UNIT-I		

INTRODUCTION to HYDROLOGY:

Engineering Hydrology and Its Applications; Hydrologic Cycle; Precipitation- Types and forms, Rainfall Measurement, Types of Rain Gauges, Computation of Average Rainfall Over A Basin, Presentation and Interpretation of Rainfall Data. Evaporation- Factors Affecting Evaporation, Measurement of Evaporation; Infiltration- Factors Affecting Infiltration, MeasurementofInfiltration,InfiltrationIndices;Runoff-FactorsAffectingRun-off, Computation of Run-Off; Design Flood; Estimation of Maximum Rate of Run-Off; Separation of Base Flow.

1. Introduction

Water is the most precious natural resource that supports all forms of life on earth. It is essential for drinking, agriculture, industry, transportation, power generation and many other human activities.

Engineering Hydrology is the branch of science which deals with the occurrence, measurement, movement, distribution and properties of water on and below the earth's surface and in the atmosphere, and its application to solve practical engineering problems.

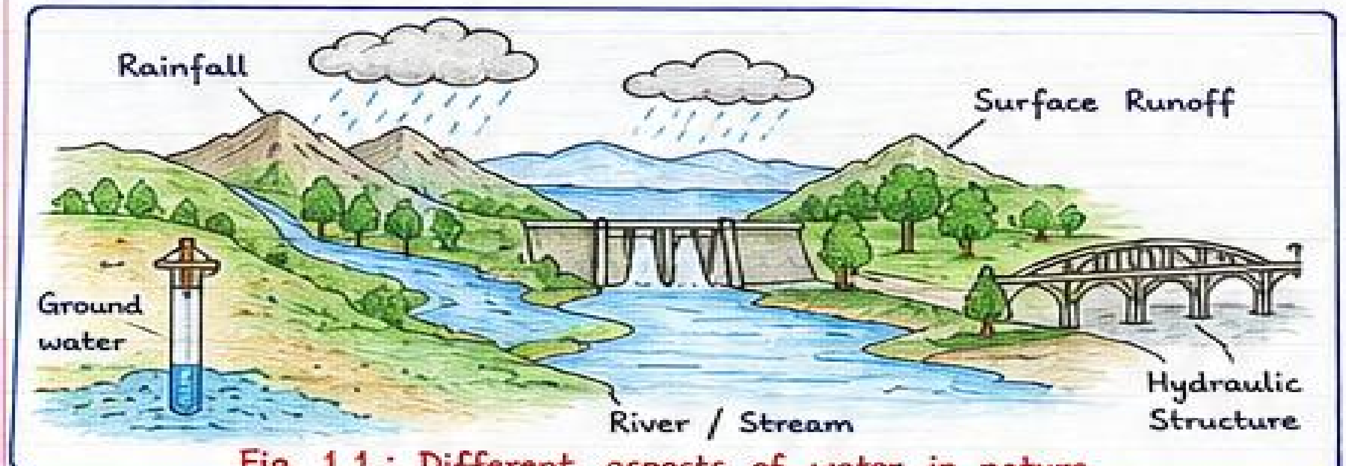


Fig. 1.1 : Different aspects of water in nature

★ Key Point

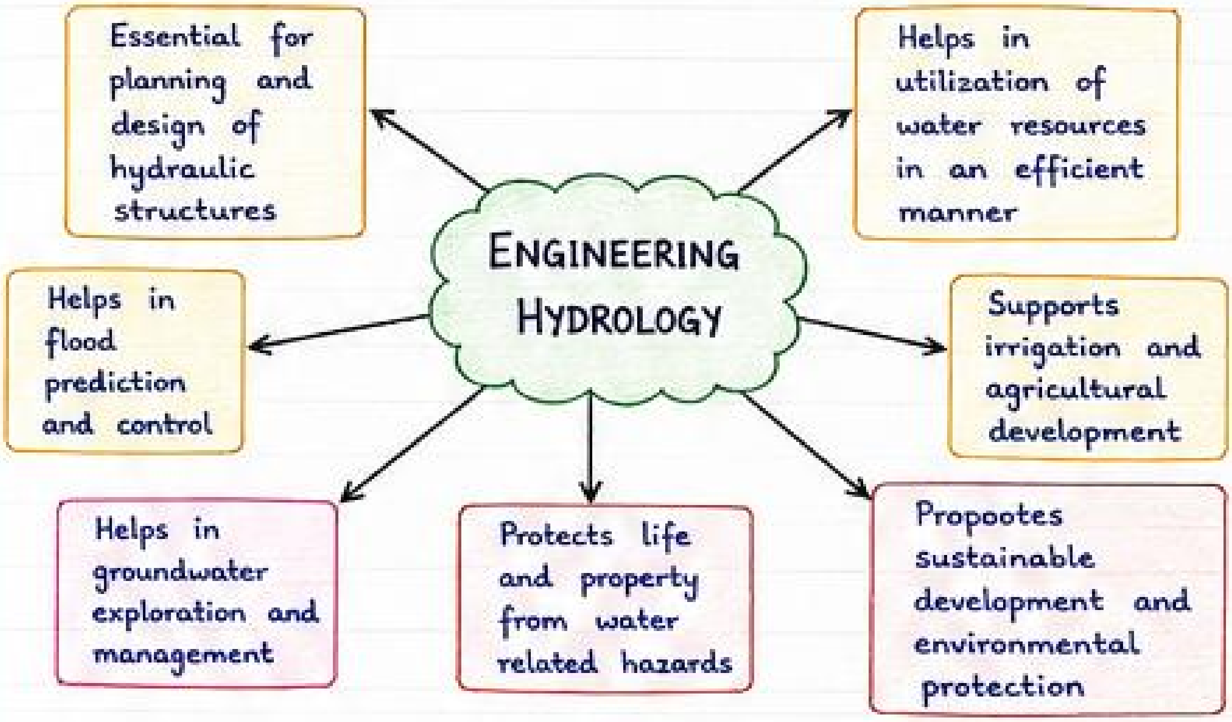
Engineering Hydrology applies the principles of hycrology to the planning, design, construction and operation of hydraulic structures and water resources systems.

2. Need for Study of Engineering Hydrology

The study of engineering hydrology is necessary to :

* Estimate the availability of water resources.
* Design hydraulic structures (dams, bridges, culverts, etc.).
* Estimate floods and design flood control structures.
* Plan for irrigation and water supply.
* Manage groundwater resources.
* Conserve water and protect environment.
* Support sustainable development.

3. Importance of Engineering Hydrology



4. Objectives of Engineering Hydrology

1. To measure and analyze precipitation.
2. To estimate runoff and its characteristics.
3. To predict floods and droughts.
4. To design hydraulic structures safely and economically.
5. To manage groundwater resources.
6. To conserve water and prevent pollution.
7. To ensure sustainable development and wise use of water.

5. Scope of Engineering Hydrology

Engineering Hydrology covers a wide range of studies related to water resources.

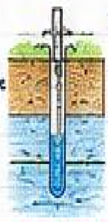
Scope of Engineering Hydrology

1. Rainfall Analysis
* Measurement of rainfall
* Rainfall distribution
* Rainfall intensity
* Frequency analysis

2. Runoff Analysis
* Surface runoff
* Streamflow estimation
* Watershed response
* Peak discharge

3. Flood Studies
* Flood prediction
* Flood routing
* Flood frequency analysis
* Flood control measures

4. Groundwater Hydrology
* Aquifers
* Water table
* Groundwater recharge
* Well hydraulics



5. Evaporation and Infiltration
* Evaporation estimation
* Soil infiltration
* Soil moisture movement

6. Watershed Management
* Catchment analysis
* Soil conservation
* Water conservation
* Sustainable watershed development

7. Reservoir Planning
* Storage capacity
* Reservoir operation
* Sedimentation studies

8. Irrigation Engineering
* Water requirement
* Canal design
* Irrigation scheduling

6. Applications in Civil Engineering

S.No.	Field	Application of Hydrology	Example
1.	Dam Engineering	Reservoir capacity, Spillway design, Flood estimation	Hirakud Dam, Bhakra Dam
2.	Bridge Engineering	Design flood, Scour depth, Waterway area	Godavari Bridge, Narmada Bridge
3.	Highway Engineering	Drainage design, Culverts, Storm water management	National Highways, Expressways
4.	Irrigation Engineering	Water requirement, Canal design, Irrigation scheduling	Indira Gandhi Canal
5.	Urban Water Supply	Estimation of demand, Storage capacity, Distribution planning	Municipal water supply systems
6.	Flood Management	Flood forecasting, Flood routing, Flood control works	Levees, Embankments
7.	Groundwater Development	Borewell design, Aquifer studies, Recharge estimation	Tube wells, Open wells
8.	Hydroelectric Projects	Flow analysis, Storage planning, Power generation estimation	Tehri Hydro Project

7. Role of Engineering Hydrology

Study of water in all its forms

↓

Collection and analysis of data

↓

Planning and estimation

↓

Design of hydraulic structures

↓

Operation and maintenance

↓

Sustainable development and water conservation

Remember

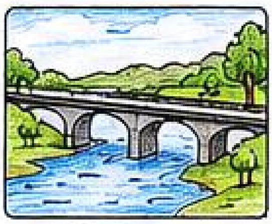
★ Hydrology studies the occurrence, movement and distribution of water.

★ Engineering Hydrology applies this knowledge to solve real world problems related to water resources and hydraulic structures.

8. Engineering Hydrology in Civil Engineering Projects

Water is involved in almost every civil engineering project either directly or indirectly.

Dam



Bridge

Irrigation Canal

Urban Drainage

9. Relation Between Hydrology and Engineering

Rainfall (Precipitation) → Runoff (Flow of water over land) → Streams / Rivers (Concentration of flow) → Storage Structures (Dams, Reservoirs)

↓

Utilization of Water (Irrigation, Power, Water supply etc.) → Benefit to Society (Agriculture, Industry, Domestic use) → Sustainable Development

★ **Key Point**

Hydrology provides the necessary data and understanding to plan, design, construct and operate hydraulic structures safely and efficiently.

10. Engineering Hydrology – What It Deals With?

- ★ Quantitative and qualitative aspects of water.
- ★ Natural water cycle and its analysis.
- ★ Measurement of rainfall, runoff and other components.
- ★ Prediction of floods and droughts.
- ★ Design and operation of hydraulic structures.
- ★ Groundwater occurrence, movement and utilization.
- ★ Water resource planning and management.

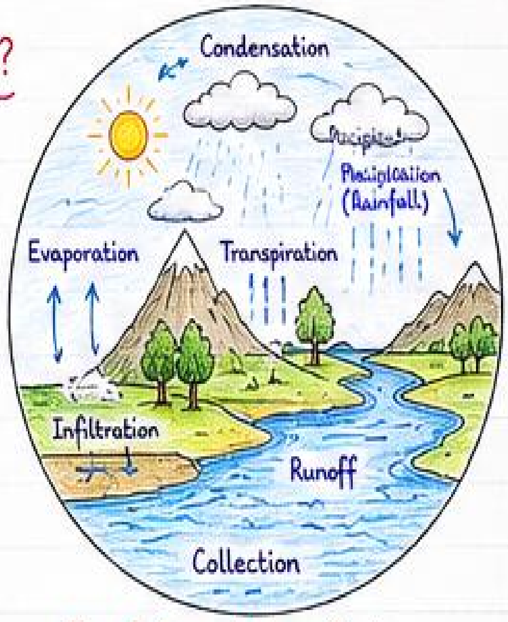


Fig. 1.2 : Water Cycle

Remember

- ★ Engineering Hydrology is the application of hydrological science for solving water related engineering problems.
- ★ It is the link between natural water system and human needs.

11. Major Benefits of Engineering Hydrology

- ★ Helps in efficient planning and design of projects.
- ★ Ensures optimum use of available water resources.
- ★ Helps in flood control and drought management.
- ★ Protects life, property and environment.
- ★ Supports food production through irrigation.
- ★ Generates hydroelectric power.
- ★ Promotes public health and hygiene.
- ★ Contributes to sustainable development goals (SDGs).

Sustainable Water Management

12. Summary – Application Areas

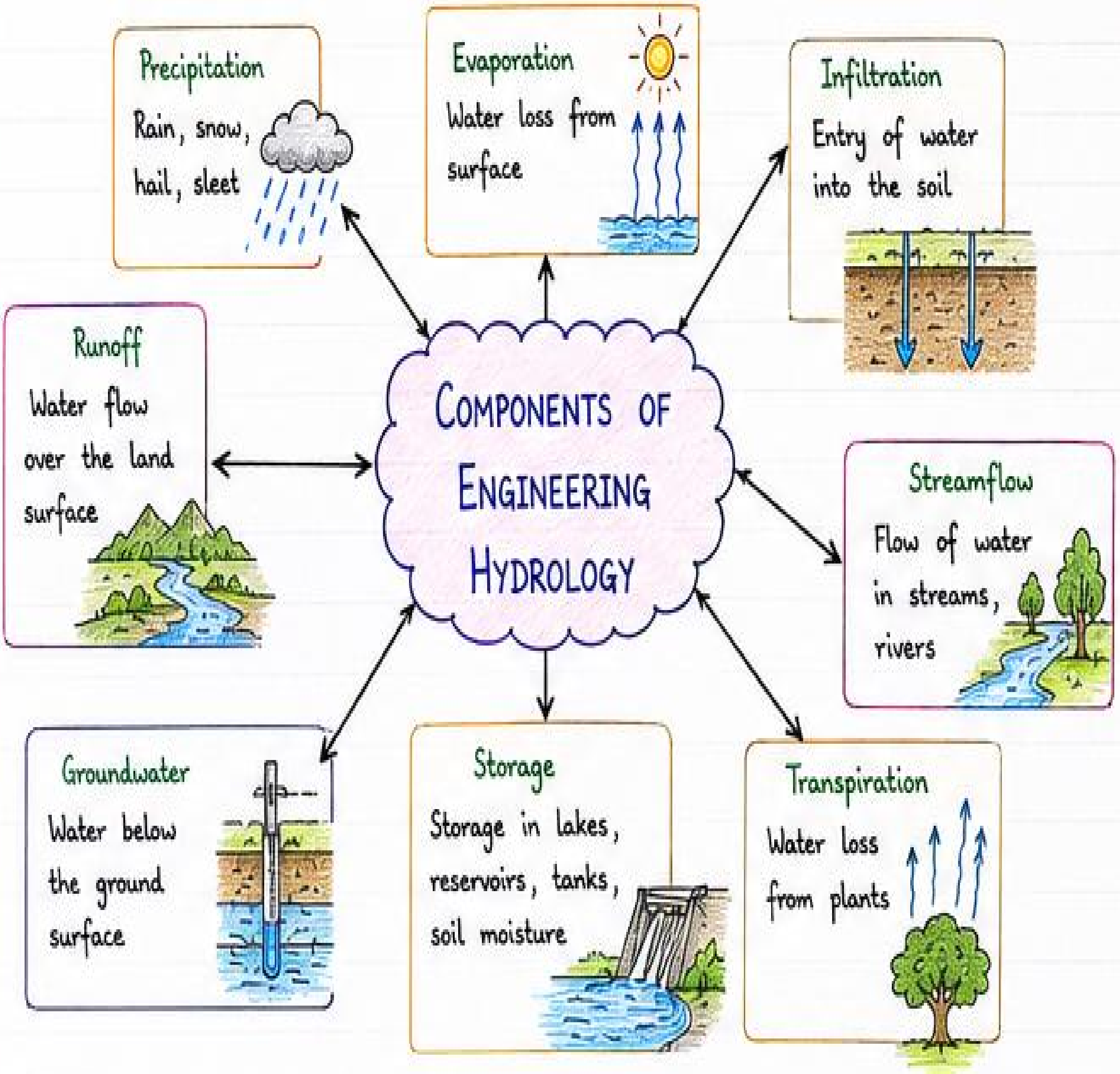
S.No.	Application Area	Hydrological Use	Example
1.	Water Resources Planning	Estimate availability of water	Reservoir, Water supply
2.	Flood Management	Flood estimation and control	Levees, Dams, Spillways
3.	Bridge and Highway Engineering	Design for safe passage of water	Culverts, Bridges
4.	Irrigation Engineering	Estimate crop water requirement	Canals, Irrigation systems
5.	Hydroelectric Projects	Estimate flow and storage	Power houses, Dams
6.	Urban Drainage	Storm water analysis	Drains, Sewer systems
7.	Groundwater Development	Groundwater occurrence & recharge	Wells, Borewells
8.	Environmental Protection	Conserves water and protects ecosystem	Watershed management

13. Limitations of Engineering Hydrology

- Hydrological events are uncertain and variable.
- Data may be inadequate or not available.
- Natural disasters like extreme floods and droughts are difficult to predict accurately.
- Climate change is altering hydrological patterns.

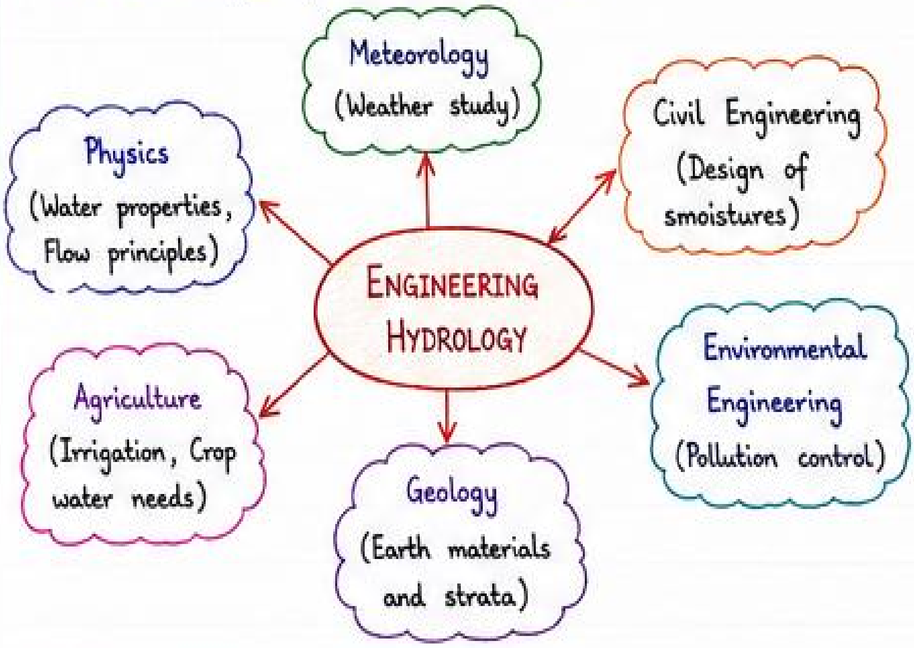
14. Components of Engineering Hydrology

Hydrology is complete only when we study various components of water and their inter-relationship.



15. Interdisciplinary Nature

Engineering Hydrology is an interdisciplinary subject which includes the knowledge from various fields.



★ **Key Point**

Hydrology is a combination of Natural Sciences and Engineering Applications to solve water related problems in a sustainable manner.

Remember

★ Hydrology deals with both quantity and quality of water.

★ It helps engineers to work with nature and not against nature.

16. Hydrologic Data Required for Engineering Projects

Various types of hydrologic data are required for planning and design.

S.No.	Hydrologic Data	Purpose / Use	Example
1.	Rainfall data	To estimate runoff and floods	Daily, Monthly rainfall
2.	Streamflow data	To design hydraulic structures	Discharge of rivers
3.	Evaporation data	To estimate water losses	Class 'A' pan data
4.	Groundwater data	To plan groundwater projects	Water table depth
5.	Soil data	To study infiltration, runoff	Soil texture, porosity
6.	Meteorological data	To support hydrologic analysis	Temperature, humidity, wind speed

17. Engineering Hydrology as a System

Input (Hydrologic Data)
Rainfall, Streamflow, Evaporation etc.

↓

Process (Analysis & Computation)
Data analysis, Estimation, Modelling

↓

Output (Results)
Design rainfall, Peak discharge, Water requirement etc.

↓

Application (Engineering Use)
Design of Dams, Bridges, Canals, Drainage, Flood control etc.

↓

Feedback (Monitoring & Improvement)
Performance monitoring and system upgradation

18. Career Opportunities

* ★ Water Resources Engineer
* ★ Hydrologist
* ★ Irrigation Engineer
* ★ Environmental Consultant
* ★ Flood Forecasting Expert
* ★ Groundwater Specialist
* ★ Researcher / Academician
* ★ Municipal Water Manager

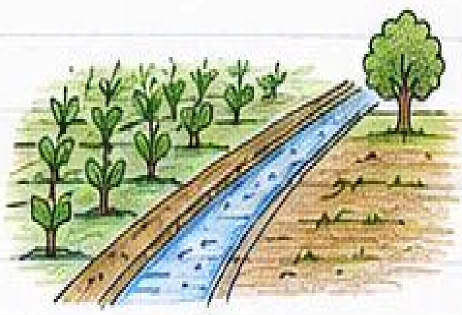
19. Summary

* ★ Engineering Hydrology is the application of hydrological science to solve practical engineering problems.
* ★ It plays a vital role in planning, design, construction and management of water resources systems.
* ★ It helps in optimum utilization of water and in protection from floods and droughts.
* ★ It is essential for sustainable development and better quality of life.

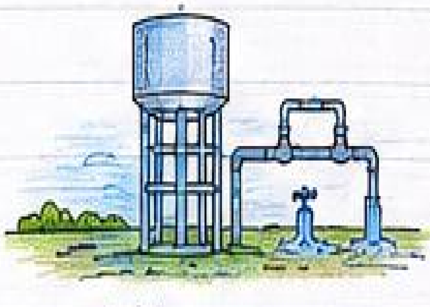
University Questions

20. Applications in Different Sectors

1. **Agriculture** : Helps in irrigation planning, water requirement estimation and crop management.



2. **Water Supply** : Used in estimation of water demand, reservoir sizing and distribution system design.

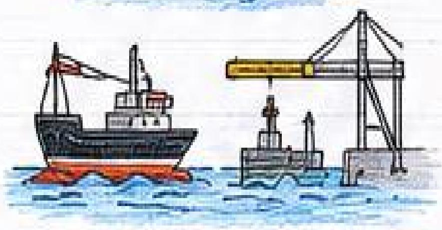


3. **Industry** : Required for process water, cooling water requirement and wastewater management.

4. **Environment** : Helps in watershed management, pollution control, wetland conservation and climate change studies.

5. **Disaster Management** : Used for flood forecasting, drought assessment and early warning systems.

6. **Navigation & Ports** : Water level, flow and sedimentation studies are essential for safe navigation.



21. COMPLETE HYDROLOGIC CYCLE

The hydrologic cycle (water cycle) describes the continuous movement of water on, above and below the surface of the earth.

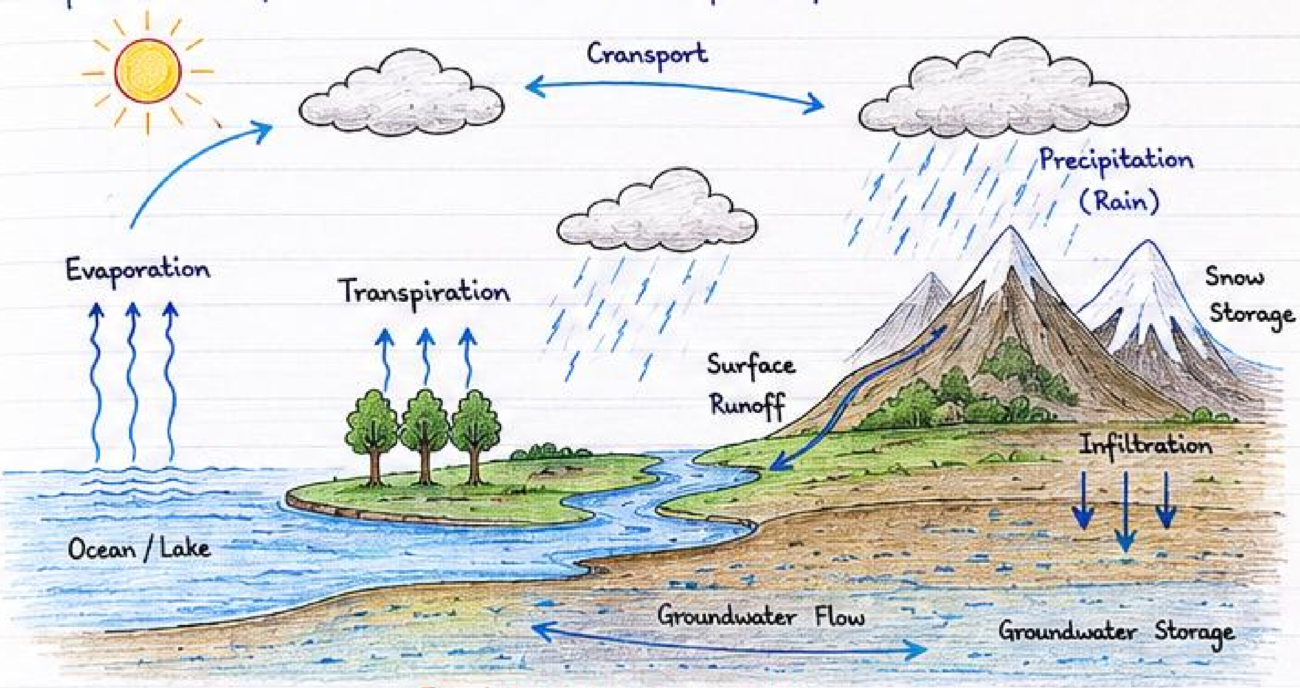


Fig. 1.3 : Hydrologic Cycle

22. Water Budget Equation

The inflow, outflow and change in storage of water in a system can be expressed by water budget equation.

$$\boxed{I - O = \Delta S}$$

Where, I = Inflow (Input)

O = Outflow (Output)

ΔS = Change in storage

Example

Rainfall (I) = 100 mm

Evaporation (O) = 40 mm

Change in storage (ΔS) = 60 mm

(Increase in soil moisture, groundwater etc.)

23. Summary of Chapter-1

This chapter introduces the basic concepts of Engineering Hydrology, its scope, components, importance and applications. It forms the foundation for understanding detailed hydrologic processes such as rainfall analysis, runoff estimation, evaporation, infiltration and flood studies.

★ WATER IS LIFE, MANAGE IT WISELY FOR A BETTER TOMORROW. ★

24. Hydrologic Cycle – Description

The hydrologic cycle is the continuous circulation of water between the earth and the atmosphere through various processes.

Main Processes in Hydrologic Cycle

1. Evaporation : Conversion of water from surface into water vapour due to heat.
2. Transpiration : Release of water vapour from plants through stomata.
3. Condensation : Cooling of water vapour and conversion into tiny droplets forming clouds.
4. Precipitation : Water falls from clouds to earth in the form of rain, snow, hail etc.
5. Infiltration : Entry of water into the soil surface.
6. Percolation : Movement of infiltrated water to lower layers of soil.
7. Groundwater Flow : Movement of groundwater through aquifers.
8. Surface Runoff : Flow of water over the land surface into streams, rivers, lakes and oceans.
9. Collection / Storage : Water is stored in oceans, lakes, reservoirs, soil moisture and groundwater.

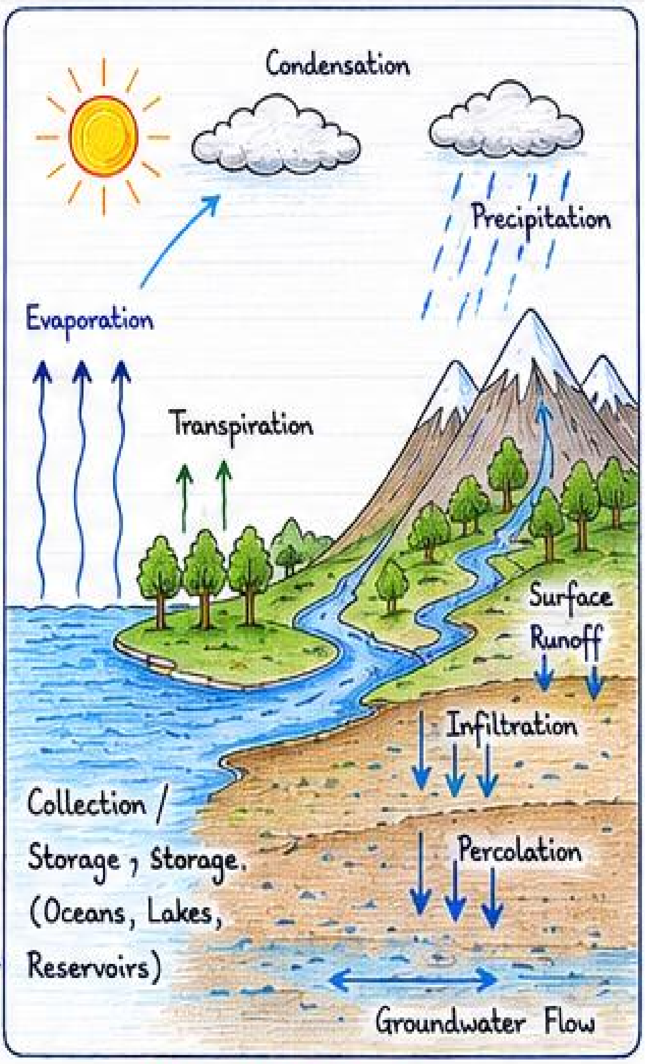


Fig. 1.4 : Hydrologic Cycle

25. Importance of Hydrologic Cycle

★ Maintains constant supply of water on earth.
★ Supports all living organisms.
★ Helps in natural purification of water.
★ Recharges groundwater.
★ Regulates climate and temperature.
★ Essential for agriculture, industry and domestic use.

Key Point

Hydrologic cycle is a natural phenomenon that keeps water circulating in a closed system with no beginning and no end.

Remember Sun → Evaporation → Clouds (Condensation) → Precipitation → Infiltration → Runoff / Groundwater → Storage → Evaporation

26. Natural and Man-Made Interference in Hydrologic Cycle

Natural Interference	Man-made Interference
• Changes in climate and rainfall pattern	• Deforestation
• Droughts and floods	• Urbanization and concretization
• Earthquakes, volcanic eruptions	• Construction of dams and reservoirs
• Landslides, soil erosion	• Over-extraction of groundwater
• Natural vegetation changes	• Pollution of water bodies

27. Hydrologic Cycle and Water Resources

All available water resources are a part of the hydrologic cycle.
Understanding the cycle helps in :

★ Estimating availability of water

★ Planning storage and conservation measures

★ Designing sustainable water resource systems

★ Managing floods and droughts

Water Resources

- Surface Water (Rivers, Lakes, Reservoirs)
- Groundwater
- Soil Moisture
- Atmosphere Water

28. Hydrologic Cycle – Quick Review

Evaporation – Water from oceans, lakes, rivers, soil changes into vapour.

→ **Condensation** – Water vapour rises, cools and forms clouds.

→ **Precipitation** – Clouds release water as rain, snow, hail etc.

→ **Infiltration** – Water enters the soil surface.

→ **Percolation** – Water moves to deeper layers of soil.

→ **Evaporation (Again)** – Same cycle repeats.

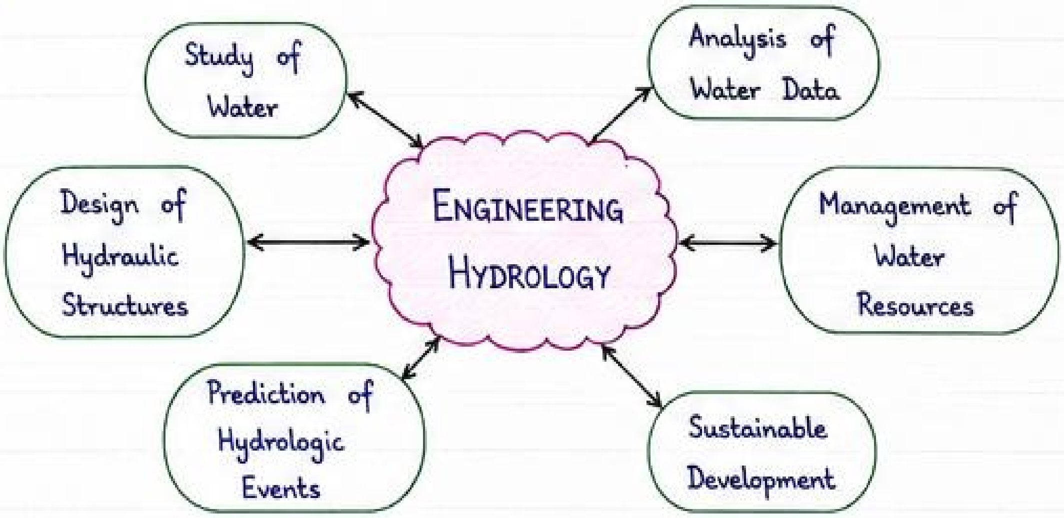
→ **Collection / Storage** – Water stored in oceans, lakes, reservoirs etc.

→ **Surface Runoff** – Water flows over the land surface to streams.

→ **Groundwater Flow** – Water moves through aquifers.

30. Engineering Hydrology – At a Glance

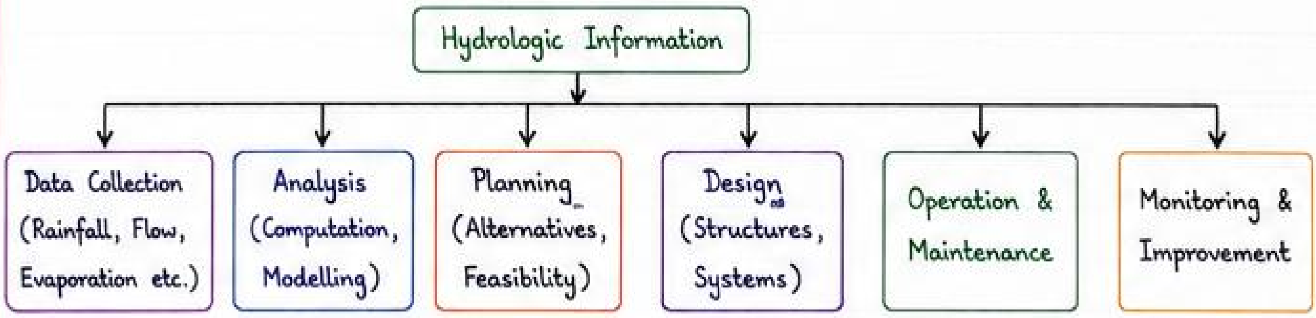
It is the application of hydrological principles for solving engineering problems related to water.



31. Hydrologic Variables Studied

- ★ Rainfall – Amount, intensity, duration, frequency.
- ★ Runoff – Quantity and rate of flow in streams and rivers.
- ★ Evaporation – Loss of water from surface.
- ★ Infiltration – Entry of water into the soil.
- ★ Groundwater – Occurrence, movement and quality.
- ★ Floods – Magnitude, frequency and control.
- ★ Water Quality – Physical, chemical and biological characteristics.

32. Hydrology in Engineering Decision Making

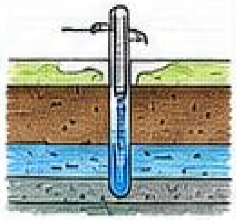


Remember

- ★ No engineering structure is complete without the knowledge of hydrology.
- ★ Water is dynamic – its quantity and quality keep changing.
- ★ Good hydrologic data = Good engineering decision.

33. Types of Water Resources

Water resources are generally classified as:

Surface Water	Groundwater	Meteoric Water	Ocean Water	Glacier & Snow
				
Water available on the surface such as rivers, lakes, ponds, reservoirs.	Water present below the ground in aquifers.	Precipitation from atmosphere in the form of rain, snow, hail etc.	Water contained in seas and oceans.	Water stored in ice and snow in polar and mountain regions.

34. Interrelationship Between Variables

Rainfall → Infiltration → Soil Moisture → Runoff → Streamflow

Soil Moisture ↓ Evaporation

Streamflow ↓ Groundwater Recharge

All the hydrologic variables are interdependent and influence each other within the hydrologic cycle.

35. Examples of Engineering Application

Project / Structure	Use of Hydrology	Purpose
Dam and Reservoir	Rainfall analysis, runoff estimation, evaporation loss	Determine storage capacity, spillway design
Bridge	Flood estimation, scour depth calculation	Safe design of piers and foundations
Highway & Road	Storm water analysis, runoff estimation	Design of culverts and drainage systems
Irrigation Projects	Water requirement, rainfall analysis, evaporation	Canal design, water allocation
Urban Water Supply	Demand estimation, storage analysis	Design of reservoirs, distribution systems
Flood Control	Flood forecasting, flood routing	Design of levees, dams, flood warning systems

★ Key Point

Hydrology gives the right data for the right decision.

Chapter-2 Hydrologic Cycle (Detailed)

1. Introduction

The hydrologic cycle is the natural process by which water circulates continuously between the earth and the atmosphere in its various forms.

It has no beginning and no end.

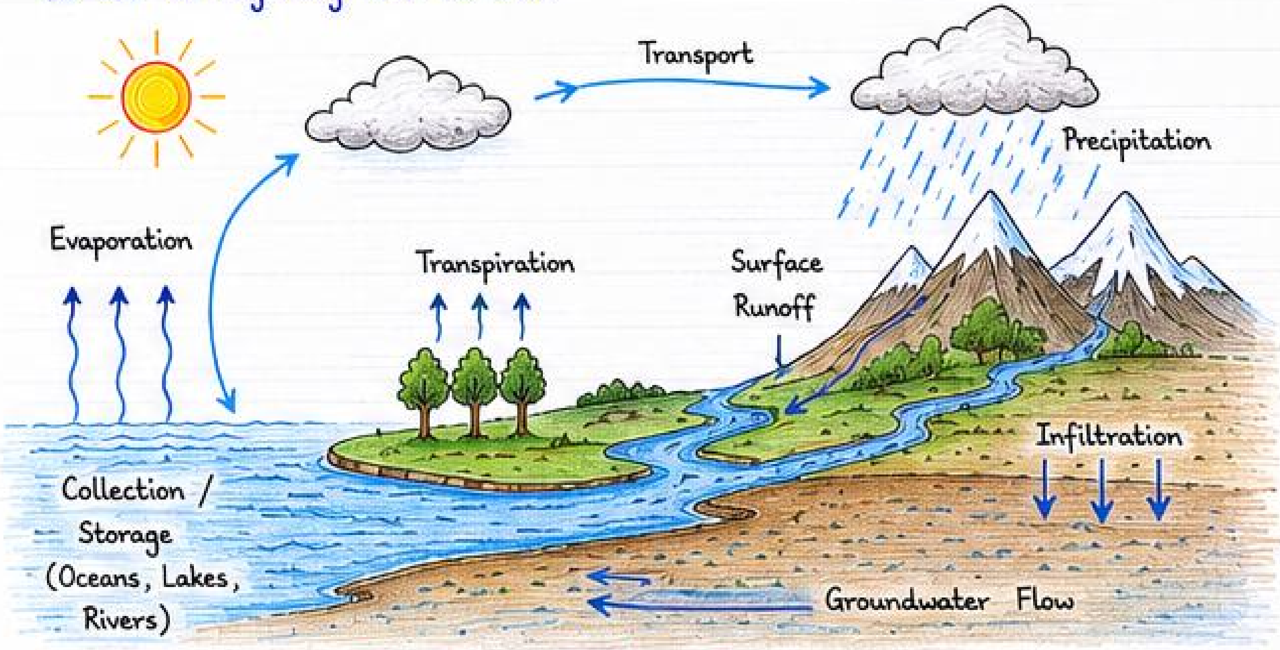


Fig. 2.1 : Hydrologic Cycle

2. Main Processes in Hydrologic Cycle

- ★ Evaporation : Conversion of water from surface water bodies into water vapour due to heat.
- ★ Transpiration : Release of water vapour from plants through stomata.
- ★ Condensation : Cooling of water vapour and conversion into tiny droplets forming clouds.
- ★ Precipitation : Water falls from clouds to earth in the form of rain, snow, hail, sleet etc.
- ★ Infiltration : Entry of water into the soil surface.
- ★ Percolation : Movement of infiltrated water to lower layers.
- ★ Runoff : Flow of water over the land surface to streams, rivers, lakes and oceans.
- ★ Storage : Water is stored in various forms like oceans, lakes, reservoirs, soil moisture and groundwater.

★ Key Point

The hydrologic cycle explains the movement of water between the earth and the atmosphere through natural processes.

Remember

★ Sun is the ultimate driving force of the hydrologic cycle.

★ All the processes are interdependent and continuous.

3. Water Balance (Water Budget)

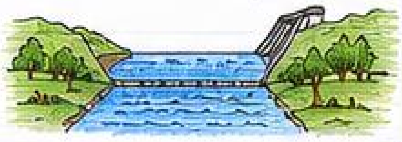
The water budget represents the inflow, outflow and change in storage of water in a system over a period of time.

General Water Budget Equation

$$I - O = \Delta S$$

Where, I = Inflow to the system
O = Outflow from the system
ΔS = Change in storage

Components :

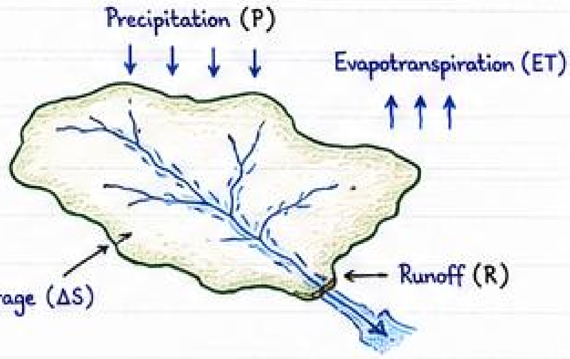
Inflow (I)	Outflow (O)	Change in Storage (ΔS)
• Precipitation	• Evapotranspiration	• Increase in storage (+)
• Inflow from streams	• Surface runoff	• Decrease in storage (−)
• Inflow from groundwater	• Outflow to streams	
• Return flow	• Percolation to groundwater	
• Import of water	• Export of water	

4. Basin Water Balance

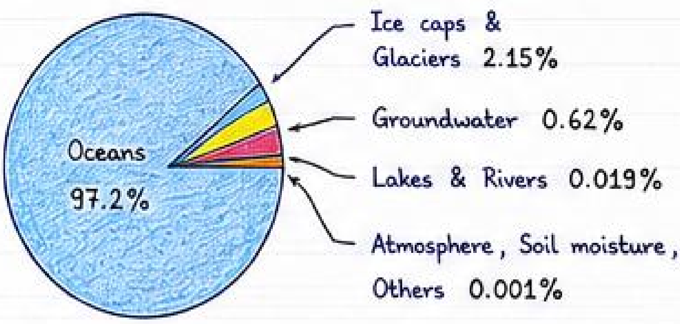
For a drainage basin over a time period,

Precipitation = Runoff + Evapotranspiration + Change in Storage

$$\boxed{P = R + ET + \Delta S}$$



5. Global Distribution of Water



★ Key Facts

★ 97.2% of water is in oceans (Salty).
★ Only 2.8% is freshwater.
★ Less than 1% of freshwater is easily available for human use.

6. Hydrologic Equation (General Form)

The general form of hydrologic equation is :

$$\boxed{P + Q_{in} = Q_{out} + ET + \Delta S}$$

Where,
P = Precipitation
Q_{in} = Inflow to the system
Q_{out} = Outflow from the system
ET = Evapotranspiration
ΔS = Change in storage

Units

$P, Q \rightarrow$ mm
$ET \rightarrow$ mm
$\Delta S \rightarrow$ mm
(1 mm over 1 km^2 = 1000 m^3)

Always wrute the water balance equation first in any hydrologic problem. This helps in understanding the problem clearly.

7. RESIDENCE TIME

Residence time is the average time water spends in a particular component of hydrologic cycle.

COMPONENT	AVERAGE RESIDENCE TIME
• Atmosphere	9 days
• Rivers	2 weeks
• Lakes	17 years
• Soil moisture	1 – 2 months
• Groundwater	100 – 1000 years
• Oceans	~ 2500 years
• Ice caps & glaciers	100 – 1000 years

Key Point

Water is always in motion. It may take few days to thousand years depending on the component.

8. BASIN WATER BALANCE

For a river basin over a time period,

$$\boxed{P + Q_{in} = Q_{out} + ET + \Delta S}$$

Where,

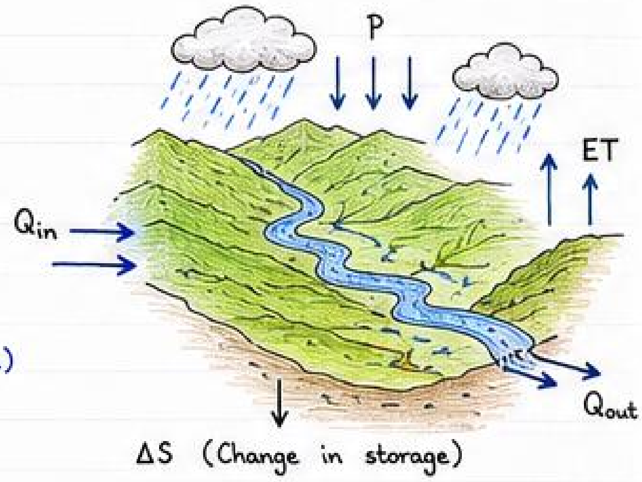
P = Precipitation over the basin

Q_{in} = Inflow to the basin (surface + subsurface)

Q_{out} = Outflow from the basin

ET = Evapotranspiration from the basin

ΔS = Change in storage within the basin



9. WATER BUDGET PROBLEMS

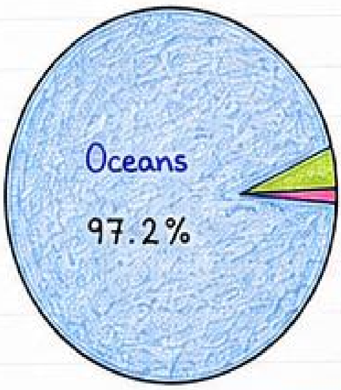
(i) If any three components are known, the remaining can be computed using the water budget equation.

(ii) Always convert all quantities to the same units before substituting in the equation.

Example : A basin receives 1200 mm rainfall in a year. Runoff is 450 mm and Evapotranspiration is 500 mm. Find change in storage.	Solution : $P = 1200$ mm, $R = 450$ mm $ET = 500$ mm, $\Delta S = ?$ $P = R + ET + \Delta S$ $1200 = 450 + 500 + \Delta S$ $\Delta S = 250$ mm (Increase in storage)

10. Global Water Distribution

Total water on Earth = 100%



Freshwater = 2.8%

- → Ice caps & Glaciers = 2.15%
- → Groundwater = 0.62%
- → Lakes, Rivers & Others = 0.03%

★ Only a very small portion of water is available for human use. Hence, proper management of water resources is essential.

11. Importance of Water Balance Study

★ Helps in planning and management of water resources.

★ Used in design of hydraulic structures like dams, reservoirs, canals.

★ Essential for flood forecasting and drought assessment.

★ Useful in irrigation planning and water supply systems.

★ Ensures optimum utilization and conservation of water.

Remember

"Measure it,
Manage it,
Save it."

12. Summary

1. Hydrologic cycle is the continuous circulation of water between the earth and atmosphere.
2. Main processes are : Evaporation, Transpiration, Condensation, Precipitation, Infiltration, Percolation, Runoff and Storage.
3. Water balance equation helps in understanding the inflow, outflow and change in storage of water in a system.
4. Water exists in different forms and its distribution on Earth is uneven.
5. Proper study of hydrologic cycle is the base for all water resource engineering applications.

Exam Tip

Draw hydrologic cycle diagram whenever asked in the exam. It can fetch good marks.

★ Water is a Precious Resource – Conserve it for Future ★

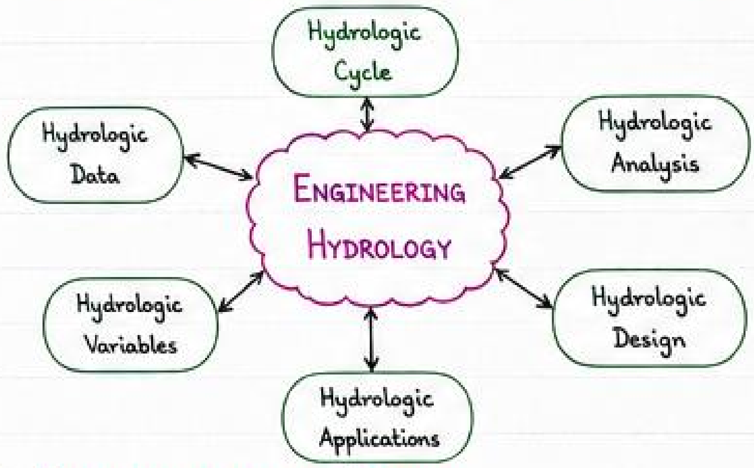
13. LIMITATIONS OF HYDROLOGIC CYCLE

- ★ The hydrologic cycle is a very complex natural process.
- ★ It varies from place to place and time to time.
- ★ Some components are difficult to measure accurately.
- ★ Human activities disturb the natural balance.
- ★ Climate change is altering the intensity and frequency of hydrologic processes.

Remember

Hydrology is not just a cycle, it is a continuous interaction of nature.

14. COMPONENTS OF ENGINEERING HYDROLOGY

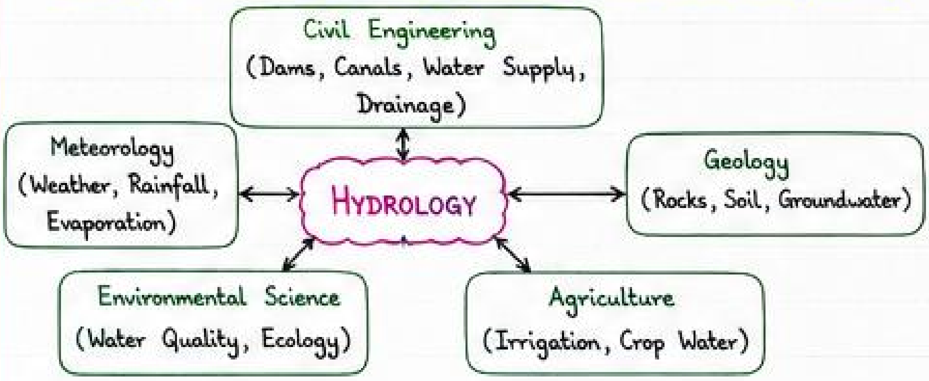


Key Point

Engineering Hydrologic uses hydrologic data and principles to solve practical engineering problems.

15. INTERDISCIPLINARY NATURE

Hydrology is related to many branches of science and engineering.



Memory Tip

Hydrology connects all elements of nature and human needs.

16. HYDROLOGIC DATA REQUIRED IN ENGINEERING APPLICATIONS

Types of Data	Other Required Data
• Rainfall data	• Soil and land use data
• Evaporation data	• Topographic data
• Stream flow data	• Water quality data
• Groundwater data	• Climatic data

EXAM TIP

Good quality data is the backbone of any hydrologic analysis.

17. Engineering Hydrology as a System

Engineering hydrology works as an integrated system.

Data Collection (Rainfall, Runoff, etc.) → Data Analysis (Processing, Computation) → Hydrologic Design (Structures, Systems) → Implementation (Construction & Operation) → Evaluation (Performance Monitoring)

This system helps in effective planning, design and management of water resources.

18. Career Opportunities in Engineering Hydrology

- ★ Water resources engineer
- ★ Hydrologist
- ★ Environmental consultant
- ★ Irrigation engineer
- ★ Flood forecasting specialist
- ★ Research scientist
- ★ Water supply and sanitation engineer

Areas of Work

- Dams and reservoirs
- Irrigation projects
- Hydropower projects
- Urban water supply
- Flood control projects
- Drainage and storm water systems

Save Water,
Save Life.

19. Chapter Summary

- Hydrologic cycle is a continuous natural process with no beginning and no end.
- Water is always in motion and changes its form continuously.
- The main processes are Evaporation, Transpiration, Condensation, Precipitation, Infiltration, Percolation, Runoff and Storage.
- Water balance helps in understanding the inflow, outflow and change in storage.
- Water is distributed unevenly and only a small portion is available for human use.
- Hydrologic principles are essential for planning, design and management of water resources.

Recall Box

$I - O = \Delta S$

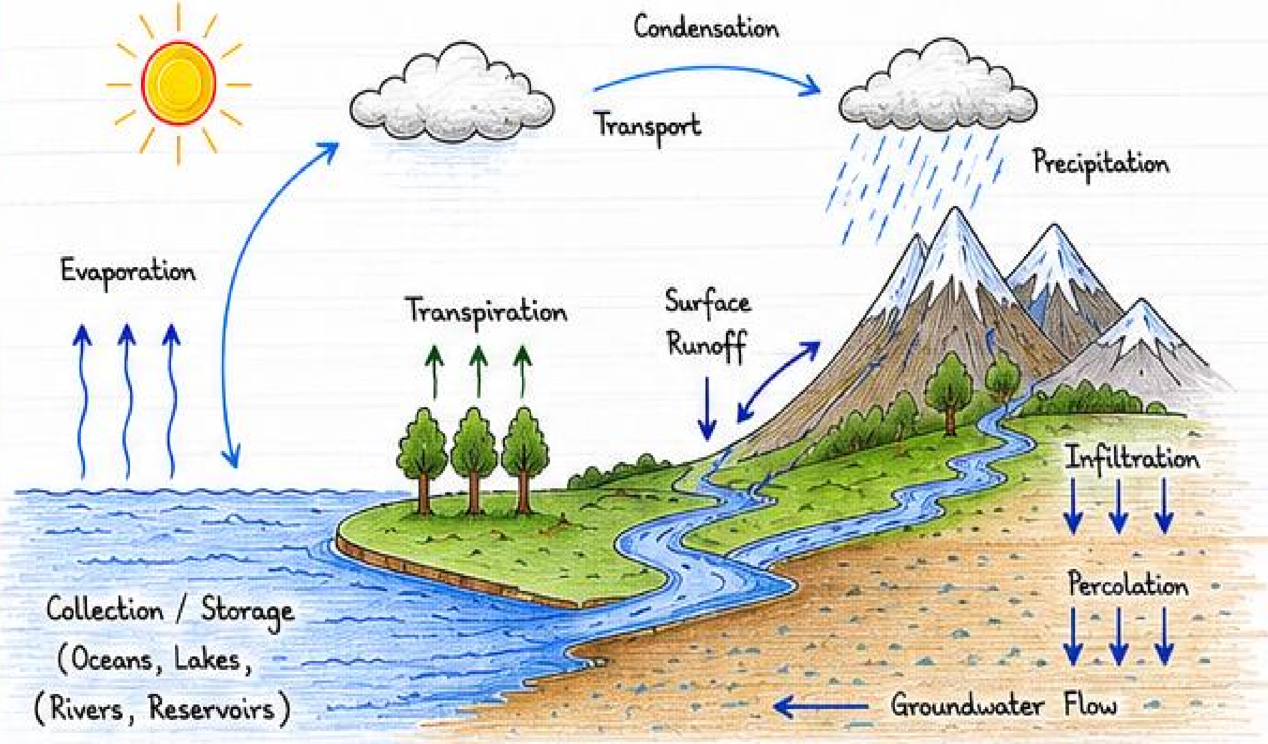
Inflow − Outflow = Change in Storage

20. Important Formulas (Chapter-2)

S. No.	Formula	Where,
1.	Water Budget Equation $I - O = \Delta S$	I = Inflow, O = Outflow, ΔS = Change in storage
2.	Basin Water Balance $P = R + ET + \Delta S$	P = Precipitation, R = Runoff, ET = Evapotranspiration, ΔS = Change in storage
3.	Hydrologic Equation (General Form) $P + Q_{in} = Q_{out} + ET + \Delta S$	Q_{in} = Inflow to the system, Q_{out} = Outflow from the system

★ Understand the Cycle, Respect Water and Manage it Wisely. ★

21. Complete Hydrologic Cycle – Summary Diagram



22. Water Budget Equation for a Basin

For a basin over a time period,

$$\boxed{P = Q_{out} + ET + \Delta S}$$

Where,

P = Precipitation over the basin

Q_{out} = Outflow from the basin

ET = Evapotranspiration from the basin

ΔS = Change in storage within the basin

23. Hydrologic Cycle – Key Points

★ Hydrologic cycle has no beginning and no end.

★ Water continuously changes its form and location.

★ Energy from the sun drives the cycle.

★ All components are interconnected.

★ Human activities can disturb natural balance.

★ Understanding the cycle is essential for water resource planning.

Memory Aid

E T C P I P R S

(Easy To Collect Precipitation In Proper Reservoirs Safely)

24. Summary of Chapter-2

The hydrologic cycle is the continuous circulation of water between the atmosphere and the earth through various processes. The water budget equation helps in understanding the inflow, outflow and change in storage of water in a system. Proper analysis of the cycle is essential for sustainable water resource management.

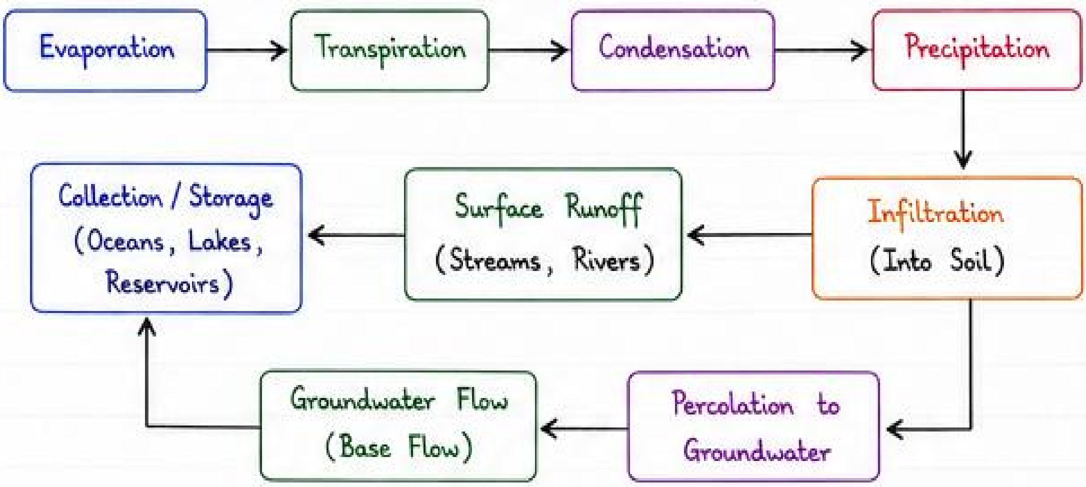
25. Applications of Hydrologic Cycle Study

1. Flood forecasting and control
2. Design of hydraulic structures (Dams, Spillways, Canals)
3. Irrigation planning and scheduling
4. Urban water supply and drainage design
5. Groundwater exploration and management
6. Drought assessment and mitigation
7. Water quality and pollution control
8. Climate change impact studies

Key Message

Study of hydrologic cycle is the foundation of all water resources engineering applications.

26. Hydrologic Cycle - Flow Chart



27. Important Facts - Quick Review

Topic	Important Fact	Remark
Driving Force	Sun is the ultimate source of energy.	Drives evaporation.
Direction of Flow	Water moves from higher energy level to lower energy level.	e.g., from clouds to earth.
Storage	Water is stored in oceans, lakes, reservoirs, soil and aquifers.	Storage changes with time.
Data Requirement	Accurate data is essential for analysis and design.	Rainfall, runoff, ET, soil data etc.
Balance	Input must equal output plus change in storage.	Law of conservation of mass applies.

Think & Write

Why is it important to consider change in storage (ΔS) in the water budget equation? Write in exam.

★ WATER CONNECTS EVERY LIVING THING ON EARTH. SAVE WATER, SAVE LIFE. ★

CHAPTER – 3 PRECIPITATION

1. INTRODUCTION

★ Precipitation is any product of condensation of atmospheric water vapour that falls from clouds and reaches the ground.

★ It is the primary source of water in the hydrologic cycle.

★ It occurs in different forms and amounts depending on time and place.

Fig. 3.1 : Precipitation

3. TYPES OF PRECIPITATION

Type	Description	Sketch
(a) Cyclonic (Frontal)	Caused by the meeting of warm moist air and cold air. Common in mid-latitude regions.	
(b) Orographic (Relief)	Moist air forced to rise over mountains, cools and produces rain on windward side.	
(c) Convective	Surface heating causes warm air to rise rapidly, cool and produce rain.	

2. Formation of Precipitation

- Sun heats the surface water → Evaporation occurs.
- Warm moist air rises → Cools as it rises.
- Water vapour condenses around tiny particles (dust, salt, smoke) → Cloud formation.
- When the cloud droplets become large and heavy, they fall to the ground as precipitation.

Evaporation ⟶ Condensation ⟶ Cloud Formation ⟶ Precipitation (Rain)

4. Forms of Precipitation

★ Rain – Liquid water drops (> 0.5 mm diameter).

★ Drizzle – Very small drops (< 0.5 mm).

★ Snow – Ice crystals in the form of flakes.

★ Sleet – Ice pellets formed by refreezing melted snow or rain.

★ Hail – Balls or irregular lumps of ice.

★ Graupel – Soft, white pellets formed by rimed snow.

5. Measurement of Precipitation

★ Measured in terms of depth (mm) of water collected on a horizontal surface.

★ Measured using rain gauges.

★ Recorded for a specific duration (hour, day, month, year).

Fig. 3.2 : Rain Gauge

6. Rainfall Intensity

★ Rainfall intensity is the depth of rainfall per unit time.

★ It is expressed in mm/hr or cm/hr.

★ Higher intensity means more rainfall in a short duration.

Example : 25 mm of rain in 30 min
→ Intensity = 25 / 0.5 = 50 mm/hr

7. Duration of Rainfall

★ Duration is the total time for which rainfall occurs.

★ It affects the amount of runoff.

★ Short duration → less runoff
Long duration → more runoff

8. Frequency of Rainfall

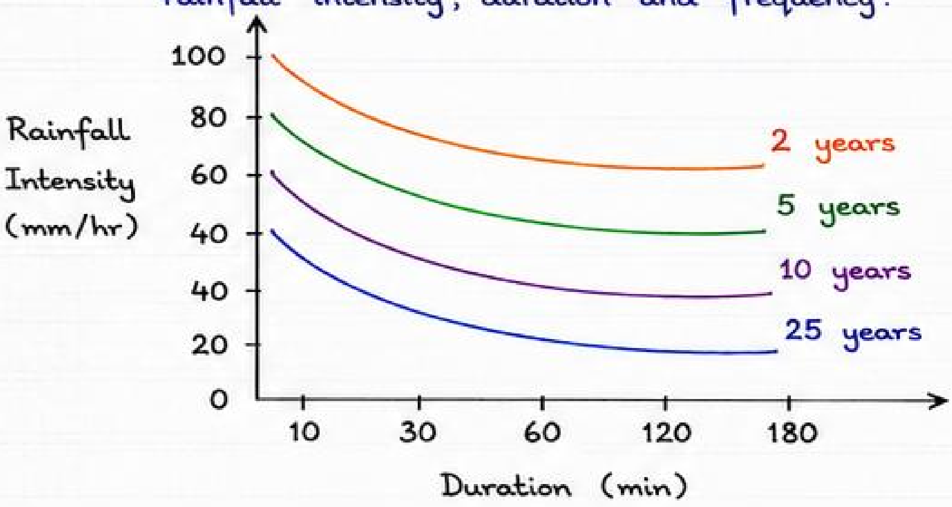
★ Frequency is the average number of times a rainfall event of a given magnitude occurs in a year.

★ It is expressed as "once in N years".

Example :
If a rainfall of 100 mm occurs once in 10 years, then its frequency = 10 years.

9. Intensity – Duration – Frequency (IDF) Curves

IDF curves show the relationship between rainfall intensity, duration and frequency.



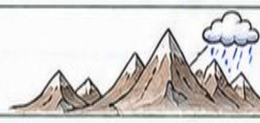
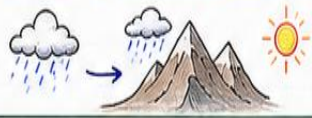
Key Point

As duration increases, intensity decreases.

As frequency increases, intensity increases.

10. Factors Affecting Precipitation

Duration (min)

Factor	Description	Effect on Precipitation	Sketch
(i) Latitude	Near equator – more evaporation and convection.	More rainfall	
(ii) Altitude	Higher altitude → air cools and causes rainfall.	More rainfall on mountains	
(iii) Distance from Sea	Near sea → more moisture far inland → less moisture.	More rainfall near coast	
(iv) Wind Direction	Winds carrying moisture cause rainfall.	Windward side → more rain Leeward side → less rain	

★ **Remember** : Precipitation is the lifeline of all water resources. Its quantity and distribution control the availability of water.

Chapter – 4 Rainfall Measurement

1. Introduction

★ Measurement of rainfall is essential for hydrologic analysis and design.

★ Rainfall is measured in terms of depth (mm) of water collected on a horizontal surface.

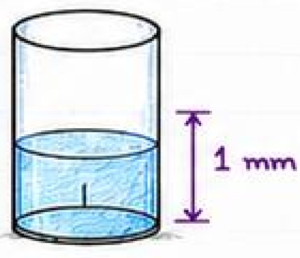
★ Accurate measurement depends on the type of instrument and its proper maintenance.

Fig. 4.1 : Rainfall Measurement

2. Units of Rainfall

Rainfall is usually expressed as depth of water.

- 1 mm of rainfall = 1 litre of water collected over 1 m^2 area.
- Other units : cm, metre
  (1 cm = 10 mm)
  (1 m = 1000 mm)



3. Methods of Measuring Rainfall

Rainfall can be measured by two methods.

(i) Non-recording (Symon's Rain Gauge)

(ii) Recording (Tipping Bucket, Weighing Bucket, Float Type, etc.)

4. Requirements of a Good Rain Gauge

★ Should collect all rainfall without any loss.

★ Should be simple in construction and operation.

★ Should be accurate and reliable.

★ Should be easily accessible for observation.

★ Should have adequate capacity.

Key Point

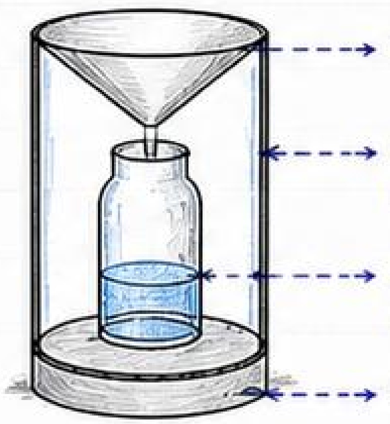
A good rain gauge ensures accurate data for hydrologic studies.

5. Recording of Rainfall

Rainfall data can be recorded in the following ways.

Method	Instruments	Data Obtained	Remarks
(i) Direct Reading	Non-recording rain gauge	Total rainfall over a period	Simple, but does not show distribution of rainfall.
(ii) Continuous Recording	Recording rain gauges	Intensity, duration and distribution	Used for detailed hydrologic analysis.

6. Schematic of Rainfall Measurement



Functions

- Funnel collects rainfall.
- Outer cylinder prevents losses.
- Collecting bottle measures depth.

7. Data Collection

- ★ Observations are taken at regular intervals (usually 24 hours).
- ★ Data should be recorded at the same time every day.
- ★ Instruments must be installed at an open and level location.
- ★ Regular maintenance ensures accurate data.

Chapter – 5 Types of Raim Gauges

1. Introduction

- ★ Rain gauges are instruments used to collect and measure the amount of rainfall.
- ★ Different types of rain gauges are used depending on the accuracy required and the duration of recording.

Remember :

Accurate measurement of rainfall is the foundation of all hydrologic analysis and design.

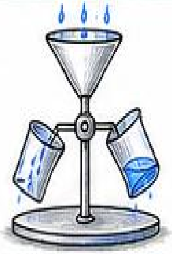
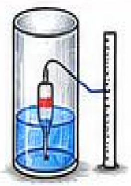
2. Commonly Used Types of Rain Gauges

- (i) Symon's Rain Gauge
- (ii) Tipping Bucket Rain Gauge
- (iii) Weighing Bucket Rain Gauge
- (iv) Float Type Rain Gauge
- (v) Automatic Rain Gauge

Key Point

Selection of raingauge depends on purpose, accuracy required, and duration of record.

3. Description of Different Rain Gauges

Type	Diagram	Construction	Working	Advantages	Disadvantages
(i) Symon's Rain Gauge		• Consists of a cylindrical metal container. • Mounted on a base at a standard height (30 cm above ground).	• Rainfall collected in the container. • Measured using a measuring cylinder.	• Simple in construction. • Inexpensive. • Easy to install and maintain.	• Not suitable for continuous recording. • Human error in reading.
(ii) Tipping Bucket Rain Gauge		• Consists of a funnel connected to two small buckets balanced on a pivot.	• When one bucket is filled, it tips and empties, the other bucket takes position. • Each tip = fixed amount of rainfall.	• Automatic recording. • Suitable for intensity-duration studies. • Accurate.	• Affected by debris. • Needs regular calibration.
(iii) Weighing Bucket Rain Gauge		• Rain collected in a bucket placed on a weighing mechanism.	• Increase in weight due to rainfall is recorded continuously.	• Very accurate. • Suitable for all intensities of rainfall.	• Costly. • Requires careful maintenance.
(iv) Float Type Rain Gauge		• Consists of a float inside a stilling well. • Float connected to a counter or recorder.	• Rise in water level raises the float. • Rainfall depth is recorded.	• Continuous recording. • Simple mechanism.	• Affected by wave action and wind. • Needs stilling well.
(v) Automatic Rain Gauge		• Equipped with electronic sensor and data logger. • May use tipping bucket or weighing principle.	• Rainfall data is automatically recorded and stored.	• Real-time data. • No manual reading. • Suitable for remote areas.	• Expensive. • Requires power supply and maintenance.

Comparison at a Glance

Type	Recording Method	Accuracy
Symon's	Manual	Low
Tipping Bucket	Automatic	Medium
Weighing Bucket	Automatic	High
Float Type	Automatic	Medium
Automatic	Automatic	High

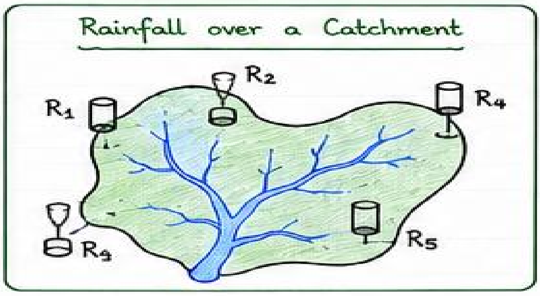
Exam Tip

For hydrologic analysis and design, accurate and continuous rainfall data is very important.

CHAPTER – 6 COMPUTATION OF AVERAGE RAINFALL

1. INTRODUCTION

- ★ Rainfall varies from place to place.
- ★ For hydrologic analysis, we need representative rainfall over a catchment area.
- ★ This is obtained by computing average rainfall from observations at different raingauge stations.



2. METHODS OF COMPUTING AVERAGE RAINFALL

The commonly used methods are :

(i) Arithmetic Mean Method

(ii) Thiessen Polygon Method

(iii) Isohyetal Method

Key Point

The method used depends on the availability of data and size of the catchment area.

3. ARITHMETIC MEAN METHOD

★ When the raingauges are uniformly distributed over the catchment area.

Formula :

$$\overline{P} = \frac{P_1 + P_2 + P_3 + \dots + P_n}{n}$$

Example :

Station	Rainfall, P (mm)
1	56
2	42
3	48
4	54

Average Rainfall,

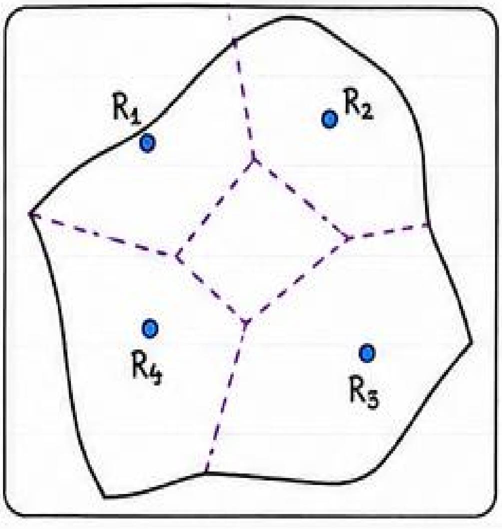
$$\overline{P} = \frac{56 + 42 + 48 + 54}{4} = 50 \text{ mm}$$

4. THIESSEN POLYGON METHOD

When raingauges are irregularly distributed.

Steps :

1. Join all raingauges with straight lines.
2. Draw perpendicular bisectors to form polygons.
3. Calculate area of each polygon.
4. Average rainfall is the weighted mean of rainfall at each station.



Formula :

$$\overline{P} = \frac{P_1 A_1 + P_2 A_2 + P_3 A_3 + \dots + P_n A_n}{A}$$

where, A = Total area of catchment

5. Isohyetal Method

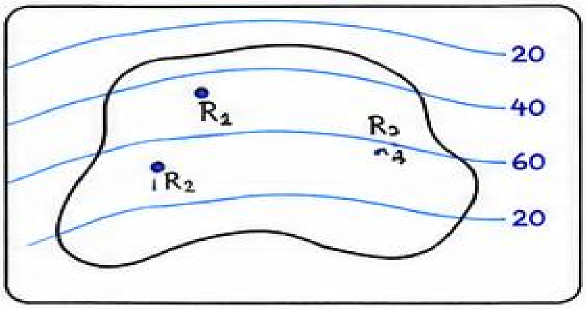
★ Based on the principle that rainfall is a function of distance.

Steps :

① Draw isohyets (lines of equal rainfall).

② Measure the area between successive isohyets.

③ Compute average rainfall using formula.



Formula : $\overline{P} = \dfrac{\sum P_i A_i}{A}$

P_i = Mean rainfall between two successive isohyets
A_i = Area between two successive isohyets
A = Total area of catchment

6. Comparison of Methods

Method	Suitable For	Advantages	Limitations
Arithmetic Mean	Small & flat catchments	Simple & quick to apply	Not accurate for large irregular catchments
Thiessen Polygon	Medium to large catchments	Considers influence area of each gauge	Does not consider variation of rainfall between gauges
Isohyetal	Large & mountainous catchments	Considers actual variation of rainfall	Requires more data & time consuming

Chapter - 7 Runoff and its Measurement

1. Introduction

★ Runoff is the portion of rainfall that flows over the land surface as surface flow.

★ It is an important component of the hydrologic cycle.

★ Runoff is used for the design of dams, canals, drainage and flood control structures.

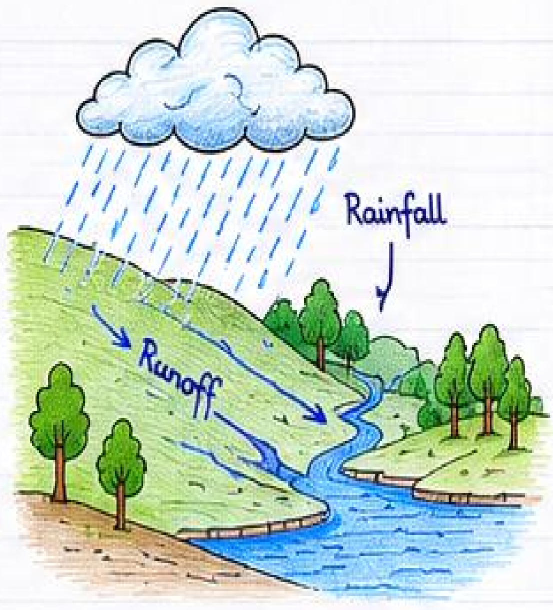


Fig. 7.1 : Runoff

2. Forms of Runoff

- ★ Surface Runoff – Flows over the ground surface.
- ★ Subsurface Runoff – Flows just below the ground surface (through soil).
- ★ Ground Water Runoff – Flows through deeper geological formations and joins rivers.

3. Factors Affecting Runoff

- ★ Intensity and duration of rainfall.
- ★ Infiltration capacity of the soil.
- ★ Slope of the catchment area.
- ★ Land use and land cover (forests, urban areas, etc.).
- ★ Geological formations.
- ★ Size and shape of the catchment.

4. Measurement of Runoff

Runoff is measured by :

(i) Stream Gauges (Direct Measurement)

(ii) Indirect Methods (From rainfall data)

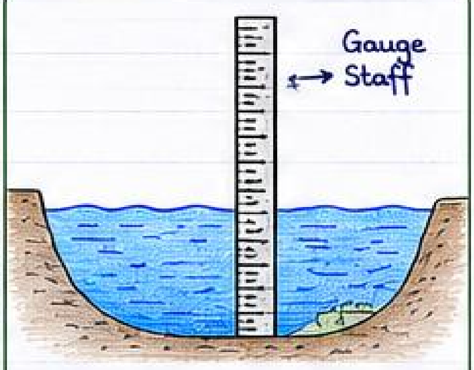


Fig. 7.2 : Stream Gauge

(i) Stream Gauges :

- ★ Installed in rivers and streams.
- ★ Measures the stage (water level) which is converted to discharge using a rating curve.

(ii) Indirect Methods :

- ★ Use empirical formulae based on rainfall.
- ★ Common methods : Rational Method, Runoff Coefficient Method.

5. Runoff Coefficient

- ★ Runoff coefficient (C) is the ratio of runoff to rainfall.
- ★ C depends on the nature of the catchment.

$$C = \frac{\text{Runoff}}{\text{Rainfall}}$$

6. Typical Values of Runoff Coefficient

Type of Area	Runoff Coefficient (C)
Concrete / Roofed area	0.8 – 0.95
Urban residential area	0.4 – 0.7
Agricultural area	0.2 – 0.5
Open grassy land	0.1 – 0.3
Forest area	0.05 – 0.2

Chapter – 8 Infiltration

1. Introduction

- ★ Infiltration is the process by which water on the ground surface enters into the soil.
- ★ It is an important component of the hydrologic cycle.
- ★ Infiltration replenishes soil moisture and ground water.

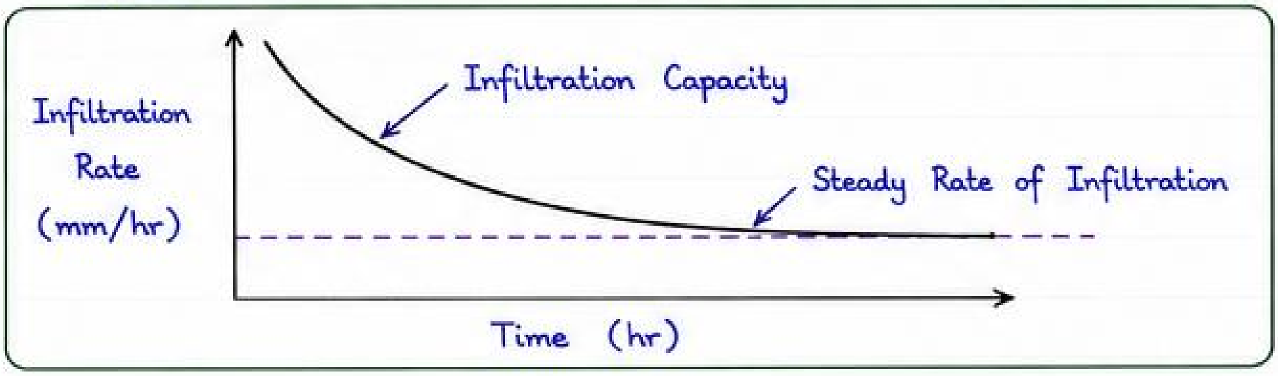
Fig. 8.1 : Infiltration

2. Factors Affecting Infiltration

Factor	Effect on Infiltration
(i) Soil type	Coarse soils have high infiltration; clay soils have low.
(ii) Antecedent moisture	Dry soil → high infiltration; wet soil → low infiltration.
(iii) Vegetation cover	More vegetation → more infiltration.
(iv) Surface slope	Steep slope → less infiltration.
(v) Rainfall characteristics	Low intensity & long duration → more infiltration.
(vi) Soil compaction	Compacted soil → low infiltration.

3. Infiltration Capacity

- ★ Infiltration capacity is the maximum rate at which water can enter the soil.
- ★ It is high when the soil is dry and decreases with time.
- ★ Finally it becomes constant and equal to the steady rate of infiltration.

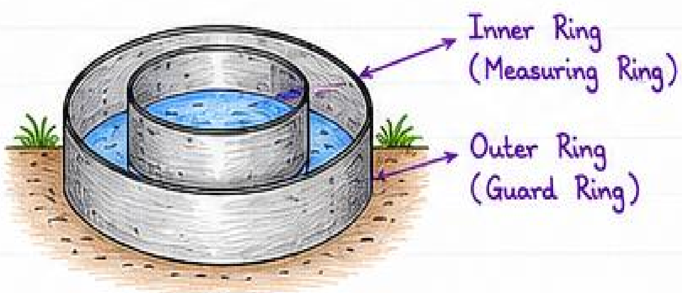


4. Infiltration Measurement

Infiltration can be measured by the following methods.

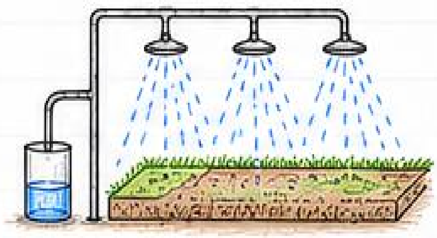
(i) Double Ring Infiltrometer

- ★ Consists of two concentric rings driven into the soil. Water is filled in both rings. The outer ring minimizes lateral flow.



(ii) Rainfall Simulator

- ★ Artificial rainfall is produced over a small plot and the infiltration rate is measured.



5. Infiltration Rate Equation

The general form of infiltration rate is given by :

$$f = f_c + (f_o - f_c)\, e^{-kt}$$

where,

f = Infiltration rate at time t (mm/hr)
f_o = Initial infiltration rate (at $t = 0$)
f_c = Final or constant infiltration rate (mm/hr)
k = Infiltration constant (hr^{-1})
t = Time (hr)

Where,

$f_o > f_c$
k = constant
e = base of natural log (2.718)

6. Infiltration and Runoff Relationship

For a given rainfall intensity (i) :

- If $i <$ infiltration rate (f) → No runoff occurs.
- If $i >$ infiltration rate (f) → Runoff occurs.

Excess rainfall = $i - f$

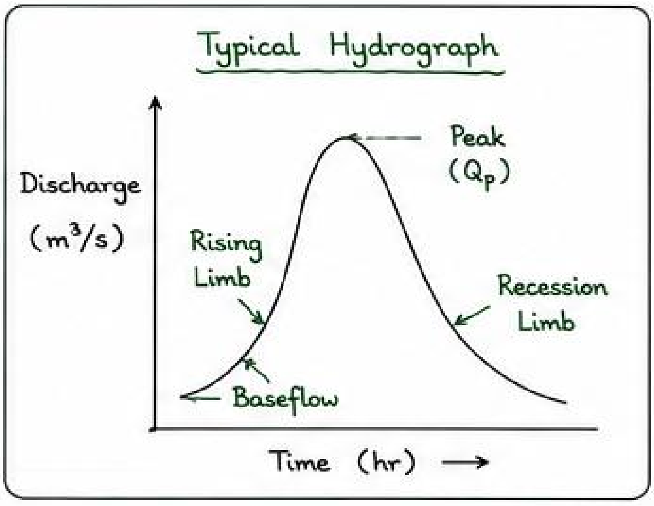
Runoff increases as infiltration decreases.

Chapter – 9 Hydrograph

1. Introduction

★ A hydrograph is a graph showing the variation of discharge with time at a particular point in a stream.

★ It is an important tool for design of hydraulic structures and flood studies.



2. Components of a Hydrograph

(i) Baseflow (Groundwater flow)

(ii) Rising limb

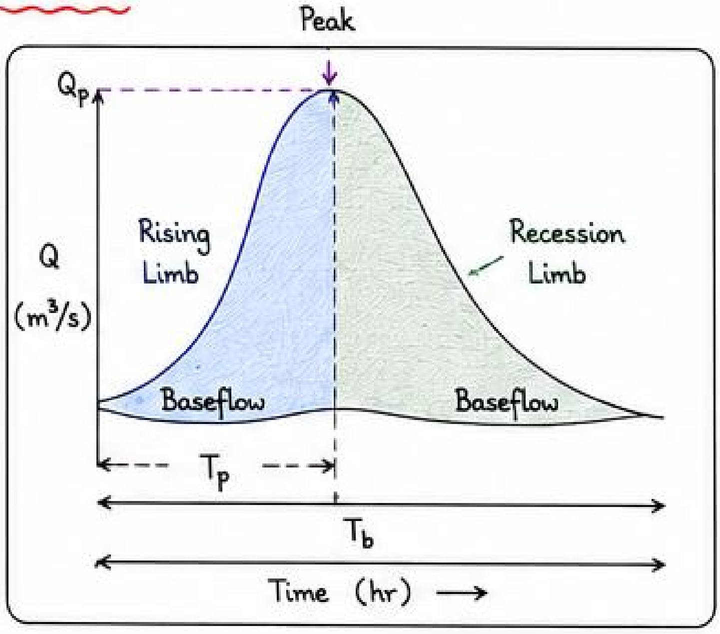
(iii) Peak discharge (Q_p)

(iv) Time to peak (T_p)

(v) Recession limb

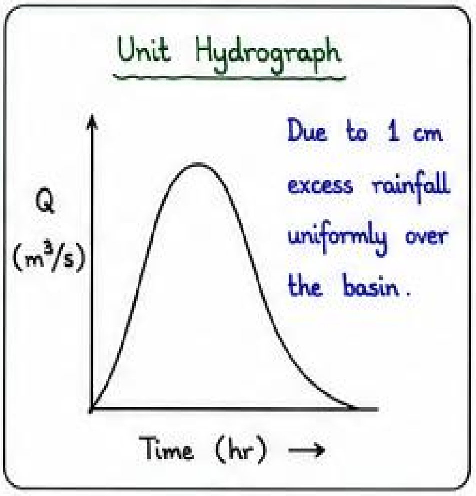
(vi) Direct runoff

(vii) Time base (T_b)



3. Types of Hydrographs

Type	Description
(i) Storm Hydrograph	Hydrograph due to a single storm of effective rainfall.
(ii) Composite Hydrograph	Hydrograph due to two or more storms in succession.
(iii) Unit Hydrograph	Direct runoff hydrograph resulting from 1 cm of effective rainfall uniformly distributed over the catchment area.



4. Unit Hydrograph

- ★ It is the most useful hydrograph in flood estimation.
- ★ It assumes linearity between rainfall and runoff.
- ★ It is used to convert rainfall into runoff.

Properties of Unit Hydrograph

- Area is proportional to rainfall depth.
- Time base remains same for rainfall of same duration.
- Peak discharge is proportional to rainfall depth.
- Shape of U.H. remains constant.

5. Derivation of Unit Hydrograph (Concept)

If a basin receives D cm of effective rainfall in duration d hours and produces direct runoff hydrograph, then:

$$\text{U.H. for 1 cm rainfall} = \frac{\text{Direct runoff hydrograph ordinates corresponding to D cm rainfall}}{D}$$

– Divide each ordinate of the storm hydrograph by D to get unit hydrograph for 1 cm rainfall.

6. APPLICATIONS OF HYDROGRAPH

- ★ Design of spillways, dams and reservoirs.
- ★ Flood forecasting and flood control.
- ★ Design of bridges and culverts.
- ★ Water resources planning.
- ★ Urban drainage design.

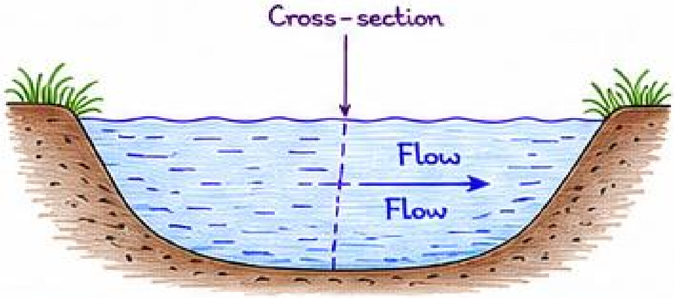
Key Points

Hydrograph converts rainfall into runoff and is essential for safe and economical design of hydraulic structures.

CHAPTER – 10 MEASUREMENT OF DISCHARGE OF A STREAM

1. INTRODUCTION

- ★ Discharge is the volume of water flowing past a cross-section of a stream per unit time.
- ★ It is an important parameter in design of hydraulic structures, water resources planning and flood estimation.



Discharge, Q = Volume of water flowing per second (m^3/s)

2. METHODS OF MEASUREMENT OF DISCHARGE

Method	Description
(i) Velocity-Area Method	Most accurate method. Discharge is obtained by measuring the area of cross-section and the velocity of flow.
(ii) Float Method	Suitable for small streams and canals. Based on surface velocity.
(iii) Dilution Method	Based on dilution principle using salt or dye.
(iv) Weirs and Flumes Method	Discharge is computed from head over a weir or through a flume.

3. Velocity–Area Method

Steps :

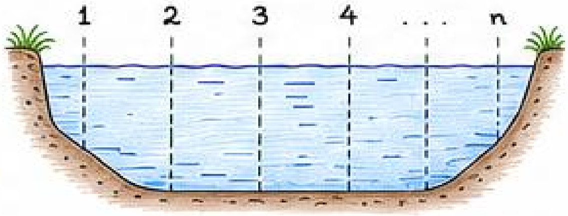
① Select a straight reach with uniform flow.

② Divide the cross-section into a number of verticals.

③ Measure depth at each vertical.

④ Measure velocity at suitable points in each vertical.

⑤ Compute discharge.



Divide section into n verticals

Discharge Calculation :

(i) Area of subsection	(ii) Discharge
$A_i = d_i \times b_i$ where, d_i = Depth at i^{th} vertical b_i = Width of subsection	$Q = \sum_{i=1}^{n} A_i \times V_i$ where, V_i = Mean velocity in i^{th} vertical

---

4. Float Method

Steps :

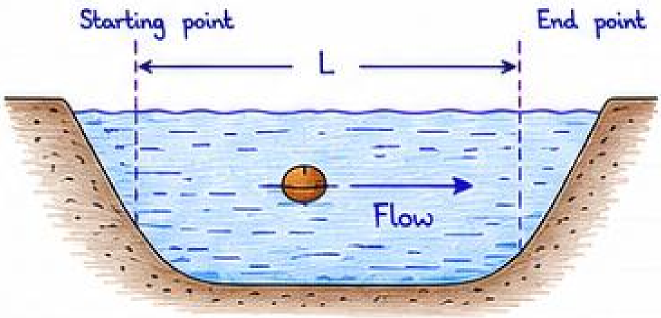
① Select a straight reach.

② Mark a known distance (L) along the flow.

③ Release the float and note the time (t) taken to travel the distance.

④ Measure the cross-sectional area (A).

⑤ Compute discharge.

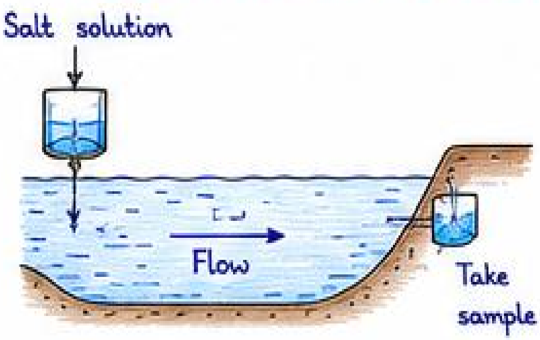


Formulas :

Surface velocity,	Mean velocity,	Discharge,
$V_s = \dfrac{L}{t}$	$V = k\,V_s$ $(k = 0.8 \text{ to } 0.9)$	$Q = A \times V$ $= A \times k\,V_s$

Note : k = coefficient of velocity depends on float and flow conditions.

5. Dilution Method (Salt or Dye Method



Principle :

If a substance is mixed uniformly in a stream, then,

$$\boxed{Q = \frac{W}{C \times t}}$$

where,

W = Weight of substance added (kg)

C = Concentration (kg/m^3)

t = Time of mixing (s)

6. Weirs and Flumes Method

Discharge is computed from the head (H) measured over the weir or in the flume.

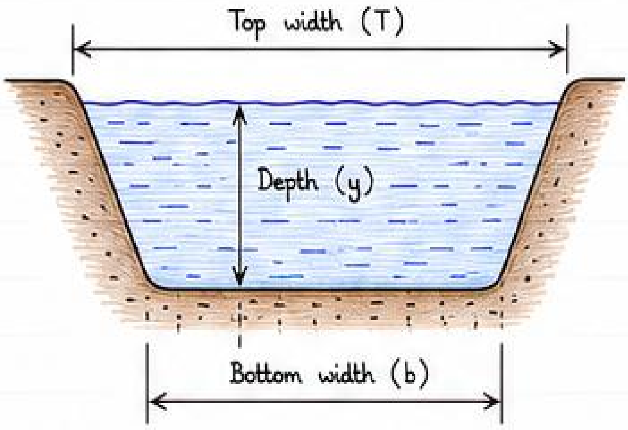
Structure	Discharge Formula
Rectangular Weir	$Q = \frac{2}{3} C_d b \sqrt{2g} \; H^{3/2}$
V-Notch Weir	$Q = \frac{8}{15} C_d \tan(\frac{\theta}{2}) \sqrt{2g} \; H^{5/2}$
Parshall Flume	$Q = CH^n$ (values of C and n depend on flume size)

Chapter - 11 Manning's Equation (Open Channel Flow)

1. Introduction

★ Manning's equation is an empirical formula used to compute the average velocity and discharge in open channels.

★ It is widely used in the design of canals, drains, and rivers.



2. Manning's Equation

Manning's equation for velocity (V) :

$$V = \frac{1}{n} R^{2/3} S^{1/2}$$

where,

- V = Mean velocity (m/s)
- n = Manning's roughness coefficient ($s/m^{1/3}$)
- R = Hydraulic radius (m)
- S = Slope of energy grade line (≈ bed slope for uniform flow)

Key Points

★ Larger n → lower velocity (higher roughness).

★ Larger R → higher velocity (larger flow area or less wetted perimeter).

★ Larger S → higher velocity (steeper slope).

3. Terms in Manning's Equation

- ★ Area of flow (A) : Cross-sectional area of water flow (m^2)
- ★ Wetted perimeter (P) : Length of boundary in contact with water (m)
- ★ Hydraulic radius (R) : Ratio of area to wetted perimeter.

$$\boxed{R = \frac{A}{P}}$$

where,

b = Bottom width (m)

y = Depth of flow (m)

m = Side slope (horizontal : vertical)

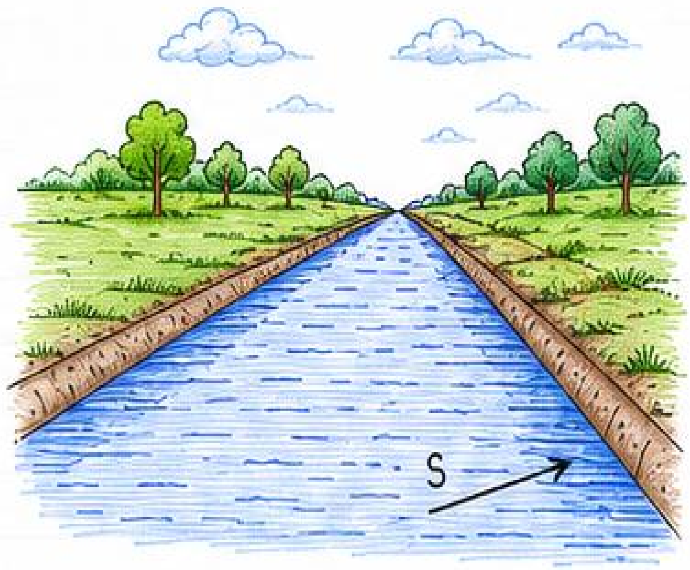
(for triangular channel, $b = 0$)

Common Channel Sections		
Section	Area (A)	Wetted Perimeter (P)
Rectangular	$b\,y$	$b + 2y$
Trapezoidal	$y\,(b + m\,y)$	$b + 2y\sqrt{1 + m^2}$
Triangular	$m\,y^2$	$2y\sqrt{1 + m^2}$

4. Discharge Formula

Discharge (Q) is given by :

$$\boxed{Q = A\;V = \frac{1}{n}\,A\,R^{2/3}\,S^{1/2}}$$



where,

Q = Discharge (m^3/s)

A = Area of flow (m^2)

R = Hydraulic radius (m)

S = Slope of energy grade line

5. Manning's Roughness Coefficient (n)

The value of n depends on the nature of the channel boundary.

Type of Channel	Value of n
Concrete (well finished)	0.012 – 0.015
Concrete (ordinary)	0.015 – 0.017
Earth (clean, straight)	0.020 – 0.025
Earth (weeds, some stones)	0.025 – 0.035
Rock cut	0.030 – 0.040

Note

n varies with condition of surface, degree of irregularity, and vegetation.

6. Assumptions in Manning's Equation

1. Flow is steady and uniform.
2. Channel is prismatic (shape and slope are constant).
3. Flow is fully rough (laminar sublayer is negligible).
4. Channel is not subject to backwater effect.
5. The effect of wind is neglected.

7. Limitations

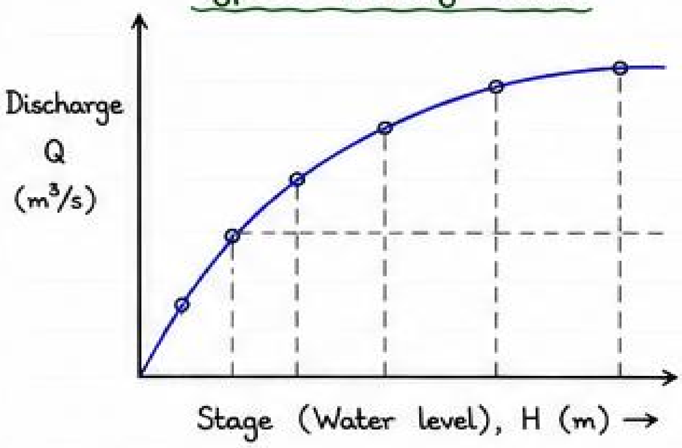
- ★ Empirical equation; not valid for all conditions.
- ★ Not accurate for very steep slopes, sudden expansions or contractions.
- ★ Not suitable for flow with heavy vegetation or highly irregular boundaries.

Chapter – 12 Rating Curve and Stage-Discharge Relation

1. Introduction

- ★ A rating curve is a graph relating the stage (water level) to the discharge in a stream at a particular section.
- ★ It is an essential tool for converting observed water levels into discharges.
- ★ It is site specific and changes with time.

Typical Rating Curve



2. Terms

Term	Description
Stage (H)	Water level with respect to a fixed datum (m).
Discharge (Q)	Volume of water flowing per unit time (m^3/s).
Datum	Arbitrary reference level to which stage is referred.
Control	A section in the channel where stage is uniquely related to discharge.

3. Importance of Rating Curve

- ★ Helps to determine discharge from observed stage.
- ★ Used in flood forecasting and warning.
- ★ Essential for design of hydraulic structures.
- ★ Useful in reservoir operation and water resources planning.
- ★ Helps in sediment and pollution studies.

4. Conditions for a Good Rating Curve

1. The control section should remain stable.
2. No significant backwater effect.
3. Flow should be steady and uniform.
4. Channel and control should not change during the period of observation.

5. Method of Developing Rating Curve

Steps :

① Select a suitable straight reach with a well defined control.

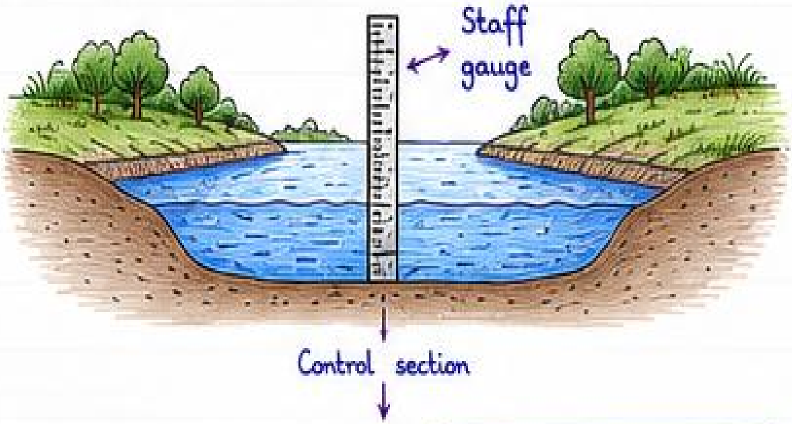
② Establish a staff gauge to measure stage (H).

③ Measure discharge (Q) for a range of stages.

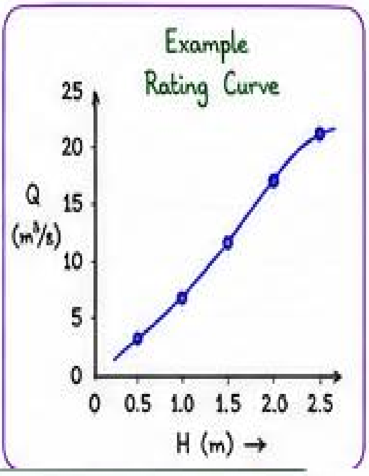
④ Plot stage (H) on x-axis and discharge (Q) on y-axis.

⑤ Draw a smooth curve (rating curve) through the plotted points.

⑥ Extend the curve carefully if necessary.



Sample Observations		
S. No.	Stage, H (m)	Discharge, Q (m^3/s)
1	0.50	2.1
2	1.00	4.8
3	1.50	8.7
4	2.00	13.6
5	2.50	19.2



6. Shifting of Rating Curve

The rating curve may shift due to :

★ Change in channel bed level (scour or deposition).

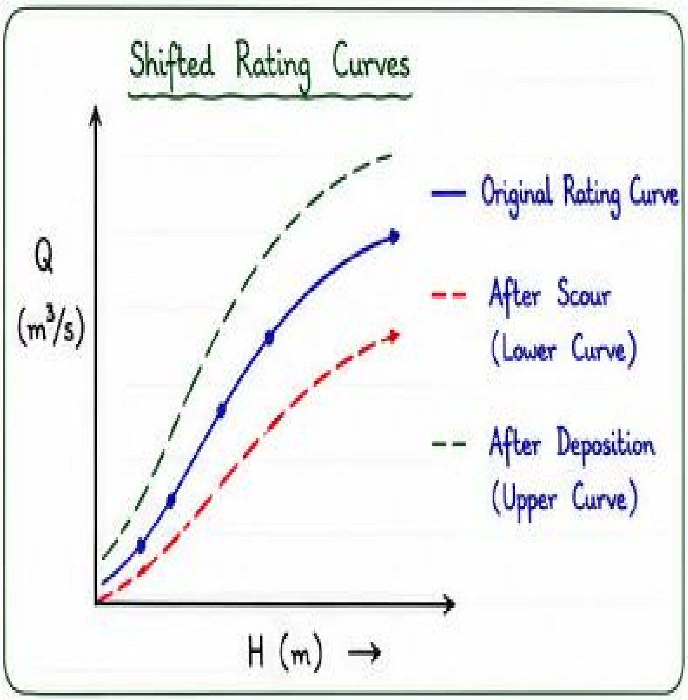
★ Change in vegetation or roughness.

★ Change in control condition.

★ Floods or other natural disturbances.

Remedy :

Apply a shift factor (additive or multiplicative) or develop a new rating curve.



Chapter – 15

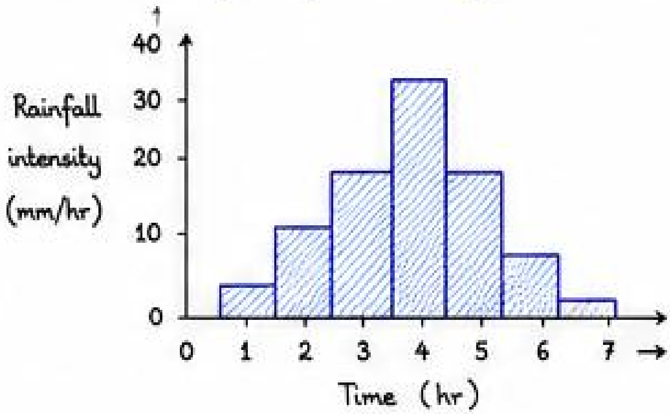
Presentation and Interpretation of Rainfall Data

1. Introduction

- ★ Rainfall data is recorded as a function of time.
- ★ For analysis and design, the data is presented in graphical forms called hyetograph, mass curve and double mass curve.
- ★ These graphs help in study of rainfall pattern, consistency and reliability of data.

2. Hyetograph

A hyetograph is a bar chart showing the variation of rainfall intensity with time.

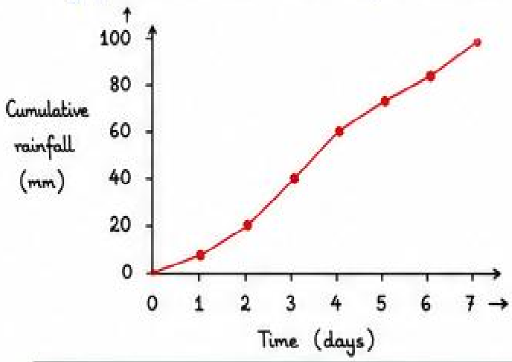


Uses :

- Helps to study the distribution of rainfall over a period of time.
- Useful in runoff, flood and drainage analysis.

3. Mass Curve

A mass curve (cumulative rainfall curve) is a graph between cumulative rainfall and time.

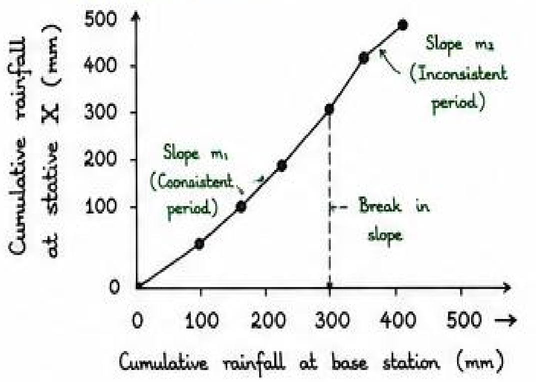


Uses :

- Gives total rainfall received over a period.
- Helps to identify wet and dry periods.

4. Double Mass Curve

A double mass curve is a graph between cumulative rainfall at a station and cumulative rainfall at a nearby base station.



Uses :

- Checks consistency of rainfall data.
- Detects change in catch conditions or instrumentation.

Note : Change in slope indicates inconsistency in data.

5. Double Mass Curve Analysis

Condition	Interpretation
Straight line (Uniform slope)	Rainfall data is consistent. No change in catch conditions.

Change in slope (Break point)	Data is inconsistent due to change in location, instrumentation, environment, or catch area conditions.
Parallel straight lines	Data is consistent but for different periods (different average rainfall).
Curved line	Gradual change in catch conditions or non-uniformity in data.

CHAPTER – 16 EVAPORATION

1. INTRODUCTION

★ Evaporation is the process by which water changes from liquid state to vapour state from water surface, soil surface, plants, etc.

★ It is an important component of the hydrologic cycle.

★ Evaporation loss reduces the quantity of water available for various uses.

Water balance in a reservoir :
Inflow − Outflow = ΔStorage + Evaporation
(+ Seepage, if any)

2. FACTORS AFFECTING EVAPORATION

1. Temperature of water and air
2. Humidity of air
3. Wind velocity
4. Intensity of solar radiation
5. Atmospheric pressure
6. Salinity of water
7. Depth and exposed area of water surface

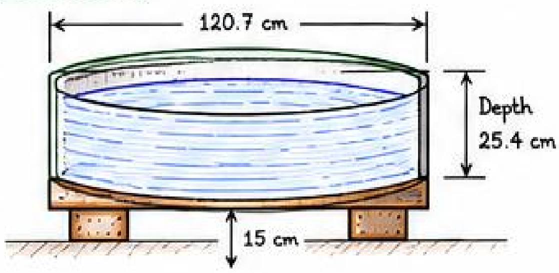
Key Point

★ Evaporation increases with increase in temperature, wind speed and exposed surface area and decreases with increase in humidity.

3. MEASUREMENT OF EVAPORATION

Evaporation is measured by evaporation pans. The standard pan used is Class-A Pan.

Class-A Pan :



★ Standard diameter = 120.7 cm (4 ft)

★ Standard depth = 25.4 cm (10 in)

★ Pan is placed on a platform about 15 cm above ground level.

★ Water level is maintained 5 cm below the rim.

4. CLASS-A PAN

Specifications of Class-A Pan	
Shape	Circular
Material	Galvanized iron (G.I.)
Diameter	120.7 cm
Depth	25.4 cm
Area	1.214 m^2
Location	Open, level and unobstructed place
Water level	5 cm below the rim

Notes :

★ Pan should be placed away from obstructions (buildings, trees, etc.)

★ Water should be renewed at regular intervals to prevent algae growth.

★ Evaporation measured is affected by local climatic conditions.

5. Pan Coefficient (K_p)

Pan evaporation is always more than lake evaporation because pan is shallow.

To convert pan evaporation (E_p) to lake evaporation (E_L), a pan coefficient (K_p) is used.

$$\boxed{E_L = K_p \times E_p}$$

where,

E_L = Lake evaporation (mm/day)

E_p = Pan evaporation (mm/day)

K_p = Pan coefficient (dimensionless)

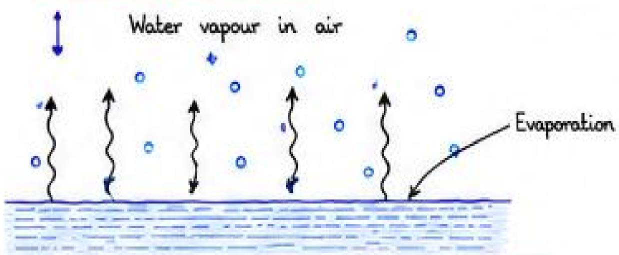
- K_p depends on location and climatic conditions.

Typical Values of Pan Coefficient (K_p)

Location / Condition	K_p
Inland areas (humid)	0.60 – 0.70
Inland areas (arid)	0.70 – 0.80
Coastal areas	0.70 – 0.85
Tropical regions	0.60 – 0.75
Temperate regions	0.70 – 0.80

climatic conditions.

6. Evaporation Process



Process :

① Water molecules at the surface gain energy.
② They overcome intermolecular forces.
③ They escape into the atmosphere as water vapour.
④ Wind carries away the vapour, reducing humidity near the surface and causing more evaporation.

7. Importance / Applications

★ Water loss from reservoirs, lakes and ponds is estimated.

★ Design of water storage structures and irrigation systems.

★ Planning of water resources.

★ Useful in computation of water balance.

★ Important in meteorology and climate studies.

Chapter – 17 Design Flood

1. Introduction

★ A design flood is the flood having a certain probability of being equalled or exceeded in any given year.

★ It is used for the design of hydraulic structures such as dams, spillways, bridges, culverts, etc.

★ Design flood is also called as probable maximum flood (PMF) or project flood.

2. Methods of Flood Estimation

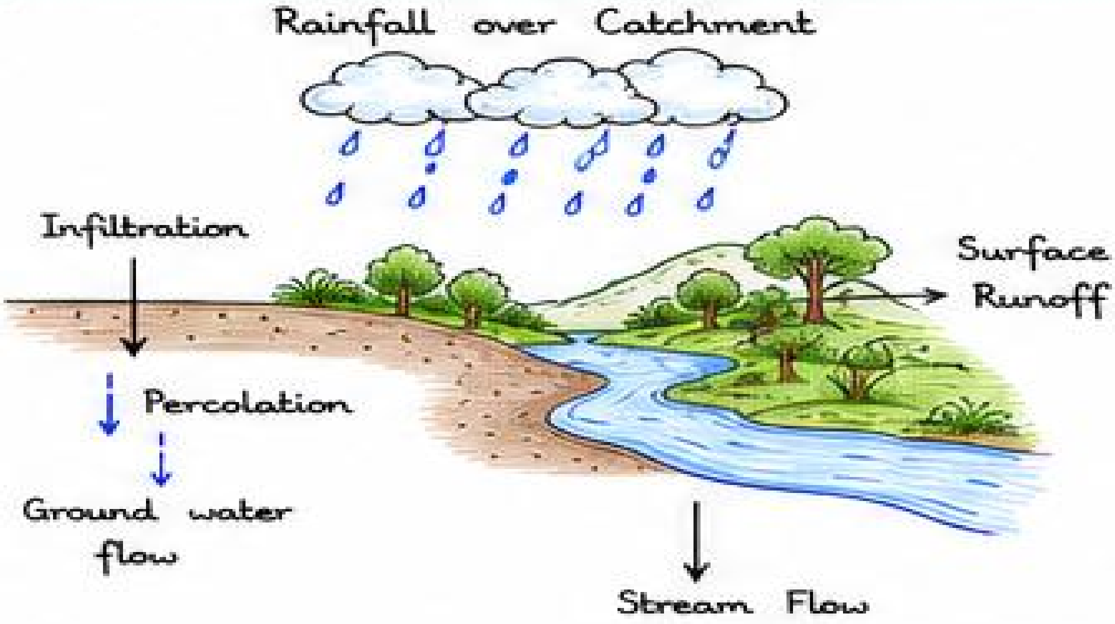
Flood can be estimated by the following methods.

1. Hydrological Methods
   Based on rainfall, catchment characteristics and their relationships.
2. Statistical (Frequency) Methods
   Based on analysis of past flood data using probability theory.
3. Empirical Methods
   Based on empirical formulae developed from observed data.
4. Regional Methods
   Flood is estimated on the basis of data from hydrologically similar regions.

3. Flood Estimation by Hydrological Method

Steps involved :

1. Collection of rainfall data.
2. Rainfall analysis (Intensity – Duration – Frequency).
3. Runoff estimation.
4. Flood hydrograph development.
5. Peak discharge obtained from hydrograph.



Discharge at outlet = Base flow + Direct runoff

4. Flood Estimation by Statistical Method

Based on frequency analysis of annual maximum flood series.

The probability of exceedence (P) is given by :

$$\boxed{P = \frac{m}{n+1}}$$

where,

- m = Rank of flood (1 for largest, 2 for second largest, ...)
- n = Total number of floods

Return period (T) = $\frac{1}{P}$ years

Example :

Data of annual maximum floods at a station

Year	Annual Max. Flood (m^3/s)	Rank (m)	$P = \frac{m}{n+1}$	Return Period, $T = \frac{1}{P}$ (years)
2018	3200	1	1/11 = 0.091	11.0
2019	2500	2	2/11 = 0.182	5.5
2020	2100	3	3/11 = 0.273	3.67
2021	1800	4	4/11 = 0.364	2.75
2022	1400	5	5/11 = 0.455	2.20
⋮	⋮	⋮	⋮ ⋮	⋮
2027	500	10	10/11 = 0.909	1.10

From the table, flood corresponding to any return period can be obtained.

5. Flood Estimation by Empirical Formulae

Different empirical formulae are used for flood estimation.

Some commonly used formulae are :

(i) Dickens Formula

$$\boxed{Q = C\,A^{3/4}}$$

where,

- Q = Peak flood (m^3/s)
- A = Catchment area (km^2)
- C = Coefficient (depends on catchment characteristics)

(ii) Ryve's Formula

$$\boxed{Q = C\,A^{2/3}}$$

where, C = Coefficient

Note :

Values of C depend on catchment features such as slope, soil, rainfall intensity, land use, etc. Empirical formulae are suitable for small and ungauged catchments.

6. Flood Estimation by Regional Method

In this method, flood is estimated using data from hydrologically similar catchments.

$$\boxed{Q = C_r A^{3/4} F_r}$$

where,

Q = Design flood (m^3/s)

A = Catchment area (km^2)

C_r = Regional coefficient

F_r = Adjustment factor for differences in rainfall, catchment characteristics, etc.

Key Point

Regional method is useful when flood data at site is not available but data from nearby similar catchments exists.

7. Applications of Design Flood

★ Design of spillways and overflow structures of dams.

★ Design of bridges, culverts and causeways.

★ Design of drainage systems in urban area.

★ Determination of freeboard for protection against flood.

★ Flood forecasting and flood control planning.

Chapter – 18 Maximum Rate of Runoff

1. Introduction

★ The maximum rate of runoff is the maximum rate at which runoff occurs in a drainage basin for a given rainfall.

★ It is important for the design of hydraulic structures like storm water drains, culverts, bridges, spillways, etc.

★ Rational method is most commonly used to estimate the maximum rate of runoff.

2. Rational Formula

The rational formula is given by :

$$\boxed{Q = C\ I\ A}$$

where,

Q = Maximum rate of runoff (m^3/s)

C = Runoff coefficient (dimensionless)

I = Rainfall intensity (mm/hr)

A = Area of catchment (ha)

3. Runoff Coefficient (C)

The value of C depends on land use, soil type, slope, vegetation and antecedent moisture condition.

Land Use / Surface Type	Runoff Coefficient (C)
Business areas (CBD)	0.70 - 0.95
Residential areas (detached houses)	0.30 - 0.50
Residential areas (apartments)	0.50 - 0.70
Industrial areas	0.60 - 0.90
Paved streets and roads	0.70 - 0.95
Gravel roads	0.20 - 0.40
Parks, playgrounds	0.10 - 0.25
Cultivated land	0.20 - 0.40
Forest areas	0.05 - 0.20

Note : Higher the imperviousness, higher is the runoff coefficient.

4. Time of Concentration (t_c)

Time of concentration is the time taken by water from the hydraulically most distant point of the catchment to reach the outlet.

It can be estimated by :

(i) Kirpich formula (for small catchments)

$$\boxed{t_c = 0.0195\ L^{0.77}\ S^{-0.385}}$$

(ii) Bransby - Williams formula

$$\boxed{t_c = \frac{0.87\ L^3}{(1000\ S)^{0.385}}}$$

where,

t_c = Time of concentration (min)

L = Length of overland flow (m)

S = Slope of the catchment (m/m)

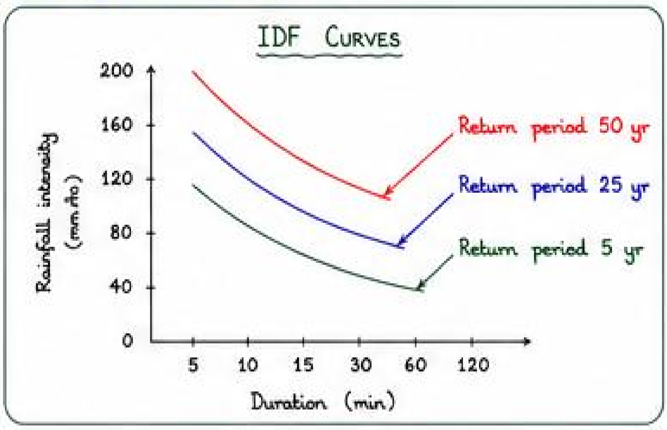
Key Point

- ★ Rainfall intensity should be taken for duration equal to t_c.
- ★ Accurate estimation of t_c is very important.

5. Rainfall Intensity (I)

Rainfall intensity is the rate of rainfall for a specified duration.

It is obtained from Intensity - Duration - Frequency (IDF) curves.



6. Numerical Example

A catchment of area 250 ha has a runoff coefficient of 0.60. The rainfall intensity for a duration equal to time of concentration is 75 mm/hr. Calculate the maximum rate of runoff.

Solution :

Given : $A = 250$ ha

$C = 0.60$

$I = 75$ mm/hr

Using rational formula, $Q = C\ I\ A$

$Q = 0.60 \times 75 \times 250$

$Q = 11250\ m^3/hr$

Convert to m^3/s,

$$Q = \frac{11250}{3600} = 3.125\ m^3/s$$

$$\boxed{\text{Max. rate of runoff, } Q = 3.125\ m^3/s}$$

7. Applications

- ★ Design of storm water drains in urban areas.
- ★ Design of culverts and small bridges.
- ★ Estimation of peak flow for flood forecasting.
- ★ Planning of drainage systems.

Assumptions of Rational Method

1. Rainfall is uniform over the entire catchment.
2. The catchment area is small (generally < 200 ha).
3. Runoff coefficient is constant for the duration.
4. Time of concentration is uniform for the catchment.
5. Storage and infiltration are relatively uniform.

CHAPTER – 19

SEPARATION OF BASE FLOW

1. INTRODUCTION

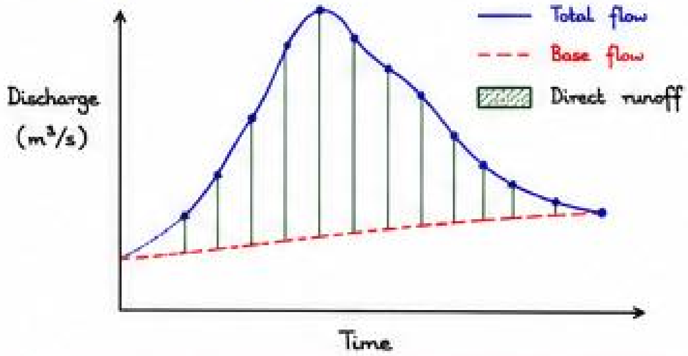
- In a stream, total flow at any time consists of two parts.
  - (i) Base flow (ground water contribution)
  - (ii) Direct or surface runoff (storm flow)
- Base flow separation is the method of estimating the base flow from the total stream flow hydrograph.

Importance :

- Useful in hydrologic studies.
- Helps in determining low flow characteristics of streams.
- Important in design of water resources projects.

2. STRAIGHT LINE METHOD

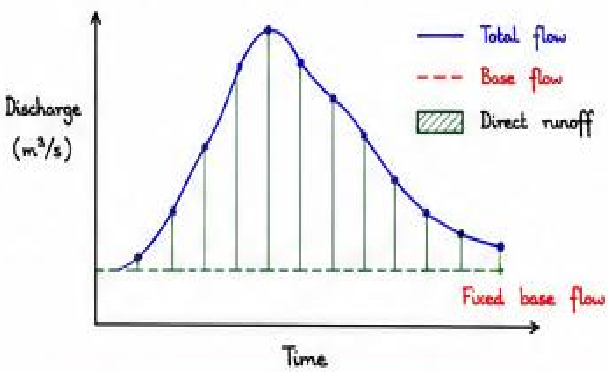
1. Identify the starting point of rise of the hydrograph.
2. Draw a straight line from this point to a point on the recession limb.
3. This line represents the base flow.
4. Vertical ordinates from this line give base flow at various times.



Merit : Simple and quick.
Demerit : Depends on the judgment of the analyst.

3. FIXED BASE METHOD

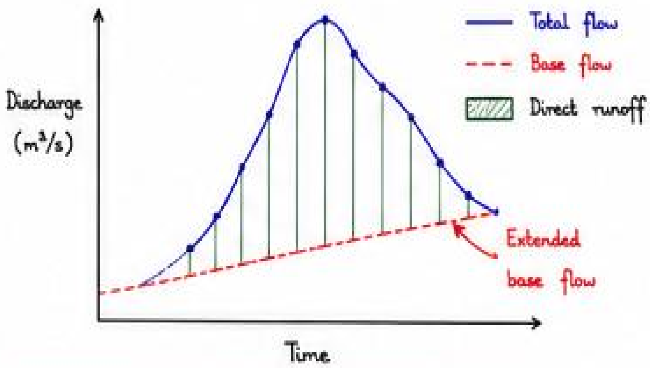
1. Select a point on the recession limb where flow is assumed to be entirely base flow.
2. A horizontal line parallel to time axis is drawn through this point.
3. This horizontal line represents the base flow.
4. Difference between total flow and base flow gives direct runoff.



Merit : Very simple and easy to apply.
Demerit : Not accurate for long duration storms.

4. VARIABLE SLOPE METHOD

1. The recession limb of the hydrograph is assumed to be the continuation of the base flow.
2. Extend the straight line portion of the recession limb backwards.
3. This extended line represents the base flow.
4. Difference between total flow and base flow gives direct runoff.



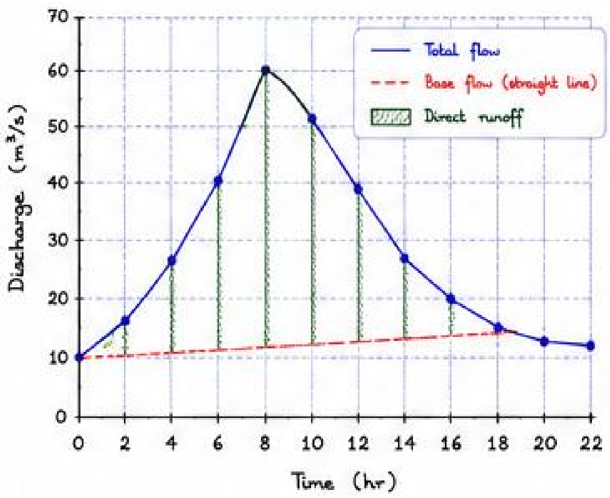
Merit : More realistic and accurate.
Demerit : Requires well defined recession limb.

5. Hydrograph Separation – Example

Given : Stream flow hydrograph data

Time (hr)	Discharge (m^3/s)
0	10
2	15
4	25
6	40
8	60
10	50
12	35
14	25
16	18
18	14
20	11
22	10

Separation by Straight Line Method



Separated Values

Time (hr)	Total Flow (m^3/s)	Base Flow (m^3/s)	Direct Runoff (m^3/s)
0	10	10.0	0.0
2	15	10.6	4.4
4	25	11.2	13.8
6	40	11.9	28.1
8	60	12.5	47.5
10	50	13.1	36.9
12	35	13.8	21.2
14	25	14.5	10.5
16	18	15.1	2.9
18	14	15.8	0.0
20	11	16.5	0.0
22	10	17.2	0.0

Note : Area under direct runoff = Runoff volume.
Area under base flow = Base flow volume.

6. Comparison of Methods

Method	Merits	Demerits	Best Use
Straight Line	Simple, quick, easy to apply	Subjective, depends on judgment	Small catchments, short duration storms
Fixed Base	Very simple, easy to understand	Not realistic for long duration storms	Small streams, approximate studies
Variable Slope	More accurate and realistic	Requires well defined recession limb	Large catchments, long duration storms

Key Points

- ★ Base flow is ground water contribution.
- ★ Direct runoff is surface runoff due to storm.
- ★ Choice of method depends on catchment characteristics and data availability.

CHAPTER – 20

HYDROGRAPH

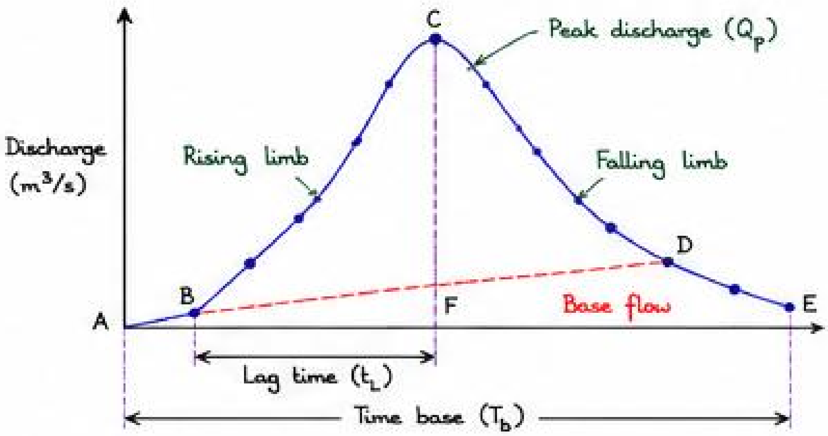
1. INTRODUCTION

- ★ A hydrograph is a graph showing the variation of discharge of a stream with respect to time.
- ★ It is the most important tool in hydrologic analysis and design of hydraulic structures.
- ★ It is also called as "discharge hydrograph" or "runoff hydrograph".

Importance :

- Helps in flood forecasting.
- Useful for design of reservoirs, spillways, culverts, bridges.
- Helps in estimation of peak discharge.
- Important in irrigation and water resources planning.

2. TYPICAL HYDROGRAPH AND ITS PARTS



Definitions of components :

AB : Initial or base flow segment
BC : Rising limb
C : Peak or crest
CD : Falling limb
DE : Recession limb
BF : Lag time (time between center of mass of rainfall excess and peak discharge)
AE : Time base (total time of hydrograph)

3. TYPES OF HYDROGRAPHS

(i) Storm Hydrograph
It represents the direct runoff resulting from a single storm event.

(ii) Flood Hydrograph
It includes both direct runoff and base flow. It is obtained for a long duration of rainfall.

(iii) Average Hydrograph
It is the mean of a number of hydrographs of similar characteristics.

(iv) Unit Hydrograph
It is the hydrograph resulting from 1 cm of effective rainfall over the catchment in a specified duration.

Note :
Unit hydrograph is a useful tool in flood estimation and water resources planning.

4. DERIVATION OF HYDROGRAPH

Steps :

1. Collect rainfall data and hyetograph.
2. Obtain stream stage (water level) data.
3. Convert stage to discharge using rating curve.
4. Separate base flow from total flow to get direct runoff.
5. Plot discharge (direct runoff) vs time to obtain the hydrograph.

Example Data

Time (hr)	Stage (m)	Discharge (m^3/s) (Total)	Base Flow (m^3/s)	Direct Runoff (m^3/s)
0	1.00	10	8	2
2	1.20	25	9	16
4	1.50	45	10	35
6	1.80	70	12	58
8	2.00	85	14	71
10	1.70	65	13	52
12	1.40	40	11	29
14	1.20	25	9	16
16	1.10	15	8	7
18	1.05	10	8	2

Plot Direct Runoff vs Time to obtain Hydrograph.

5. Separation of Direct Runoff From Total Flow

Methods :

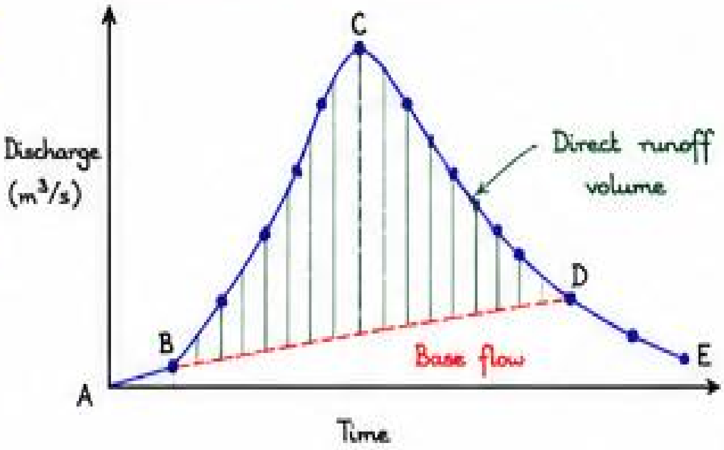
(i) Straight Line Method
A straight line is drawn from the point of rise to a point on recession limb where the curve becomes parallel to time axis.

(ii) Fixed Base Method
Base flow is assumed as a constant value before and after the storm.

(iii) Variable Slope Method
Base flow is assumed to vary during the storm period.

(iv) Concave Method
A smooth concave curve is drawn between the points of rise and return to base flow.

Separation by Straight Line Method



Direct runoff = Area between hydrograph and base flow
Base flow = Area under base flow line (ABDE)

6. Characteristics Affecting Hydrograph

Factor	Effect on Hydrograph
1. Intensity of rainfall	Higher intensity → higher peak discharge and steeper rising limb.
2. Duration of rainfall	Longer duration → larger time base and lower peak.
3. Area of catchment	Larger area → longer time base and higher peak.
4. Shape of catchment	Circular → higher peak and shorter lag time. Elongated → lower peak.
5. Slope of catchment	Steeper slope → higher peak and shorter lag time.
6. Soil type and land use	Impervious surface → higher peak. Vegetation → lower peak.
7. Antecedent condition	Wet condition → higher peak. Dry condition → lower peak.

7. Applications of Hydrograph

- Design of dams, spillways and diversion works.
- Design of bridges, culverts and drains.
- Flood forecasting and warning.
- Irrigation and water supply planning.
- Hydrologic studies and research.

Key Point

Hydrograph is the most important tool in hydrologic analysis and forms the basis for safe and economical design of hydraulic structures.