outflow = Change in storage

1.5 RESIDENCE TIME

It is the average duration of a particle of water to pass through a phase of the hydrological cycle is known as the residence time of that phase.

$$\text{Residence time} = \frac{\text{Volume of water in a phase}}{\text{Average flow rate in that phase}} \qquad \text{...(i)}$$

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

PRACTICE QUESTIONS

Question : 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 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?

[8 Marks]

Solution:s

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 = 54,000/157500 = 0.343

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