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ENGINEERS ACADEMY

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CIVIL

Rajasthan Public Service Commission (RPSC)

Volume - 5

Hydrology and Irrigation

SIERRA
INNOVATIONS

1

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 :

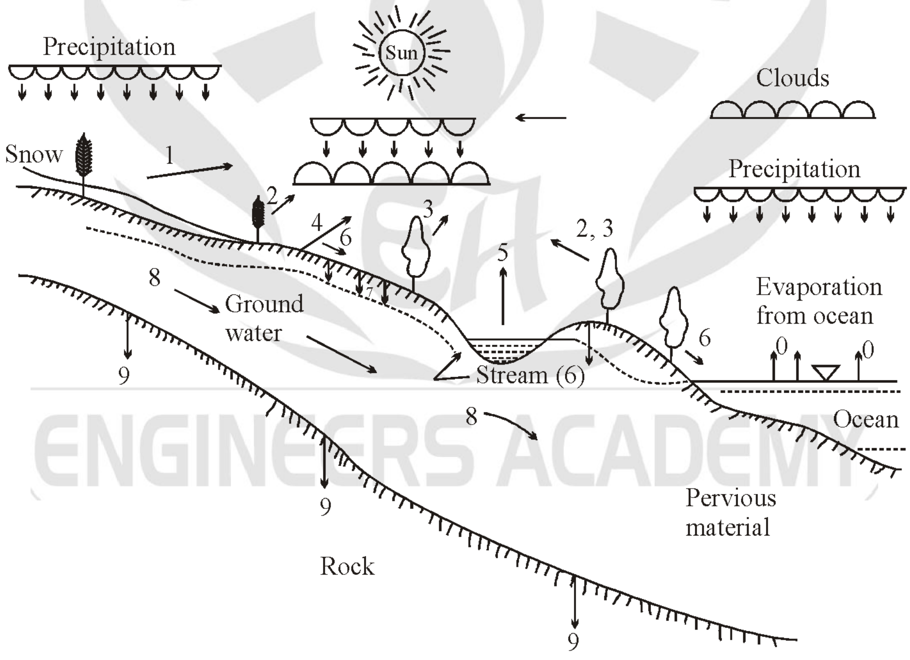
Precipitation (P), Infiltration (I)

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.

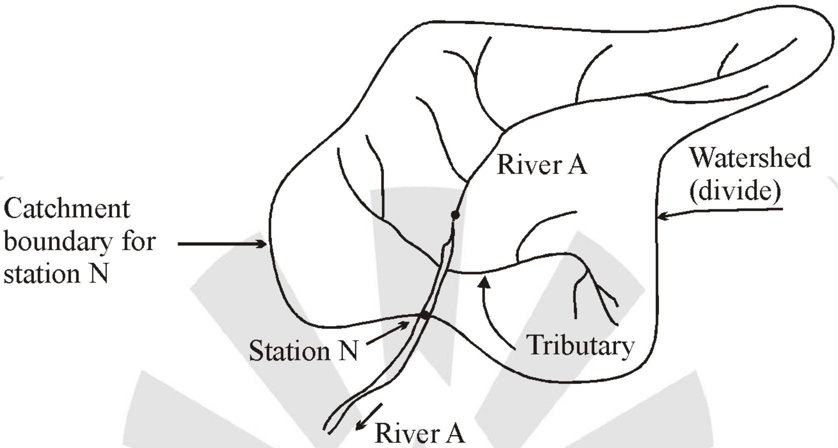


Fig. 1.2 : Schematic sketch of catchment of river A at station N.

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

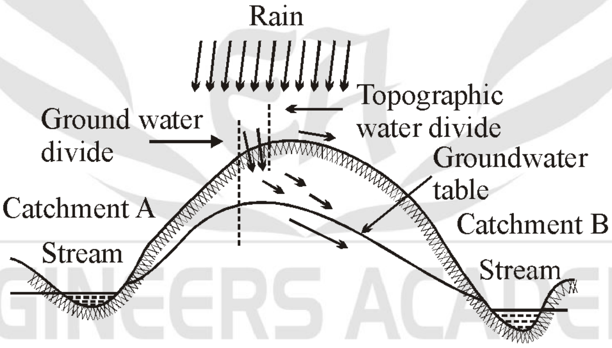


Fig. 1.3 : Topographical and ground water divide

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)

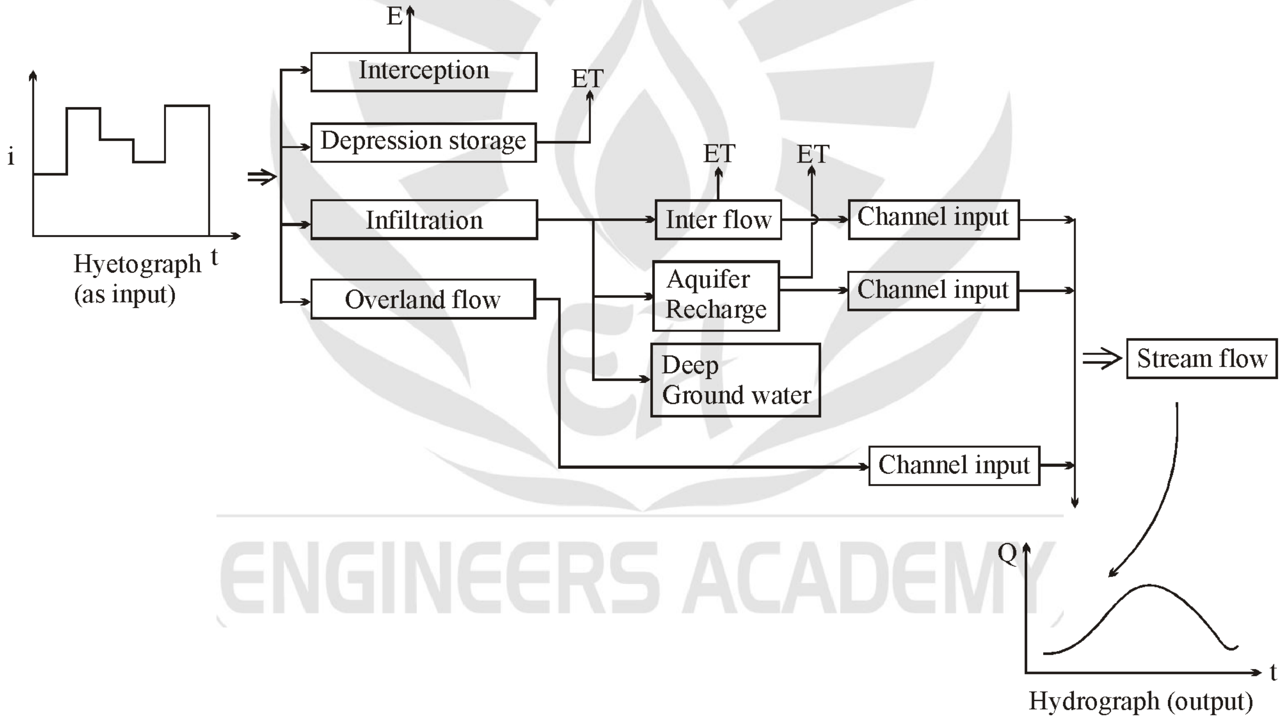


Fig. 1.4 : Distribution of precipitation

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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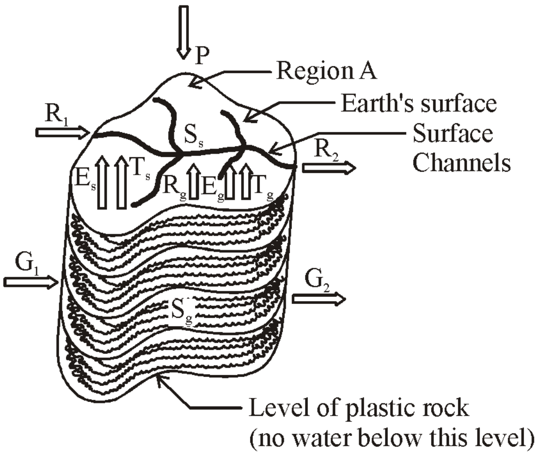
OBJECTIVE QUESTIONS

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

$$\begin{aligned} E &= 12\text{cm} \times \text{pan coefficient} \times \text{Area} \\ &= 12 \times 10^{-2} A \times 0.7 \\ &= 12 \times 10^{-2} \times 10^{6} \times 0.7 \\ &= 8.4 \times 10^{4}\ \text{m}^3 = 8.4\ \text{ha-m} \end{aligned}$$

Rainfall, $P = 3$ cm

$$\begin{aligned} &= 0.03 \times 10^{6}\ \text{m}^3 \\ &= 3 \times 10^{4}\ \text{m}^3 = 3\ \text{ha-m} \end{aligned}$$

Change in storage

$$\begin{aligned} \Delta S &= -\ 20\ \text{cm} \\ &= -\ 0.20 \times 10^{6}\ \text{m}^3 = -\ 20\ \text{ha-m} \end{aligned}$$

In flow – outflow = change in storage

$(I + P) - (O + E + \text{seepage}) = -\ 20$

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

Seepage = 4.6 ha-m

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

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

$$\begin{aligned} \text{Total rainfall volume} &= 300 \times 10^{4}\ \text{m}^2 \times 10\ \text{cm} \\ &= 300{,}000\ \text{m}^3 \end{aligned}$$

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

$$\begin{aligned} \Rightarrow \quad \text{runoff} &= 0.2 \times \text{rainfall} \\ &= 0.2 \times 300{,}000\ \text{m}^3 \end{aligned}$$

$$\begin{aligned} \text{runoff rate} &= \frac{0.2 \times 300{,}000\text{m}^2}{10 \times 60} \\ &= 100\ \text{m}^3/\text{minute} \end{aligned}$$

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

$$\begin{aligned} \text{Total rainfall volume} &= 6 \times 20\ \text{mm} \times 100\ \text{ha} \\ &= 12000\ \text{ha-mm} = 120{,}000\ \text{m}^3 \end{aligned}$$

Direct runoff volume = 30,000 m^3

The precipitation not available is

$$\begin{aligned} &= 120{,}000 - 30{,}000\ \text{m}^3 \\ &= 90{,}000\ \text{m}^3 \end{aligned}$$

$$\begin{aligned} 80 &= \frac{90000\text{m}^3}{100 \times 10^{4}\text{m}^2 \times 20 \times 10^{-3}\text{m}} \\ &= 9\ \text{cm} \end{aligned}$$

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

The annual runoff from the catchment

$$\begin{aligned} &= \frac{61 \times 52 + 39 \times 42 + 20 \times 32}{61 + 39 + 20} \\ &= 45.41\ \text{cm} \end{aligned}$$

* * *

WATER REQUIREMENTS OF CROPS

THEORY

Irrigation

Three basic requirements of agricultural production are soil, seed, and water. In addition,fertilisers, insecticides, sunshine, suitable atmospheric temperature, and human labour are also needed. Of all these, water appears to be the most important requirement of agricultural production. The application of water to soil is essential for plant growth and it serves the following functions:

- o It supplies moisture to the soil essential for the germination of seeds, and chemical and bacterial processes during plant growth.
- o It cools the soil and the surroundings thus making the environment more favourable for plant growth.
- o It washes out or dilutes salts in the soil.
- o It softens clods and thus helps in tillage operations.
- o It enables application of fertilisers.
- o It reduces the adverse effects of frost on crops.
- o It ensures crop success against short-duration droughts

Water Requirements of a Crop

• The total quantity and the way in which a crop requires water, from the time it is sown to the time it is harvested

• It vary with the crop as well as with the place

• Depending on

o Climate

o Type of soil

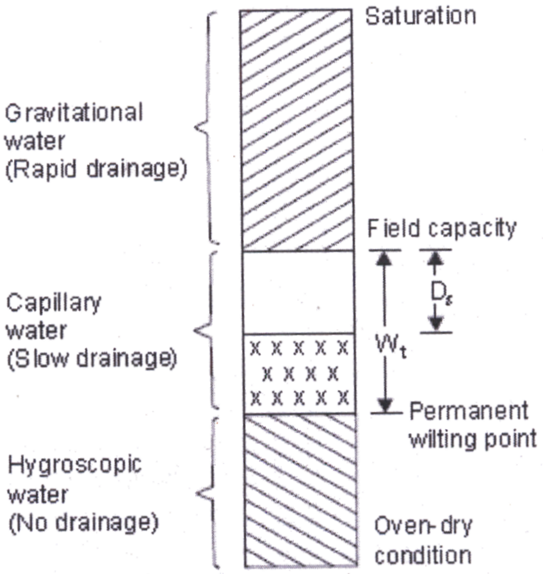
o Method of cultivation

o Useful rainfall

Classification of soil water

- **Gravitational water:** A soil sample saturated with water and left to drain the excess out by gravity holds on to a certain amount of water. The volume of water that could easily drain off is termed as the gravitational water. This water is not available for plants use as it drains off rapidly from the root zone.

- **Capillary water:** The water content retained in the soil after the gravitational water has drained off from the soil is known as the capillary water. This water is held in the soil by surface tension. Plant roots gradually absorb the capillary water and thus constitute the principle source of water for plant growth.
- **Hygroscopic water:** The water that an oven dry sample of soil absorbs when exposed to moist air is termed as hygroscopic water. It is held as a very thin film over the surface of the soil particles and is under tremendous negative (gauge) pressure. This water is not available to plants.



Soil water constants :

For a particular soil, certain soil water proportions are defined which dictate whether the water is available or not for plant growth. These are called the soil water constants, which are described below.

- **Saturation Capacity:** This is the total water content of the soil when all the pores of the soil are filled with water. It is also termed as the maximum water holding capacity of the soil. At saturation capacity, the ***soil moisture tension*** is almost equal to zero.
- **Field Capacity:** This is the water retained by an initially saturated soil against the force of gravity. Hence, as the gravitational water gets drained off from the soil, it is said to reach the field capacity. At field capacity, the macro-pores of the soil are drained off, but water is retained in the micropores. Though the soil moisture tension at field capacity varies from soil to soil, it is normally between 1/10 (for clayey soils) to 1/3 (for sandy soils) atmospheres.
- **Permanent Wilting Point:** Plant roots are able to extract water from a soil matrix, which is saturated up to field capacity. However, as the water extraction proceeds, the moisture content diminishes and the negative (gauge) pressure increases. At one point, the plant cannot extract any further water and thus ***wilts.***

Two stages of wilting points are recognized and they are:

- Temporary wilting point: this denotes the soil water content at which the plant wilts at day time, but recovers during right or when water is added to the soil.

- Ultimate wilting point: at such a soil water content, the plant wilts and fails to regain life even after addition of water to soil.

Crop Period or Base Period: The time period that elapses from the instant of its sowing to the instant of its harvesting

Base Period: The time between the first watering of a crop at the time of its sowing to its last watering before harvesting. It is represented by B (in days)

- Crop period is slightly more than the base period
- But for all practical purposes, they are taken as one and the same thing

Delta (Δ)

- Depth to which water would stand on the irrigated area if the total quantity supplied were to stand above the surface without percolation or evaporation
- This total depth of water (in cm) required by a crop to come to maturity.

Duty of Water

- It is the relationship between the volume of water and the area of the crop it matures
- A unit discharge flowing for a time equal to the base period of the crop., called Base of the duty
- If water flowing at a rate of one m^3/s, runs continuously for B days, and matures 200 hectares, then the duty of water for that particular crop will be defined as 200 hectares/cumec to the base of B days
- Duty is defined as the area irrigated per cumec of discharge running for base period B
- The duty is generally represented by D

Relationship Between Duty and Delta

- Let there be a crop of base period B days
- Let 1 cumec of water be applied to this crop on the field for B days
- Now, the vol. of water applied to this crop during B days

$= V = (1 \times 60 \times 60 \times 24 \times B)\ m^3$

$= 86400\ B\ (m^3)$

- By definition of duty (D), 1 m^3 supplied for B days matures D hectares of land
- Therefore this quantity of water (V) matures D hectares of land or 10^4 D sq. m of area
- Total depth of water applied on this land

$$\frac{\text{Volume}}{\text{Area}} = \frac{86400B}{10^4 D}$$

$$= \frac{8.64B}{D} \text{ meters } = \frac{864B}{D} \text{cm}$$

- By definition, this total depth of water is called delta (Δ)

– Therefore, $\Delta = \dfrac{8.64B}{D}$ metres

or

$$\Delta = \frac{864B}{D} \text{cm}$$

- Duty of water for a crop, is number of hectares of land which the water can irrigate
- Therefore, if the water requirement of the crop is more, less number of hectares of land it will irrigate
- If water consumed is more, duty will be less
- The duty of water at the head of the water course will be less than the duty of water 'on the field'; because when water flows from the head of the water course and reaches the field, some water is lost as transit losses (evaporation, percolation)

Commanded area (CA): This is defined as the area that can be irrigated by a canal system. CA may further be classified as under:

Gross command area (GCA): This is defined as total area that can be irrigated by a canal system on the perception that unlimited quantity of water is available. It is the total area that may theoretically be served by the irrigation system. But this may include inhibited areas, roads, ponds, uncultivable areas etc which would not be irrigated.

Culturable command area (CCA): This is the actually irrigated area within the GCA. However, the entire CCA is never put under cultivation during any crop season due to the following reasons:

- The required quantity of water, fertilizer, etc. may not be available to cultivate the entire CCA at a particular point of time. Thus, this is a physical constraint.
- The land may be kept fallow that is without cultivation for one or more crop seasons to increase the fertility of the soil. This is a cultural decision.
- Due to high water table in some areas of the CCA, irrigated water may not be applied as the crops get enough water from the saturation provide to the surface water table.

During any crop season, only a part of the CCA is put under cultivation and this area is termed as ***culturable cultivated area***. The remaining area which is not cultivated during a crop season is conversely termed as ***culturable uncultivated area***.

Intensity of irrigation

Intensity of irrigation is defined as the percentage of the irrigation proposed to be irrigated annually. Usually the areas irrigated during each crop season (Rabi, Kharif, etc) is expressed as a percentage of the CCA which represents the intensity of irrigation for the crop season. By adding the intensities of irrigation for all crop seasons the yearly intensity of irrigation to be obtained.

Factors on which duty depends

- **Type of crop :**
  - Duty will be less for a crop requiring more water and vice versa

- **Climate and season**
  - – Duty includes the water lost in evaporation and percolation which vary with time, season and climate
- **Useful rainfall**
  - – If some of the rain, falling directly over the irrigated land, is useful for the growth of the crop, then so less irrigation water will be required to mature the crop
- **Type of soil**
  - – If the permeability of the soil under the irrigated crop is high, the water loss due to percolation will be more and hence, the duty will be less
  - – Therefor sandy soils, the duty of water is less
- **Efficiency for cultivation method**
  - – If the cultivation method (including tillage and irrigation) is faulty and less efficient, resulting in the wastage of water, the duty of water will naturally be less
  - – If the irrigation water is used economically, then the duty of water will improve, as the same quantity of water would be able to irrigate more area

Measures for Improving Duty of water

- **Precautions in field preparation and sowing**
  - – Land to be used for cultivation should, as far as possible, be levelled
  - – The fields should be properly ploughed to the required depth
  - – Improved modern cultivation methods may preferably be adopted
  - – Porous soils should be treated before sowing crops to reduce seepage of water
  - – Alkaline soils should be properly leached before sowing
  - – Manure fertilisers should be added to increase water holding capacity of the soil
  - – Rotation of crops should be preferred, as this will ensure increased crop yields with minimum use of water
- **Precautions in handling irrigation supplies**
  - – The source of irrigation water should be situated within the prescribed limits, and be capable of good quality of water
  - – Canals carrying irrigation supplies should be lined to reduce seepage and evaporation
  - – Water courses may preferably be lined or RCC pipes may be used for the same
  - – Free flooding of fields should be avoided and furrow irrigation method may preferably be adopted, if surface irrigation is restored.
  - – Subsurface irrigation and drip irrigation may be preferred to ordinary surface irrigation
  - – If canals are not lined, then two canals running side by side may be preferred to a single canal, as this will reduce the FSL, thereby reducing percolation losses.
  - – Irrigation supplies should be economically used by proper control.

Type of Soils	Favourablve for raising crops	Water requirement
Heavy retentive soil (40% clay)	Sugarcane, rice, etc.	Require more water
Light sandy soil (2-8% clay)	Gram, fodder, etc.	Require less water
Medium or normal soil (having about 10-20% of clay)	Wheat, cotton. Maize, vegetables, oil seeds, etc.	Require normal amount of water

Types of irrigation methods

- Surface irrigation method
- Subsurface irrigation method
- Sprinkler irrigation system
- Drip irrigation system

SURFACE IRRIGATION METHOD

In this system of field water application the water is applied directly to the soil from a channel located at the upper reach of the field. It is essential in these methods to construct designed water distribution systems to provide adequate control of water to the fields and proper land preparation to permit uniform distribution of water over the field.

- One of the surface irrigation method is ***flooding method*** where the water is allowed to cover the surface of land in a continuous sheet of water with the depth of applied water just sufficient to allow the field to absorb the right amount of water needed to raise the soil moisture up to field capacity.
- The flooding method applied in a controlled way is used in two types of irrigation methods as under:
    - ***Border irrigation method***
    - ***Basin irrigation method***

Border irrigation method

- Borders are usually long uniformly graded strips of land separated by earth bunds (low ridges).
- The essential feature of the border irrigation is to provide an even surface over which the water can flow down the slope with a nearly uniform depth.
- Each strip is irrigated independently by turning in a stream of water at the upper end.

Basin irrigation method

- Basins are flat areas of land surrounded by low bunds.
- The bunds prevent the water from flowing to the adjacent fields.
- The basins are filled to desired depth and the water is retained until it infiltrates into the soil. Water may be maintained for considerable periods of time.

- Basin irrigation is suitable for many field crops. Paddy rice grows best when its roots are submerged in water and so basin irrigation is the best method for use with this crop

Furrow Irrigation

- Furrows are small channels, which carry water down the land slope between the crop rows.
- Water infiltrates into the soil as it moves along the slope.
- The crop is usually grown on ridges between the furrows.
- This method is suitable for all row crops and for crops that cannot stand water for long periods, like 12 to 24 hours, as is generally encountered in the border or basin methods of irrigation
- Furrow irrigation is suitable to most soils except sandy soils that have very high infiltration water and provide poor lateral distribution water between furrows.

As compared to the other methods of surface irrigation, the furrow method is advantageous as:

- Water in the furrows contacts only one half to one-fifth of the land surface, thus reducing puddling and clustering of soils and excessive evaporation of water.
- Earlier cultivation is possible

Subsurface irrigation methods

The application of water to fields in this type of irrigation system is below the ground surface so that it is supplied directly to the root zone of the plants.

- The main advantages of these types of irrigation is reduction of evaporation losses and less hindrance to cultivation works which takes place on the surface.
- There may be two ways by which irrigation water may be applied below ground and these are termed as:
  - Natural sub-surface irrigation method
  - Artificial sub-surface irrigation method

Sprinkler Irrigation System

- Sprinkler irrigation is a method of applying water which is similar to natural rainfall but spread uniformly over the land surface just when needed and at a rate less than the infiltration rate of the soil so as to avoid surface runoff from irrigation.
- This is achieved by distributing water through a system of pipes usually by pumping which is then sprayed into the air through sprinklers so that it breaks up into small water drops which fall to the ground.
- The system of irrigation is suitable for undulating lands, with poor water availability, sandy or shallow soils, or where uniform application of water is desired.
- No land leveling is required as with the surface irrigation methods.
- Sprinklers are, however, not suitable for soils which easily form a crust. The water that is pumped through the pump pipe sprinkler system must be free of suspended sediments.

Drip Irrigation System

- Drip Irrigation system is sometimes called trickle irrigation and involves dripping water onto the soil at very low rates (2-20 litres per hour) from a system of small diameter plastic pipes filled with outlets called emitters or drippers.
- Water is applied close to the plants so that only part of the soil in which the roots grow is wetted, unlike surface and sprinkler irrigation, which involves wetting the whole soil profile.
- With drip irrigation water, applications are more frequent than other methods and this provides a very favourable high moisture level in the soil in which plants can flourish.

Some Important Definitions

Kharif-Rabi ratio or Crop Ratio

- The area to be irrigated for Rabi crop is generally more than that for the Kharif crop.
- This ratio of proposed areas, to be irrigated in Kharif season to that in the Rabi season
- This ration is generally 1:2, i.e. Kharif area is one-half of the Rabi area

Paleo Irrigation

- Sometimes, in the initial stages before the crop is sown, the land is very dry.
- This particularly happens at the time of sowing of Rabi crops because of hot September.
- In such a case, the soil is moistened with water

Kor-watering

- The first watering which is given to a crop, when crop is few centimeters high
- It is usually the maximum single watering followed by other watering at usual intervals, as required by drying of leaves
- The optimum depth of kor-watering for different crops are different
- For example For wheat (in U.P.) is about 13.5 cm For sugarcane is 16.5 cm
- The kor-watering must be applied within a fixed limited period, called kor-period

Puddling -watering

- Preparation of land for transplantation
- Requires lump sum of water
- 200 mm at field level for rice crop

Cash Crop

- A crop which has to be encashed in the market for processing, etc. as it cannot be consumed directly by the cultivators
- All non-food crops, are thus, included in cash crop
- Examples, jute, tea, cotton, tobacco, sugarcane, etc.

Crop rotation

- The method of growing different crops in rotation, one after the other, in the same field
- When the same crop is grown again and again in the same field, the fertility of land gets reduced as the soil become deficient in plant foods favourable to that particular crop
- In order to enhance the fertility of the land and to make soil regain its original structure, allow land to lie fallow without any cultivation for some time, or to grow crops which do not mainly require those salts or foods which were mainly required by the earlier grown crop

Crop rotation will thus help in

- Increasing the fertility of soil
- Reducing the diseases
- Wastage due to insects
- Increasing the overall crop yield

Irrigation Interval: The time gap usually expressed in days, between two subsequent irrigations

Irrigation Period

- The time, usually expressed in days, that can be allowed for applying one irrigation to a given design crop area during the peak consumptive use period of crop
- Function of the peak-period consumptive use rate
- Considered for designing the irrigation system capacity and equipment
- Irrigation system must be so designed
- Irrigation period is not greater than the irrigation interval

$$\boxed{\begin{array}{l}\text{Irrigation} \\ \text{period} \\ \text{(days)}\end{array} = \frac{\begin{array}{l}\text{Depth of soil depletion in the design crop area just before} \\ \text{irrigation, cm}\end{array}}{\text{Peak period consumptive use rate of crop, cm}}}$$

Design Irrigation Frequency

- It is same as the irrigation period
- The time, usually expressed in days, between two irrigations that is necessary to irrigate the design crop area during the period of peak consumptive use of the crop to be irrigated
- Used to decide the capacity of the irrigation system to be able to supply the required water to crops in the area
- The average consumptive use rate during this period is used for planning the system

$$\boxed{\begin{array}{l}\text{Design irrigation} \\ \text{frequency(days)}\end{array} = \frac{(F_c - M_b) \times A_s \times D / 100}{\text{Peak period consumptive use ratio of crop, cm}}}$$

– Where, F_c is field capacity (%), M_b = soil water content just before irrigation(%)

A_s = apparent Sp. Gravity of soil or bulk density of soil

D = Depth of crop root zone, cm

Depth of Irrigation

- Function of the water retentive capacity of the root-zone soil and the extent of soil water depletion at the time of irrigation
- The depth to which the applied water would cover an area
- Ex. 10 cm depth of irrigation to a hectare of land means if the vol. of water is allowed to stand without any loss and infiltration into the soil would stand over one hectare area to a depth of 10 cm
- The net depth of irrigation is decided by the amount of water required to bring the soil water content just before an irrigation to field capacity in the root zone soil
- The water content of soil just before irrigation must be known to calculate the net depth of water required to be applied

$$d = \sum_{i=1}^{n} \frac{F_{ci} - M_{bi}}{100} \times A_{si} \times D_i$$

– Where, d = Net depth of water to be applied or net irrigation or net irrigation, cm

F_{ci} = Field capacity of the i^{th} layer of soil in % by weight.

M_{bi} = Water content of the i^{th} layer of soil just before irrigation, % by weight

A_{si} = Apparent sp. Gravity of i^{th} layer of soll, g/cm^3

D_i = Depth of i^{th} layer of soil in the root zone, cm

n = Number of soil layers in the root zone D

Consumptive use or Evapotranspiration (Cu)

- Quantity of water used by plant to perform its metabolic activities and that lost due to evaporation and transpiration.
- The total amount of water used by the plant in transpiration (building of plant tissues, etc.) and evaporation from the adjacent soils or from plants leaves, in any specified time
- It (Cu) may be different for different crops, and may be different for the same crop at different times and places
- Values of daily Cu or monthly Cu, are generally determined for a given crop and at a given place
- Values of monthly Cu over the entire crop period, are then used to determine the irrigation requirement of the crop

Method to fine consumptive use of plant:

Blaney-Criddle method

$ET_r = a + b \{P (0.46 T + 8.13)\}$

Where,

ET_r = Reference crop evaportranspiration in mm/day a & b = Calibration factors

P = Mean daily percentage of total annual daytime hours.

T = Mean daily air temperature in °C

$a = 0.0043\ RH_{min} - (n/N) - 1.41$

$b = ((0.82 - (0.0041RH_{mean}) + (1.07\ n/N) + (0.066U) - (0.006RH_{mean}n/N) - (0.0006RH_{mean}U)$

n/N = Mean ratio of actual to possible sunshine hours.

RH_{min} = Minimum daily relative humidity

U = Wind speed at a height of 2 m from ground surface $U_2 = U_x(2/x)^{(1/7)}$

Factors Affecting Consumptive Use

Consumptive Use or Evapotranspiration depends upon all those factors on which evaporation and transpiration depend such as:

- Sunlight
- Humidity
- Wind movement, etc

Effective rainfall (Re)

Precipitation falling during the growing period of the crop which is available to meet the evapotranspiration requirement of the crop

Consumptive Irrigation Requirement (CIR)

- It is the amount of Irrigation Water required in order to meet the evapotranspiration needs of the crop during its full growth
- It is, therefore, nothing but the consumptive use itself, but exclusive of effective precipitation, stored soil moisture, or ground water
- When the last two are ignored, then we can write

  CIR = Cu – Re

Net Irrigation Requirement (NIR)

- It is the amount of irrigation water required in order to meet the evapotranspiration need of the crop as well as other needs such as leaching
- Therefore,NIR = Cu – Re + Water lost as percolation in satisfying other needs such as leaching

Irrigation efficiencies

Efficiency is the ratio of the water output to the water input, and is usually expressed as percentage

Water is lost in irrigation during various processes and therefore, there are different kinds of irrigation efficiencies:

- Efficiency of water-conveyance

- Efficiency of water-application
- Efficiency of water-storage
- Efficiency of water-use

Efficiency of Water-Conveyance

- It is the ratio of the water delivered into the fields from the outlet point of the channel, to the water pumped into the channel at the starting point.
- It may be represented by η_c
- It takes the conveyance or transit losses into account

Efficiency of Water-Application

- Ratio of the quantity of water stored into the root zone of the crops to the quantity of water actually delivered into the field
- It may be represented by η_a
- It may also be termed as field efficiency
- As it takes into account the water lost in the field

Efficiency of Water-Storage

- Ratio of the water stored in the root zone during irrigation to the water needed in the root zone prior to irrigation (i.e. field capacity – existing moisture content)
- It may be represented by η_s

Efficiency of Water Use

- Ratio of the water beneficially used, including leaching water, to the quantity of water delivered
- It may be represented by η_u

Uniformity Coefficient or Water Distribution Efficiency

- The effectiveness of irrigation may also be measured by its water distribution efficiency η_d

$$\eta_d = \left(1 - \frac{d}{D}\right)$$

– Where,

– η_d = water distribution efficiency

– D = Mean depth of water stored during irrigation

– d = Average of the absolute values of deviations from the mean

- It represents the extent to which the water has penetrated to a uniform depth, throughout the field
- When the water has penetrated uniformly throughout the field, the deviation from the mean depth is zero and water distribution efficiency is 1.0.

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