Hydrology

Class	: III B.Tech. – II Semester	Year: 2020–21
Branch	: Civil Engineering	Credits: 03

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1. **Brief History and Scope of the Subject**

In R-17 Curriculum the subject of hydrology is offered at III B. Tech II semester level. The basic principles studied in this subject will be the foundation for students to initiate the subject hydrology. The content involves irrigation engineering, surface runoff analysis, climate change, ground water hydrology. Hydrology is the profession that is responsible for planning, development and management of water resources. From estimating the amount of water available to designing the physical and non-physical infrastructure needed to meet the water needs of society and environment. To ensure access to clean safe drinking water, civil engineers design, build and manage the water intakes, water treatment plants and network of pipes that convey of water. Civil engineers use state-of-the-art technologies to treat domestic and industrial wastewaters before discharging treated water back into the environment. Civil engineers also devise physical (dams, dikes) and non-physical (flood forecasting) solutions to minimize the threat to lives and property due to flooding.

2. **Pre-Requisites**
   * **Fluid Mechanics**
3. **Course Objectives**:

   * To impart the knowledge of essential components of the hydrologic cycle.
   * To provide an overview and understanding of Unit Hydrograph theory and its analysis.
   * To familiarize with different methods of flood frequency analysis and flood routing.
   * To impart knowledge on groundwater movement and well hydraulics.
   * To familiarize with the relationships between soil, water and plant and their significance in planning an irrigation system.

4. **Course Out comes**:

Upon successful completion of the course, the students will be able to

- Measure and analyze the rainfall in any given area and develop intensity duration-frequency curves.
- Quantify the abstractions from precipitation and factors affecting.
- Determine the runoff in catchment and prepare the unit hydrograph which in-turn determines the runoff for any given rainfall.
- Estimate flood magnitude and carry out flood routing.
- Determine hydraulic properties of an aquifer and specific capacity, efficiency and yield of the well.
- Choose appropriate method of irrigation for different crops and cropping patterns and determine the quality and quantity of water required for a crop.

5. PROGRAM OUTCOMES

Engineering Graduates will be able to:

1. Engineering knowledge: Apply the knowledge of mathematics, science, engineering fundamentals and an engineering specialization to the solution of complex engineering problems.

2. Problem analysis: Identify, formulate, review research literature and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences and engineering sciences.

3. Design/development of solutions: Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for public health and safety and the cultural, societal and environmental considerations.

4. Conduct investigations of complex problems: Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data and synthesis of the information to provide valid conclusions.

5. Modern tool usage: Create, select and apply appropriate techniques, resources and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.

6. The engineer and society: Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.

7. Environment and sustainability: Understand the impact of professional engineering solutions in societal and environmental contexts and demonstrate the knowledge of and need for sustainable development.

8. Ethics: Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.

9. Individual and team work: Function effectively as an individual and as a member or leader in diverse teams and in multidisciplinary settings.

10. Communication: Communicate effectively on complex engineering activities with the engineering community and the society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations and give and receive clear instructions.

11. Project management and finance: Demonstrate knowledge and understanding of the engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.

12. Life-long learning: Recognize the need for and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.

6. PROGRAMME SPECIFIC OUTCOMES (PSOs)

Students will be able to

1. Survey, plot and prepare layout for buildings, dams, canals and highway alignments and conduct geotechnical and geological investigations of the project.
2. Test, analyze and design of the various substructure and superstructure by considering the environmental and societal issues.

3. Organize various construction projects considering modern construction techniques, equipment and management issues.

7. Mapping of Course Outcomes with Program Outcomes:

	1	2	3	4	5	6	7	8	9	10	11	12
CO1	3	2	1	3	1	2	2	1	3	2	1	3
CO2	1	2	2	2	1	3	2	2	1	1	1	3
CO3	2	1	2	2	2	1	2	3	3	1	2	3
CO4	3	2	2	2	1	1	1	3	3	2	1	3
CO5	2	1	1	1	3	3	1	2	2	3	2	1
CO6	2	3	3	3	1	1	1	1	3	3	3	3

7. Prescribed Text Books

1. Engineering Hydrology P. Jayaram Reddy, third edition, Laxmi publications

2. Irrigation and water power engineering by B.C. Punmia, Pande B.B Lal, Ashok Kumar Jain & Arun Kumar Jain sixteenth edition, Laxmi publications.

8. Reference Text Books

1. Engineering Hydrology by K. Subramanya, third edition, Tata McGraw-Hill.

2. Hydrology principles, analysis and design by HM Raghunath, revised second edition, New Age International Publishers.

3. Irrigation Water Resources and Water Power Engineering by P.N. Modi, seventh edition, Standard Book House.

9. URLs and Other E-Learning Resources

http://nptel.ac.in/courses/Webcourse-contents/IIT%20Kharagpur/Water%20Resource%20Engg/New_index1.html

LESSON PLAN

Topic	No. of Periods	
	Theory	**Tutorial**
UNIT-I HYDROLOGIC CYCLE		
Engineering hydrology and its applications, Hydrologic cycle	**2**	
Precipitation: Types and forms of precipitation	**1**	
Rainfall measurement, types of rain gauges	**2**	
Rain gauge network, average rainfall over a basin, consistency of rainfall data	**1**	
Frequency of rainfall, intensity-duration-frequency curves, probable maximum precipitation	**2**	
UNIT-II ABSTRACTIONS		
Evaporation, factors affecting evaporation	**1**	

Measurement of evaporation, evaporation reduction	**2**	
Evapotranspiration, factors affecting evapotranspiration	**1**	
Measurement of evapotranspiration	**1**	
Infiltration, factors affecting infiltration	**1**	
Measurement of infiltration, Infiltration indices	**1**	
UNIT-III RUNOFF		
Components of runoff	**1**	
Factors affecting runoff	**1**	
Computation of runoff-rational and SCS methods, separation of base flow	**1**	
Unit Hydrograph, assumptions, derivation of Unit Hydrograph	**2**	
Unit hydrographs of different durations	**1**	
Principle of superposition and S-hydrograph methods	**1**	
Limitations and applications of UH	**1**	
UNIT-IV FLOODS		
Floods-causes and effects	**1**	
Flood frequency analysis-Gumbel's method	**2**	
Flood control methods, flood routing-hydrologic routing	**1**	
Hydraulic routing, channel and reservoir routing- Muskingum method of routing	**2**	
UNIT-V GROUND WATER		
Ground water occurrence	**1**	
Ground water hydrologic cycle, origin of ground water, rock properties effecting ground water	**1**	
Vertical distribution of ground water, zone of aeration and zone of saturation	**1**	
Geologic formation as Aquifers	**1**	
Types of aquifers, porosity, Specific yield and Specific retention	**2**	
Steady radial flow- confined & unconfined aquifer	**1**	
Recuperation test	**1**	
UNIT-VI IRRIGATION		
Necessity and importance of irrigation	**1**	

Advantages and ill effects of irrigation, types of irrigation	1	
Methods of application in Irrigation water, Water logging and drainage	1	
Standards of quality for Irrigation water	1	
Principal crops and crop seasons, crop rotation	2	
Soil-water-plant relationship, duty and delta relation, factors affecting duty and delta	1	
Frequency of Irrigation	1	
Total No. of Periods:	**45**	

UNIT-I
HYDROLOGIC CYCLE
Assignment-Cum-Tutorial Questions

I. Objective Questions

1. Illustrate how the precipitation can be measured? BL=2

2. Explain the demerits of Non-recording type rain gauge?

3. Enlist the three types of recording type rain gauge?

4. What is the use of Double mass curve?

5. Mention the various types of precipitation?

6. Differentiate between rainfall and runoff.

7. Define evapotranspiration?

8. What do you mean by orographic precipitation?

9. What are the demerits of Non-recording type rain gauge?

10. What factors you consider in selecting a site for rain gauge station?

11. Precipitation caused by lifting of an air mass due to the pressure difference, is called

   a) Cyclonic precipitation   b) convective precipitation

   c) Orographic precipitation   d) none of these.

12. The standard height of standard rain gauge, is

   a) 10cm   b) 20cm   c) 30cm   d) 50cm

13. A recording type rain gauge

   a) Produces a mass curve of rain fall   b) Records the cumulative rain

   c) Is sometimes called integrating rain gauge or continuous rain gauge

   d) All the above

14. In India the recording type rain gauge generally used is

    a) Weighing type   b) Tipping type c) Float recording type   d) None of these

15. For determination of average annual precipitation in catchment basin, the best method is

    a) Arithmetical method   b) Thiessen's mean method

    c) Iso-hyetal method   d) None of these.

16. Hydrology helps in

    a) Predicting maximum flows   b) Deciding the minimum reservoir capacity

    c) Forecasting the availability of quantity of water at reservoir site

    d) Predicting the effects on river water level on completion of dams

    e) All the above

II) Descriptive Questions

1. Distinguish between recording and non recording gauges in India, giving examples of such gauges in India?

2. Explain three methods of determining the mean real depth of precipitation over a basin covered by several rain gauge stations?

3. With the help of neat sketch explain various process of hydrological cycle and how it is useful in water resources engineering?

4. Write a note on different types and forms of precipitation.

5. Hydrology is a highly inter-disciplinary science, Justify. List out various practical applications of hydrology.

6. With the help of neat sketch explain various process of hydrological cycle and how it is useful in water resources engineering?

7. Describe how you determine statistically the optimum number of rain gauges required to be installed in a given catchment.

8. Explain the method for testing the consistency of rainfall records at a station and necessary adjustment.

9. The average annual rainfall of 5 rain gauges in a basin is 89, 54, 45, 41 and 55cm. If the error in the estimation of basin mean rainfall should not exceed 10%, how many additional gauges should be installed in the basin?

10. Briefly explain the automatic type rain gauges with neat sketches.

11. Explain the procedure for developing IDF curves. What are its uses?

12. In a certain river basin there are six rain gauge stations. The normal annual rainfall depths at the stations being 42.4, 53.6, 67.8, 78.5, 82.7 and 95.5 cm respectively. Determine the optimum number of rain gauge stations to be established in the basin, if it is desired to limit the error in the mean value of rainfall over the catchment of 10% and indicate how you distribute them.

13. What are the conditions required for establishing rain gauge station and what are the parameters monitored?

14. Discuss briefly the three important methods which are used for determining the mean rainfall over a drainage basin.

15. The annual rainfalls at 7 rain gauge stations in a basin are 58, 94, 60, 45, 20, 88 and 68cm respectively. How many additional gauges are required, if it is desired to limit the error of only 10%.

16. Explain about the following relationships relating to precipitation over a basin
   a) Depth-area relationship
   b) Maximum depth-area- duration curves

UNIT-II

ABSTACTIONS

Assignment-Cum-Tutorial Questions

I. **Objective Questions**

 1. Explain the following: (i) Evaporation (ii) Transpiration
 2. Explain the following (i) Infiltration (ii) consumptive use
 3. What are the factors affecting evaporation losses.
 4. Explain the difference between evaporation, interception and transpiration ratio.
 5. Distinguish between the potential evapotranspiration and actual evapotranspiration.
 6. Write down the most common empirical formula used to calculate evaporation.
 7. Potential evapotranspiration (PET)

   a) The evaporation when there is sufficient moisture available to fully vegetated area

   b) The evapotranspiration of forest area

   c) Actual evapotranspiration of crop before application of irrigation water.

   d) Amount of water needed to bring the moisture content of soil "t" its field capacity

8. The ISI standard pan evaporimeter

   a) Is the same as the US class A evaporation pan

   b) Has CP which is 14% more than the US pan

   c) For a given area the maximum average depth of rainfall increase with the duration

   d) Used for measurement of transpiration also

9. Interception losses

   a) Include evaporation, transpiration and through fall

   b) Consists of only evaporation loss

   c) Include evaporation and stem flow

   d) Consists of transpiration and through fall

10. A 6 hours storm with hourly intensities of 7, 18, 25, 12, 10 and 3 mm\h produced a run-off of 33mm. Then the Φ –index is

   a) 7 mm/h   b) 3 mm/h   c) 10 mm/h   d) 8 mm/h

11. The average pan coefficient for the standard US weather bureau class a pan is

   a) 0.90   b) 0.80   c) 0.70   d) 0.50

12. Transpiration is

   a) Confined to night time only   b) confined to day –light hours only

   c) Land surface only   d) A combination of evaporation and transpiration process

13. Lysimeter is an instrument to measure

   a) Infiltration   b) Evaporation

   c) Evapotranspiration   d) Transpiration

14. Penman's equation is based on

   a) Energy budgeting only   b) Energy budgeting and water budgeting

   c) Energy budgeting and mass transfer   d) Water budgeting and mass transfer

15. The ratio of actual evapotranspiration to potential evapotranspiration is in the range

   a) 0.0 to 0.4   b) 0.60 to 0.9

   c) 0.0 to 1.0   d) 1.0 to 2.0

16. Identify the chemical suitable for use as water evaporation inhibiter

   a) Cetyl alcohol   c) Butyl alcohol

   b) Methyl alcohol   d) ethyl alcohol

II. Descriptive Questions

1. Briefly describe any method by which you can measure the evaporation loss from a free water surface.

2. What is evaporation? Mention the factors controlling the evaporation process.

3. Explicate Φ-index method and W-index method for calculating the net storm rainfall.

4. Differentiate between Φ-index and w-index? How is Φ index determined from the rainfall hyetograph?

5. What do you understand by the term infiltration? How can you measure it in the field?

6. Discuss the use of pan measurements for the determination of evaporation from water surface.

7. The following are rates of rainfall (intensity of rainfall) for successive 20 min period of 140 min storm 2.5, 2.5, 10.0, 7.5, 1.25, 1.25, 5.0 cm/hr. taking the value of Φ- index at 3.2 cm/hr. Find the net runoff in cm, the total rainfall and the value of W- index

8. A watershed of 50 km^2 produces a runoff of 2Mm^3 from the rainfall pattern of the storm given below, Calculate Φ-index.

Time (hr)	0	2	4	6	8	10	12	14
Rain fall (mm)	0	1.1	2.2	6	5	3	1	0

9. Compute the infiltration index Φ for the following data: total rainfall during storm= 76.25×10^6 m^3, estimated groundwater contribution in total runoff = 1.25×10^6 m^3, area of the basin = 250m^2

Hours	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16
mm/hour	25	50	50	35	20	20	15	12.5

10. A storm with 10cm precipitation produced a direct runoff of 5.8 cm. The time distribution of the Storm as given below, estimate the Φ-index of the storm.

Time from start (hr)	1	2	3	4	5	6	7	8
Increments/ Rainfall in each hour (cm)	0.4	0.9	1.5	2.3	1.8	1.6	1	0.5

11. Describe the factors that affect evaporation from water bodies and explain the remedial measures to control evaporation.

12. The total observed runoff volume during 6h storm with uniform intensity of 1.5cm/h is 21.6x10^{6}m^3, if the area of basin is 300km^2, find the average infiltration rate of basin.

13. Explain the different types of infiltration indices?

14. Explain measurement of evaporation by evaporation pan with neat sketch.

15. Explain estimation of evapotranspiration by Blaney-Criddle method.

16. The total observed runoff volume during a 6h storm with a uniform intensity of 1.5cm/h is $21.6 \times 10^6 m^3$, if the area of basin is $300 km^2$, find the average infiltration rate of basin.

UNIT-III

RUNOFF

Assignment-Cum-Tutorial Questions

I. **Objective Questions:**

1. What are the uses of unit hydrograph?

2. What do you mean by unit hydrograph?

3. What is meant by runoff?

4. What is S-curve hydrograph?

5. What are the factors that affecting runoff

6. State the limitations of unit hydrograph theory.

7. What is the relation between run off and catchment?

8. Define time of concentration and basin lag.

9. What do you understand by unit hydrograph?

10. Explain Khosla's formula for computing run off over a catchment.

11. What are the methods available for determining peak flood discharges?

12. The shape of hydrograph is effected by

   a) Non-uniform areal distribution of rainfall   b) Varying rainfall intensity

   c) Shape of the basin   d) All the above factors

13. When an accumulated mass of snow melts, the resulting flow entering in stream is classified as

   a) Direct runoff   b) Base flow

   c) Subsurface flow   d) Interflow

14. The flow duration curve is plot of

   a) Accumulated flow against time   b) Discharge against time in chronological

   c) The base flow against percentage

   d) The stream flow against the percentage of times in flow is equaled or exceeded

15. When base flow is separated from storm-hydrograph the resulting plot is known as

   a) Excess- runs off hydrograph   b) Excess- rainfall hydrograph

   c) Direct – runoff hydrograph   d) Direct –rainfall hydrograph

16. A rainfall of 1.2 cm occurred in a 6h storm. If the Φ index was 0.25 cm/h, the rainfall excess of this storm was

   a) -0.3 cm   b) 0.0   c) 1.5 cm   d) 1.2 cm

II   Descriptive questions

1. What is meant by runoff and how is it produced? Discuss briefly the various factors on which it depends.

2. Describe the method of computing the ordinates of unit-hydrograph from the data of flood hydrograph.

3. Draw a unit hydrograph and explain the salient features. What is synthetic unit hydrograph?

4. What is S-curve hydrograph? How it constructed and what is it used for?

5. Explain the procedure for derivation of synthetic unit hydrograph for an engaged Catchment?

6. Sketch a typical hydrograph resulting from an isolated storm and explain different features of it.

7. Describe how unit hydrograph can be used to predict the runoff from storm. What are the uses of unit hydrograph?

8. What do you mean by unit hydrograph? Describe the step by step procedure of the derivation of a unit hydrograph from an isolated storm.

9. The ordinates of 2hr unit hydrograph are given below. Determine the ordinates of 6 hr. unit hydrograph using S – Curve technique.

Time (2hr)	0	2	4	6	8	10	12	14	16	18	20	22
2-h UH ordinates	0	20	90	150	200	175	100	70	30	20	6	0

10. Compute and plot the ordinates of storm hydrograph resulting from a 4 hr storm with rainfall of 40 mm. The ordinates of 4 hr unit hydrograph are given below

Time in hr	0	3	6	9	12	15	18	21	24	27
3-hr UH ordinates(cumecs)	0	1.5	4.5	8.6	12.0	9.4	4.6	2.3	0.8	0

11. Determine the unit hydrograph of an effective duration of 3 hours. The flood hydrograph due to an isolate storm of 3 hours duration has 6 hours ordinates as under in cumecs: 2, 4, 33, 116,

86, 64, 46, 32, 18, 15, 9, 7, 5 and 3. Assume a base flow of 2 cumec. The catchment area of basin is 200 km^2.

12. The ordinates of 6-hour UG are given below. Derive the ordinates of 12-hour UG without resorting to the S-curve technique.

Time (hr)	0	6	12	18	24	30	36	42	48	54	60
6hr UH Ordinates	0	5	13	30	35	32	20	14	8	4	0

13. A drainage basin has the following characteristics. Basin area = 2500 sq. km. Length of the main stream L = 110 km. Distance from the centroid of basin to outlet = 70 km. Construct the 4 hour synthetic unit hydrograph for the basin if C$_t$ = 1.50 and C$_p$ = 0.6.

14. Explain the schematic diagram of runoff process resulting from precipitation over a basin.

15. Explain how runoff was estimated by rational method.

16. The peak ordinate of flood hydrograph produced by 4 hr storm of 6.5 cm is observed to be 600 m^3/s. If the base flow and ϕ-index of basin are 15m^3/s and 0.4cm/hr respectively, what is the peak ordinate of 4 hr UH.

UNIT-IV
FLOODS
Assignment-Cum-Tutorial Questions

I Objective Questions

1. What is Maximum probable flood and Standard project flood?
2. What is flood routing?
3. Write the rational formula for computing the runoff.
4. What are the methods available for determining peak flood discharges?
5. What is a recurrence interval?
6. Give any two flood control methods?
7. Distinguish between channel routing and reservoir routing.
8. Explain briefly the following terms: (i) design flood (ii) probability of exceedance.
9. Differentiate between the hydraulic routing and hydrologic routing?
10. Define hydraulic routing.

11. In the muskingum method of channel routing the weighing factor x can have a value

a) Between -0.5 to 0.5   b) Between 0.0 to 0.5

c) Between 0.0 to 1.0   d) Between -1.0 to 1.0

12. The muskingum method of flood routing is a

a) Form of reservoir routing method   b) Hydraulic routing method

c) Complete numerical solution of st.venant equations   d) Hydrologic channel-routing method

13. In routing flood through a reach the point of intersection of inflow and outflow hydrograph coincides with the peak of outflow hydrograph

a) In all cases of flood routing

b) When the flow is into reservoir with an uncontrolled outlet

c) In channel routing only

d) In all cases of reservoir routing

14. The prism storage in river reach during the passage of flood wave is

a) A constant   b) A function of inflow and outflow

c) Function of inflow only   d) A function of outflow only

15. The hydrologic flood routing method use

(a) Equation of continuity only   (b) Both momentum and continuity equation

(c) Energy equation only   (d) Equation of motion only

16. The hydraulic method of flood routing use

(a) Equation of continuity only (b) Both equation of motion and equation of continuity

(c) Energy equation only   (d) Equation of motion only

II Descriptive questions

1) Describe the method of estimating a T_r– year flood using Gumbel's distribution.

2) Define 'flood routing'. What are the usual assumptions made in routing flood in a reservoir?

3) Describe the Muskingum method of routing an inflow hydrograph through a channel reach.

4) What are the basic equations used for flood routing by

   (i) Hydrologic method and

   (ii) Hydraulic method

5) What are the various methods of estimating the design flood of catchment? Distinguish between channel routing and reservoir routing.

6) Describe the various methods adopted for control of floods?

7) An analysis of annual flood series of a stream indicated the mean value and standard deviation of flood series as 940m^3/sec 203m^3/sec respectively. What is the magnitude of flood of return period of 500 years in the stream? Assume that the annual flood series follow gumbel's distribution and sample size is very large.

8) The mean annual flood of river is 600m^3/sec and standard deviation of annual flood series is 150 m^3/sec. What is the probability of flood in magnitude 1000m^3/sec occurring over the river within next 5 years? By use gumbel's method and assume the sample size to be very large.

9) For a river valley project, the following results were obtained from flood frequency analysis using gumbel's method. Estimate the flood magnitude with a return period of 240 years.

Return period T (years)	Peak flood (m^3/sec)
40	27000
80	31000

10) From the analysis of available data over annual flood peaks of stream for a period of 40 years, the 50 year and 100 year floods have been estimated to be 878m^3/sec and 970 m^3/sec. Using gumbel's method estimate the 200-year flood for stream.

11) A coffer dam is designed for 30 year flood and constructed if it takes 6 years to complete the construction of main dam, what is the risk that the coffer dam may fail before the end of construction period? What return period in the design of coffer dam would have reduced the risk to 10%.

12) A flood of certain magnitude has a return period of 40 years, determine: (a) the probability of exceedance (b) probability of the flood of magnitude equal to or greater than the given magnitude occurring (i) at least once in 10 successive years (ii) two times in 10 successive years (iii) once in 10 successive year.

13) From the analysis of available data an annual flood peaks of small stream for a period of 35 year, the 50 year and 100 year flood have been estimated to be 650m^3/s and 750 m^3/s using Gumbel's method. Estimate the 200 year flood for the stream. For n = 35, (y$_n$)

mean and standard deviation (σ_n) of reduced extremes are 0.54034 and 1.12847 respectively.

14) Explain the components of single peak hydrograph.

15) Describe the Muskingum method of routing an inflow hydrograph through a channel reach.

16) Explain Log pearson type-III distribution of flood analysis.

UNIT-V
GROUNDWATER

Assignment-Cum-Tutorial Questions
I. Objective Questions

1. Explain the following terms: (i) Radius of influence (ii) Water table

2. Explain the following terms: (i) Partially penetrating well (ii)Transmissibility

3. Distinguish between: Specific capacity of a well and specific yield of an aquifer

4. Distinguish between aquifer and aquiclude

5. Distinguish between Water table and artesian aquifers

6. Define 'transmissibility' and 'storage coefficient' of an aquifer

7. What is an aquifer?

8. What are the different types of aquifer?

9. Define specific yield.

10. Define transmissibility of an aquifer.

11. What are the properties of rock affecting the ground water?

12. Define zone of aeration.

13. What is Perched ground water?

14. What is the pressure of upper surface of unconfined aquifer

   a) Very high pressure   b) Equal to atmospheric

   c) Greater than atmospheric   d) Less than atmospheric

15. Which aquifer is called water table aquifer

   a) confined   b) unconfined   c) ground   d) connate

II Descriptive questions

1. What do you understand by recuperation test? Derive the equations used in the test.

2. Derive the equilibrium flow equations for confined aquifer

3. Derive the equilibrium flow equations for unconfined aquifer

4. Explain the following terms: (i) Radius of influence (ii) Water table (iii) Partially penetrating well (iv) Transmissibility

5. Calculate the discharge in m³/day from a tube well under the following conditions of an unconfined aquifer: Diameter of the well = 50 cm; Drawdown at the well = 10 m; length of strains = 25 m; radius of influence in the well = 250 m; coefficient of permeability = 0.01 cm/s.

6. A 25cm well penetrates 50 m below the water table. After a long period of pumping at a rate of 1000lpm, the drawdown in the wells 20 m and 40 m from the pumped well is found to be 4 m and 2.5 m respectively. Determine the transmissibility of aquifer. What is the draw down in the pumped well?

7. Calculate the discharge in m³/day from a tube well under the following conditions of an unconfined aquifer: Diameter of the well = 50 cm; Drawdown at the well = 10 m; length of strainer = 25 m; radius of influence of the well = 250 m; coefficient of permeability = 0.01 cm/s.

8. A 30 cm well fully penetrates an unconfined aquifer of saturated depth 25m. When a discharge of 2100lpm was being pumped for a long time, observation wells at radial distances of 30 m and 90 m indicated drawdown of 5 and 4 m respectively. Estimate the coefficient of permeability and transmissibility of the aquifer. What is the drawdown at the pumping well?

9. A tube well penetrates fully an unconfined aquifer. Calculate the discharge from well in lpm from the following data:

   Diameter of the well 30 cm

   Drawdown in the well 3 m

   Effective length of strainer under the above drawdown 10 m

   Coefficient of permeability of aquifer 40 m/day

   Radius of zero drawdown 300 m

10. A 20cm well penetrates 25m below the static water table. After 24 hours of pumping out at the rate of 800 lpm, the water level in a test well at 80 m from the pumping well is lowered by 0.53m and in a test well 20m away 2.11m. Find the coefficient of transmissibility of aquifer.

11. A well penetrates into an unconfined aquifer having a saturated depth of 50m. The discharge is 250 1pm at 8 m drawdown. What would be the discharge at 10 m drawdown. The radius of influence in both cases may be taken as same.

13. Derive an expression for discharge from well fully penetrating a confined aquifer.

14. A well penetrates fully on 10m thick confined aquifer water bearing stratum of medium sand having coefficient of permeability of 0.005m/s. The well radius is 10cm and worked under a drawdown of 4m at the well face. Calculate the discharge from well. What will be the % increase in discharge if the radius of well is doubled. Take radius of influence R=300 m in each case.

15. Briefly explain the following terms:

| i) Radius of influence | ii) Water table | iii) Porosity |
| iv) Specific retention | v) Confined aquifer | vi) unconfined aquifer |

16. Explain the different standards of quality of water for irrigation?

UNIT-VI
IRRIGATION
Assignment-Cum-Tutorial Questions

I. Objective questions

1. Define irrigation

2. Name the methods of distribution of water

3. Define base duty and delta

4. Define duty

5. Define water logged area?

6. How do you access requirement of irrigation water?

7. What do you understand by crop rotation?

8. Distinguish the crop period and base period?

9. What do you mean by principal crops?

10. State the importance of irrigation

11. What are the factors effecting irrigation?

12. Define field capacity.

II Descriptive questions

1. Explain briefly on standards of irrigation water.

2. What is the necessity and importance of irrigation?

3. Explain the terms 'duty' and 'delta' of canal water. Derive a relationship between the two.

4. How do you access requirement of irrigation water?

5. An ayacut of 10,000 hectares has to be irrigated from a distributary, 70% in Kharif and 30% in Rabi. The average duty at head of distributaries is 1000 hectares/cumec in Kharif and 2,500 hectares/cumec in Rabi. Determine total discharge required at the head of distributary.

6. A field of channel has culturable commanded area of 2000 hectares. The intensity of irrigation for gram is 30% and for wheat is 50%. Gram has a kor period of 18 days and kor depth of 12 cm, while wheat has kor period of 15 days and kor depth of 15 cm. Calculate the discharge of field channel.

7. Explain the various types of irrigation methods bringing out advantages and disadvantages.

8. Explain the sprinkler irrigation and drip irrigation methods bringing out suitable cropping pattern.

9. Explain   i) Water logging   ii) Salinity and alkalinity hazards

10. The following data pertains to the healthy growth of crop

a. Field capacity of soil = 30%

b. Permanent wilting point = 11%

c. Density of soil = 1300kg/m^2

d. Effective root zone depth = 700mm

e. Daily consumptive use of water for the given crop = 12mm

11. For healthy growth moisture content must not fall 25% of the water holding capacity between the field capacity and permanent wilting point. Determine the watering interval in days.

12. A water course has culturable commanded area of 1200 hectares. The intensity of irrigation for a crop A is 40% and for B is 35%, both the crop being Rabi crops. Crop A has a kor period of 20 days and crop B has kor period of 15 days. Calculate the discharge of water course if the kor depth for crop A is 10 cm and for B it is 16 cm.

13. Explain the terms 'duty' and 'delta' of canal water. Derive a relationship between the two.

14. A field channel has culturable commanded area of 2000 hectares. The intensity of irrigation for gram is 30 % and for wheat is 50%. Gram has a kor period of 18 days and kor depth of 12 cm, while wheat has a kor period of 15 days and kor depth of 15 cm. Calculate the discharge of field channel.

15. After how many days will you supply water to field in order to get efficient irrigation? If the field capacity of soil is 27%, permanent wilting point is 14%, density of soil =1.5g/cc, effective depth of root zone is 75cm and daily consumptive use of water for the crop is 11mm?

16. Discuss briefly the various techniques used for distributing water in the farms.

17. What are the factors that affect duty? Discuss in brief.

HYDROLOGY
UNIT-I
HYDROLOGIC CYCLE

SYLLABUS:

Introduction: Engineering hydrology and its applications, Hydrologic cycle. Precipitation: Types and forms of precipitation, rainfall measurement, types of rain gauges, rain gauge network, average rainfall over a basin, consistency of rainfall data, frequency of rainfall, intensity-duration-frequency curves, probable maximum precipitation.

LEARNING MATERIAL

INTRODUCTION:

Hydrology means the science of water. It is the science that deals with the occurrence, circulation and distribution or water of the earth and earth's atmosphere. As a branch of earth science, it is concerned with the water in streams and lakes, rainfall and snow fall, snow and ice on the land and water occurring below the earth's surface in the pores of the soil and rocks. In general sense of hydrology is very broad subject of an inter-disciplinary nature drawing support from allied sciences, such as meteorology, geology, statistics, chemistry, physics and fluid mechanics. The importance of hydrology in the assessment, development, utilisation and management of water resources of any region is being increasingly realised at all levels.

Hydrology is basically an applied science. To further emphasise the degree of applicability. The subject is sometimes classified as
1. **Scientific hydrology**- The study which is concerned with the academic aspects.
2. **Engineering or applied hydrology**- A study concerned with engineering applications.
In a general sense engineering hydrology deals with
  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

WORLD'S WATER RESOURCES:

The World's total water resources are estimated at 1.36×10^8 M ha-m. Of these global water resources, about 97.2% is salt water mainly in oceans and only 2.8% is available as fresh water at any time on the planet of earth. Out of this 2.8% of fresh water, about 2.2% is available as surface water and 0.6% as ground water. Even out of this 2.2% of surface water, 2.15% is fresh water in glaciers and icecaps and only of the order of 0.01% is available in lakes and streams, the remaining 0.04% being in other forms. Out of 0.6% of stored ground water, only about 0.25% can be economically extracted with the present drilling technology (the remaining being at greater depths). It can be said that the ground water potential of Ganga Basin is roughly about forty times the flow of water in the river Ganga.

The geographical area of country (India) is 3.28 Mkm^2 and the annual runoff (from rainfall) is 167 M ha-m (or 167 × 104 Mm^3), which is approximately two-and half-times of the Mississippi-Missouri river Basin, which is almost equal in area to the whole of India. Due to limitations of terrain, non-availability of suitable storage sites, short period of occurrence of rains, etc. The surface water resources that can be utilised for estimated of only 67 M ha-m. The total arable land in India is estimated to be 1.47 Mkm^2 which is 45% of the total geographical area against 10% for USSR and 25% for USA. India has great potential for agriculture and water resources utilisation.

HYDROLOGY AND HYDROLOGIC CYCLE:

Hydrology is the science, which deals with the occurrence, distribution and disposal of water on the planet earth, it is the science which deals with various phases of the hydrologic cycle. Hydrologic cycle is the water transfer cycle, which occurs continuously in nature; the three important phases of hydrologic cycle are: (*a*) Evaporation and evapotranspiration (*b*) precipitation and (*c*) runoff and is shown in Figure 1.1. The globe has one-third land and two-thirds ocean. Evaporation from the surfaces of ponds, lakes, reservoirs, ocean surfaces, etc. and transpiration from surface vegetation *i.e.,* from plant leaves of cropped land and forests, etc. take place. These vapours rise to the sky and are condensed at higher altitudes by condensation nuclei and form clouds, resulting in droplet growth. The clouds melt and sometimes burst resulting in precipitation of different forms like rain, snow, hail, sleet, mist, dew and frost. A part of this precipitation flows over the land called runoff and part infilters into the soil which builds up the ground water table. The surface runoff joins the streams and water is stored in reservoirs. A portion of surface runoff and ground water flows back to the ocean again. Evaporation starts from the surfaces of lakes, reservoirs and ocean and the cycle repeats. Of these three phases of hydrologic cycle, namely, evaporation, precipitation and runoff, it is the 'runoff phase', which is important to civil engineer since he is concerned with the storage of surface runoff in tanks and reservoirs for the purposes of irrigation, municipal water supply hydroelectric power etc.
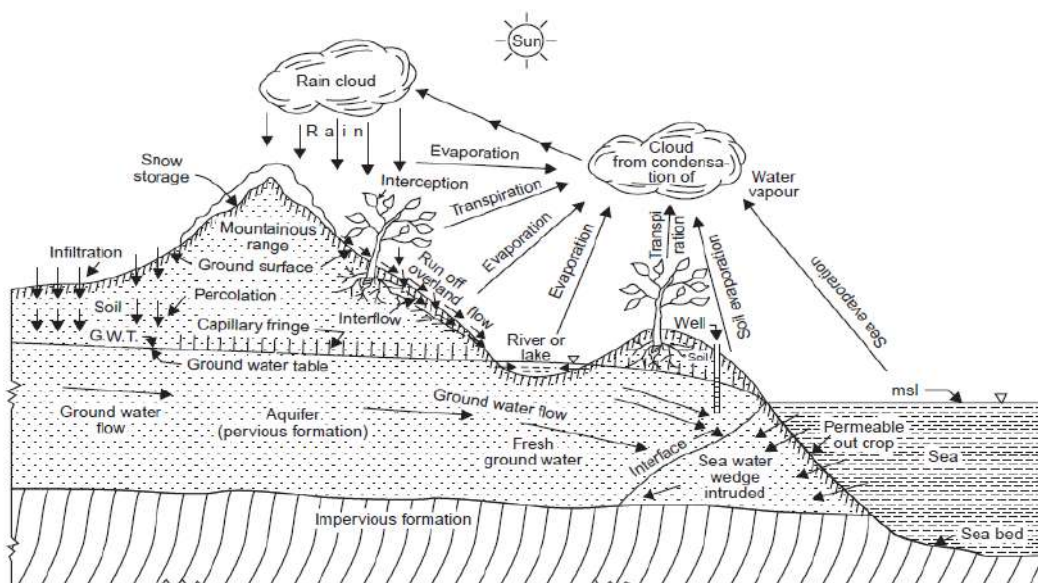
Figure 1.1: The Hydrologic Cycle

FORMS OF PRECIPITATION:

Drizzle   - A light steady rain in fine drops (0.5 mm) and intensity <1 mm/hr
Rain   - The condensed water vapour of the atmosphere falling in drops
                  (>0.5 mm, maximum size-6 mm) from the clouds
Glaze   - Freezing of drizzle or rain when they come in contact with cold objects
Sleet   - Frozen rain drops while falling through air at subfreezing temperature.
Snow   - Ice crystals resulting from sublimation (*i.e.,* water vapour condenses to ice)
Snowflakes   - Ice crystals fused together
Hail   - Small lumps of ice (>5 mm in diameter) formed by alternate freezing and
                  melting, when they are carried up and down in highly turbulent air currents.

SCOPE OF HYDROLOGY:

The study of hydrology helps us to know
  i.   The maximum probable flood that may occur at a given site and its frequency, this is required for safe design of drains and culverts, dams and reservoirs, channels and other flood control structures.
  ii.   The water yield from a basin-its occurrence, quantity and frequency, etc, this is necessary for the design of dams, municipal water supply, water power, river navigation, etc.
  iii. The ground water development for which a knowledge in the hydrogeology of area, *i.e.,* of the formation soil, recharge facilities like streams and reservoirs, rainfall pattern, climate, cropping pattern, etc. are required.
  iv.   The maximum intensity of storm and its frequency for the design of drainage project in the area.

HYDROLOGIC EQUATION:

The hydrologic equation is simply the statement of law of conservation of matter and is given by

$$I = O + \Delta S \text{ ---------------Eq. 1.1}$$

Where I = Inflow
       O = Outflow
       ΔS = Change in storage

This equation states that during a given period, the total inflow into a given area must equal to the total outflow from this area plus the change in storage. While solving this equation, the ground water is considered as an integral part of surface water and it is the subsurface inflow and outflow that pose problems in the water balance studies of basin.

PRECIPITATION:

The **precipitation** in the country (India) is mainly in the form of rain fall though there is appreciable snowfall at high altitudes in the Himalayan range and most of the rivers in north India are perennial since they receive snow-melt in summer (when there is no rainfall).

TYPES OF PRECIPITATION:

i.   **Convective precipitation**: This type of precipitation is mainly form of local whirling thunder storms and is typical of the tropics. The air close to the warm earth gets heated and rises due to its low density, cools adiabatically to form a cauliflower shaped cloud, which finally bursts into thunder storm as shown in Fig. 1.2. When accompanied by destructive winds, they are called 'tornados'.
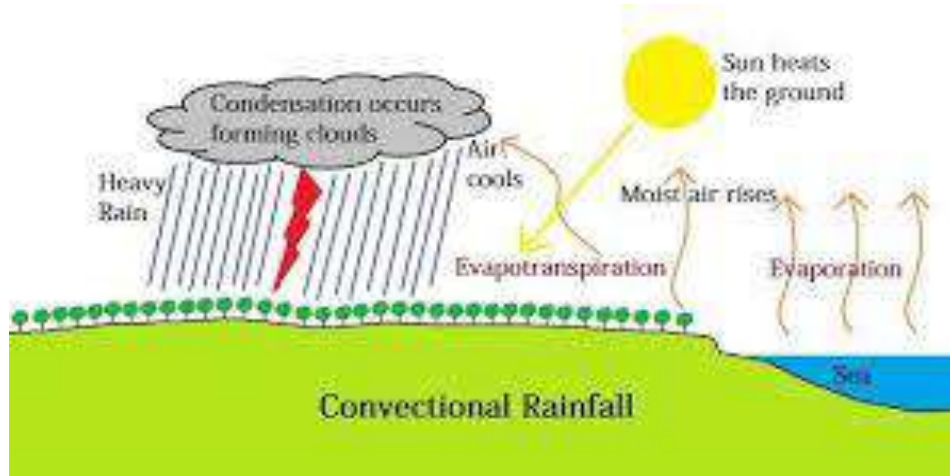
Fig. 1.2: Convective Precipitation

ii. **Frontal precipitation**: When two air masses due to contrasting temperatures and densities clash with each other, condensation and precipitation occur at the surface of contact as shown in the Figure 1.3. This surface of contact is called 'front' or 'frontal surface'. If a cold air mass drives out a warm air mass' it is called a 'cold front' and if a warm air mass replaces the retreating cold air mass, it is called a 'warm front'. On the other hand, if the two air masses are drawn simultaneously towards low pressure area, the front developed is stationary and is called a 'stationary front'. Cold front causes intense precipitation on comparatively small areas, while the precipitation due to warm front is less intense but is spread over a larger area.
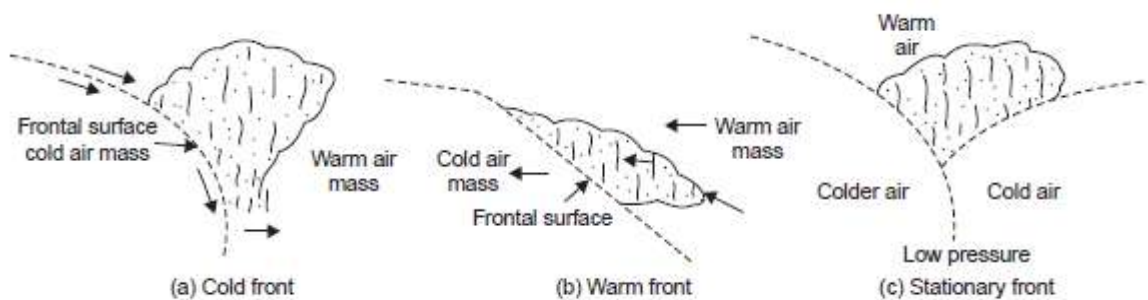
Figure 1.3: Frontal precipitation

iii. **Orographic precipitation:** The mechanical lifting of moist air over mountain barriers causes heavy precipitation on the windward side shown in Figure 1.4. For example Cherrapunji in the Himalayan range and Agumbe in the western Ghats of south India get very heavy orographic precipitation of 1250 cm and 900 cm (average annual rainfall), respectively.
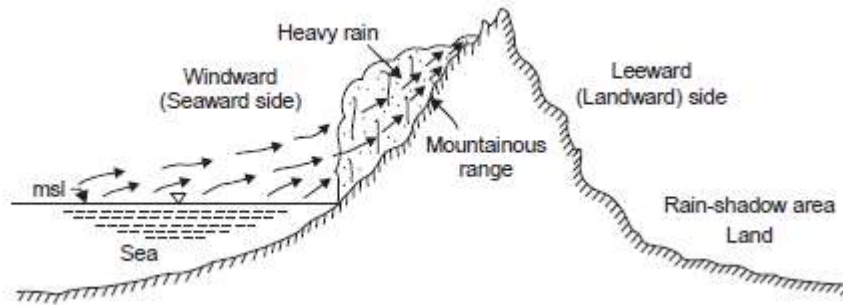
Figure 1.4: Orographic precipitation

iv. **Cyclonic precipitation**: This type of precipitation is due to lifting of moist air converging into low pressure belt, *i.e.,* due to the pressure differences created by unequal heating of the earth's surface. Here the winds blow spirally inward counter clockwise in the northern hemisphere and clockwise in the southern hemisphere. There are two types of cyclones, first is tropical cyclone (also called hurricane or typhoon) of comparatively small diameter of 300-1500 km causing high wind velocity and heavy precipitation and second is extra-tropical cyclone of large diameter up to 3000 km causing wide spread frontal type precipitation.
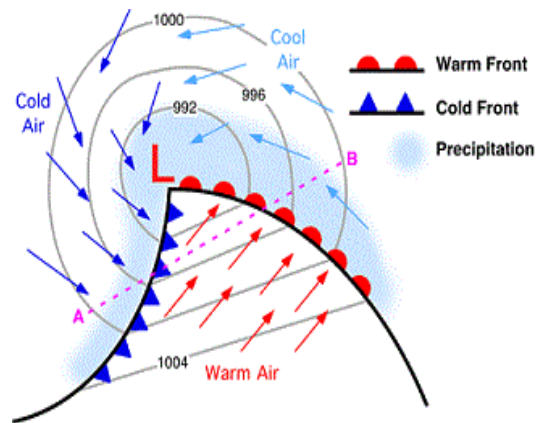
MEASUREMENT OF PRECIPITATION:

Rainfall may be measured by a network of rain gauges which may be non-recording or recording type. The non-recording rain gauge used in India is the Symon's rain gauge (Figure 1.5). It consists of funnel with a circular rim of 12.7cm diameter and glass bottle as a receiver. The cylindrical metal casing is fixed vertically to the masonry foundation with the level rim of 30.5cm above the ground surface. The rain falling into the funnel is collected in the receiver and is measured in a special measuring glass graduated in mm of rainfall; when is full it can be measured 1.25cm of rain.
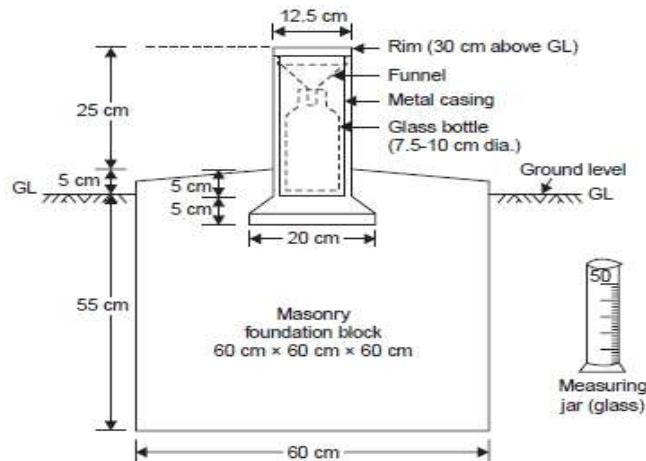
Figure 1.4: Symon's rain gauge

The rainfall is measured every day at 08.30 hours IST. During heavy rains, it must be measured three or four times in the day, least the receiver fill and overflow, but the last measurement should be at 08.30 hours IST and the sum of total in all measurements during the previous 24hours entered as the rainfall of the day in the register. Usually, rainfall measurements are made at 08.30 hr IST and sometimes at 17.30 hr IST also. Thus the non-recording or Symon's rain gauge gives only the total depth of rainfall for the previous 24 hours (*i.e.,* daily rainfall) and does not give the intensity and duration of rainfall during different time intervals of the day. It is often desirable to protect the gauge from being damaged by cattle and for this purpose a barbed wire fence may be erected around it.

Recording Rain Gauge:

This is also called self-recording, automatic or integrating rain gauge. This type of rain gauge has an automatic mechanical arrangement consisting of clockwork, a drum with graph paper fixed around it and a pencil point, which draws the mass curve of rainfall. From this mass curve, the depth of rainfall in a given time, the rate or intensity of rainfall at any instant during the storm, time of onset and cessation of rainfall, can be determined. The gauge is installed on concrete or masonry platform 45 cm square in the observatory enclosure by the side of ordinary rain gauge at a distance of 2-3 m from it. The gauge is installed at the rim of funnel was horizontal and at the height of exactly 75cm above the ground surface. The self-recording rain gauge is generally used in conjunction with an ordinary rain gauge exposed close by, for use as standard, by means of which the readings of recording rain gauge can be checked and if necessary adjusted. There are three types of recording rain gauges- tipping bucket gauge, weighing gauge and float gauge.

Tipping bucket rain gauge:

This consists of cylindrical receiver in 30 cm diameter with a funnel inside. Just below the funnel pair of tipping buckets is pivoted such that when one of the bucket receives a rainfall of 0.25 mm it tips and empties into a tank below, while the other bucket takes its position and the process is repeated. The tipping bucket rain gauge is shown in Fig. 1.6. The tipping of bucket actuates on electric circuit which causes a pen to move on a chart wrapped round a drum which revolves by a clock mechanism. This type cannot record snow.
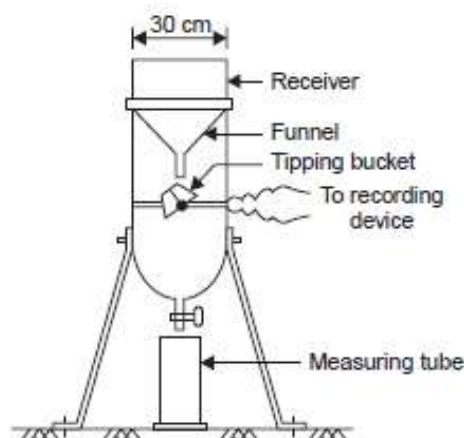
Figure 1.6: Tipping bucket gauge

Weighing type rain gauge:

In this type of rain-gauge, when a certain weight of rainfall is collected in a tank as shown in Fig. 1.7, which rests on spring-lever balance, it makes a pen to move on chart wrapped round a clock driven drum. The rotation of drum sets the time scale while the vertical motion of the pen records the cumulative precipitation.
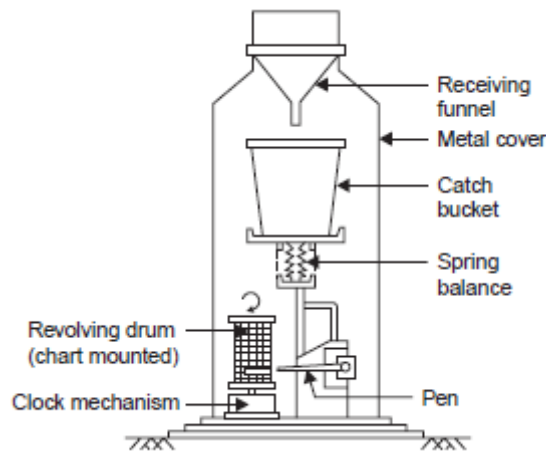
Figure 1.7: Weighing type rain gauge

Float type rain gauge:

In this type, as the rain is collected in float chamber, the float moves up which makes the pen to move on chart wrapped round a clock driven drum. When the float chamber fills up, the water siphons out automatically through a siphon tube kept in an interconnected siphon chamber. The clockwork revolves the drum once in 24 hours. The clock mechanism needs rewinding once in a week when the chart wrapped round the drum is also replaced. This type of gauge is use by IMD. The weighing and float type rain gauges can store a moderate snow fall which the operator can weigh or melt and record the equivalent depth of rain. The float type rain gauge is shown in Fig. 1.8.
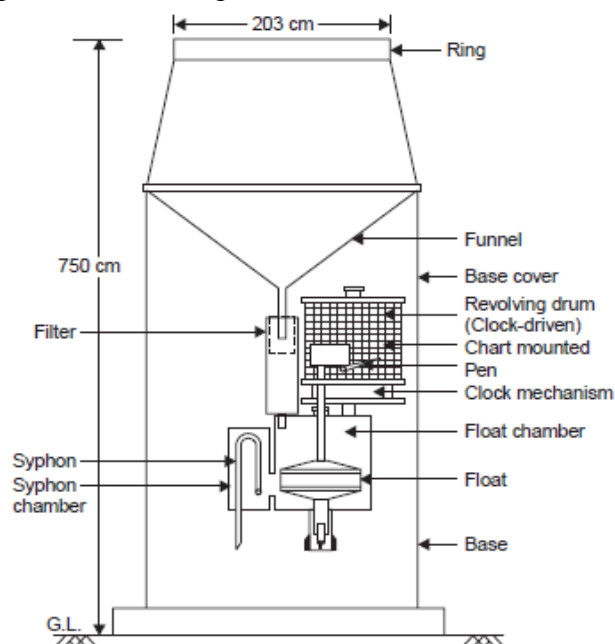
Figure 1.8: Float type rain gauge

Mass Curve

A **mass** diagram shown in Fig. 1.9 is the plot of accumulated inflow (i.e. supply) or outflow (i.e. demand) versus time. Calculate the plot of cumulative demand against time, and thus plot the **mass curve** of demand. A hyetograph is graphical representation of distribution against rainfall over time.
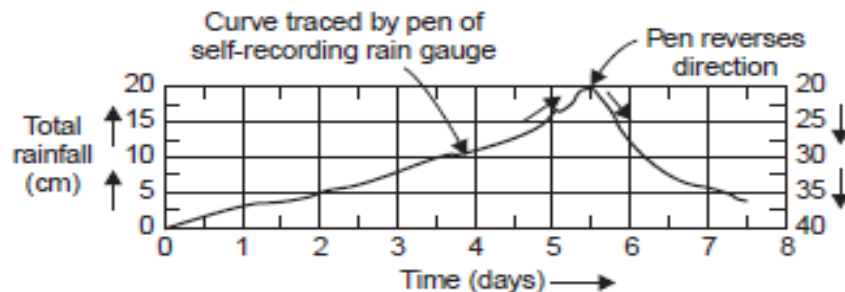
Figure 1.9: Mass curve of rainfall

Rain gauge Network: The rain gauge density or network density is defined as the ratio of total area of catchment to total number of gauges in the catchment. Thus rain gauge density gives the average area served by each gauge.

The World Meteorological Organisation, WMO, has laid down certain norms regarding the minimum network density as given below:

Region I   : Flat regions of temperate, mediterranean and tropical zones:

Minimum = 1 gauge for 600 to 900 km^2

Tolerance = 1 gauge for 900 to 3000 km^2

Region II   : Mountainous areas of temperate, mediterranean and tropical zones:

Minimum = 1 gauge for 100 to 250 km^2

Tolerance = 1 gauge for 250 to 1000 km^2

Region III   : Arid zones :

Minimum = 1 gauge for 1500 to 10000 km^2

For small mountainous islands with irregular precipitation one gauge for every 25 km^2 was suggested. Ten percent of these gauges should be recording type to enable the determination of rainfall intensities.

IS code recommendations (IS: 4987-1968):

1. One guage per 520km^2 in plain areas, with denser network for areas lying in the path of low pressure systems.
2. One guage per 260 to 390 km^2 in regions with average elevation of 1000m above mean sea level.
3. One guage per 130 km^2 in predominantly hilly regions with heavy rainfall, higher density being preferred wherever possible.

OPTIMUM RAIN-GAUGE NETWORK DESIGN: The aim of optimum rain-gauge network design is to obtain all quantitative data averages and extremes that define the statistical distribution of hydro meteorological elements, with sufficient accuracy for practical

purposes. When the mean areal depth of rainfall is calculated by the simple arithmetic average, the optimum number of rain-gauge stations to be established in a given basin is determined by the equation (IS, 1968)

$$N = \left(\frac{C_v}{p}\right)^2$$ ---------------Eq. 1.2

Where N = Optimum number of raingauge stations to be established in the basin
C_v = Coefficient of variation of rainfall in the existing rain gauge stations (say, n)
p = Desired degree of percentage error in the estimate of average depth of rainfall over the basin.

The number of additional rain-gauge stations ($N–n$) should be distributed in the different zones (caused by isohyets) in proportion to their areas, *i.e.,* depending upon the spatial distribution of existing rain-gauge stations and variability of rainfall over the basin.

Average rainfall over a basin:

Point rainfall - It is the rainfall in single station. For small areas less than 50 km^2, point rainfall may be taken as the average depth of area. In large areas, there will be a network of rain-gauge stations. As the rainfall over large area is not uniform, the average depth of rainfall over the area is determined by one of the following three methods:

(*i*) **Arithmetic average method** - It is obtained by simply averaging arithmetically the amounts of rainfall at the individual rain-gauge stations in the area, *i.e.,*

$$P_{ave} = \frac{\Sigma P_1}{n}$$ ---------------Eq. 1.3

where P_{ave} = Average depth of rainfall over the area
ΣP_1 = Sum of rainfall amounts at individual rain-gauge stations
n = Number of rain-gauge stations in the area

This method is fast and simple and yields good estimates in flat country if the gauges are uniformly distributed and rainfall at different stations do not vary widely from the mean. These limitations can be partially overcome if topographic influences and aerial representative are considered in the selection of gauge sites.

(*ii*) **Thiessen polygon method** - This method attempts to allow for non-uniform distribution of gauges by providing a weighting factor for each gauge. The stations are plotted on base map and connected by straight lines. Perpendicular bisectors are drawn to the straight lines, joining adjacent stations to form polygons, known as Thiessen polygons as shown in Fig. 1.9. Each polygon area assumed to be influenced by the raingauge station inside it, *i.e.,* if $P1$, $P2$, $P3$, ... are the rainfalls at the individual stations, and $A1$, $A2$, $A3$, ... are the areas of polygons surrounding these stations, (influence areas) respectively, the average depth of rainfall for the entire basin is given by

$$P_{ave} = \frac{\Sigma A_1 P_1}{\Sigma A_1}$$ ---------------Eq. 1.4

where $\Sigma A_1 = A$ = Total area of the basin.

The results obtained are usually more accurate than those obtained by simple arithmetic averaging. The gauges should be properly located over the catchment to get regular shaped polygons. However, one of the serious limitations of the Thiessen method is its non-flexibility since a new Thiessen diagram has to be constructed every time if there is change in the rain gauge network.
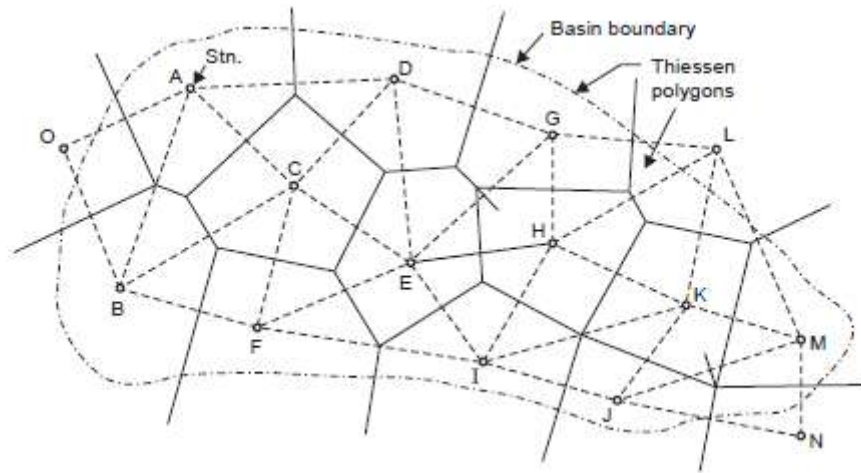
Figure 1.10 Thiessen polygon methods

(*iii*) **The isohyetal method** - In this method, the point rainfalls are plotted on suitable base map and lines of equal rainfall (isohyets) are drawn giving consideration to orographic effects and storm morphology in Fig.1.10. The average rainfall between succesive isohyets taken as the average of two isohyetal values are weighted with the area between isohyets added up and divided by the total area which gives the average depth of rainfall over the entire basin.

$$P_{ave} = \frac{\Sigma A_{1-2} P_{1-2}}{\Sigma A_{1-2}}$$

--------------Eq. 1.5

where A_{1-2} = Area between the two successive isohyets P_1 and P_2

$$P_{1-2} = \frac{P_1 + P_2}{2}$$

--------------Eq. 1.6

$$\Sigma A_{1-2} = A = \text{Total area of basin.}$$

This method if analysed properly gives the best results.
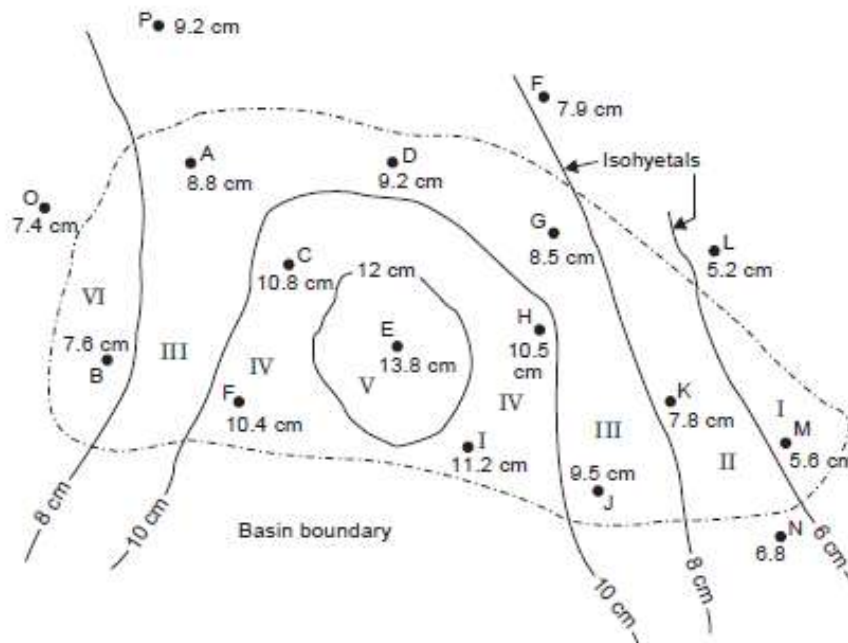
Figure 1.11 Isohyetal method

Consistency of rain fall data

  Double Mass Curve Technique: The trend of rainfall records at a station may slightly change after some years due to change in the environment (or exposure) of a station either due to coming of new building, fence, planting of trees or cutting of forest nearby, which affect the catch of gauge due to change in the wind pattern or exposure. It is commonly used data analysis approach for investigating the behaviour of records made of hydrological or meteorological data at a number of locations. It is used to determine whether there is a need for corrections the data - to account for changes in data collection procedures or other local conditions. Double mass analysis for checking consistency of hydrological or meteorological record is considered to be an essential tool before taking it for analysis purpose.
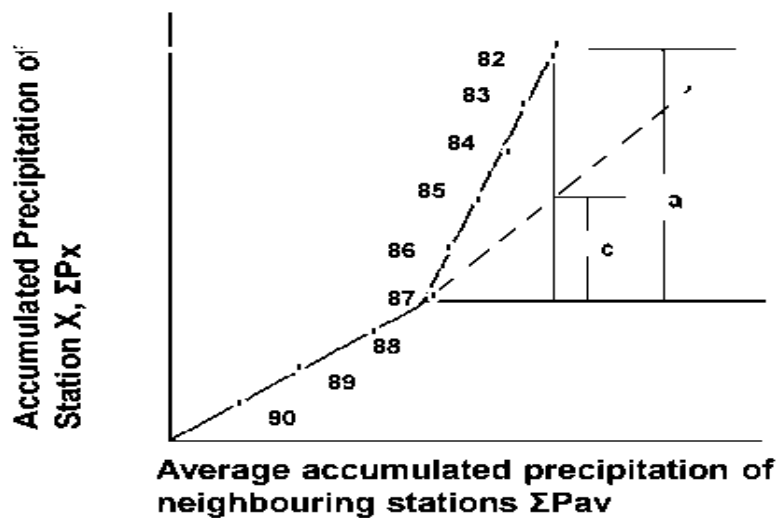
Correction Ratio : $M_c/M_a = c/a$

$Pcx = Px*M_c/M_a$

Pcx – Corrected precipitation at any time period t_1 at station X

Px – Original recorded precipitation at time period t_1 at station X

M_c – Corrected slope of the double mass curve

M_a – original slope of the mass curve

Frequency of rainfall: The frequency of rainfall of specified period is determined by assuming that the rainfall is random variable and mathematical theory of probability is applicable. The frequency of rainfall is the number of time that a given magnitude of rainfall may occur in given period. The study of probability of occurrence of particular extreme rain fall is extreme importance to the determination of design flood. This is determined with the help of frequency analysis. The recurrence interval is the interval in years for occurrence of event of the same magnitude and reciprocal of the frequency. The recurrence interval also known as return period.

$T = \frac{1}{P_r}$ P_r is the probability of occurrence

California formula : $P_r = m/N$ or $T = N/m$ N = number of years of record, m = descending order of magnitude

Hazen formula : $p_r = 2m-1/2N$

Weibull formula : $p_r = m/(n+1)$ most commonly used formula

Frequency (f) : The probability of occurrence of an event, expressed as percentage is known as frequency, $f = 100*p_r$

Intensity-Duration-Frequency (IDF) curves

It is necessary to know that the rainfall intensities of different durations and different return periods, in case of many design problems such as runoff disposal, erosion control, highway construction and culvert design etc. The curve that shows the inter-dependency between i (cm/hr), D (hour) and T (year) is called IDF curve.

The relation can be expressed in general form as:

$$i = \frac{kT^x}{(D+a)^n}$$ i – Intensity (cm/hr), T – Return period

D – Duration (hours)
K, x, a, n – are constant for a given catchment
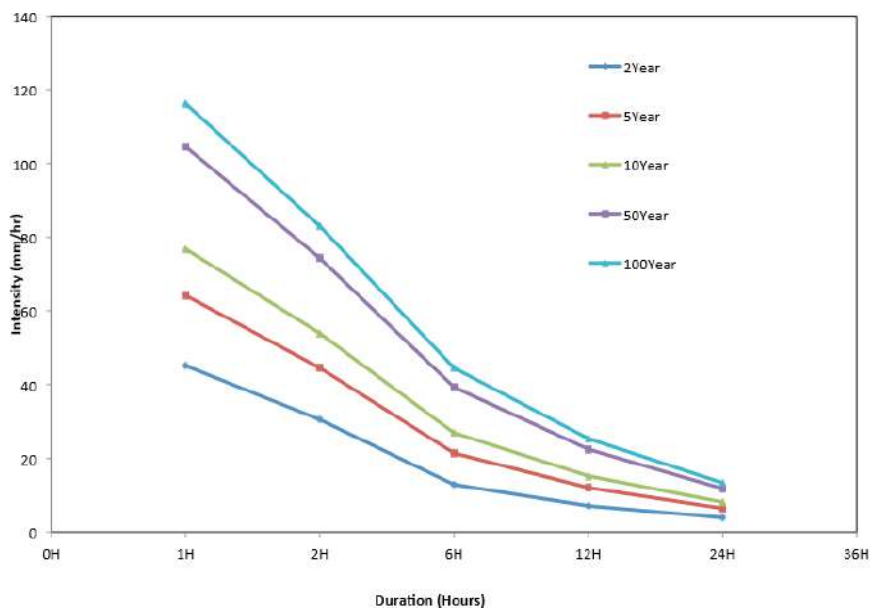
Depth-Area-Duration relationships

It indicates that the areal distribution characteristic of storm of given duration.

The development of maximum depth-area-duration relationship is known as DAD analysis. It is an important aspect of hydro-meteorological study.

Depth-Area relationship

For a rainfall of given duration, the average depth decreases with the area in an exponential fashion is given by:

$P = P_0 \exp(-kA^n)$

where : P = Average depth in cms over an area A km^2,

Po : Highest amount of rainfall in cm at the storm centre

K, n : Constants for a given region
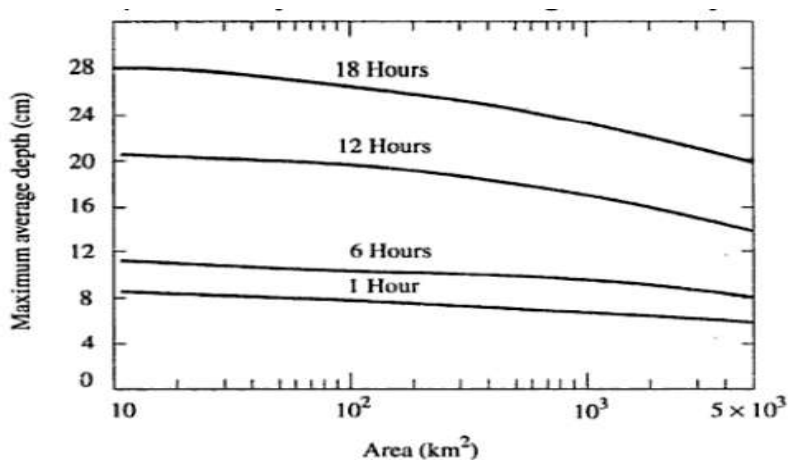
Depth area duration curves

Probable Maximum Precipitation (PMP)

➢ This is the amount of rainfall over a region which cannot be exceeded over at that place.

➢ The PMP will of course vary over the earth's surface according to the local climatic factors.

➢ Naturally, it would be expected to be much higher in the hot humid equatorial regions than in the colder regions of the mid-latitudes when the atmospheric is not able to hold as much moisture.

➢ PMP also varies within India, between the extremes of dry deserts of Rajasthan to the ever humid regions of South Meghalaya plateau**.**

PMP = P +Ks

P = Mean of annual maximum rainfall series

s = Standard deviation of the series

K = Frequency factor

HYDROLOGY
UNIT-II
ABSTRACTIONS

Syllabus: Abstractions Evaporation, factors affecting evaporation, measurement of evaporation, evaporation reduction, evapo-transpiration, factors affecting evapo-transpiration, measurement of evapo-transpiration - Infiltration, factors affecting infiltration, measurement of infiltration, infiltration indices.

LEARNING MATERIAL

LOSSES OR ABSTRACTIONS FROM PRECIPITATION:

When precipitation takes place on the land surface, whole of it is not available as runoff because of losses that take place during or after the precipitation.

Precipitation – Surface runoff = Total loss

Total loss = interception+ evaporation+ transpiration+ infiltration+ depression storage+ watershed leakage

EVAPORATION: It is the process of substance in liquid state changing into gaseous state due to an increase in temperature and/or pressure. Evaporation is the fundamental part of water cycle and is constantly occurring throughout nature.

The rate of evaporation depends of following factors

1) Vapour pressure
2) Air & water temperature
3) Solar radiation
4) Wind speed
5) Atmospheric pressure
6) Nature and size of evaporating surface
7) Quality of water

Dolton's law of evaporation

$E = C(e_s - e_a) = (a+bv)(e_s-e_a)$

E = evaporation loss (mm/day)

e_s = saturated vapour pressure

e_a = actual vapour pressure

a, b = constants

v = wind speed in km/h

FACTORS AFFECTING EVAPORATION:

Nature of the evaporating surface: Different evaporating surfaces like soil barren land, forest area, houses & lakes affect evaporation to the extent they have the potential. Black cotton soil evaporates soil water faster than red soil.

Area of water surface: We know that the evaporation is a surface phenomenon. Hence with increase in surface area, the rate of evaporation also increases.

Depth of water in water body: Deep water bodies evaporate slower than shallow water bodies in summer while in winter season, they evaporate faster.

Temperature of air: Rate of evaporation increases with the rise in temperature as increasing temperature increases the kinetic energy of molecules in the liquid which facilitates the molecule to convert into vapour.

Humidity: The rate of evaporation decreases with the rise in Humidity. Humidity is defined as the amount of water vapour in the air. On a particular or defined temperature, air cannot hold or carry definite amount of moisture. Hence this high humidity reduces the rate of evaporation as air cannot hold any more water vapour.

Wind velocity: The rate of evaporation increases with the winds speed. An increase in speed of wind causes water vapour particles to move away with the winds and this decreases the amount of water vapour in the surroundings. As a result, the rate of evaporation increases. Thus on a windy day, wet clothes dry faster.

Atmospheric pressure: Evaporation is also affected by the atmospheric pressure exerted on the evaporating surface. Evaporation will be less if the atmospheric pressure is more while in deep valleys evaporation is less.

Quality of water: Evaporation is inversely proportional to the salinity of water. Rate of evaporation is always greater over fresh water than over salt water. Under similar conditions, the ocean water evaporates about 5 per cent slowly than the fresh water.

MEASUREMENT OF EVAPORATION

This is done by the following methods

1. Measurement using evaporation pans (evaporimeters)

2. Using empirical equations

3. Analytical methods of evaporation estimation

Evaporimeters: These are pans containing water which are exposed to the atmosphere. Loss of water by evaporation from these pans is measured at regular intervals (daily). Meteorological data such as humidity, wind velocity, air and water temperatures and precipitation are also measured and noted along with evaporation.

1. IS STANDARD PAN

1. Specified by IS: 5973 and known as the modified Class A Pan

2. A pan of diameter 1220mm and depth 255mm.

3. The pan is made of copper sheet 0.9mm thick, tinned inside and painted white outside.

4. The pan is placed on square wooden platform of width 1225mm and height 100mm above ground level to allow free air circulation below the pan.

5. A fixed point gauge indicates the level of water.

6. Water is added to or removed from the pan to maintain the water level at a fixed mark using a calibrated cylindrical measure.

7. The top of pan is covered with a hexagonal wire net of GI to protect water in the pan from birds.

8. Presence of wire mesh makes the temperature of water more uniform during the day and night.

9. Evaporation from this pan is about 14% lower is compared to that from an unscreened pan.
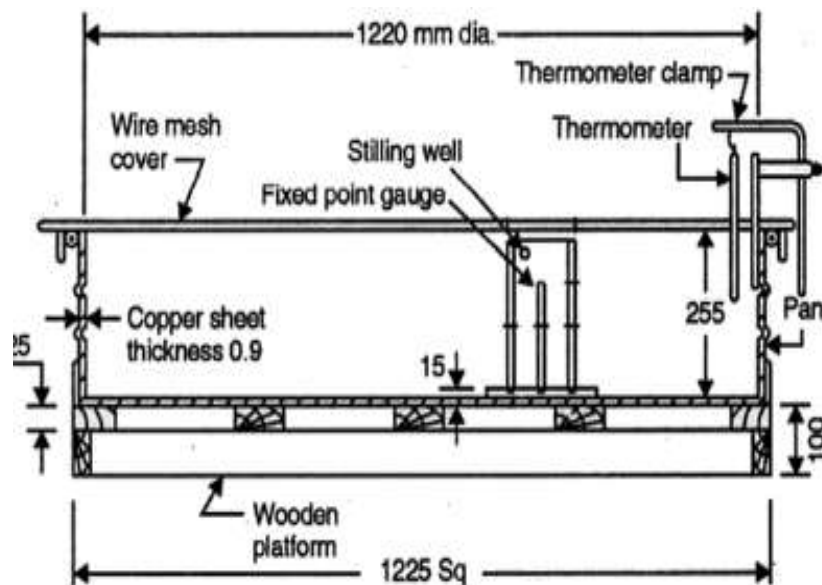
Figure 2.1 IS Evaporation Pan

2. COLORADO SUNKEN PAN

1. The 920mm square pan made of unpainted GI sheet, 460mm deep and buried into the ground within 100mm of top.

2. Main advantage of this pan – It's aerodynamic and radiation characteristics are similar to that of lake.

3. Disadvantages – Difficult to detect leaks, expensive to install, extra care is needed to keep the surrounding area free from tall grass and dust etc.
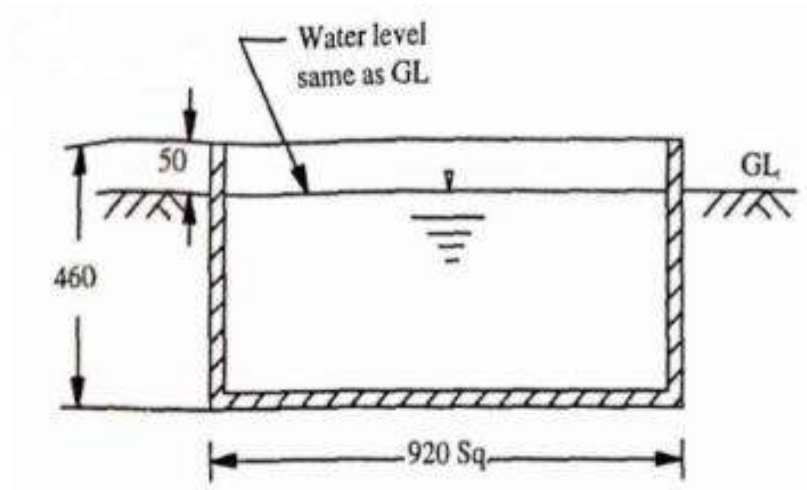
Figure 2.2 Colorado Sunken Pan

Pan Coefficient

• Evaporation pans are not exact models of large reservoirs

Their major drawbacks are the following:

- They differ from reservoirs in the heat storage capacity and heat transfer characteristics from the sides and bottom (sunken and floating pans aim to minimise this problem). Hence evaporation from a pan depends in some extent on its size (Evaporation from a pan of about 3m dia. is almost the same as that from a large lake whereas that from a pan of about 1m dia. is about 20% in excess of this).

- The height of rim in an evaporation pan affects wind action over the water surface in the pan. Also it casts a shadow of varying size on the water surface.

- The heat transfer characteristics of pan material are different from that of reservoir.

- Hence evaporation measured from a pan has to be corrected to get the evaporation from a large lake under identical climatic and exposure conditions.

    Lake Evaporation = Pan Coefficient+ x Pan Evaporation

Table: Values of Pan Coefficients

Sl. No.	Types of Pan	Average Value	Range
1	Class A Land Pan	0.70	0.60 – 0.80
2	ISI Pan (Modified Class A)	0.80	0.65 – 1.10
3	Colorado Sunken Pan	0.78	0.75 – 0.86
4	USGS Floating Pan	0.80	0.70 – 0.82

EMPIRICAL EQUATIONS

Most of the available empirical equations for estimating lake evaporation:

(1) Meyer's Formula

$$E = K_m (e_s - e_a) \left[1 + \frac{v9}{16}\right]$$

E = Evaporation (mm/day)

e_s = Saturation vapour pressure at the water surface temperature (mm of mercury)

e_a= Actual vapour pressure of the overlying air at a specified height (mm of mercury)

v_9 = Monthly mean velocity (kmph) at a height of 9 m above the ground

K_m= Coefficient accounting for other factors (0.36 for large deep waters and 0.50 for small shallow lakes)

(2) Rohwer's Formula

$$E = 0.771(1.465 - 0.000732\, p_a)(0.44 + 0.0733\, v_{0.6})(e_s - e_a)$$

P_a= Mean barometric pressure (mm of mercury)

$V_{0.6}$= Mean wind velocity in kmph at ground level 0.6

(Taken as the wind velocity at 0.6m height above the ground)

E, e_w and e_a are as mentioned earlier

Wind Velocity

In the lower part of atmosphere, up to a height of about 500m above the ground level, wind velocity follows the one-seventh power law as

$$V_h = c\, h^{1/7}$$

V_h = wind velocity (in kmph) at a height h (in m) above the ground level

C = constant

ESTIMATION OF EVAPORATION BY USING ANALYTICAL METHODS:

Water budget or water balances method:

This method balances all the incoming, outgoing and stored water in the lake or reservoir over a period of time, using the following equation:

$\sum$Inflow-$\sum$Outflow = change in storage + evaporation loss

(or) $E = \sum I - \sum O \pm \Delta S$

The above equation can be generalised as under, taking all the factors of inflow and outflow:

$E = (P + I_{sf} + I_{gf}) - (O_{sf} + O_{gf} + T) \pm \Delta S$

P = Precipitation

I_{sf} = Surface water inflow

I_{gf} = Ground water inflow

O_{sf} = Surface water outflow

O_{gf} = Ground water outflow

T = Transpiration loss, which may be neglected.

ΔS = Change in storage.

The above method does not give any accurate results because it is very difficult to measure I_{sf} and O_{gf} for a lake/reservoir.

Energy budget or energy balance:

This method uses the conservation of energy by incorporating all the incoming, outgoing and stored energy of lake/reservoir in the following form:

$$H_n = H_a + H_e + H_g + H_s + H_i \qquad \text{------------------- (1)}$$

Where H_n = Net heat energy received by water surface $+ H_c (1-r) - H_b$

$H_c (1-r)$ = Incoming solar radiation into a surface of reflection coefficient 'r'

The value of r for water surface approximates 0.05 for newly laid snow, r=0.90
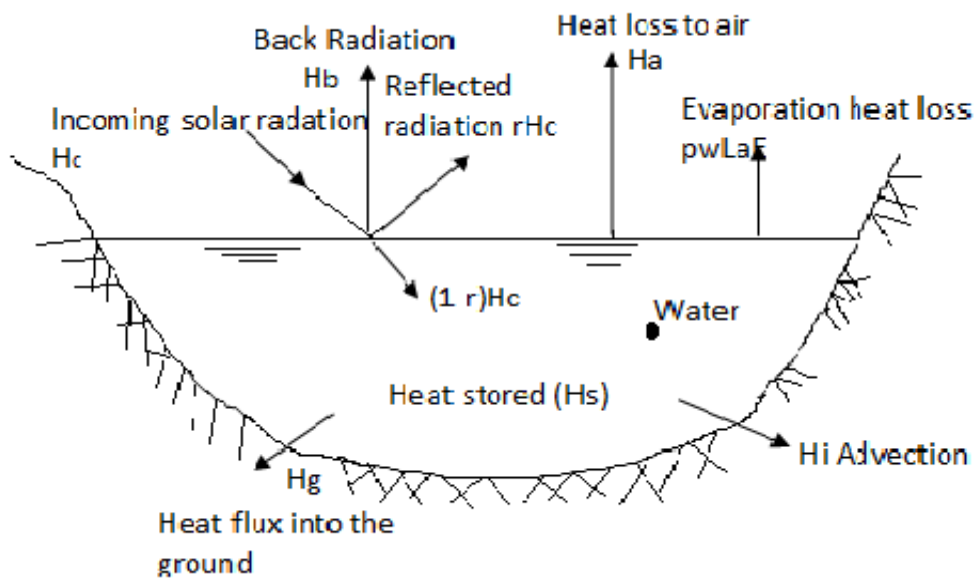
Fig.4: Energy balance in a water body

H_b = Back radiation from the body

H_a = Sensible heat transfer from water surface to air

H_e = Heat energy used up in evaporation = $\rho_w L_a E$

Where ρ_w = Density of water

$\qquad H_g$ = Heat flux into the ground

$\qquad H_i$ = Net heat conducted out of the system by water flow

$\qquad H_s$ = Heat stored in water body

$\qquad L_a$ = Latent heat of evaporation.

In the above equation, all the energy terms are in calories per square mm per day. All the terms except H_a can either be measured or evaluated. For small time period, the terms H_s and H_i can be neglected. However, the sensible heat term H can be estimated by using Bowen's ratio (β) by the following expression:

$$\beta = H_a / \rho_w L_a E = 6.1 \times 10^4 pa (Tw - T_a/e_s - e_a) \text{ ------------------ (2)}$$

Where T_w = Temperature of water surface

T_a = Temperature of air in ^oC

P_a = Atmospheric pressure in mm of mercury

Combining the eq^n. 1 and 2 we obtain the following equation for evaporation E :

$$E = \frac{Hn - Hg - Hs - Hi}{\rho w\, La\, (1+\ \beta)}$$

The above method gives satisfactory results, with the errors order of about 5%, when applied to periods less than a week.

EVAPORATION REDUCTION

There are wide ranges of products available for controlling evaporation loss. These systems include:

• Continuous floating covers

• Modular covers

• Shade structures

• Chemical covers

Continuous floating covers

Continuous floating plastic covers act as an impermeable barrier that floats on the water surface and can achieve above 90% evaporation savings for full cover of the dam. Most of these products have a high capital cost and replacement life varies (typically between 10 and 20 years). The structural integrity of product under windy conditions and fluctuating water levels is important. Water quality can be impacted by reduced dissolved oxygen, light penetration and change in water temperature. This can have a positive impact on reducing algal growth. Significant difficulties can be encountered with installation on large storages above 5ha. In some cases these covers can be deployed as a series of large rafts covering up to 1Hour.

Modular systems

Modular floating covers come in size range of typically up to $3m^2$ in area and act in a similar manner to floating covers. However they do not have the structural challenges of continuous

sheet. Modular floating covers can also be deployed to cover only a portion of the storage, for example that portion always holding water. Modules can be free-floating or connected together to form a larger raft. Modules are typically made from plastic material and generally provide up to 90% savings for 100% area covered. The actual area covered will depends upon the number, shape and size of module and storage characteristics. Generally these systems have a very high capital cost (in excess of US$17/m^2). Repair and replacement of modules is possible and water quality impacts will depend on the relative area covered oxygen transfer and changes to water temperature.

Shade structures

Shade structures in general are suspended above the water surface using cables creating a web-like structure with shade cloth fitted between the cables. The shade cloth can come in a range of UV ratings (to describe the amount of UV blocked by the shade cloth). Evaporation savings of 70 to 80% have been demonstrated in trials. Floating shade of cloth modules or rafts has recently been marketed. Most of these products have a relatively high capital cost. In general shade structures are not as effective in reducing evaporation as floating covers. They allow free flow of oxygen to the water, although wind velocity and wave action will be reduced, which impacts dissolved oxygen levels. Algae may be reduced owing to less light penetration.

Chemical covers

Chemical covers have been promoted as a low cost method to reduce evaporation losses. Some products are true monolayers (i.e. a single molecule thick) while others are multiple layers with different water saving characteristics and water quality impacts. These products are generally biodegradable and there is need to reapply frequently (between three and ten days). Water savings have been shown to be highly variable, from less than 10% to up to 50% and are impacted by prevailing wind, temperature and water quality. True monolayer's are applied at very low application rates and rely on the self spreading ability of the chemical. Advantages of these products are low capital cost and choice to apply only when needed. Monolayers offer much potential for affecting evaporation savings but inconsistent evaporation saving performance has limited their adoption in Australia. It has been recognised that further research is needed and Cooperative Research Centre for Irrigation Futures (CRC-IF) is currently working on such a project.

EVAPOTRANSPIRATION

Evapo-transpiration is the combined term of evaporation and transpiration, defined as the total loss of water through evaporation and transpiration from the plants. It is denoted by ET,

the sum of water used by plants in a given area in transpiration and water evaporated from the adjacent soil in the area in any specified time.

$$ET = CU$$

CU is the Evapo-transpiration from an area plus the water used directly in the metabolic process of building plant tissue. (if it is covered with vegetation so, we find ET directly). It represents most important aspect of water loss in hydrologic cycle. Potential Evapo-transpiration (PET) is defined as the Evapo-transpiration which would occur if there was always an adequate water supply available to the fully vegetated surface. Actual Evapo-transpiration (AET) is defined as the real Evapo-transpiration occurring in a specific situation. Seasonal consumptive use (SCU) of a crop is the total quantity of water used by it in ET during the entire grow season. PET, AET, SCU are useful in the designing of irrigation system.

FACTORS THAT AFFECT EVAPOTRANSPIRATION

The rate of Evapo-transpiration at any location on the Earth's surface is controlled by the several factors:

- **Energy availability**. The more energy available, the greater rate of Evapo-transpiration. It takes about 600 calories of heat energy to change 1 gram of liquid water into gas.
- **The humidity gradient away from the surface**. The rate and quantity of water vapour entering into the atmosphere both become higher in drier air.
- **The wind speed immediately above the surface**. The process of Evapo-transpiration moves water vapour from ground or water surfaces to an adjacent shallow layer that is only a few centimetres thick. When this layer becomes saturated Evapo-transpiration stops. However, wind can remove this layer replacing it with drier air which increases the potential for Evapo-transpiration. Winds also affect Evapo-transpiration by bringing heat energy into an area. A 5-mile-per-hour wind will increase still-air Evapo-transpiration by 20 percent; a 15-mile-per-hour wind will increase still-air Evapo-transpiration by 50 percent.
- **Water availability**. Evapo-transpiration cannot occur if water is not available.
- **Physical attributes of the vegetation**. Such factors as vegetative cover, plant height, leaf area index and leaf shape and reflectivity of plant surfaces can affect rates of Evapo-transpiration. For example coniferous forests and alfalfa fields reflect only about 25 percent of solar energy, thus retaining substantial thermal energy to promote transpiration;

in contrast, deserts reflect as much as 50 percent of solar energy, depending on the density of vegetation.

- **Stomata resistance**. Plants regulate transpiration through adjustment of small openings in the leaves called stomata. As stomata close, the resistance of leaf to loss of water vapour increases, decreasing to the diffusion of water vapour from plant to the atmosphere.

- **Soil characteristics**. Soil characteristics that can affect Evapo-transpiration include its heat capacity and soil chemistry. Seasonal trends of Evapo-transpiration within a given climatic region follow the seasonal declination of solar radiation and resulting air temperatures. Minimum Evapo-transpiration rates generally occur during the coldest months of year. Maximum rates generally coincide with the summer season. However since Evapo-transpiration depends on both solar energy and availability of soil moisture and plant maturity the seasonal maximum Evapo-transpiration actually may precede or follow the seasonal maximum solar radiation and air temperature by several weeks.

MEASUREMENT OF EVAPOTRANSPIRATION

The consumptive use or Evapo-transpiration can be measured by five principal methods:

1. Tank and Lysimeter
2. Field Experiment plots

1. Tank and Lysimeter:

Tanks are containers set flush with the ground level having an area of 10 m^2 and three 3 m deep. Larger the size of tank greater is the resemblance to root development. The tank is filled with soil of field and crop is grown in it. Consumptive use is determined by measuring the quantity of water required to maintain constant moisture conditions within the tank for satisfactory proper growth of crop. In lysimeters, the bottom is pervious. Consumptive use is the difference of water applied draining through pervious bottom and collected in a pan.

2. Field Experiment:

This method is more dependable on tank and lysimeter method. In this method, the irrigation water is applied to the selected field experimental plots in such a way that there is neither runoff nor deep percolation. Yield obtained from different fields are plotted against the total water used and, as basis for arriving at the consumptive use, those yields are selected which appear to be most profitable. It is seen from observations that for every type of crop, the yield increases rapidly with an increase of water used to a certain point, and then decreases with further increase in water. At the 'break in the curve" the amount of water used is considered as the consumptive use.

EVAPOTRANSPIRATION EQUATIONS

1. Blaney- Criddle formula

This method is used throughout the world for the consumptive use determinations and is given by

$$U = \Sigma \frac{ktp}{100} \quad \text{in FPS units}$$

$$U = \Sigma \frac{kp\,(4.6t + 81.3)}{100} \quad \text{in metric units}$$

$$U = \Sigma\, kf = K\,\Sigma\, f = KF$$

$$f = \frac{tp}{100} \quad \text{in FPS units}$$

$$f = \frac{p(4.6t + 81.3)}{100} \quad \text{in metric units}$$

Where U = Seasonal consumptive use (inches in FPS units and cm in metric units)

t = Mean monthly temperature (°F in FPS units and °C in metric units)

p = Monthly percentage of hours of bright sunshine (of the year)

k = Monthly consumptive use coefficient determined from experimental data

f = Monthly consumptive use factor

K, F = Seasonal values of consumptive use coefficient and factor, respectively

INFILTRATION:

It is the process by which water on the ground surface enters the soil. Infiltration rate in soil science is measure of the rate at which the soil is able to absorb rainfall or irrigation. It is measured in inches per hour or millimetres per hour. The rate decreases as the soil becomes saturated. If the precipitation rate exceeds the infiltration rate, runoff will usually occur unless there is some physical barrier. It is related to the saturated hydraulic conductivity of the near-surface soil. The rate of infiltration can be measured using an infiltrometer.

FACTORS AFFECTING INFILTRATION:

(i)Intensity and duration of rainfall:

When the precipitation takes place with heavy intensity, the impact of water causes mechanical compaction and wash of fine particles, resulting in faster decrease in the rate of infiltration. However, the rainfall of lesser intensity results in higher infiltration rate. The rainfall with higher duration will result in lower infiltration in comparison to the same quantity of rain falling as "n" number of isolated storms.

(ii) Soil Texture and Structure:

It is already made clear that the water cannot continue to enter soil more rapidly than it is transmitted downward. The conditions at the surface, therefore, cannot increase infiltration unless the transmission capacity of the soil profile is adequate.

The continuity of non-capillary or large pores provides easy paths for percolating water. If the subsoil formation has coarse texture the water may infiltrate into the soil so quickly that no water will be left for runoff even if rainfall is quite heavy. On the contrary clayey soils after soaking some water in the initial stages of rainfall may swell considerably. It makes the soil almost watertight and infiltration may get reduced to practically negligible extent.

(iii) Conditions at Soil Surface:

Even if the subsoil has excellent under drainage but at the surface soil pores are sealed due to turbid water or by in wash of fine soil particles it may prevent entry of water into the soil and infiltration rate will be low.

(iv) Soil-Moisture Content:

When the soil is fairly dry the rate of infiltration into the soil is quite high. The infiltration rate diminishes as the soil-moisture storage capacity was exhausted. After this infiltration rate equals transmission rate. The rate of infiltration in early phases of rainfall will be less if the soil pores are still filled from previous rain storm.

(v) Movement of man and animal activities:

When there is heavy movement of man and/ or animal, the soil gets compacted, resulting in reduction in the infiltration rate.

(vi) Type of Vegetative Cover:

Vegetative cover affects the surface entry of water significantly. The vegetation or mulches protect the soil surface from impact of rain drops. The lengthy and extensive root system penetrates the soil and increases its porosity. Organic matter from crops promotes a crumbly by structure and improves soil permeability. Forest canopy protects soil surface whereas row crops provide less protection to soil.

(vii) Soil Temperature:

If saturated soil mass gets frozen due to severe low temperature it becomes nearly impermeable. It affects the infiltration.

(viii) Human Activities on Soil Surface:

If the soil surface gets compacted due to construction of roads, operation of tractors and other farm implements and machinery the porosity of soil is decreased. As a result bigger pores are almost eliminated making soil impermeable. It reduces the infiltration rates appreciably.

MEASUREMENT OF INFILTRATION:

Infiltration in the field can be measured with the help of two types of infiltrometers:

(a) Single cylindrical or single tube infiltration and (b) concentric double cylindrical or double ring infiltrometers.

Single tube infiltrometer:

It consists of hollow metal cylinder of 30 cm diameter and 60 cm length with both ends open. The cylinder is driven in the ground such that 10 cm of it projects above the ground. The cylinder is filled with water, such that a head of 7 cm within the infiltrometer is maintained above ground level. Due to infiltration of water, the level in cylinder will go on decreasing. Water is added to the cylinder, through graduated jar or burette, so as to maintain constant level. The volume of water added over a predetermined time interval gives the infiltration rate for that time interval. The observations are continued till almost uniform infiltration rate is obtained, which may take about 3 to 6 hour, depending upon the type of soil. A plot of abscissa against the rate of water added in mm/h gives the infiltration capacity curve for area. The major drawback of single tube infiltrometer is that infiltrated water percolates laterally at the bottom of ring as shown in the below fig. Hence it does not truly represent the area through which infiltration takes place.
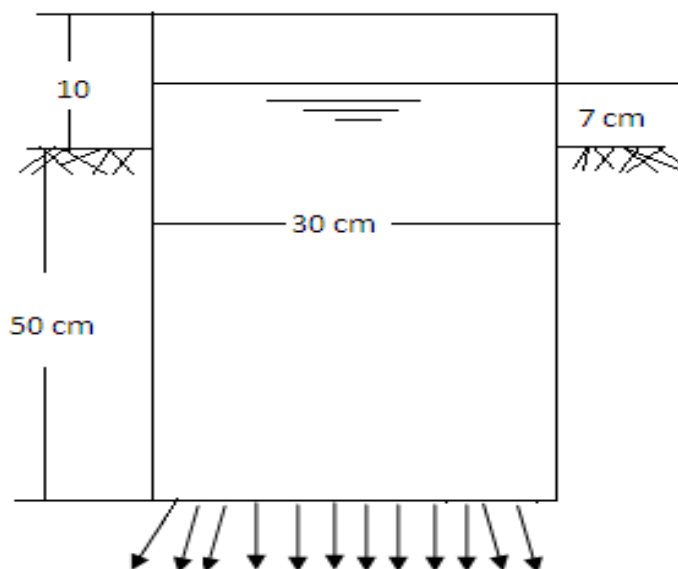
Single tube infiltrometer

Double tube (or double ring) infiltrometer:

The above defect of lateral percolation of water is rectified in the double tube infiltrometer which consists of two concentric hollow rings (or cylinders) driven into the soil uniformly without any tilt and disturbing the soil, to the least depth of 15cm. The diameter of rings may vary from 25 to 60 cm water is applied in both the inner and outer rings to maintain a constant depth of about 5 cm. Water is replenished after the level falls by about 1 cm the water depth in the inner and outer rings should be kept same during the observation period. However, the measurement includes the recording of volume of water added into the inner compartment, to

maintain the constant water level and corresponding elapsed time. As the purpose of outer ring is to suppress the lateral percolation of water from the inner ring the water added to it need not be measured though water is added to it to maintain the same depth as the inner ring. Observations are continued till constant infiltration rate was observed.
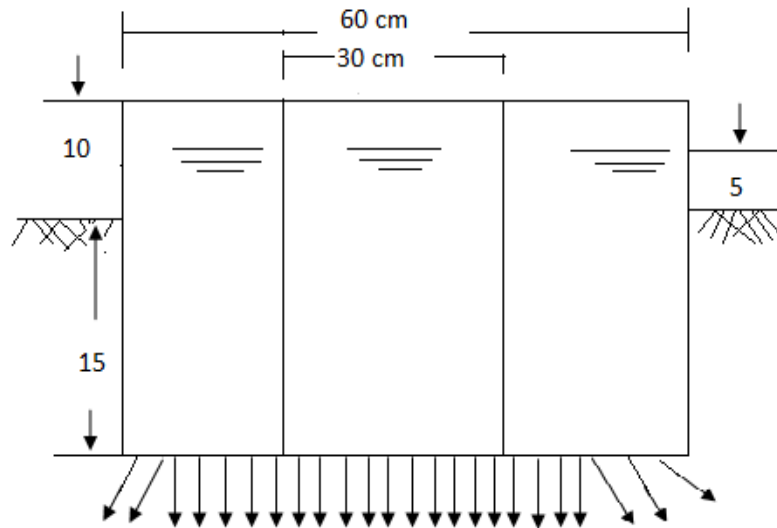
Double ring infiltrometer

INFILTRATION INDICES:

In the hydrological calculations involving flood is found convenient use a constant value of infiltration rate for duration of the storm. The defined average of infiltration index. Various infiltration indices give rates of infiltration in different ways to help assessment of the water lost by way of infiltration.

The two important types of indices are the following:

(ii) ϕ Index:

The ϕ index is that portion of average rate of rainfall during any storm which gets lost by the processes of interception, depression storage and infiltration taken together. It can, therefore, defined as that rate of average rainfall during any storm beyond which the volume of remaining rainfall equals the volume of direct surface runoff. The index can be calculated from a hyetograph (time versus intensity of rainfall graph) of the storm in such a way that the rainfall volume in excess of this rate will equal to the volume of storm runoff. If the rainfall intensity throughout the storm remains equal to or more than ϕ index then the ϕ index represents basin recharge because ϕ index represents sum total of infiltration, interception and depression storage.

(ii) W-Index: This index gives the average rate of infiltration for that time period of storm rainfall during which rainfall intensity is greater than W. Thus it can be said to be refinement over ϕ index which apart from infiltration also includes interception and depression storage. The W index can be obtained from the following equation:

$$W = P\text{-}R\text{-}Sa/t_r$$

Where

W is the average rate of infiltration

P is the total storm rainfall corresponding to t

Q is the total storm run-off.

t is the time during which rainfall intensity is more than W and

S is effective surface retention.

$W = \phi$ average rate of retention

For all practical purposes ϕ index can be taken to represent average rate of infiltration. Since ϕ indices assume average rate of infiltration which in fact is less than initial infiltration rate and more than ultimate infiltration rate their utility is limited to major flood producing storms. Such storms generally occur on wet soil and storms are of such intensity and duration that the infiltration rate could be very nearly taken to be constant for whole storm or majority period of storm. Obviously for short isolated storms ϕ and W indices are not useful.

HYDROLOGY

UNIT-III

RUNOFF

Syllabus:

Factors affecting runoff, components of runoff, computation of runoff-rational and SCS methods, separation of base flow, Unit Hydrograph, assumptions, derivation of Unit Hydrograph, unit hydrographs of different durations, principle of superposition and S-hydrograph methods, limitations and applications of UH.

COMPONENTS OF STREAM FLOW: When a storm occurs, a portion of rainfall infiltrates into the ground and some portion may evaporate. The rest flows as a thin sheet of water over the land surface which is termed as overland flow. If there is relatively impermeable stratum in the subsoil, the infiltrating water moves laterally in the surface soil and joins the stream flow, which is termed as underflow (subsurface flow) or interflow, Fig. 1. If there is no impeding layer in the subsoil the infiltrating water percolates into the ground as deep seepage and builds up the ground water table (GWT or phreatic surface). The ground water may also contribute to the stream flow, if the GWT is higher than the water surface level of stream, creating a hydraulic gradient towards the stream. Low soil permeability favors overland flow. While all the three types of flow contribute to the stream flow, it is the overland flow, which reaches first the stream channel, the interflow being slower reaches after a few hours and ground water flow being the slowest reaches the stream channel after some days.
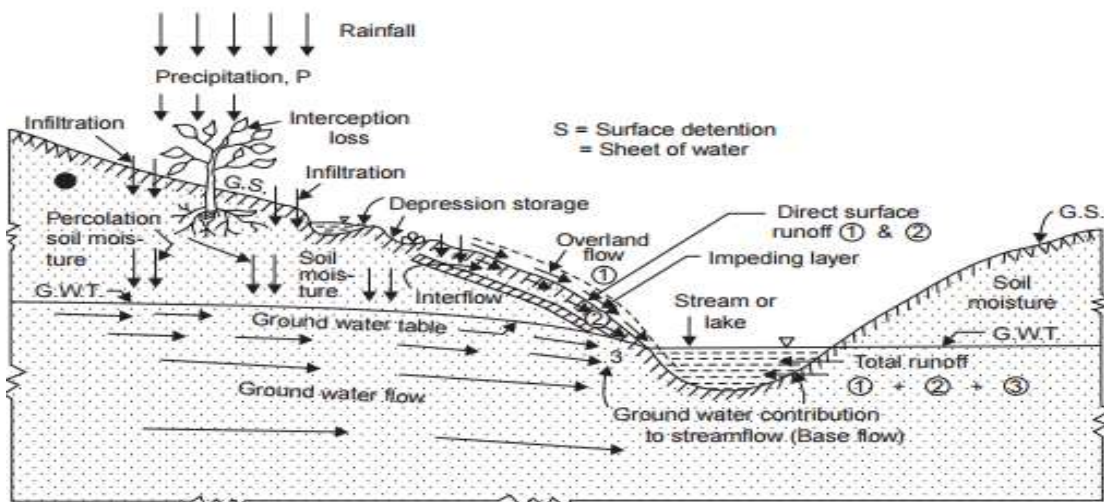
Figure 1: Disposal of rain water

The term direct runoff was used to include the overland flow and interflow. If the snow melt contributes to the stream flow it can be included with the direct runoff (from rainfall). Direct surface flow can be analyzed for relatively large drainage areas by the unit hydrograph method and for smaller areas by overland flow analysis. The direct runoff results from the occurrence of an immediately preceding storm while the ground water contribution, which takes days or months to reach the stream, in all probability, has no direct relation with the immediately preceding storm. The ground water flow into stream would have continued even if there had been no storm immediately proceeding. It is termed as the base flow in hydrograph analysis. When the overland flow starts (due to storm) some flowing water is held in puddles, pits and small ponds; this water stored was called depression storage. The volume of water in transit in the overland flow which has not yet reached the stream channel is called surface detention or detention storage. The portion of runoff in a rising flood over stream, which is absorbed by the permeable boundaries of stream above the normal phreatic surface, is called bank storage, Fig. 2.
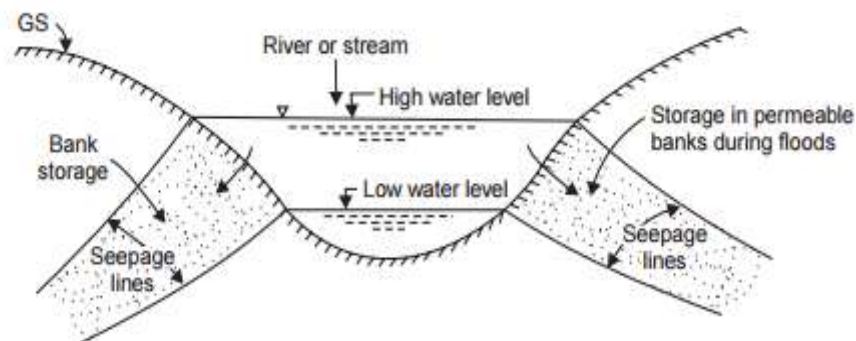
Figure 2: Bank Storage

FACTORS AFFECTING RUNOFF: The various factors, which affect the runoff from a drainage basin depend upon the following characteristics:

Low intensity storms over longer spells contribute to ground water storage and produce relatively less runoff. A high intensity storm or smaller area covered by it increases the runoff since the losses like infiltration and evaporation are less. If there is succession of storms, the runoff will increase due to initial wetness of the soil due to antecedent rainfall. Rain during summer season will produce less runoff, while that during winter will produce more. Greater humidity decreases evaporation. The pressure distribution in the atmosphere helps the movement of storms. Snow storage in specially the frozen ground greatly increases the runoff. Peak runoff (if expressed as cumec/km^2) decreases as the catchment area increases due to higher time of

concentration. A fan-shaped catchment produces greater flood intensity than a fern-shaped catchment. Steep rocky catchments with less vegetation will produce more runoff compared to flat tracts with more vegetation. If the vegetation is thick enough is the absorption of water, so less runoff. If the direction of storm producing rain is down the stream receiving the surface flow, it will produce greater flood discharge than when it is up the stream. If the catchment is located on the orographic side (windward side) of the mountains, it receives greater precipitation and hence gives a greater runoff. If it is on the leeward side, it gets less precipitation and so less runoff. Similarly, the catchments located at higher altitude will receive more precipitation and yield greater runoff. The land use pattern—arable land, grass land, forest or cultivated area, greatly affect runoff. The storage in channels and depressions (valley storage) will reduce the flood magnitude. Upstream reservoirs, lakes and tanks will moderate the flood magnitudes due to their storage effects. For drainage basins having previous deposits, large ground water storage may be created, which may also contribute to the stream flow in the form of delayed runoff.

ESTIMATION OF RUNOFF: Runoff is the balance of rain water, which flows or runs over the natural ground surface after losses by evaporation, interception and infiltration. The yield of catchment (usually means annual yield) is the net quantity of water available for storage, after all losses, for the purposes of water resources utilization and planning, like irrigation, water supply, etc. Maximum flood discharge. It is the discharge in times of flooding of the catchment area, i.e., when the intensity of rainfall is greatest and condition of catchment regarding humidity is also favorable for an appreciable runoff.

Runoff Estimation

The runoff from rainfall may be estimated by the following methods:
(i) Empirical formulae, curves and tables
(ii) Infiltration method
(iii) Rational method
(iv) Overland flow hydrograph
(v) Unit hydrograph method

(i) Empirical formulae:
- C.C. Inglis' formula for Bombay—Deccan catchments (Ghat areas)

$$R = 0.85P + 30.5$$

and for plains
$$R = \frac{(P - 17.8)P}{254}$$

- Lacey's formula for Indo-Gangetic plain
$$R = \frac{P}{1 + \dfrac{304.8}{P}\left(\dfrac{F}{S}\right)}$$

Where F is a monsoon duration factor varying between 0.5 to 1.5 and S is the catchment factor depending upon the slope and varies from 0.25 for flat areas to 3.45 for hilly areas.

- A.N. Khosla's formula for north India
$$R = P - \frac{T}{3.74}$$

Formulae for the some drainage basins in India:

- Ganga basin $R = 2.14\ P^{0.64}$
- Yamuna basin (Delhi) $R = 0.14\ P^{1.1}$
- Rihand basin (U.P.) $R = P - 1.17\ P^{0.86}$
- Chambal basin (Rajasthan) $R = 120P - 4945$
- Tawa basin (M.P.) $R = 90.5P - 4800$
- Tapti basin (Gujarat) $R = 435P - 17200$

(ii) Infiltration Method. By deducting the infiltration loss, i.e., the area under infiltration curves, from the total precipitation or by the use of infiltration indices, which are already discussed. These methods are highly empirical and derived values are applicable only when the rainfall characteristics and initial soil moisture conditions are identical to those for which these are derived.

(iii) Rational Method: A rational approach is to obtain the yield of catchment by assuming a suitable runoff coefficient.

$$\text{Yield} = CAP$$

Where A = area of catchment, P = precipitation and C = runoff coefficient. The value of runoff coefficient C varies depending upon the soil type, vegetation geology etc. (shown in table 1)

Table 1 Runoff coefficients for various types of catchments

Type of catchment	Value of C
Rocky and impermeable	0.8–1.0
Cultivated or covered with vegetation	0.4–0.6
Sandy soil	0.2–0.3
Rocky and impermeable	0.8–1.0
Cultivated or covered with vegetation	0.4–0.6
Sandy soil	0.2–0.3

HYDROGRAPH: A hydrograph is a graph showing discharge (i.e., stream flow at the concentration point) versus time. The various components of natural hydrograph are shown in the Fig.3. At the beginning, there is only base flow (i.e., the ground water contribution to the stream) gradually depleting in an exponential form. After the storm commences, the initial losses like interception and infiltration are met and then the surface flow begins.
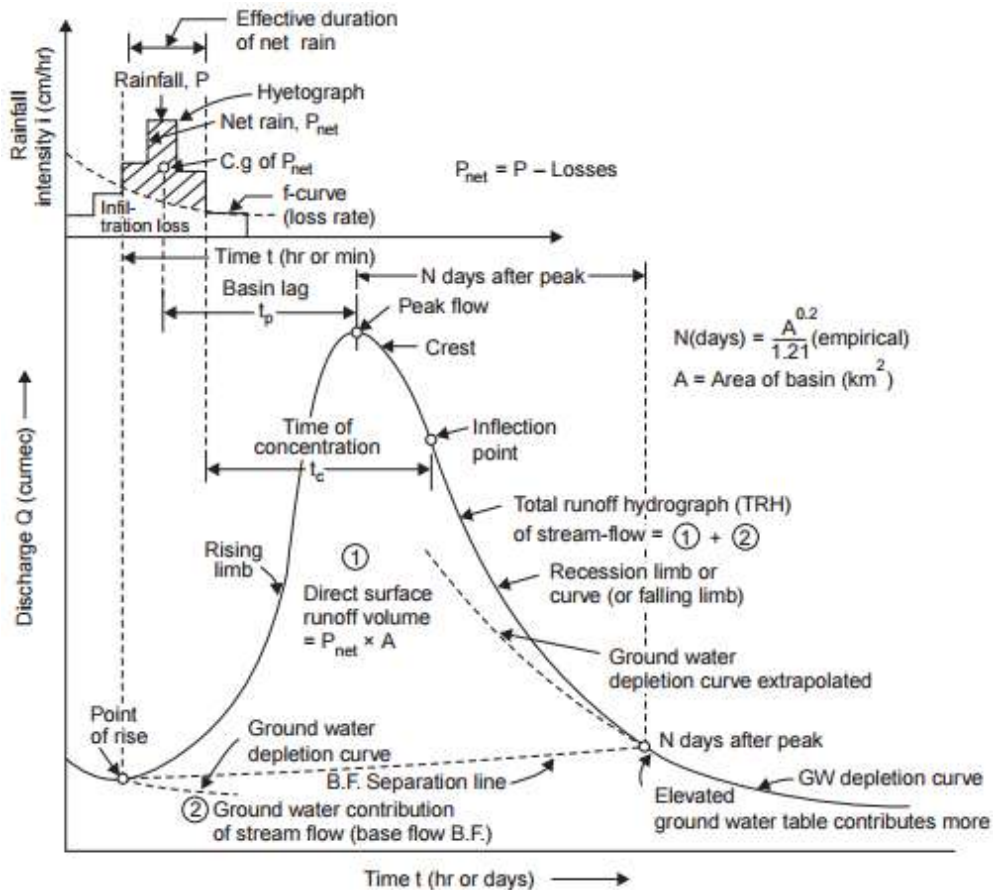
Figure 3: Components of stream flow hydrograph

The hydrograph gradually rises and reaches its peak value after a time t_p (called lag time or basin lag) measured from the controid of hyetograph of net rain. Thereafter it declines and there is a change of slope at the inflection point, i.e., there has been, inflow of the rain up to this point and after there is gradual withdrawal of catchment storage. By this time the ground water table has been built up by the infiltrating and percolating water, and now the ground water contributes more into the stream flow than at the beginning of storm, but thereafter the GWT declines and hydrograph again goes on depleting in the exponential form called the ground water depletion curve or the recession curve. If a second storm occurs now, again the hydrograph starts rising till it reaches the new peak and falls the ground water recession begins as shown in Fig. 4.
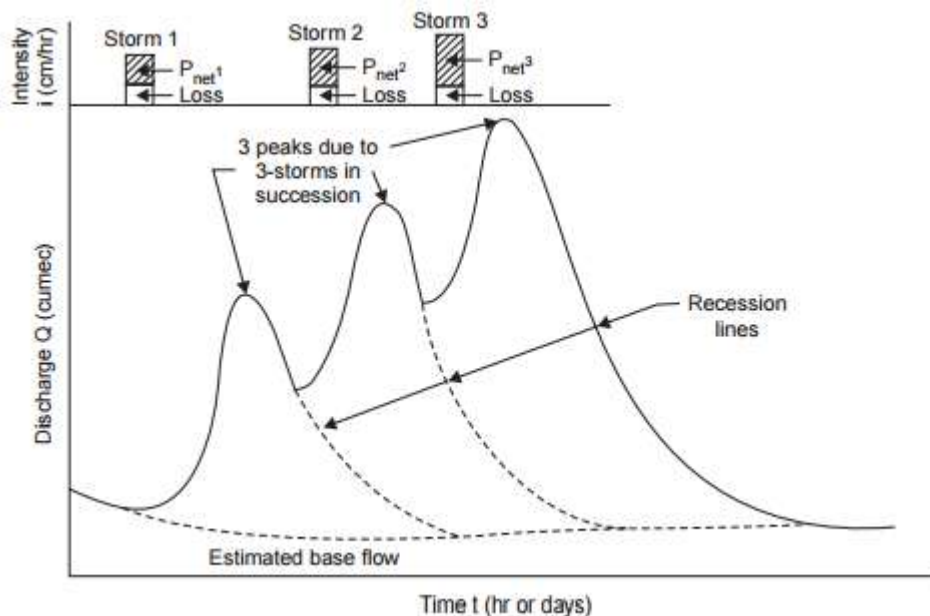
Figure 4: Hydrograph with Multiple Peaks

Thus, in actual streams gauged, the hydrograph may have a single peak or multiple peaks according to the complexity of storms. For flood analysis and derivation of unit hydrograph, a single peaked hydrograph was preferred. A complex hydrograph, however, can be resolved into simple hydrographs by drawing hypothetical recession lines as shown in Fig. 4.

HYDROGRAPH SEPARATION

For the derivation of unit hydrograph, the base flow has to be separated from the total runoff hydrograph (i.e., from the hydrograph of gauged stream flow). Some of the well-known base flow separation procedures are given below in Fig. 5.

(i) Simply by drawing a line AC tangential to both the limbs at their lower portion. This method is very simple but is approximate used only for preliminary estimates.

(ii) Extending the recession curve existing prior to the occurrence of storm up to the point D directly under the peak of hydrograph then drawing a straight line DE, where E is a point on the hydrograph N days after the peak, and N (in days) is given by $N=0.83A^{0.2}$

(iii) Simply by drawing a straight line AE, from the point of rise to the point E, on the hydrograph, N days after the peak. (iv) Construct a line AFG by projecting backwards the ground water recession curve after the storm, to a point F is directly under the inflection point of falling limb and sketch an arbitrary rising line from the point of rise of hydrograph to connect with the projected base flow recession. This type of separation is preferred where the ground water storage is relatively high and reaches the stream fairly rapidly, as in lime-stone terrains.
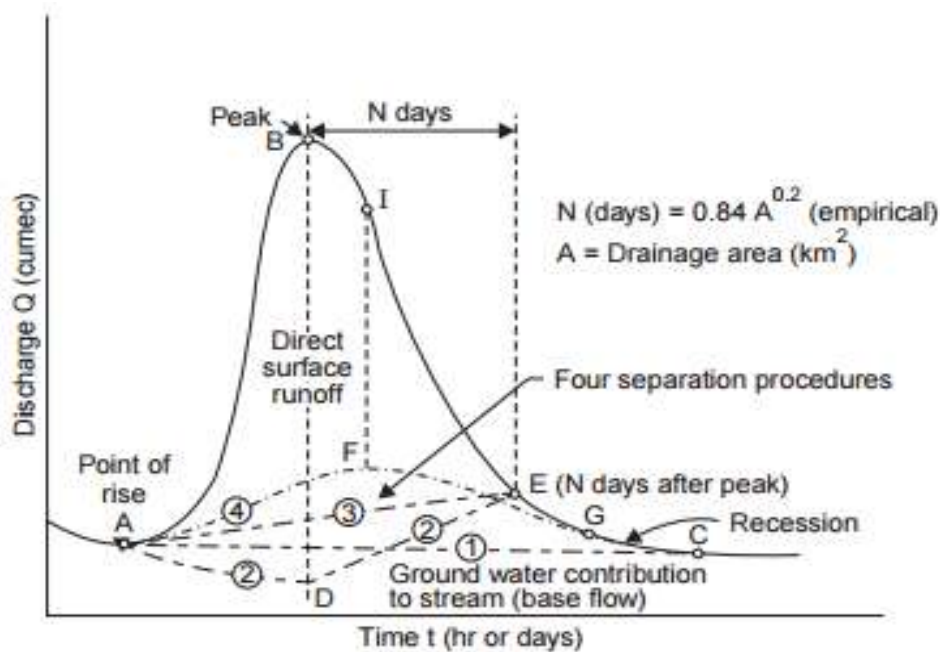
Figure 5: Hydrograph separation

UNIT HYDROGRAPH:

The unit hydrograph is defined as the hydrograph of storm runoff resulting from an isolated rainfall of some unit duration occurring uniformly over the entire area of catchment, produces a unit volume (i.e., 1 cm) of runoff. Derivation of unit hydrographs. The following steps are adopted to derive a unit hydrograph from an observed flood hydrograph.

(i) Select from the records isolated (single-peaked) intense storms, which occurring uniformly over the catchment have produced flood hydrographs with appreciable runoff (>1 cm, say, 8 to 16 cm). The unit period selected should be such that the excess rainfall (i.e., P_{net}) occurs fairly uniform over the entire drainage basin. Larger unit periods are required for bigger basins. The unit periods may be in the range of 15-30% of the 'peak time' period, i.e., the time from beginning of surface runoff to the peak and typical unit periods may be 3, 6, 8, 12 hours. (The time of concentration may be little longer than the peak time). The unit storm of storm in such duration that the period of surface runoff is not much less for any other storm of shorter duration.

(ii) Select a flood hydrograph, which has resulted from a unit storm chosen in item (i) above.

(iii) Separate the base flow from total runoff (by the well-known base flow separation procedures).

(iv) From the ordinates of total runoff hydrograph (at regular time intervals) deduct the corresponding ordinates of base flow, to obtain the ordinates of direct runoff.

(v) Divide the volume of direct runoff by the area of drainage basin to obtain the net precipitation depth over the basin.

(vi) Divide each of ordinates in direct runoff by the net precipitation depth to obtain the ordinates of unit hydrograph.

(vii) Plot the ordinates of unit hydrograph against time since the beginning of direct runoff. This will give the unit hydrograph for basin, for the duration of unit storm (producing the flood hydrograph.

Unit hydrograph assumptions

- Effective rainfall should be uniformly distributed over the basin, that is, if there are 'N' rain gauges spread uniformly over the basin, then all the gauges should record almost same amount of rainfall during the specified time.
- Effective rainfall is constant over the catchment during the unit time.
- The direct runoff hydrograph for effective rainfall in catchment is always the same irrespective of when it occurs. Hence, any previous rainfall event is not considered.
- The ordinates of unit hydrograph are directly proportional to the effective rainfall hyetograph ordinate

Unit hydrograph limitations

➢ Under the natural conditions of rainfall over drainage basins, the assumptions of unit hydrograph cannot be satisfied perfectly.

➢ However, when the hydrologic data used in the unit hydrograph analysis are carefully selected so that they meet the assumptions closely, the results obtained by the unit hydrograph theory have been found acceptable for all practical purposes.

➢ In theory, the principle of unit hydrograph is applicable to basin of any size. However, in the practice, to meet the basic assumption in derivation of unit hydrograph as closely as possible, it is essential to use storms which are uniformly distributed over the basin and producing rainfall excess at uniform rate.

➢ The size of catchment is, therefore, limited although detention, valley storage, and infiltration all tend to minimize the effect of rainfall variability. The limit is generally considered to be about 5000 sq. km. beyond which the reliability of hydrograph method diminishes.

➢ When the basin area exceeds this limit, it has to be divided into sub-basins and unit hydrograph is developed for each sub-basin. The flood discharge at the basin outlet is then estimated by combining the sub basin floods, using flood routing procedures.

Application of the unit hydrograph

➢ The development of flood hydrographs for high rainfall magnitudes (for use in the design of hydraulic structures)

➢ Extension of flood flow records based on rainfall records

➢ Development of flood forecasting and warning systems based on rainfall

➢ Calculations of direct runoff hydrograph in catchment due to given rainfall event (with recorded rainfall values), is easy if a unit hydrograph is readily available.

S – CURVE METHOD

It is the hydrograph of direct surface discharge that would result from a continuous succession of unit storms producing 1cm (in.) in tr–hr. If the time base of unit hydrograph is T_{bs} hr, it reaches constant outflow (Qe) at T hr, since 1 cm of net rain on the catchment is being supplied and removed every t_r hour and only T/t_r unit graphs are necessary to produce an S-curve and develop constant outflow given by,

$$Qe = (2.78.A) / t_r$$

Where Qe = constant outflow (cumec), t_r = duration of the unit graph (hr) and A = area of the basin (km^2 or acres)
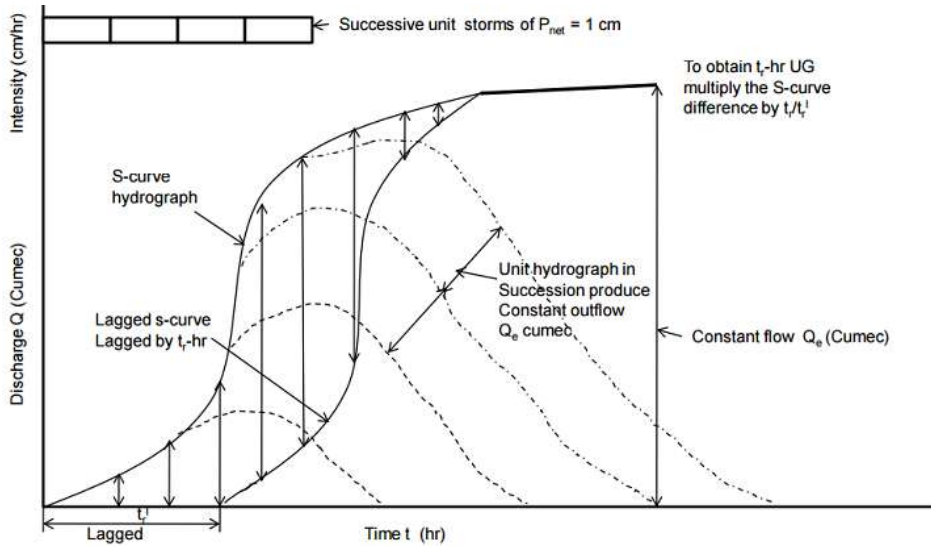
SUPERPOSITION METHOD:

If a D – h unit hydrograph is available, and it is desired to develop unit hydrograph of nD h, where n is the integer, it is easily accomplished by superposing "n" unit hydrograph with each graph separated from the previous one by "D" h. if two-unit hydrograph is added graphically or analytically, the combined hydrograph curve (3) is obtained. It gives a direct runoff of 2 cm. Now if the ordinates of DRH are now divided by n, we obtain 2 hr unit hydrograph.
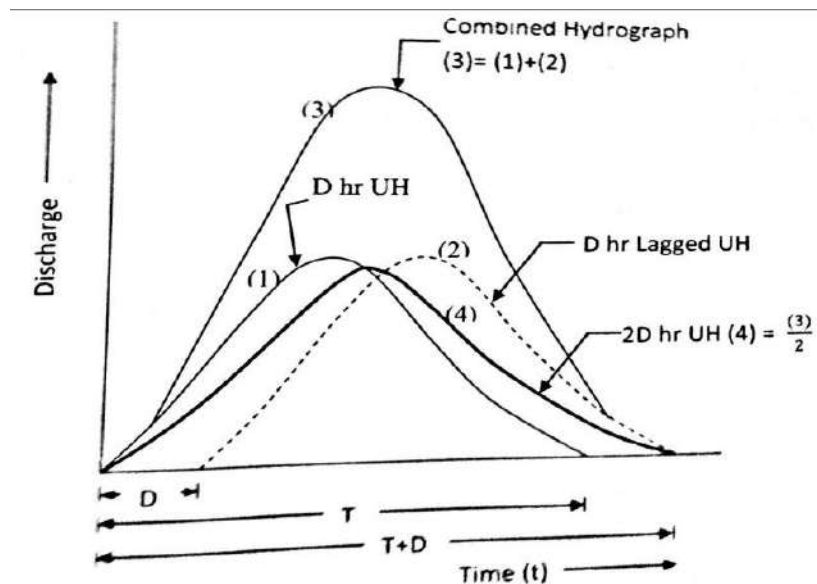
Hydrograph
UNIT-IV
FLOODS

Syllabus

Floods-Causes and effects, flood frequency analysis-Gumbel's method, flood, control methods, flood-routing hydrologic routing, hydraulic routing, channel and reservoir routing-Muskingum method of routing

Floods are natural phenomena which cannot be prevented. Floods have the adverse impact on human health, environment, cultural heritage and economic activity. Flood is a temporary covering by water of land normally not covered by water. This shall include floods from rivers, mountain torrents, Mediterranean ephemeral water courses, and floods from the sea in coastal areas and may exclude floods from sewerage systems (EFD).Floods are extreme events /actions of nature, in which the flow of water cannot be contained within the banks of rivers and/or retention areas. As a result it overflows into areas with human settlements, infrastructure facilities and economic activities.

1) CAUSES AND EFFECTS OF FLOODS

1) Meteorological 2) Hydrological 3) Anthropogenic

Meteorological Cause:

Most flood damages are result of extreme, intense and long duration floods caused by meteorological phenomena such as: 1) Prolonged and intense rainfall 2) Cyclones 3) Typhoons, storms and tidal surges

Hydrological:

Flooding can also be caused by increased run off due to: 1) Ice and snow melt 2) Impermeable surfaces 3) Saturated land 4) Poor infiltration rates 5) Land erosion

Anthropogenic Cause:

Mankind plays very important role in the magnitude and frequency of floods in many different ways.

1) Actually, it is the human activities in water catchments, which drastically intensify floods.
2) In this connection, human actions associated with land use changes are most important.
3) Population growth
4) Land use change, deforestation, intensive agriculture, unplanned flood control measures
5) Socio economic and development activities
6) Urbanization
7) Climate change
8) Global Warming

1.1 Effects of Floods:

a) Primary effects

The primary effects of flooding include loss of life and damage to buildings and other structures, including bridges, sewerage systems, roadways, and canals.

Floods also frequently damage power transmission and sometimes power generation, which then has knock-on effects caused by the loss of power. This includes loss of drinking water treatment and water supply, which may result in loss of drinking water or severe water contamination. It may also cause the loss of sewage disposal facilities. Lack of clean water combined with human sewage in the flood waters raises the risk of waterborne diseases, which can include typhoid, cholera and many other diseases depending upon the location of flood.

Damage to roads and transport infrastructure may make it difficult to mobilize aid to those affected or to provide emergency health treatment. Flood waters typically inundate farm land, making the land unworkable and preventing crops from being planted or harvested, which can lead to shortages of food both for humans and farm animals. Entire harvests for country can be lost in extreme flood circumstances. Some tree species may not survive prolonged flooding of their root systems.

b) Secondary and long-term effects

Economic hardship due to temporary decline in tourism, rebuilding costs, or food shortages leading to price increases is common after-effect of severe flooding. The impact on those affected may cause psychological damage to those affected, in particular where deaths, serious injuries and loss of property occur.

Urban flooding can cause chronically wet houses, leading to the growth of indoor mold and resulting in adverse health effects, particularly respiratory symptoms. Urban flooding also has significant economic implications for affected neighbourhoods.

Occurrence

Flooding occurs along rivers, in coastal areas of sea and along lakes. There are a lot of causes of flooding, for example: Intensive rainfall, Snowmelt, Collapse of dikes or other protective structures, Etc. The effects are always same water and/or sediments in an unwanted place outside the watercourse, irrespective of the cause of flood.

2) FLOOD FREQUENCY ANALYSIS

Exact sequence of stream flow for future years cannot be predicted, probability concepts must be used to study the probable variations in flow so that the design can be completed on the basis of calculated risk.

Flood frequency: flood frequency denotes the hood of flood being equalled or exceeded. A 10% frequency means that the flood has 10 out of 100 chances of being equalled or exceeded.

Recurrence interval: Recurrence interval denotes the number of year in which a flood can be expected once. It is the period of time between the equalling and exceeding of specific flood. This is usually denoted by a symbol "T".

Return period: It is the average recurrence interval for a certain event or flood.

Probability of occurrence (p): The probability of an event bring equalled or exceeded in any one year is the probability of its occurrence. The probability (p) of occurrence in flood having a recurrence interval of T years in any year or the probability of exceedance is

$$P = 1/T$$

The probability that will not occur in a year, is known as probability of non- exceedance (q) and is given by

$$Q = 1-P$$

Frequency (f): The probability of occurrence of an event expressed as a percent is known as frequency (f).thus f =100 P =100/T

Frequency studies for flood

1) Partial duration series

2) Annual duration series

In the annual series, the largest flood observed in each water year only was taken. It ignores the second and lower order events of each year which may sometimes exceed many of the annual maximum. In this series consists of values of annual maximum flood from a given catchment area, for large number of successive years. The data of series are arranged in the decreasing order of magnitude. The probability (p) of each event being equalled to or exceeded (known as plotting position) is computed from one of the following plotting position formula:

Gumbel's method:

$$P = \frac{m+C-1}{N} \quad \text{or} \quad T = \frac{N}{m+C-1}$$

Where c is known as gumbel's correction depends upon m/n ratio and can be found from table as given below

m/N	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.08	0.04
C	1	0.95	0.88	0.845	0.78	0.73	0.66	0.59	0.52	0.4	0.38	0.28

Gumbel's extreme value distribution

It is useful for obtaining the values of flood discharges for a high recurrence interval. According to gumbel (1941) the probability of occurrence of an event equal to or larger than a value x_0 is given by

$$P(x \geq x_0) = 1 - e^{-e^{-y}} \longrightarrow (1)$$

In the above equation, y is dimensionless variable, given by the expression

$$p = 1 - e^{-e^{-y}}$$

Where $p = 1/T$

$$e^{-e^{-y}} = 1 - 1/T$$

$$e^{-e^{-y}} = \frac{T-1}{T}$$

$$e^{-y}.In_e^e = In\frac{T-1}{T}$$

$$e^{-y} = -In\frac{T-1}{T}$$

$$e^{-y} = In\frac{T}{T-1}$$

$$Ine^{-y} = In.In\frac{T}{T-1}$$

$$y_T = -In.In\frac{T}{T-1} \longrightarrow (2)$$

$$y_T = -In[2.303log\frac{T}{T-1}]$$

$$y_T = -[In2.303 + Inlog\frac{T}{T-1}]$$

$$y_T = -[0.834 + 2.303loglog\frac{T}{T-1}] \longrightarrow (3)$$

$In_e = 2.303log_{10}$

The value x_T for variable x with a return period of T is given by

$$X_T = \overline{X} + K\sigma_X \longrightarrow (4)$$

Where K= $\dfrac{y_{T-0.577}}{1.2825} \longrightarrow$ (4a)

Eq. 4 is the basic gumbel's equation which is applicable to an infinite series (where $N \longrightarrow \infty$) in actual practice, N is finite and hence eq^n 4 is modified as under:

$$X_T = \overline{X} + K_T\sigma_{n-1} \longrightarrow (5)$$

Where σ_{n-1} = Standard deviation of the sample of size $N = \sqrt{\dfrac{\Sigma(X-\overline{X})^2}{N-1}}$

Y= a(x-x$_f$)

(or)

$Y = \alpha(X - a)$

$$\alpha = \frac{1.28255}{\sigma_x}$$

For small samples a and α to be estimated by following equation.

$$\alpha = \frac{S_n}{\sigma_x}$$

$$a = \bar{x} - \frac{\bar{y}_n}{S_n}\sigma_x$$

Let X_T denotes the magnitude of flood with a return period of T_r years then

$$Y_T = \alpha(x_T - a)$$

Substitute $\alpha = \frac{S_n}{\sigma_x}$ & $a = \bar{x} - \frac{\bar{y}_n}{S_n}\sigma_x$ in $Y_T = \alpha(x_Y - a)$ then we obtain

$$Y_T = \frac{S_n}{\sigma_x}\left(x_T - \bar{x} + \frac{\bar{y}_n}{S_n}\sigma_x\right)$$

$$Y_T = \frac{S_n}{\sigma_x}\left(x_T - \bar{X}\right) + \bar{y}_n$$

$$x_T = \bar{x} + \left[\frac{y_t - \bar{y}_n}{S_n}\right]\sigma_x$$

$$x_T = \bar{x} + k_T.\sigma_x$$

$$k_T = \left[\frac{y_t - \bar{y}_n}{S_n}\right] = \text{Modified frequency factor} \longrightarrow \quad (5a)$$

Y_T = Reduced variant given by eq^n (2)

$\bar{y}_n$ = Reduced mean, a function of sample size N, the values of which are given in table.

When N $\longrightarrow$ ∞, $\bar{y}_n$= 0.577, S_n=1.2825

S_n =reduced standard deviation, a function of sample size N, the values of which are given in table

Procedure:
1) For a given annual flood discharge data of size N, find mean $(\bar{x})$ and standard deviation (σ_{n-1})
2) Find the reduced mean $\bar{y}_n$ for the given value of N
3) Find reduced standard deviation S_n for the given value N
4) For the given value of recurrence interval T, determine Y_T from equation (3)
5) Knowing Y_T, $\bar{y}_n$ and S_n calculate the value of K_T from equation (5a)
6) Lastly compute the value of X_T (i.e desired flood discharge at recurrence interval T) from equation (5) in which $(\bar{x})$, K_T and σ_{n-1} are known.

3) FLOOD CONTROL METHODS (OR) FLOOD MANAGEMENT:

The term flood control is commonly used to denote all the measures adopted to reduce damages to life and property by floods. Currently, many people prefer to use the term flood management instead of flood control as it reflects the activity more realistically. As there is always possibility, however remote it may be, of an extremely large flood occurring in a river the complete control of flood to a level of zero loafs is neither physically possible nor economically feasible. The flood control measures that are to use can be classified as:

1. **Structural measures:**

    Storage and detention reservoirs

    Levees (flood embankments)

    Flood ways (new channels)

    Channel improvement Watershed management

2. Non-structural methods:

    Flood plain zoning

    Flood forecast/warning

    Evacuation and relocation Flood insurance

STRUCTURAL METHODS

➢ **Storage Reservoirs**:

Storage reservoirs offer one of the most reliable and effective methods of flood control. Ideally, in this method, a part of storage in the reservoir is kept apart to absorb the incoming flood. Further, the stored water is released in controlled way over an extended time so that the downstream channels do not get flooded. The ideal operating plans of flood control reservoir. As most in the present-day storage reservoirs have multipurpose commitments, the manipulation of reservoir levels to satisfy many conflicting demands is very difficult and complicated task. It so happens that many storage reservoirs while reducing the floods and flood damages do not always aim at achieving optimum benefits in the flood-control aspect. To achieve the complete flood control in the entire length of river, a large number of reservoirs at strategic locations in the catchment will be necessary.

➢ **Detention reservoirs:**

A detention reservoir consists of an obstruction to river with an uncontrolled outlet. These are normally small structures and operate "t" reduce the flood peak by providing temporary storage and by restriction of outflow rate. These structures are not common in India.

➢ **Levees:**

Levees, also known as dikes or flood embankments are earthen banks constructed parallel to the course of river in confine it to a fixed course and limited cross-sectional width. The heights of levees will be higher than the design flood level with sufficient free board. The confinement of river to a fixed path frees large tracts of land from inundation and consequent damage. Levees are one of the oldest and most common methods of flood-protection works adapted to the world. Also, they are probably the cheapest of structural flood-control measures. While the protection offered by a levee against food damage is obvious, what is not often appreciated is the potential damage in the event of a levee failure. The levees, being earth embankments require considerable care and maintenance, In the event of being overtopped, they fail and damage caused can be enormous. In fact, the sense of protection offered by a levee encourages economic activity along the embankment and if the levee is overtopped the loss would be more than what would have been if there were no levees. Confinement of flood banks of river by levees to a narrower space leads to higher flood levels for a given discharge. Further, if the bed levels of river also rise, as they do in aggrading rivers, the top of levees have to be raised at frequent time intervals to keep up its safety margin. The design of levee is major task in which the costs and economic benefits have to be considered. The cross section of levee will have to be designed like an earth dam. Regular maintenance and contingency arrangements to fight floods are absolutely necessary to keep the levees functional. Masonry structures used to confine the river in manner similar to levees are known as flood walls. These are used to protect important structures against floods, especially where the land is at a premium.

➢ **Flood ways:**

Floodway's are natural channels into which the part of flood will be diverted during the high stages. A floodway can be natural or man-made channel and its location is controlled by the topography. Generally, wherever they are feasible, floodway's offer an economical alternative to other structural flood-control measures. To reduce the level of river Jhelum at Srinagar, a supplementary channel has been constructed to act as a floodway with a capacity of $300\text{m}^3/\text{s}$. This channel is located at 5 km upstream of Srinagar city and its outfall in Lake Wullar. In Andhra Pradesh a floodway has been constructed to transfer part of the flood waters of river Budamaru to river Krishna to prevent flood damages to the urban areas lying on the downstream reaches of the river Budamaru.

➢ **Channel improvement:**

The works under this category involve:

1. Widening or deepening of the channel to increase the cross-sectional area.

2. Reduction of channel roughness, by clearing the vegetation from channel perimeter.

3. Short circuiting of meander loops by cut-off channels, leading to increased slopes.

All these three methods are essentially to short-term measures and require continued maintenance.

➢ **Watershed management:**

Watershed management and land treatment in the catchment aims at cutting down and delaying the runoff before it gets into the river. Watershed management measures include developing the vegetative and soil cover in conjunction with land treatment words like Nalabunds, check dams, contour bunding and zing terraces etc. These measures are towards improvement of water infiltration capacity of soil and reduction of soil erosion. These treatments because increased infiltration, greater evapotranspiration and reduction in the soil erosion; all leading to moderation of peak flows and increasing of dry weather flows. Watershed treatment is nowadays an integral part of flood management. It is believed that while small and medium floods are reduced by watershed management measures, the magnitude of extreme floods are unlikely to be affected by these measures.

NON-STRUCTURAL METHODS

The flood management strategy has to include the philosophy of living with the floods. The following non-structural measures encompass this aspect.

➢ **Flood plain zoning:**

When the river discharges are very high, it is to be expected that the river will overflow its banks and spill into flood plains. In view of increasing pressure of population this basic aspects of river are disregarded and there are greater encroachment of flood plains by man leading to distress. Flood plain management identifies that the flood prone areas of river and regulates the land use to restrict the damage due to floods. The locations and extent of areas affected by floods of different return periods are identified and development plans of these areas are prepared in such a manner that the resulting damages due to the floods are within acceptable limits of risk.

➢ Flood forecasting and warning

Forecasting of floods sufficiently in advance enables a warning to be given to the people likely to be affected and further enables civil authorities to take appropriate precautionary measures. It thus forms a very important and relatively inexpensive non-structural flood management measure. However, it must be realized that a flood warning is meaningful only if it is given sufficiently in advance. Further, erroneous warnings will cause the populace to lose confidence and faith in the system. Thus the dual requirements of reliability and advance notice are essential ingredients of flood-forecasting system.

The flood forecasting techniques can be broadly divided into three categories:

(i) Short range forecasts

(ii) Medium range forecasts

(iii) Long range forecasts.

- ### Short-Range Forecasts

In this the river stages at successive stations on river are correlated with hydrological parameters, such as rainfall over the local area, antecedent precipitation index and variation of stage at the upstream base point during the travel time of flood. This method can give advance warning of 12-40 hours for floods. The flood forecasting used for metropolitan city of Delhi is based on this technique.

- ### Medium-Range Forecasts

In this method rainfall-runoff relationships are used to predict flood levels with warning of 2-5 days. Coaxial graphical correlations of runoff, with rainfall and other parameters like the time of year, storm duration and antecedent wetness have been developed to a high stage of refinement by the US Weather Bureau.

- ### Long-Range Forecasts:

Using radars and meteorological satellite data, advance information about critical storm-producing weather systems, their rain potential and time of occurrence of the event are predicted well in advance.

- ### Evacuation and relocation:

Evacuation of communities along with their live stocks and other valuables in the chronic flood affected areas and relocation of them in nearby safer locations is an area specific measure of flood management. This would be considered as non-structural measure when this activity is temporary measure confined to high floods. However, the permanent shifting of communities to safer locations would be termed as structural measure. Raising the elevations

of buildings and public utility installations above normal flood levels is termed as flood proofing and is sometimes adopted in coastal areas subjected to severe cyclones.

- **Flood insurance:**

Flood insurance provides a mechanism for spreading the loss over large numbers of individuals and thus modifies the impact of loss burden. Further, it helps, though indirectly, flood plain zoning, flood forecasting and disaster preparedness activities.

4) FLOOD ROUTING

It may be defined as the procedure where by the shape of flood hydrograph at a particular location on the stream is determined from the known or assumed flood hydrograph at some other location upstream. Flood routing is the technique in hydrology to compute the effect of storage on the shape and movement of flood wave. It is used in establishing the height of flood peak at a downstream location. Flood routing is the technique of determining the flood hydrograph at section of river by utilizing the data of flood flow at one or more upstream sections. The hydrologic analysis of problems such as flood forecasting, flood protection, reservoir design and spillway design invariably include flood routing. In these applications two broad categories of routing can be recognized.

These are:

HYDRAULIC ROUTING:

In this we use continuity equation and moment's equation

$$\frac{\partial Q}{\partial x} + T.\frac{\partial Y}{\partial t} = 0$$

Moment equation

$$\frac{\partial y}{\partial x} + \frac{v}{g}\frac{\partial v}{\partial x} + \frac{1}{g}\frac{\partial v}{\partial t} = S_0 - S_f$$

HYDROLOGIC ROUTING:

Inflow –outflow = change in storage

$$I - O = \frac{ds}{dt}$$

1. **Reservoir routing:**

➤ **Level pool routing**: In this we assume that reservoir level is horizontal.

$$I - O = \frac{ds}{dt} \quad \text{Where I is a f(t)}$$

For small interval Δt

$$\overline{I}\,\Delta t - \overline{Q}\Delta t = \Delta s$$

Where $\overline{Q}$ = Average outflow

$\overline{I}$ = Average inflow

Δs = Change in storage = $S_2 - S_1$

I_1 = Before time period Δt

I_2 = After time period Δt

➢ **Good rich method**:

This is same as modified plus method

Now,

$$\left(\frac{I_1+I_2}{2}\right) - \left(\frac{Q_1+Q_2}{2}\right) = \frac{S_2-S_1}{\Delta t}$$

2) Channel routing

Channel routing the storage is a function of both outflow and inflow discharges. The total volume in storage can be considered fewer than the two categories as:

1. Prism storage

2. Wedge storage
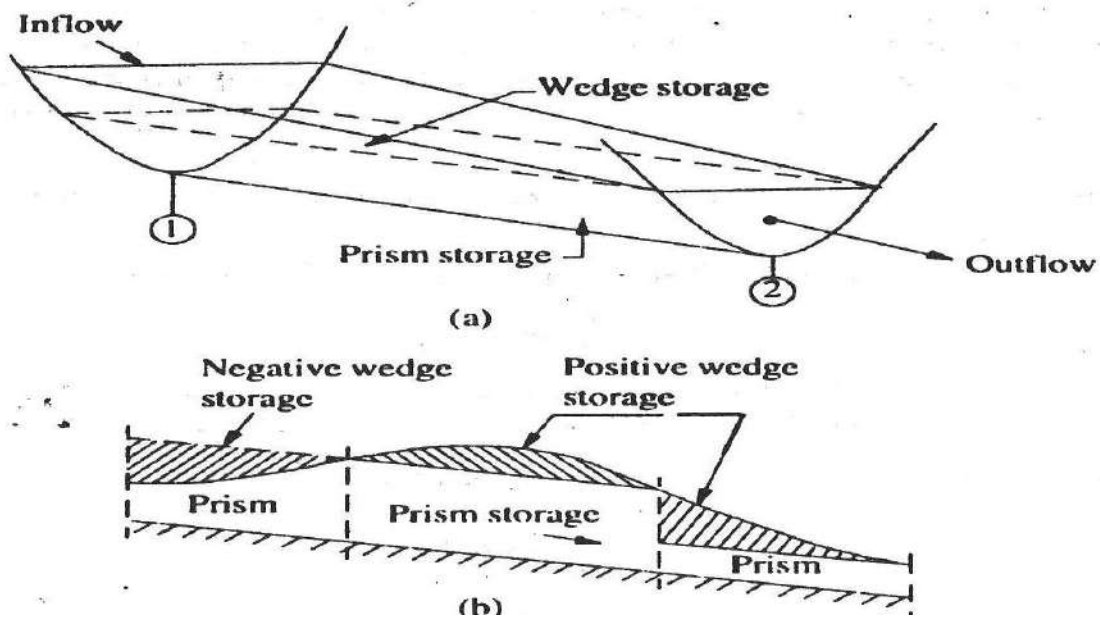
Storage in a channel reach

$S_{Prism} = KQ$

$S_{Wedge} = KX(I - Q)$

K = Travel time of peak through the reach

X = Weight on inflow versus outflow ($0 \le X \le 0.5$)

X = 0 ➔ Reservoir, storage depends on outflow, no wedge

X = 0.0 - 0.3 ➔ Natural stream

$S = S_p + S_w$ $S_p = f(Q)$, $S_w = f(Q)$

Muskingum method of routing:

$$S = KQ + KX(I - Q)$$

$$S = K[XI + (1 - X)Q]$$

Where X = 0+0.05

If X= 0 then S= KQ

The continuity equation is

$$\frac{I_1 + I_2}{2} - \frac{O_1 + O_2}{2} = \frac{S_2 - S_1}{\Delta t} \longrightarrow (1)$$

Now,

$S_2 - S_1 = K[x(I_2-I_1) + (I-X)(Q_2-Q_1)] \longrightarrow (2)$

By solving eq^n 1 and 2 we get

$$Q_2 = C_0 I_2 + C_1 I_1 + C_2 Q_1$$

$C_0 = (-Kx + 0.5\Delta t)/k(1-X) + 0.5\Delta t$

$C_1 = (Kx + 0.5\Delta t)/k(1-X) + 0.5\Delta t$

$C_2 = ((K-Kx) - 0.5\Delta t)/k(1-X)+0.5\Delta t$

Subtract equation (2) from (1) we get

$Q_2 = I_2 C_0 + I_1 C_1 + Q_1 C_2$

Hydrology

GROUND WATER

Syllabus

Ground water occurrence: Ground water hydrologic cycle, origin of ground water, rock properties effecting ground water, vertical distribution of ground water, zone of aeration and zone of saturation, geologic formation as aquifers, types of aquifers, porosity, specific yields and specific retention.

Types of aquifers and formations

Ground water is widely distributed in the ground and is replenish able resource unlike other resources of earth. The problems in Ground Water Investigation are the zones of occurrence and recharge. A water bearing geologic formation or stratum capable of transmitting water through its pores at a rate sufficient for economic extraction by the wells is called **'aquifer'.**

Formations that serve as good aquifers are:

• Unconsolidated gravels, sands, alluvium
 • Lake sediments, glacial deposits
• Sand stones
 • Limestone's with cavities (caverns) formed by the action of acid waters
 • Granites and marble with fissures and cracks, weathered gneisses and schist
A geologic formation, which can absorb water but cannot transmit significant amounts, is called an **'aquiclude'**. Examples are clays, shale's, etc.

A geologic formation with no interconnected pores and hence can neither absorb nor transmit water is called an **'aquifuge'**. Examples are basalts, granites, etc.

 A geologic formation of rather impervious nature, which transmits water at a slow rate compared to an aquifer (insufficient for pumping from wells) is called an **'aquitard'.** Examples are clay lenses interbedded with sand.

CONFINED AND UNCONFINED AQUIFERS
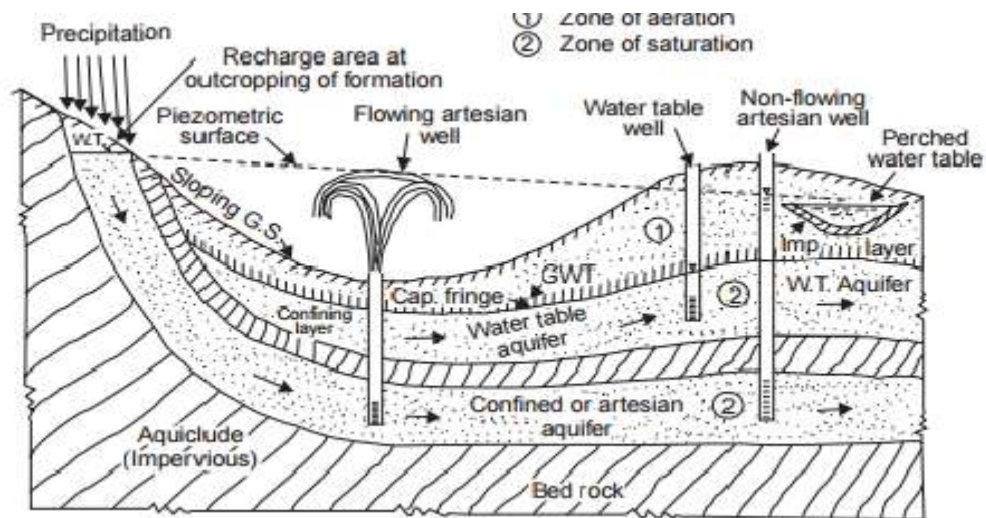
Figure 5.1 Types of aquifers and location of wells

If there is homogeneous porous formation extending from the ground surface up to an impervious bed underneath as shown in Fig. 5.1, rainwater percolating down in the soil saturates the formation and builds up the ground water table (GWT). This aquifer under water table conditions is called an unconfined aquifer (water-table aquifer) and well drilled into this aquifer is called a water table well. On the other hand, if a porous formation underneath is sandwiched between two impervious strata (aquicludes) and is recharged by natural source (by rain water when the formation outcrops at ground surface recharge area, or outcrops into a river-bed or bank) at a higher elevation so that the water is under pressure in the aquifer (like pipe flow), i.e., artesian condition. Such an aquifer is called an artesian aquifer or confined aquifer. If a well is drilled into an artesian aquifer, the water level rises in the well to its initial level at the recharge source called the piezometric surface. If the piezometric surface is above the ground level at the location of well, the well is called 'flowing artesian well' since the water flows out of the well like a spring, and if the piezometric surface is below the ground level at the well location, the well is called a non-flowing artesian well. In practice, a well can be drilled through 2-3 artesian aquifers (if multiple artesian aquifers exist at different depths below ground level). Sometimes a small band of impervious strata lying above the main ground water table (GWT) holds part of the water percolating from above. Such small water bodies of local nature can be exhausted quickly and are deceptive. The water level in them is called '**perched water table'.**

AQUIFER PARAMETERS

Specific yield : While porosity (n) is measure of water bearing capacity of the formation, all this water cannot be drained by gravity or by pumping from wells as a portion of water is held in the void spaces by molecular and surface tension forces. The volume of water expressed as a percentage of total volume of saturated aquifer, that will drain by gravity when the water table (Ground Water Table (GWT) drops due to pumping or drainage, is called the 'specific yield (Sy)' and that percentage volume of water, which will not drain by gravity is called 'specific retention (Sr)' and corresponds to 'field capacity' i.e., water holding capacity of soil (for use by plants and is an important factor for irrigation of crops). Thus, porosity = specific yield + specific retention n = Sy + Sr. Specific yield depends upon grain size, shape and distribution of pores and compaction of the formation. The values of specific yields for alluvial aquifers are in the range of 10–20% and for uniform sands about 30%.

Storage coefficient: The volume of water moves out by a unit prism of aquifer (i.e., a column of aquifer standing on a unit horizontal area) when the piezometric surface (confined aquifers) or the water table (unconfined aquifers) drops by unit depth is called the storage coefficient of aquifer (S) and is dimensionless (fraction). It is the same as volume of water taken into storage by a unit prism of aquifer when the piezometric surface or water table rises by unit depth. In the case of water table (unconfined) aquifer, the storage coefficient is the same of specific yield (Sy). Since the water is under pressure in an artesian aquifer, the storage coefficient of an artesian aquifer is attributable to the compressibility of aquifer skeleton and expansibility of pore water (as it comes out of the aquifer to atmospheric pressure when the well is pumped) and is given by the relationship

$$S = \gamma_w n b \left(\frac{1}{K_w} + \frac{1}{nE_s} \right)$$

S = Storage coefficient (decimal)

γ_w = Specific weight of water

n = Porosity of soil (decimal)

b = Thickness of the confined aquifer

K_w = Bulk modulus of elasticity of water

E_s = Modulus of compressibility (elasticity) of soil grains in the aquifer.

The storage coefficient of an artesian aquifer ranges from 0.00005 to 0.005, while for a water table aquifer S = Sy = 0.05–0.30.

Porosity (n): Those portions of soil, not occupied by solids; Ratio of volume of pores or interstices to total volume.

Permeability – An expression of movement of water in any direction.

Vertical Distribution of ground water:

Water in the subsurface may be divided into two major zones: i) water stored in the unsaturated zone also known as vadose zone or **zone of aeration** and ii) water stored in the **saturated zone**. Soil pore spaces in the vadose zone, lying immediately below the surface. Here the small pore spaces between soil particles are filled with a mixture of water and air resulting in an area which is less than saturated zone. This zone may be divided with respect to occurrence and circulation of water into the uppermost zone of soil water, the intermediate zone and capillary fringe, immediately above the water table. Water in this zone is called capillary water. This water moves upward from the water table by capillary action. Capillary water moves slowly in any direction. Water cannot be withdrawn from this zone for residential or commercial water supply purpose because the capillary forces hold it too tightly.

The roots of trees, plants and crops, however, can tap into this water. The capillary fringe moves upwards and downwards together with the water table due to seasonal pattern. In Fig 5.2 shows that the distribution of water in the subsurface regions. Groundwater is water below the water table, falling entirely all rock interstices (void spaces) in the saturated zone. The water located in this zone can be withdrawn for various uses. The variation in flow of groundwater depends on the type of rocks or other permeable material, the size of pore spaces in the soil or rock, connectivity of pore spaces, and configuration of underground strata. Water Table: The upper surface of zone of saturation is known as water table. At the water table, the water in the pores of aquifer is at atmospheric pressure. The hydraulic pressure at any level within a water table aquifer is an equal to the depth from water table point and is referred as the hydraulic head. When the well is dug into water table aquifer, the static water level in the well stands at the same elevation of the water table. The groundwater table, sometimes called the free or phreatic surface, is not a stationary surface. This water table moves up and down due to various reasons. It may rises when more water is added to the saturated zone by vertical percolation, and drops down during drought periods when the stored water flows out towards springs, streams, well and other points of groundwater discharge.
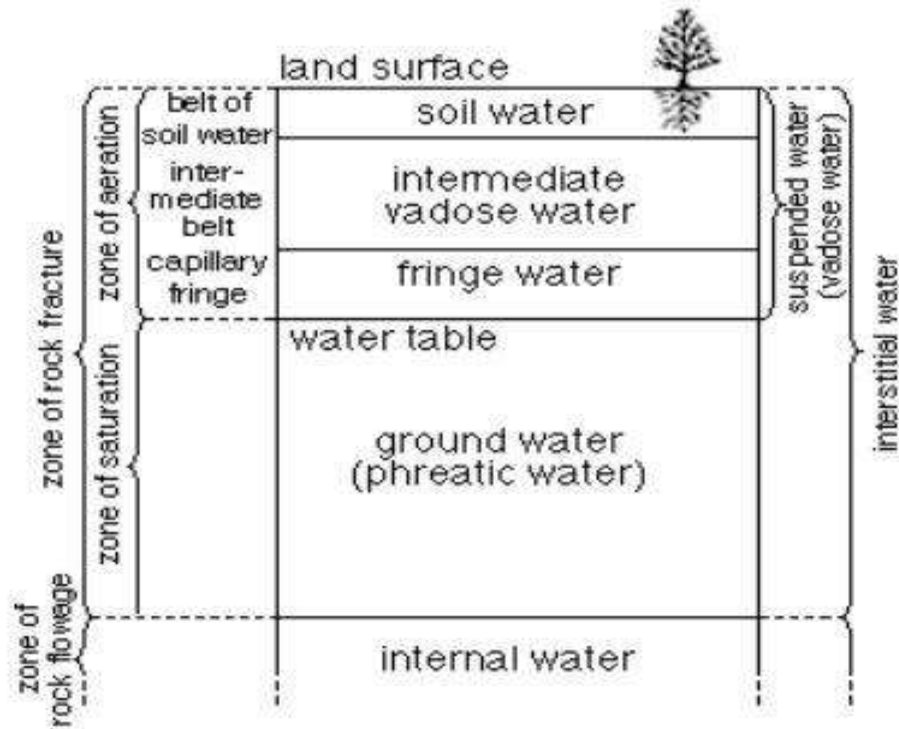
Fig: Subsurface Distribution of water

DARCY'S LAW

Flow of ground water except through coarse gravels and rock fills is laminar and velocity of flow is given by the Darcy's law (1856), which states that 'the velocity of flow in porous medium is proportional to the hydraulic gradient' as shown in Fig. 5.2.

$V = Ki$, ...(1)

$i = \Delta h/ L$ ...(2)

$Q = AV = AKi$,..(3)

$A = Wb$, $T = Kb$

$Q = WbKi$

$Q = Tiw$..(4)

Where V = Velocity of flow through the aquifer

K = Coefficient of permeability of aquifer soil

i = Hydraulic gradient = $\Delta h/L$

Δh = Head loss in a length of flow path L

A = Cross-sectional area of aquifer (= wb) w = width of aquifer b = thickness of aquifer

T = Coefficient of transmissibility in the aquifer

Q = Rate of discharge of ground water (discharge or yield)

Darcy's law is valid for laminar flow, i.e., the Reynolds number (Re) varies from 1 to 10, though most commonly is less than 1.
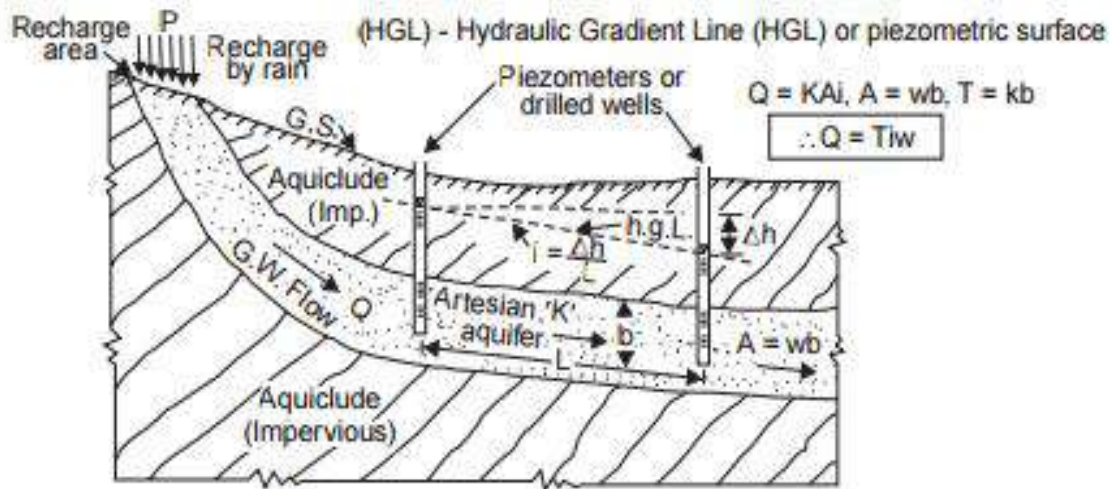
Figure 5.2 : Flow of ground water

TRANSMISSIBILITY

It can be seen from Eq. (4) that T = Q, when i = 1 and w = 1; i.e., the transmissibility is flow capacity of an aquifer per unit width under unit hydraulic gradient and is equal to the product of permeability times the saturated thickness of aquifer. In confined aquifer, T = Kb and is independent of piezometric surface. In water table aquifer, T = KH, where H is the saturated thickness. As the water table drops, H decreases and transmissibility was reduced. Thus, the transmissibility of an unconfined aquifer depends upon the depth of GWT.

WELL HYDRAULICS

Steady radial flow into well (Dupuit 1863, Thiem 1906)

Assuming that the well is pumped at a constant rate Q for a long time and the water levels in the observation wells have stabilized, i.e., equilibrium conditions have been reached, Fig. 5.3 (a).

From Darcy's law,

$$Q = K i A$$

$$Q = K \frac{dy}{dx}(2\pi xy)$$

$$Q \int_{r1}^{r2} dx/x = 2\pi K \int_{h1}^{h2} y \, dy$$

$$Q = \frac{\pi K(h_2^2 - h_1^2)}{2.303 \log_{10}\left(\frac{r_2}{r_1}\right)} \qquad \ldots\ldots\ldots 6$$
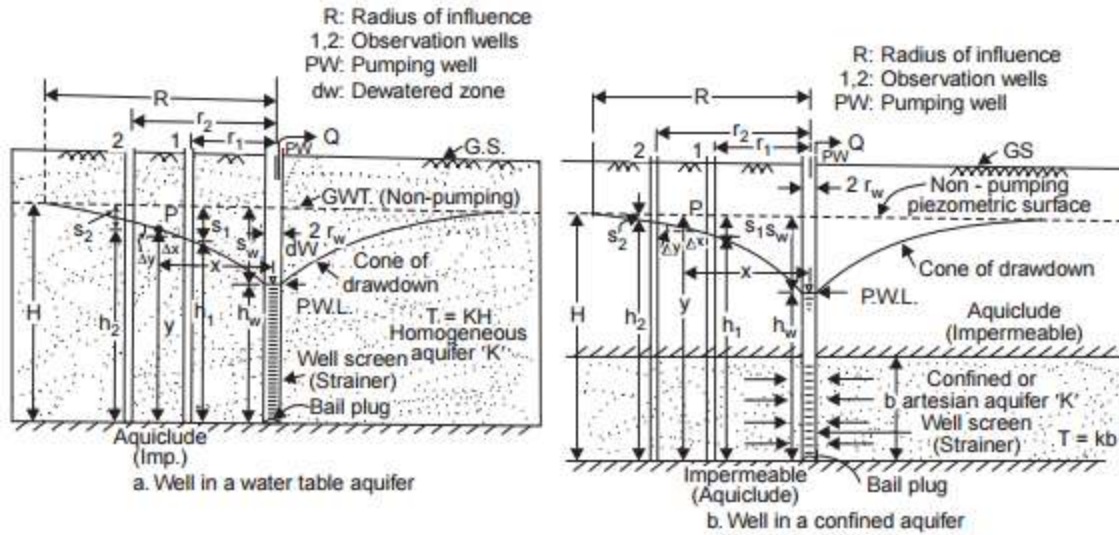
Figure 5.3: Steady radial flow into well

Applying the Eq. (6) between the face of well ($r = r_w$, $h = h_w$) and the point of zero drawdown ($r = R$, $h = H$)

$$Q = \frac{\pi K (H^2 - h^2)}{2.303 \log_{10}\left(\dfrac{R}{r_w}\right)} \qquad \ldots\ldots..7$$

If the drawdown in the pumped well ($S_w = H - h_w$) is small

$H^2 - h_w^{\,2} = (H + hw)\,(H - h_w)$, $H + h_w \approx 2H$

$= 2H\,(H - h_w)$

$$Q = \frac{2\pi KH\,(H - h_w)}{2.303 \log_{10}\left(\dfrac{R}{r_w}\right)}, \qquad \ldots\ldots.8$$

(b) Artesian conditions (confined aquifer)

If the well is pumped at constant pumping rate Q for a long time and equilibrium conditions have been reached, Fig. 5.3 (b).

From Darcy's law, $Q = K\,i\,A$

$Q = K \dfrac{dy}{dx}\,(2\pi\,xb)$

$Q \int_{r1}^{r2} dx/x = 2\,\pi\,K \int_{h1}^{h2} b\,dy$

$$Q = \frac{2\pi\,(kb)\,(h_2 - h_1)}{2.303 \log_{10}\left(\dfrac{r_2}{r_1}\right)} \qquad \ldots\ldots..9$$

Applying Eq. (7.9) between the face of well ($r = r_w$, $h = h_w$) and the point of zero drawdown ($r = R$, $h = H$), simplifying and putting $T = Kb$,

$$Q = \frac{2.72\, T\,(H - h_w)}{\log_{10}\left(\dfrac{R}{r_w}\right)}$$

Dupuit's Equations Assumptions:

The following assumptions are made in the derivation of Dupuit Thiem equations:

(i) Stabilized drawdown i.e., the pumping has been continued for sufficiently long time at a constant rate, so that the equilibrium stages of steady flow conditions have been reached.

(ii) The aquifer is homogeneous, isotropic, of infinite areal extent and of constant thickness, i.e., constant permeability.

(iii) Complete penetration of well (with complete screening of aquifer thickness) with 100% well efficiency.

(iv) Flow lines are radial and horizontal and flow is laminar, i.e., Darcy's law is applicable. (v) The well is infinitely small with negligible storage and all the pumped water comes from the aquifer.

SPECIFIC CAPACITY

The specific capacity Q/S_w of well is the discharge per unit drawdown in the well and is usually expressed as lpm/m. The specific capacity is measure of effectiveness in the well; it decreases with the increase in pumping rate (Q) and prolonged pumping (time, t). In Eq. (8) by putting $r_w = 15$ cm, $R = 300$ m, $KH = T$ $H–h_w = S_w$, the specific capacity

$$\frac{Q}{S_w} = T/1.2$$

HYDRAULICS OF OPEN WELLS

Theis equation does not apply for shallow dug open wells since there is no instantaneous release of water from the aquifer, most of the water being pumped only from storage inside the well as shown in Fig. 5.4. In alluvial soil, if the water is pumped at a high rate the depression head (static water level inside the well during pumping) will increase, which may cause excess gradients resulting in loosening of sand particles (quick sand phenomenon). This limiting head is called 'critical depression head'. The 'safe working depression head' is usually one-third of critical head and yield under this head is called the maximum safe yield of the well.
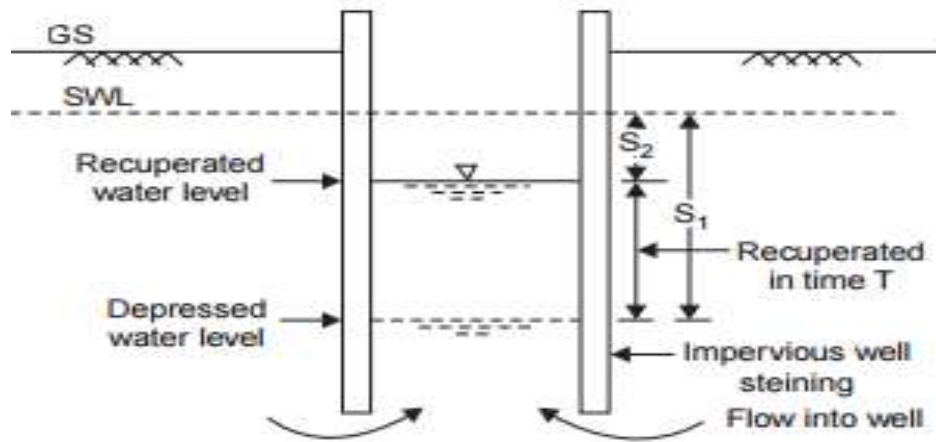
Figure 5.4: Recuperation test in open wells

Yield Tests

The following tests may be performed to get an idea of the probable yield of well: (a) Pumping test (b) Recuperation test

(b) **Recuperation Test:** In the recuperation test, the water level in the well is depressed by an amount less than the safe working head for the subsoil. The pumping is stopped and water level is allowed to rise or recuperate. The depth of recuperation in a known time is noted from which the yield of well may be calculated from the Fig. 5.4.

Let the water level inside the well rise from s_1 to s_2 (measured below static water level, swl) in time T. If s is the head at any time t, from Darcy's law

$Q = Kai$

If a head "s" is lost in a length of L for seepage path

$$Q = KA \frac{s}{L}$$

$Q = CAs$

Where the constant $C = K/L$ and has dimensions of T^{-1}.

If in a time dt, the water level rises by an amount ds $Q\ dt = -A\ ds$

the −ve sign indicates that the head decreases as the time increases. Putting $Q = CAs$

$CAs\ dt = -A\ ds$

$$C \int_0^t dt \text{ T } dt = - \int_{si}^{s2} ds/s$$

$$C = \frac{2.303}{T} \log 10 \left(\frac{s1}{s2}\right)$$

Assuming the flow is entirely from the bottom (impervious layers of masonry), the yield of well

$$Q = CAH$$

From this equation, if $Q = C$ when $A = 1$, $H = 1$, i.e., the specific yield of soil is the discharge per unit area under a unit depression head and has dimension of T^{-1} (1/time) and the usual values are

$C = 0.25$ hr^{-1} for clayey soil

$C = 0.50$ hr^{-1} for fine sand

$C = 1.00$ hr^{-1} for coarse sand

Hydrology

UNIT-VI

IRRIGATION

Syllabus

Necessity and importance of irrigation, advantages and ill effects of irrigation, types of irrigation, methods of applications of irrigation water, water logging and drainage, standards of quality for irrigation water, principal crops and crops seasons, crop rotation.

Introduction:

Irrigation may be defined as the process of artificially supplying water to the soil for raising crops. It is a science of planning and designing of an efficient low cost irrigation system to suite the natural conditions. It is the engineering of controlling and harnessing various natural sources of water by the construction of dams and reservoirs, canals and head works and finally distributing the water to the agricultural fields. Irrigation engineering includes the study and design of works connected with the river control, drainage of water logged areas and generations of hydro electric power.

Necessity of Irrigation

Necessity of irrigation is generally due to the following situations.

1. Rainfall is less than the water requirement of plants.
2. Rainfall is sufficient, but the spatial distribution of rainfall is not as per requirement.
3. Rainfall is sufficient and spatial distribution is also good, but the temporal distribution is not as per the requirement.
4. Advanced scientific development (HYV-High yield variety).

Increase in agricultural production and productivity depends, to large extent, on the availability of water. Hence, the importance of irrigation is however, the availability of irrigation facilities which is highly inadequate in India. For example, in 1950-51, gross irrigated area as percentage of gross cropped area was only 17%. Even now 60% of gross cropped area depends on rain. That is why Indian agriculture is called a gamble in the monsoon.

Importance of Irrigation

Control of drought and famines insufficient, uncertain and irregular rain causes uncertainty in the agriculture. The period of rain is restricted to only four months in a year, June to September, when monsoon arrives. The remaining eight months are dry. There is some rainfall during the months of December and January in some parts of the country. Even during monsoon, the rainfall is scanty and undependable in many parts of the country. Sometimes the monsoon delayed considerably while sometimes they cease prematurely. This pushes large areas of country into drought conditions. With the help of irrigation, droughts and famines can be effectively controlled.

1. Higher productivity on irrigated land:

Productivity on irrigated land is considerably more than the productivity on un-irrigated land.

2. Multiple cropping possible:

Since India has a tropical and sub-tropical climate, it has potentialities to grow crops for a year round basis. However, since 80% of annual rainfall is received in less than four months, multiple cropping is generally not possible. Provision of irrigation facilities can make possible the growing of two or three crops is year in most areas of country. This will considerably improve agriculture production and productivity.

3. Role in new agricultural strategy:

The successful implementation of High Yielding Programmed enhances agricultural production in great intent.

4. Bringing more land under cultivation:

Total reporting area for land utilization statistics was 306.05 million hectares in 1999-2000. In this 19.44 million hectares was current fallow land. Current fallowed include lands which are lying fallow for less than one year other than current fallows includes land lying un-ploughed for one to five years. Cultivable waste land comprises another 13.83 million hectares. Cultivation on all such lands is impossible in some cases while in others it requires substantial capital investment to make land fit for cultivation. Provision of irrigation facilities can make some portion of this land cultivable.

5. Reduces instability in output levels:

Irrigation helps in stabilizing the output and yield levels. It also plays a protective role during drought years. Since, both income and employment are positively and closely related to output,

prevention of fall in output during drought is an important instrument for achieving stability of income and employment in the countryside. Irrigation has enabled many states to acquire 'partial immunity' from drought.

6. Indirect benefits of irrigation:

Irrigation confers indirect benefits through increased agricultural production. Employment potential of irrigated lands, increase production, helps in developing allied activities means of water transport etc. are improve income of government from agriculture. Availability of regular water supply will increase the income of farmers imparting a sense of security and stability in agriculture.

Benefits of Irrigation

1. Increase in Crop Yield
2. Protection from femine
3. Cultivation of superior crops
4. Elimination of mixed cropping
5. Economic development
6. Hydro power generation
7. Domestic and industrial water supply

Advantages of Irrigation

Some of the advantages of irrigation are as follows.

- Increase of food production
- Modify soil or climate environment – leaching
- Lessen risk of catastrophic damage caused by drought
- Increase income and national cash flow
- Increase labor employment
- Increase standard of living
- Increase value of land
- National security thus self sufficiency
- Improve communication and navigation facilities
- Domestic and industrial water supply
- Improve ground water storage
- Generation of hydro-electric power

Disadvantages of Irrigation

The following are the disadvantages of irrigation:

- Water logging
- Salinity and alkalinity of land
- Ill aeration of soil
- Pollution of underground water
- Results in colder and damper climate causing outbreak of diseases like malaria

Types or Systems of Irrigation:
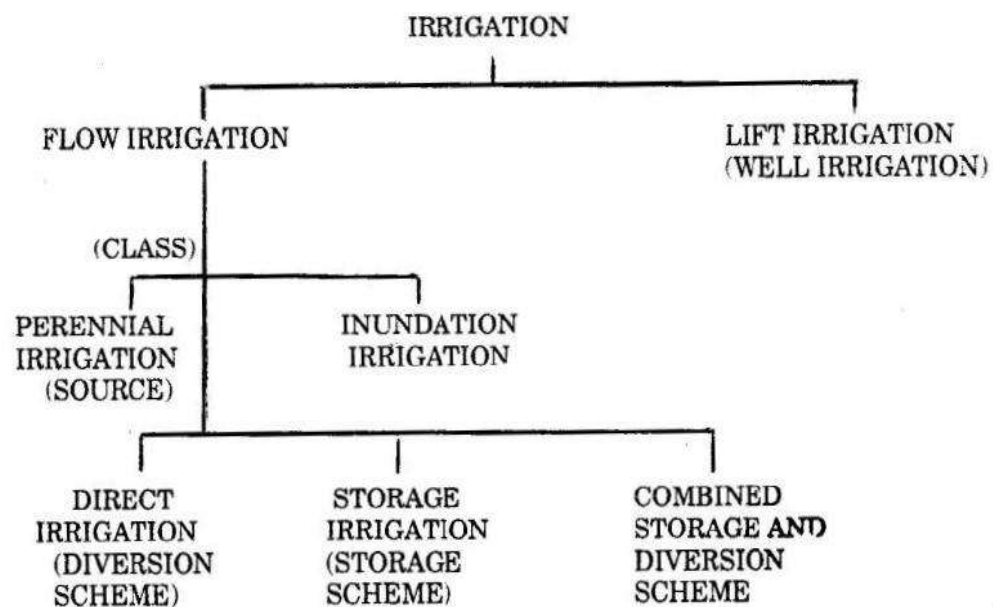
Lift Irrigation: It is that system of irrigation in which the irrigation water is available at a level lower than that of land to be irrigated and hence water is lifted by pumps or other mechanism (Hydraulic ram and siphon action) then conveyed to agriculture fields by gravity flow. Irrigation through wells is an example of lift irrigation. Water from canals or any other source can also be lifted when the level of water is lower than that of area to be irrigated.

Inundation Irrigation: It is that system of irrigation in which the large quantity of water flowing in river is allowed to flood or inundate the fields to be cultivated. The land becomes thoroughly saturated. Excess water was drained off and the land was prepared for cultivation. Moisture stored in the soil is sufficient to bring the crop to maturity. Inundation irrigation is commonly practiced in delta region of rivers. Canals may be also employed to inundate the fields when the water is available in plenty.

Perennial Irrigation: It is that system of irrigation in which the irrigation water is supplied as per the crop requirements at regular intervals throughout the crop period. The source of irrigation water may be a perennial river, stored water in reservoirs or ground water drawn from the open wells or bore wells. This is most commonly adopted irrigation system.

Direct Irrigation: It is type of flow irrigation in which the water from rivers and streams are conveyed directly to agricultural fields through a network of canals, without making any attempt to store water this is practiced in areas where the rivers and streams are perennial. Small diversion dams or barrages may be constructed areas by the rivers to raise the water level and then divert the water into canals.

HR = Head regulator
CDW = Cross-drainage works
T.C. = Tail cluster
T.E. = Tail escape
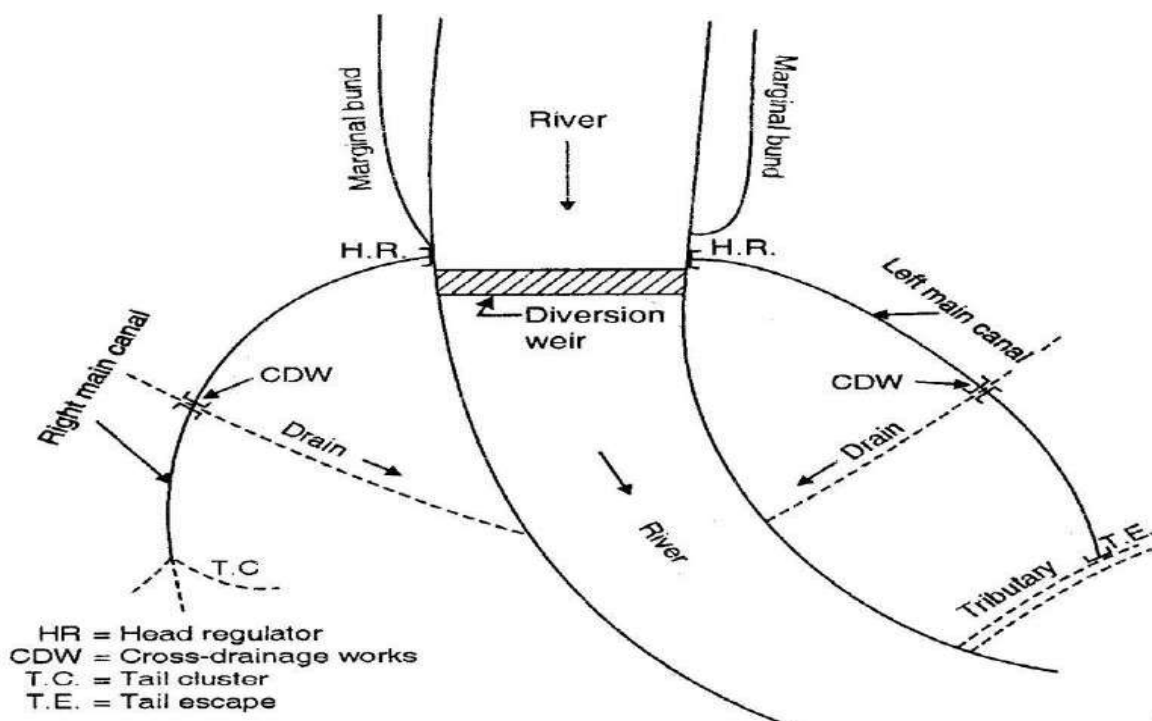
Storage Irrigation:

Dams are constructed across the rivers which are non- perennial. The discharge in such rivers may be very high during rainy season and may become less during dry stream. By constructing dams across such rivers water can be stored as reservoir during excess flow and can be utilized or diverted to agriculture fields through canals as and when required. Such a system is known as storage irrigation.

H.R. = Head regulator
C.R. = Cross regulator
T.E. = Tail escape
T.C. = Tail clusture
S. = Superpassage
T. = Tributary
A. = Aqueduct
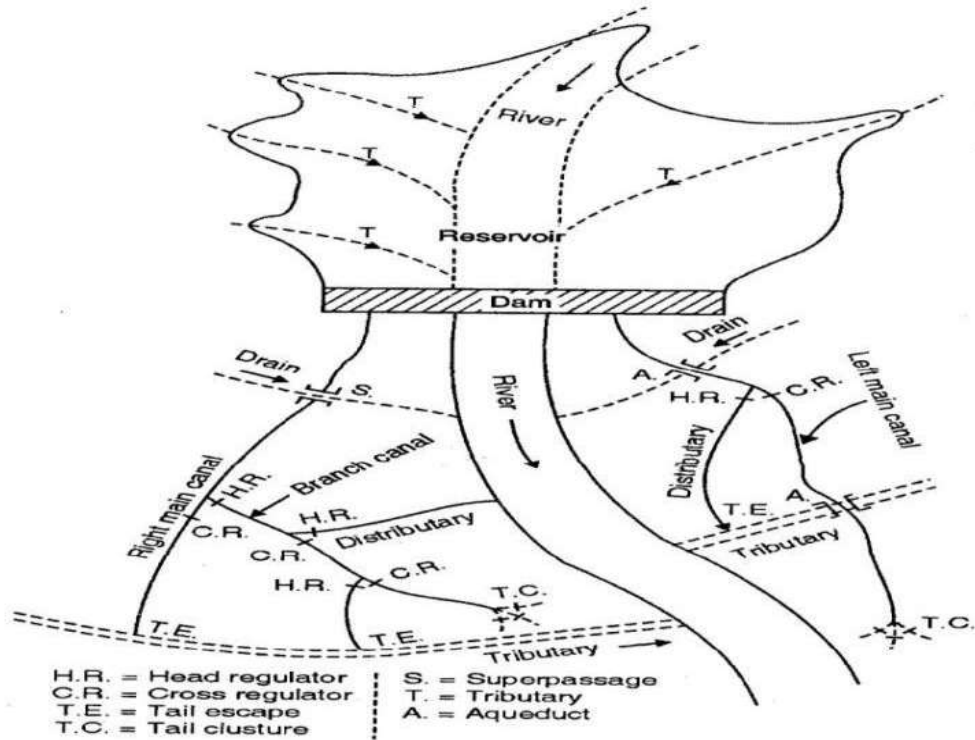
Bandhara Irrigation: It is special irrigation scheme adopted across small perennial rivers. This system lies somewhere between inundation type and permanent type of irrigation. A Bandhara is low masonry weir (obstruction) of height 1.2m to 4.5m constructed across the stream to divert water into the small canal. The canal usually takes off from one side and flow into canal is controlled by the head regulator.

(a) Bandhara irrigation layout

(b) Section of Bandhara
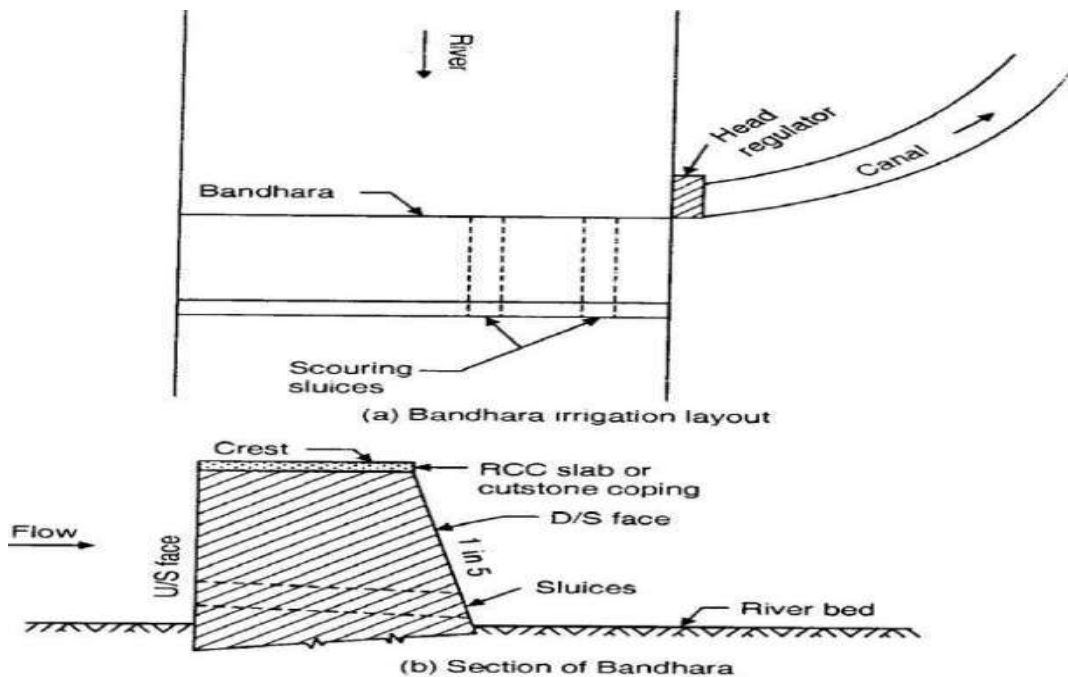
The length of main canal is usually restricted to about 8km. A series of Bandharas may be constructed one below the other on the same stream so that water spilling over from one Bandhara was checked by another Bandhara. The irrigation capacity of each Bandhara is may be about 400 hectares. Bandharas are adopted across small streams having isolated catchments which are considered to be non feasible or uneconomical to included under a large irrigation scheme. This method of irrigation is followed in Central Maharashtra and commonly known there as the "Phad" system.

Methods of application in irrigation water:
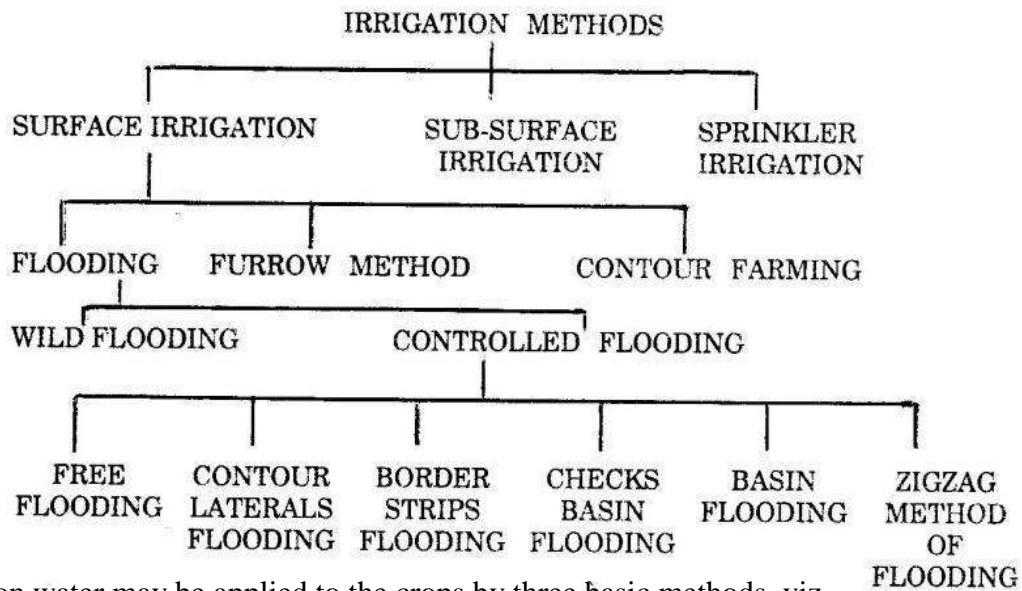
Irrigation water may be applied to the crops by three basic methods, viz.

    a. Surface irrigation methods

    b. Subsurface irrigation methods

    c. Sprinkler irrigation

Good irrigation methods result in increased yield, conservation of soil productivity and economic utilization of water. Over irrigation results in soil erosion, water logging, salt accumulation, nutrient leeching etc. The overall objective of an irrigation method is to see that the required amount of moisture is available in the root zone of crops. The objectives or reasons for adopting any irrigation method for applying water to fields are as follows:

1. For light irrigation uniform water distribution with a small depth of application, as small as cm should be possible.

2. For heavy irrigation uniform water depth application of 15 to 20 cm should be possible.

3. Large concentrated of flow should be possible for reducing conveyance losses and labor costs.

4. Mechanical farming should be facilitated.

a. Surface irrigation method: In this method the irrigation water was applied by spreading water as a sheet or as a small stream on the land to be irrigated.

Various surface irrigation methods that are practiced are listed as follows.

1. Wild flooding: In this method water is applied by spreading water over the land to be irrigated without any preparation. There is no restriction for movement of water. It follows the natural slope of land. The water may be applied to the land directly from natural stream during season of high flow as in inundation irrigation. This method is suitable for flat and smooth land but involves wastage of water and hence it can be practiced where water is abundant and inexpensive.

2. Controlled flooding: In this method water is applied by spreading it over the land to be irrigated with proper control over the flow of water as well as the quantity of water to be applied. In such methods the prior land preparation is essential.

Various controlled flooding methods are as follows:

i) Free flooding: This method is also known as irrigation by plots. Here the field is divided into number of small sized plots which are practically level. Water is admitted at the higher end of plots and water supply is cut off as soon as the water reaches the lower end of plots.
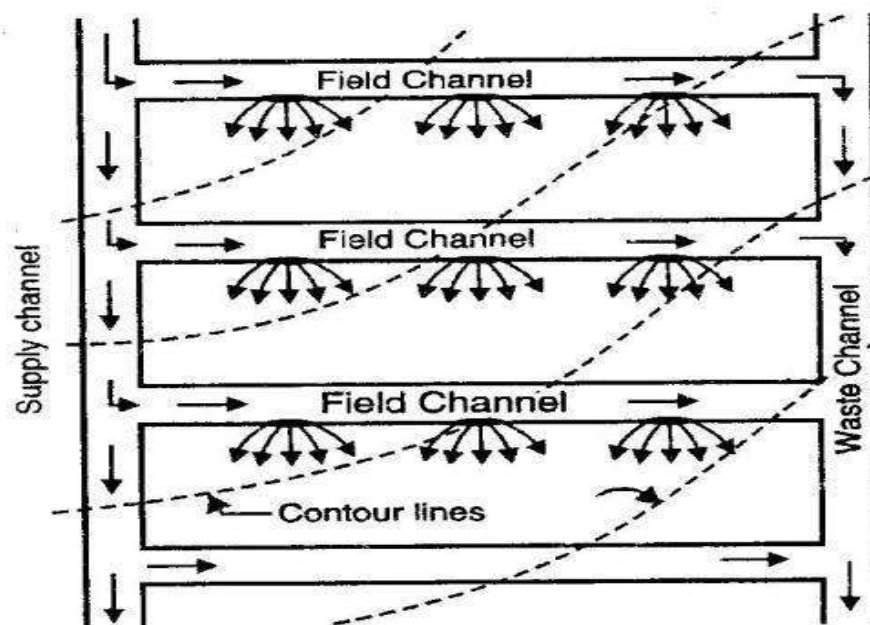
(a) Field channels at right angles
to the sides of the field

ii) Border strip method: In this method the land to be irrigated is divided into series of long narrow strips separated from each other by levees (Earthen bunds) or borders. The width of strips varies between 10 to 20 m and the length of strip varies between 60 to 300m depending upon the nature of soil and rate of water supply.
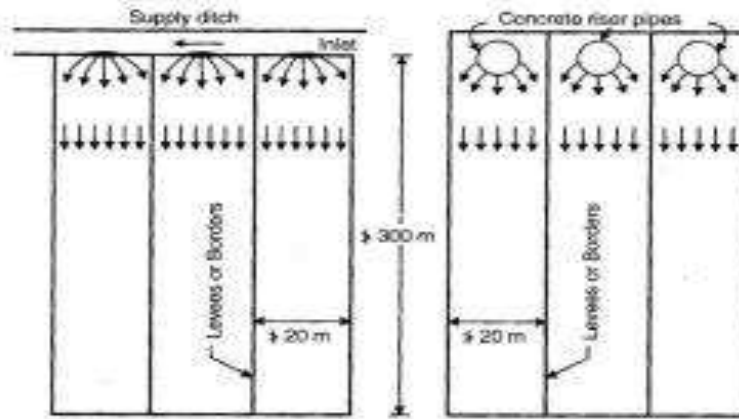

The strip of land has no cross slope and has uniform gentle slope in the longitudinal direction. This method is suitable for forage crops requiring least labor. Mechanized farming can be adopted in this method.

iii) Checks or Levees: In this method comparatively large stream of water discharged into relatively level plot surrounded by check or levees or low rise bunds. The checks are usually 30 cm high. The checks may be temporary for single crop season or semi permanent for repeated used as in case of paddy fields. The size of plots depends upon the discharge of water and porosity of soil. The usual size of plot varies between 0.04 hectares to 0.05 hectares.

iv) Basin flooding: This method of irrigation is adopted for irrigating orchards (enclosures of fruit trees). For each tree, a separate basin which is circular usually is made. However, in some cases basins are made large to include two or more trees in each basin. Water is supplied through a separate field channel, but in some cases the basins are inter connected.
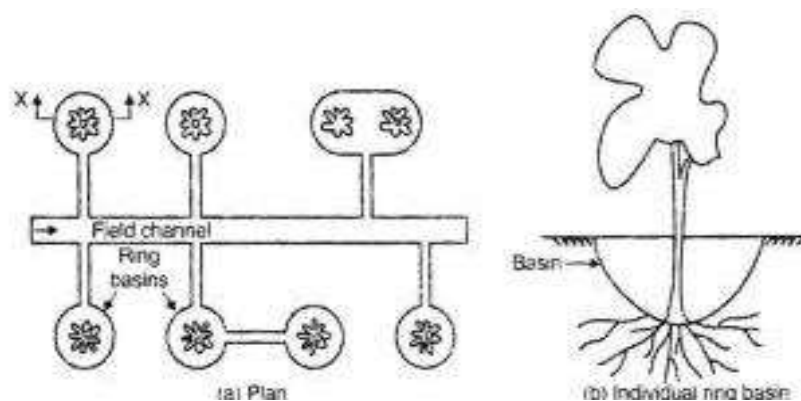
v) Zigzag flooding: This is special method of flooding where the water takes in circuitous route before reaching the dead end of each plot. Each plot is subdivided with the help of low bunds. This method is adopted in loose soils to prevent erosion at the higher ends.
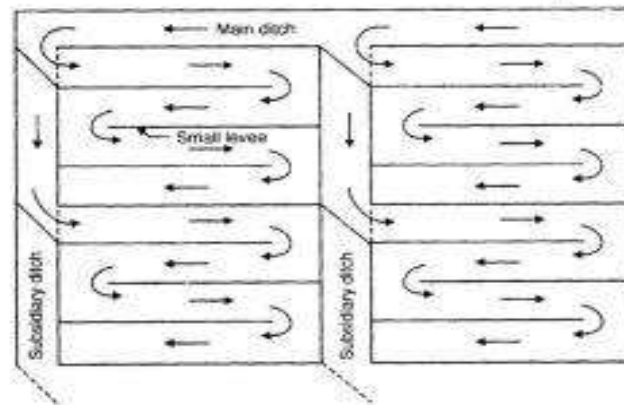
vi) Furrow method: In this method the water is applied to the land for irrigation by a series of long narrow field channels called furrows. A furrow is narrow ditch 75 to 125mm deep excavated between rows of plants to carry irrigation water. The spacing of furrows depends upon the spacing of plants. The length of furrow is usually 200m. In this method only one fifth to one half of surface was wetted. The evaporation losses are very much reduced.
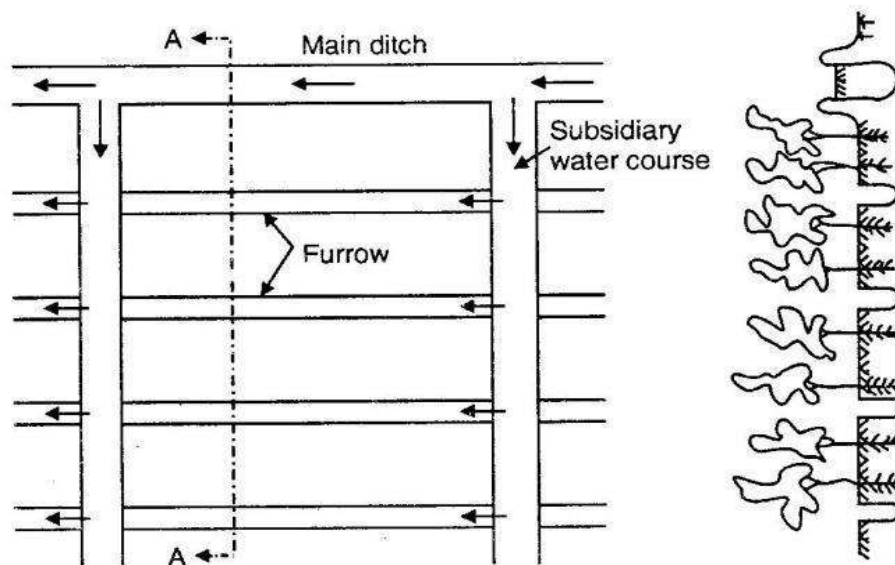

vii) Contour farming:

Contour farming was practiced in hilly regions where, the land to be irrigated has a steep slope. Here the land is divided into series of strips usually known as terraces or benches which are aligned to follow the contour of sloping area. This method also helps in controlling soil erosion.

b. Sub Surface Irrigation: This method consists of supplying water directly to the route zone through ditches at slow rate which are 0.5 m to 1 m deep and 25 to 50 cm wide. The ditches are spaced 50 to 100 m apart. Water seeps into the ground and available to the crop in the form of capillary fringe. Proper drainage of excess water was permitted either naturally or providing suitable drainage works, thereby preventing water logging in the fields. The favorable conditions to practice subsurface conditions are

1. Availability of imperious subsoil at reasonable depth (2 to 3m).
2. Water table is present at shallow depth.
3. Availability of moderate slope.
4. Availability of good quality irrigation water.

With the above favorable conditions and necessary precautions is possible to achieve the higher yields at lower cost.

(a) Plan

(b) Section
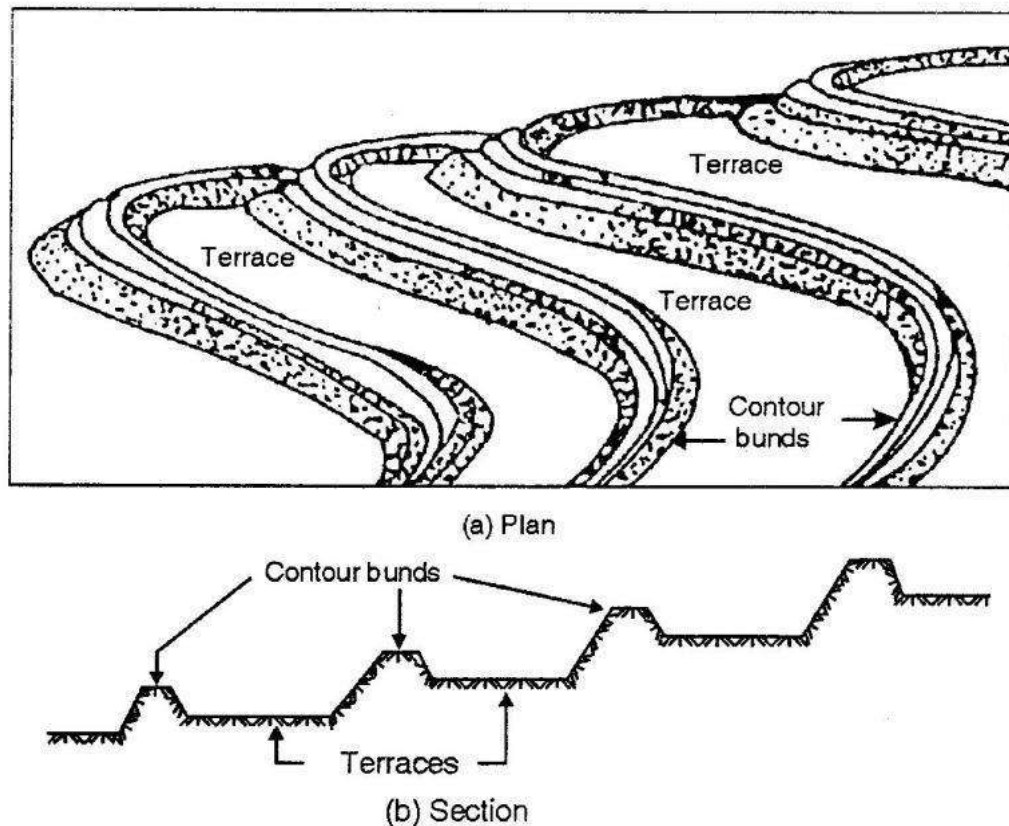
C. Sprinkler Irrigation: This method consists of applying water in the form of fine spray as similar to the rain fall. Stationary over head perforated pipes or fixed nozzle pipes installations were earlier used. However, with the introduction of light weight pipes and quick couplers, portable sprinkler systems with rotating nozzle have been developed and hence these have become popular. A pump usually lifts water from the source and supplies it through the distribution system and then through the sprinkler nozzle or sprinkler head mounted on the riser pipes. About, 80% irrigation efficiency is possible with the sprinkler irrigation, particularly in semi arid and humid regions. The efficiency of this system decreases by 5% for every 7.5 km/hour of increase in wind velocity.

Note: Irrigation efficiency (η) is given as,

$$\eta = \left(\frac{w_s}{w_p} \times 100 \right) \%$$

Where

w_s - Amount of irrigation water stored in root zone

w_p - Amount of water pumped or supplied into the system.

Sprinkler irrigation method is adopted in regions where, surface irrigation methods cannot be used due to the following reasons.

1. The soil is too pervious or impervious.
2. The nature of soil is too erosive.
3. The topography is not uniform or very steep.
4. The land is not suitable for surface irrigation method.

Advantages:

1. Soil erosion is well controlled by adjusting the discharge through the nozzle.
2. Uniform water application is possible.
3. In case of seedlings and young plants, light irrigation is possible easily.
4. Much land preparation is not essential hence labor cost was reduced.
5. More land for cropping is available since borders and ditches are not required.
6. Small amounts of irrigation water in water scarcity regions can be effectively utilized.

Disadvantages:

1. Wind will distort the sprinkling pattern.
2. Constant water supply under pressure is required for economic use of equipment.
3. Irrigation water must be free from silt, sand and impurities.
4. Initial investment is high.
5. Energy requirement for pumping water is high.
6. Heavy soil with poor infiltration (clayey soil) cannot be irrigated efficiently.

Drip or trickle irrigation:

This is the latest irrigation method, which is becoming popular in water scarcity areas and water with salt problems. In this method, the small diameter plastic or PVC pipes with drip nozzles commonly called emitters or drippers are adopted to deliver water to the land surface near the base of plant. Water can be applied at a rate varying between 2 to 10 liters per hour to keep the soil moisture within the desired range for plant growth. The main components of drip irrigation system are pumping unit, main pipelines, sub main pipe lines, lateral pipelines, emitters, and pressure gauges etc.

Water logging and drainage:

When the conditions are so created that the crop root-zone gets deprived of proper aeration due to the presence of excessive moisture or water content, the tract is said to be waterlogged. To create such conditions is not always necessary that underground table should enter the crop root-zone. Sometimes even if water table is below the root-zone depth therefore capillary water zone may extend in root-zone depth and makes the air circulation impossible by filling the pores in soil.

Causes of Water logging:

After studying the phenomenon of water logging in light of hydrologic equation main factors which help in raising the water-table may be recognized correctly.

They are:

i. Inadequate drainage of over-land run-off increases the rate of percolation and in turn helps in raising the water table.

ii. The water from rivers may infiltrate into the soil.

iii. Seepage of water from earthen canals also adds significant quantity of water to the underground reservoir continuously.

iv. Sometimes subsoil does not permit free flow of subsoil water which may accentuate the process of raising the water table.

v. Irrigation water is used to flood the fields. If it used in excess therefore help appreciably in raising the water table. Good drainage facility is very essential.

Effects of Water logging:

The water logging affects the land in various ways. The various effects are the following:

1. Creation of Anaerobic Condition in the Crop Root-Zone:

When the aeration of soil is satisfactory bacteriological activities produce the required nitrates from nitrogenous compounds present in the soil. It helps the crop growth. Excessive moisture content creates anaerobic condition in the soil. The plant roots do not get required nourishing food or nutrients. As a result crop growth is badly affected.

2. Growth of Water Loving Wild Plants:

When the soil is waterlogged water loving wild plant life grows abundantly. The growth of wild plants totally prevents the growth of useful crops.

3. Impossibility of Tillage Operations:

Waterlogged fields cannot be tilled properly. The reason is that soil contains excessive moisture content and it does not give proper tilt.

4. Accumulation of Harmful Salts:

The upward water movement brings the toxic salts in the crop root-zone. Excess accumulation of these salts may turn the soil alkaline. It may hamper the crop growth.

5. Lowering of Soil Temperature:

The presence of excessive moisture content lowers the temperature of soil. In low temperature the bacteriological activities are retarded which affects the crop growth badly.

6. Reduction in Time of Maturity:

Untimely maturity of crops is the characteristic of waterlogged lands. Due to this shortening of crop period the crop yield was reduced considerably.

Principal crops and crop seasons

Crops can be classified in the following ways:

1. Agricultural classification

This consists of following types of crops:

a) **Field crops:** Such as wheat, rice, maize, barley, oats, great millet, spiked millet, gram, pulses etc.
b) **Commercial crops:** Such as sugar cane, cotton tobacco, hemp, sugar beet etc.
c) **Oil seed crops**: Such as mustard, ground nut sesame, linseed, caster etc.
d) **Horticulture crop:** Consisting of various fruit crops, various vegetable crop and flower crop
e) **Plantation crops:** Such as tea, coffee, cocoa, coconut, rubber etc.
f) **Forage crop:** Such as fodder, grass etc.
g) **Miscellaneous crops:** Such as medicinal crops, aromatic crops, sericulture crop, condiments and spices

2. Classification based on crop seasons

Based on crop season, crops are classified as follows.

a) **Rabi crops or winter crops:** These crops are sown in autumn (or October) and harvested in spring (or March). Various crops that fall under this category are gram, wheat, barley, peas, mustard, tobacco, linseed, potato etc.

b) **Kharif crops or monsoon crops:** These crops are sown by the beginning of southwest monsoon and harvested in autumn. These consist of rice, maize, spiked millet, great millet, pulses, ground nut etc.

c) **Perennial crops:** These are the crops that require water for irrigation throughout the year. Examples of perennial crops are sugar cane, fruits, vegetables etc.

3. **Classification based on irrigation requirements:** Crops can be classified as
(i) **Dry crop:** In this type do not require water for irrigation; only rain water is sufficient for their growth.

(ii) **Wet crops:** In this type which cannot grow without irrigation.

(iii) **Garden crops:** Require irrigation throughout year.

Crop rotation:

In given plot of land different crops are grown one after the other in service in different seasons such as practice is known as crop rotation. Crop rotation is necessary for the following reasons.

1. By growing the same crop in the field continuously diseases and pests cannot be controlled easily. By crop rotation such as hazard can be minimized.
2. Different crops have different depths of root zones hence the nutrients at different levels can be well utilized by crop rotation.
3. By growing grams which are leguminous (they absorb more nitrogen) in plant, the nitrogen content soil was increased and becomes beneficial for subsequent crops.

The usual crop rotations adopted in India are

a. Wheat-Millet-gram
b. Paddy-gram
c. Cotton-wheat-gram
d. Cotton-wheat-sugarcane
e. Cotton-millet-gram

FUNCTIONS OF IRRIGATION WATER

The functions of soil moisture in plant growth are very important. Water and nutrients are two most important requirements of crop. The following are main functions of irrigation water:

1) It acts as a solvent for the nutrients. Water forms the solution of nutrients and this solution was absorbed by the roots. Thus, water acts as nutrient carrier.
2) The irrigation water supplies moisture which is essential for the life of bacteria beneficial to the plant growth.
3) Irrigation water supplies moisture which essential for chemical action within the plant leading to its growth.
4) Some salts present in soil react to produce nourishing food products only in the presence of water.
5) Water cools the soil and atmosphere and thus makes more favorable environment for healthy plant growth.
6) Irrigation water with controlled supplies washes out or dilutes salts in the soil.
7) It reduces the hazard of soil piping
8) It softens the tillage pans.

QUALITY OF IRRIGATION WATER

Good irrigation water is one which performs the above mentioned functions without any side effects which retard the plant growth. Irrigation water may be said to be unsatisfactory for its intended use if it contains.

1) Chemicals toxic to plants or persons using plant as food

2) Chemicals which react with soil to produce unsatisfactory moisture characteristics

3) Bacteria injurious to persons or animals eating plants irrigated with the water

Impurities in irrigation water:

1. Concentration of sediments in water

2. Total concentration of soluble salts

3. Proportion of sodium ions to other cations

4. Bacterial concentration

Classification of irrigation water:

1. Classification based on total concentration of soluble salts

$$C_s = CQ/Q - (C_u - P_{eff})$$

Where
C= Concentration of salt in irrigation water
Q = Total quantity of water
C_u= Consumptive use of water

P_{eff}= Useful rainfall

2. Classification based on sodium concentration

Percentage sodium = ESP = $100Na^+/Ca^{++}+Mg^{++}+Na^++K^+$

Sodium absorption ratio (SAR) = $Na^+/(\sqrt{Ca^{++}+Mg^{++}}/2)$

3. Classification based on electrical conductivity(EC)

Depth and frequency of irrigation:

The amount of irrigation water applied should be such that the moisture content was raised to the field capacity. The moisture content in soil reduces due to consumptive use by plants. However, the moisture content should not be allowed to fall below lower limit of readily available moisture. When the moisture content reaches the lower limit of readily available moisture, water should be supplied by irrigation method to raise it to the field capacity or optimum moisture content.
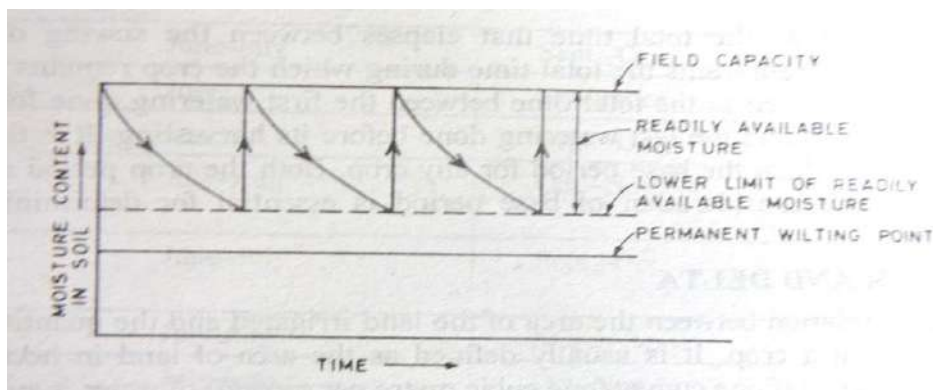
The minimum depth of water to be applied during irrigation to maintain field capacity is given by

Dw = Ws/Wxd (field capacity – weight of moisture content held by soil at lower limit of readily available moisture per unit weight of dry soil)

The frequency of irrigation is given by

$$Fw = Dw/Cu \text{ (days)}$$

Where Cu represents the consumptive use of water by crops expressed as the depth of water in cm/day

Time required irrigating in certain area

$$T = A.d_w/q \text{ seconds}$$

A= Area

d_w= Depth of water

Duty of Water:

Duty represents the irrigating capacity of unit of water.

It is usually defined as the area of land in hectares which can be irrigated to grow a crop of one cumec of water is continuously supplied for the entire period of crop.

Ex: If 5100 hectares of land can be irrigated for growing a crop with the available discharge of 3 cumec continuously for the entire crop period, then the duty of water for this crop = 5100/3 = 1700 hectares/cumec.

Different crops require different amounts of water before their harvesting and hence duty of water varies with the crops. Duty of water is said to be high, if the area of land irrigated per cumic is large.

Duty of water can be expressed in different ways as follows.

1. By the number of hectares that one cumec of water can irrigate during the base period.
2. By the total depth of water (Delta) was applied
3. By the numbers of hectares can be irrigated by one million m^3 of stored water
4. By the number of hectare-meters of water expended (used) per hectare of land irrigated.

As in case 1, the duty expressed is called flow duty of water and commonly used in canal irrigation.

As in case 2, the duty of water is suitable for tank irrigation because the area that can be irrigated is less and amount of water stored in tanks is less. It is also known as quantity duty or storage duty.

Case 3 is applicable for large storage volumes available in multi-purpose reservoirs.
The duty of water varies with the place of its measurement due to losses such as percolation; evaporation etc. The quantity of water delivered to the fields is different to the quantity of water leaving the head of canal.

Factors affecting duty:

The duty of water in canal system depends on the following factors.

1. **Methods and systems of irrigation:** Perennial system of irrigation has more duty of water than inundation irrigation system the loss of water by deep percolation is minimum in the first case. In flow irrigation by channels the duty was less as conveyance losses are more. In lift irrigation the lands to be irrigated are very near to the source of water than any surface irrigation method.

2. **Type of Crop:** Different crops are requiring different quantities of water and therefore the duty of water varies from crop to crop. Crops requiring large quantity of water have lower duty than crops requiring lesser quantity of water.

3. **Climate conditions of the area:** The climatic conditions such as wind, temperature, humidity and rainfall affect the duty of water. At high temperature losses due to evaporation and transpiration are more and hence duty decreases. At higher wind velocity, the rate of evaporation and transpiration are more thereby, duty decreased. But in humid conditions evaporations and transpiration losses are minimum there by the duty increases.

4. **Canal conditions:** In earthen canals, the seepage losses are high resulting low duty. If canal is lined, losses are minimum and therefore duty increases. If the length of canal is very large before it reaches the irrigation fields (as in hilly areas) the duty of water decreases.

5. **Quality of Water:** If water contains harmful salts and alkali contents, then more water was applied liberally to leach out these salts and in turn duty of water decreases.

6. **Characteristics of soil and subsoil in field and canals:** If the soil and subsoil of field and canals are made of coarse grained soils the seepage and percolation losses are more and hence the duty of water decreases.

7. **Topography of land:** If the area to be irrigated is level, uniform water application is possible which will result in economical views and hence duty of water increases.

8. **Method of Cultivation:** If the land is properly tilled up to the required depth and soil is made loose before irrigation, water retaining capacity of soil increases. This reduces the number of watering or frequency of watering and hence duty increases.

Delta:

It is the total depth of water required by crop during the entire crop period and is denoted as 'Δ'

Ex: A crop require 12 watering at an interval of 10 days and depth of water required in each watering is 10cms, the delta for crop is 12x10cms=120cms=1.2m
If the crop is grown in an area of "A" hectares, then the total quantity of water required is = 1.2 x A hectares-meter in a period of 120 days.

Some definitions:

1. **Crop Period**: It is the time in days that a crop takes from the instant of its sowing to that of its harvesting.

2. **Base period:** It refers to the whole period of cultivation from the time when irrigation water is first applied for the preparation of ground in planting the crop to its last watering before harvesting.

3. **Gross command area:** It is the total area laying between the drainage boundaries which can be commanded or irrigated by a canal system.

4. **Culturable command area**: Gross command area may also contain villages, ponds, barrel lands, alkaline lands etc., and such areas are turned as unculturable area. The remaining area on which crops can be grown satisfactory is known as culturable command area.

Relationship between Duty and Delta:

Let D = Duty of water in hectares/cumec

Δ = Total depth of water required during base period in 'm'

B = Base period in days

If we take a field of area D hectares, water supplied to the field corresponding to water depth Δ meters will be = Δ* D hectare-metres

$$= D*\Delta*10^4 \text{ cubic- metres. } \ldots\ldots\ldots\ldots..1$$

Again for the same field of D hectares, one cumec of water was required to flow during the entire base period. Hence, water supplied to this field

$$= (1* B*24*60*60) \text{ m}^3 \ldots\ldots\ldots\ldots\ldots.. 2$$

Equating equations 1 and 2 we get

$$\Delta = (B*24*60*60) / (D*10^4)$$

$$\Delta = 8.64B / D$$

Consider a field of 'D' hectare to be irrigated and Δ be the corresponding depth of water.

The total volume of water required to be supplied for the field of 'D' hectares, if cumec is to be supplied during the entire base period 'B'.