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Volume - 6

Hydrology & Irrigation

SIERRA INNOVATIONS

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GENERAL ASPECTS OF HYDROLOGY

THEORY

1.1 INTRODUCTION

Hydrology is the science of water which deals with

- Occurrence
- Circulation
- Distribution of water of the earth and earth's atmosphere.

It concerned with

- Water in streams and lakes
- Rainfall and snowfall
- Snow and ice on the land and water occurring below earth's surface in the pores of the soil and rocks.

1.1.1 Classification of Hydrology

- **Scientific Hydrology :** The study concerned chiefly with academic aspects.
- **Engineering or Applied Hydrology :** Study concerned with engineering applications
  - (i) Estimation of water resources.
  - (ii) The study of processes such as precipitation, runoff, evapotranspiration and their interaction.
  - (iii) The study of problems such as floods and droughts and strategies to combat them.

1.2 HYDROLOGIC CYCLE

The total water of earth, excluding deep ground water, is in constant circulation from the earth (including oceans) to atmosphere and back to the earth and oceans. This cycle of water amongst earth, oceans, and atmospheric systems is known as hydrologic cycle.

- The hydrologic cycle is a global sun-driven process. The processes in this cycle extends from an average depth of 1 km in the lithosphere (crust of the earth), to a height of about 15 km in the atmosphere.
- The hydrologic cycle does have beginning or end point. However oceans are considered as starting point for convenience of study.
- Because of heat energy provided by Sun evaporation in oceans takes place at very large scale. This water vapour moves upwards and forms clouds. Major part of these clouds condense and fall back to the oceans as in the form of rain. But some part of clouds is driven to the land areas by winds. Then they condense and precipitate onto the land mass as rain, snow, hail, sleet etc.
- A part of rainfall may evaporate book to atmosphere each while falling.

- Another part may be intercepted by vegetation, structures and other such surface modifications from which it may be either evaporated back to atmosphere or move down to the ground surface.
- A part of water that reaches ground, enters into earth's surface through infiltration, enhances the moisture content of soil and reaches to ground water.
- Through vegetation a part of water from under the ground surface to the atmosphere through the process of transpiration.
- Part of infiltrated water may to surface water bodies as interflow, while other part may become ground water flows.
- Ground water may ultimately be discharged into stream channel by a variety of paths above and below surface of the earth is called runoff.
- Once it enters a stream channel, runoff becomes stream flow.

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

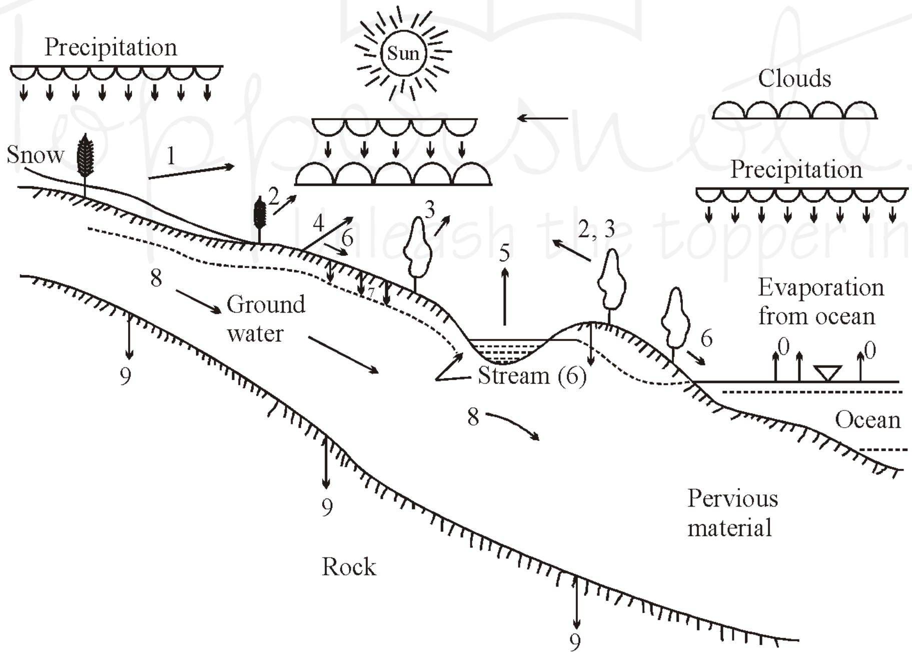
Precipitation (P), Infiltration (I)

Transpiration (T), Surface Runoff (R)

Evaporation (E), and ground water flow (G)

However for calculation purposes evaporation (E) and transpiration (T) are sometimes clubbed together as evapotranspiration (ET).

The figure given below show these components and illustrates the various paths they taken to complete hydrologic cycle.



0 = Evaporation from ocean 1 = Raindrop evaporation

2 = Interception 3 = Transpiration

4 = Evaporation from land 5 = Evaporation from water bodies

6 = Surface runoff 7 = Infiltration

8 = Groundwater 9 = Deep percolation

Fig. 1.1 : The Hydrologic Cycle

Note :

- **Evaporation** is conversion of water from liquid to gaseous state.
- **Precipitation** is the deposition of water on earth surface in the form of rain, snow, hail, frost and so on.
- **Infiltration** is the movement of water into the soil of earth's surface.
- **Percolation** is the movement of water from upper soil zone to a lower soil zone.
- **Transpiration** is the soil moisture taken up through the roots of a plant and discharged into atmosphere through the leaves of plants.
- **Storage** is the volume of water which gets stored in natural depression of a basin.
- **Runoff** is the volume of water drained by a river at the outlet of a catchment.

1.3 HYDROLOGICAL BUDGET

For a given catchment area in a time internal Δt,

Total inflow – Total outflow = change is storage (continuity equation)

This continuity equation, expressed in terms of various phases of hydrological cycle is known as water budget equation/water budget equation.

Hydrological budget equation

$$P - R - E - T - G = \Delta S, \text{ water budget equation}$$

where
P = Precipitation
R = Net runoff
E = Net evaporation
T = Net Transpiration
G = Net Ground water flow
ΔS = Net storage change

The storage S consist of three components as

$$S = S_s + S_{sm} + S_g$$

where
S_{gs} = Surface water storage
S_{sm} = Water in storage as soil moisture
S_g = Water in storage as ground water

Thus, in above equation

$$\Delta S = \Delta S_s + \Delta S_{sm} + \Delta S_g$$

In terms of rainfall-runoff relationship water budget equation can be represented as

$$R = P - L$$

where
R = Runoff
P = Precipitation
L = Losses = water not available to runoff due to (I, E, T and depression storage)

All terms in above equations have the dimensions of volume however all these terms can be expressed as depth over the catchment area (e.g. in centimeters or millimeters). In fact this is a very common unit used.

Catchment Area

- The area of land draining into a stream or into a water course at a given location is called a catchment area.
- Other terms which are used to describe a catchment area are drainage basin, drainage area, catchment, catchment basin, river basins, water basin and watershed (in USA).
- The catchment area acts as a funnel by collecting all the water within the area covered by the catchment and channelling into a single point.

Watershed Divide

- Each catchment area in separated topographically from adjacent catchment areas by a natural barrier such as a ridge, hill, mountain this line is known as topographic water divide, or the watershed divide, or simply a divide.
- The divide follows ridge line around the catchment, crossing the stream only at the outlet point, it marks the highest points between the basins, but isolated peaks with in a basin may be at higher elevations than any point on the divide.

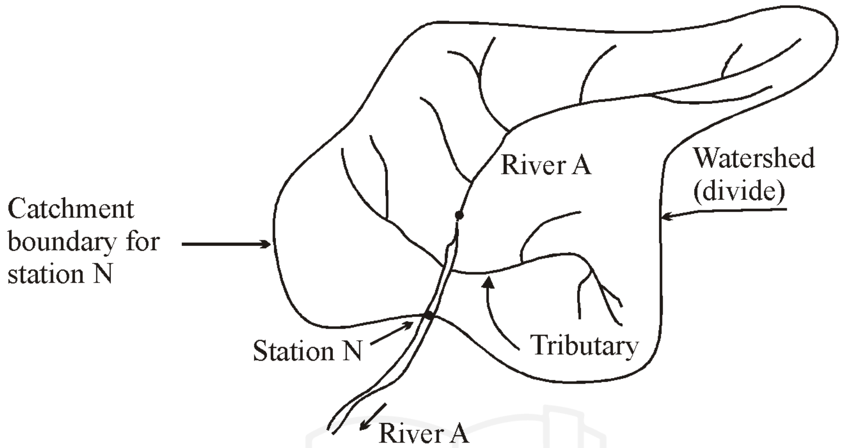


Fig. 1.2 : Schematic sketch of catchment of river A at station N.

Catchment Leakage

Sometimes the runoff measured at the outlet of a particular catchment may contain some contribution belonging to the precipitation fallen on a neighboring catchment by way of subsurface runoff. This is known as catchment leakage.

Catchment leakage also occurs when the ground water divide and catchment divide (watershed divide) are not coincident in plan as shown in figure below

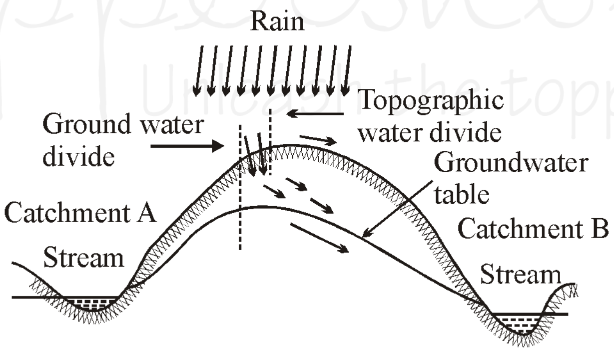


Fig. 1.3 : Topographical and ground water divide

Note :

- However for large catchments, ground water divide and topographical divide are assumed to coincide i.e. catchment leakages are neglected.
- Area between watershed shed divide on a topographic map is measured by an instrument called **Planimeter**.

Residence Time

Average duration of a particles of water to pass through a phase of the hydrological cycle is known as the residence time of that phase.

$$\text{Residence time} = \frac{\text{Volume of water in a phase}}{\text{Average flow rate in that phase}}$$

Average residence time of ocean is larger than that of global ground water.

Example 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 area can be taken as 5000 ha. Assume that there is no contribution to or from the groundwater storage.

Solution :

Given data,

$$\bar{I} = 6.0 \text{ m}^3/\text{s}$$
$$\bar{Q} = 6.5 \text{ m}^3/\text{s}$$
$$P = 145 \text{ mm}$$
$$E = 61.0 \text{ mm}$$
$$A = 5000 \times 10^4 \text{ m}^2$$

In a time interval Δt the water budget for the lake can be written as Input volume-output volume = change in 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

ΔS = change in storage volume of the lake.

Here $\Delta t = 1 \text{ month} = 30 \times 24 \times 60 \times 60 = 2.592 \times 10^6 \text{ s} = 2.592 \text{ Ms}$

In one month Inflow volume = $\bar{I}\,\Delta t = 6.0 \times 2.592 = 15.552 \text{ Mm}^3$

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

$$\text{Input due to precipitation} = PA = \frac{145 \times 5000 \times 100 \times 100}{1000 \times 10^6} \text{ Mm}^3 = 7.25 \text{ Mm}^3$$

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

Hence $\Delta S = 15.552 + 7.25 - 16.848 - 3.05 = 2.904 \text{ Mm}^3$

$$\text{Change in elevation} \quad \Delta z = \frac{\Delta S}{A} = \frac{2.904 \times 10^6}{5000 \times 100 \times 100} = 0.058 \text{m}$$

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

= 103.258 m above the datum

Example 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?

(b) 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 = Input due to precipitation in 10 hours

$= 150 \times 100 \times 100 \times (10.5/100) = 157{,}500 \text{ m}^3$

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

1.4 CONVERSION OF PRECIPITATION INTO STREAM FLOW

- In hydrological studies in engineering hydrology the precipitation (rainfall) is taken as input mathematically in the form of hyetograph (Hyetograph is a plot of rainfall intensity against time).
- Output in obtain as stream flow runoff mathematically in the form of hydrograph (Hydrograph in a plot of discharge (flow) against time).

The figure given below shows the conversion of rainfall (input) to stream flow (output)

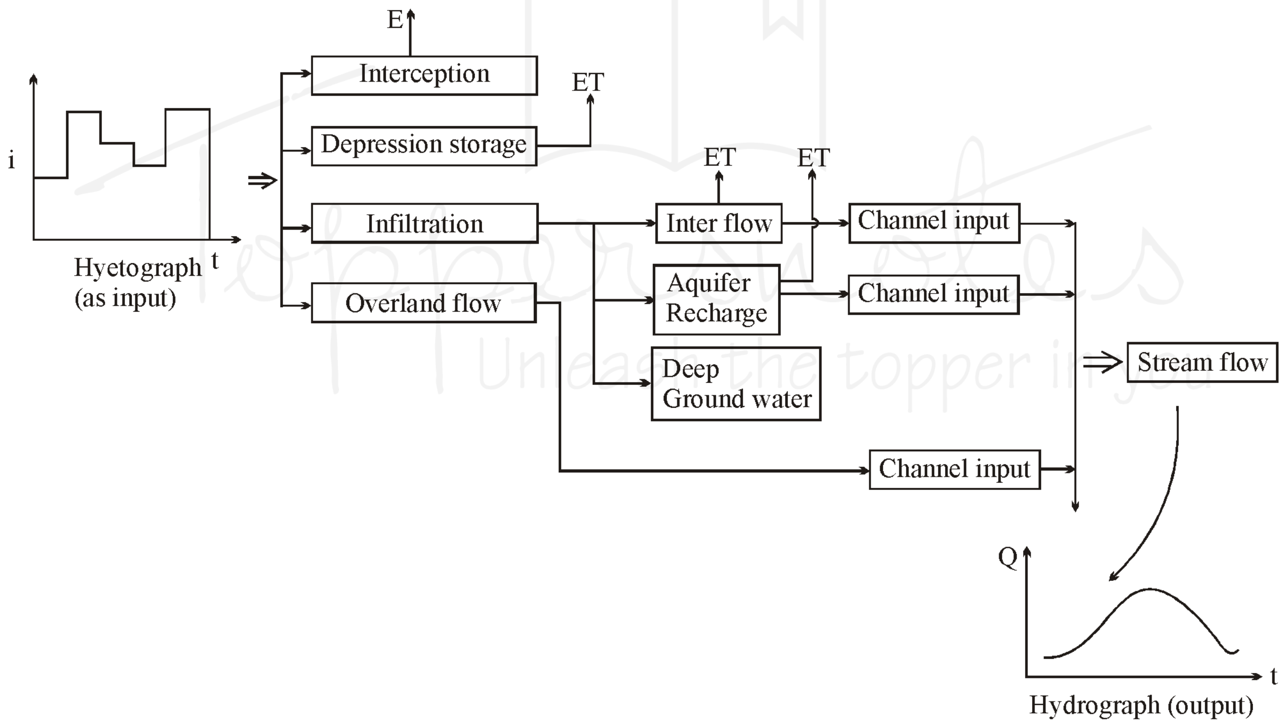


Fig. 1.4 : Distribution of precipitation

Interesting Facts

- Runoff is minimum in Africa and maximum in Europe and North America.
- In India the long term estimates of average runoff = 46%.
- In the ocean about 9% more water evaporates that falls back as precipitation.
- World's largest river, the Amazon, has an annual average discharge of 200,000 m^3/s.
- In India largest rivers, the Brahmaputra – 16,200 m^3/s the Ganga : 15,600 m^3/s.

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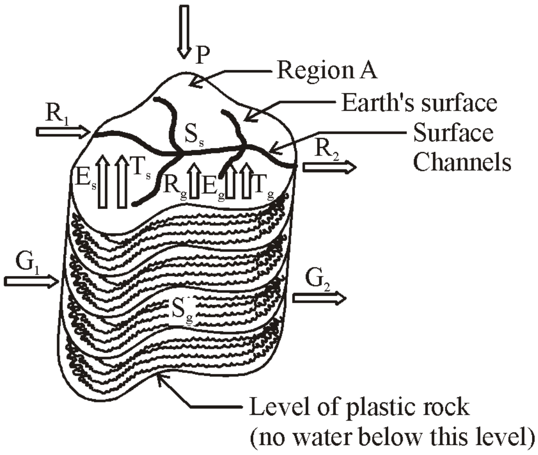
OBJECTIVE QUESTIONS

1. Regional hydrological cycle is shown in the figure



The correct hydrological budget equation is

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

(b) $I + G_1 - G_2 + R_g - E_s - T_g = \Delta S_s$

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

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

2. The quantitative statement of the balance between water gains and losses in a certain basin during a specified period of time is known as among the following?

1. Water budget
2. Hydrologic budget
3. Ground budget

(a) 1 Only (b) 2 Only
(c) 3 Only (d) None of these

3. What is the chemical symbol for ice as per UNESCO terminology

(a) H_8O_4 (b) H_2O
(c) H_6O_3 (d) H_4O_2

4. What is 'Hydrological Cycle ?

(a) Process involved in the transfer of moisture from sea to land

(b) Process involved in the transfer of moisture from sea back to sea again

(c) Processes involved in the transfer of water from snowmelt in mountains to sea

(d) Processes involved in the transfer of moisture from sea to land and back to sea again

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

6. The plan area of a reservoir is 1 km^2. The water level in the reservoir is observed is 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 par 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

7. 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

8. A watershed has an area of 300 ha. Due to a 10 cm rainfall event over the watershed a stream flow is generated and at the outlet of the watershed it lasts for 10 hours. Assuming a runoff/ rainfall ratio of 0.20 for this event, the average stream flow rate at the outlet in this period of 10 hours is

(a) 1.33 m^3/s (b) 16.7 m^3/s
(c) 100 m^3/minute (d) 60,000 m^3/h

9. Rainfall of intensity of 20 mm/h occurred over a watershed of area 100 ha for a duration of 6h. measured direct runoff volume in the stream draining the watershed was found to be 30,000 m^3. The precipitation not available to runoff in this case is

(a) 9 cm (b) 3 cm

(c) 17.5 mm (d) 5 mm

10. A catchment of area 120 km^2 has three distinct zones as below

Zone	Area (km^2)	Annual runoff (cm)
A	61	52
B	39	42
C	20	32

The annual runoff from the catchment, is

(a) 126.0 cm (b) 42.0 cm

(c) 45.4 cm (d) 47.3 cm

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ANSWERS AND EXPLANATIONS

1. ***Ans. (c)***

The hydrologic budget equation is

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

Where

P = Total precipitation

R = Net runoff = $R_2 - R_1$

= Surface runoff outflow – Surface runoff inflow

E = total evaporation

T = total Transpiration

G = net ground water flow

= Ground water outflow – Ground water inflow

ΔS = total storage increase

∴ The equation becomes

$P - (R_2 - R_1) - (E_s + E_g) - (T_s + T_g) - (G_2 - G_1)$

$= \Delta(S_s + S_g)$

∴ correct option is (c)

2. ***Ans. (a)***

For a particular basin or catchment the equation showing the water gains and losses during a specified period of time is called water budget equation.

3. ***Ans. (b)***

Chemical symbol of ice as per UNESCO is H_2O.

4. ***Ans. (d)***

Hydrological cycle is the cycle in which water is transported from the oceans to the atmosphere as vapours, from the atmosphere to the land as precipitation and back from land to oceans as runoff.

5. ***Ans. (b)***

It make no difference whether the distribution of land and water is even or uneven.

6. ***Ans. (d)***

Inflow to reservoir

I = 10 ha-m

Outflow from reservoir, O = 20 ha-m

Loss due to evaporation

E = 12cm × pan coefficient × Area

$= 12 \times 10^{-2} A \times 0.7$

$= 12 \times 10^{-2} \times 10^{6} \times 0.7$

$= 8.4 \times 10^{4}\ m^3 = 8.4$ ha-m

Rainfall, P = 3 cm

$= 0.03 \times 10^{6}\ m^3$

$= 3 \times 10^{4}\ m^3 = 3$ ha-m

Change in storage

$\Delta S = -20$ cm

$= -0.20 \times 10^{6}\ m^3 = -20$ ha-m

In flow – outflow = change in storage

(I + P) – (O + E + seepage) = – 20

(10 + 3) – (20 + 8.4 + seepage) = – 20

Seepage = 4.6 ha-m

7. ***Ans. (d)***

8. ***Ans. (c)***

Total rainfall volume = $300 \times 10^{4}\ m^2 \times 10$ cm

$= 300{,}000\ m^3$

$\because \quad \frac{\text{runoff}}{\text{rainfall}} = 0.2$

$\Rightarrow \quad \text{runoff} = 0.2 \times \text{rainfall}$

$= 0.2 \times 300{,}000\ m^3$

$$\text{runoff rate} = \frac{0.2 \times 300{,}000 m^2}{10 \times 60}$$

$= 100\ m^3/\text{minute}$

9. ***Ans. (c)***

Total rainfall volume = 6 × 20 mm × 100 ha

$= 12000$ ha-mm $= 120{,}000\ m^3$

Direct runoff volume = $30{,}000\ m^3$

The precipitation not available is

$= 120{,}000 - 30{,}000\ m^3$

$= 90{,}000\ m^3$

$$80 = \frac{90000 m^3}{100 \times 10^4 m^2 \times 20 \times 10^{-3} m}$$

= 9 cm

10. ***Ans. (c)***

The annual runoff from the catchment

$$= \frac{61 \times 52 + 39 \times 42 + 20 \times 32}{61 + 39 + 20}$$

= 45.41 cm

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