Department of Civil Engineering

Course File

WATER RESOURCES ENGINEERING
(Course Code: CE604PC)

IIIB.Tech II Semester

2023-24

Mrs.D.VNV Laxmi Alekhya
Asst Professor

ANURAG Anurag ENGINEERING COLLEGE
(An Autonomous Institution)
Ananthagiri, Kodad, Telangana 508 206, India.

WATER RESOURCES ENGINEERING

Check List

Department of Civil Engineering

Int. Marks:30 Ext. Marks:70 Total Marks:100

(CE604PC) WATER RESOURCES ENGINEERING

B.Tech. III Year II Sem.

L	T	P	C
3	0	0	3

UNIT- I

Introduction to hydrology and its applications, Hydrologic cycle, types and forms of precipitation, rainfall measurement, types of rain gauges, computation of average rainfall over a basin, processing of rainfall data – Adjustment of record – Rainfall double mass curve.

Abstraction from rainfall-evaporation, factors affecting evaporation, measurement of evaporation-Eva po transpiration-Infiltration, factors affecting infiltration, measurement of infiltration, infiltration indices.

UNIT - II

Runoff – factors affecting Runoff – Runoff over a catchment – Empirical and Rational Formulae. Distribution of Runoff-Hydrograph Analysis Flood Hydrograph – effective Rainfall - base flow separation – Direct Runoff Hydrograph- Unit Hydrograph, definition, and limitations of applications of Unit hydrograph, derivation of Unit Hydrograph, from Direct Runoff Hydrograph and vice versa - S-hydrograph, Synthetic Unit Hydrograph.

UNIT- III

Ground water Occurrence, types of aquifers, aquifer parameters, porosity, specific yield, permeability, transmissibility and storage coefficient, Darcy's law, radial flow to wells in confined and unconfined aquifers. Types of wells – Well Construction – Well Development

UNIT- IV

Necessity and Importance of Irrigation, advantages and ill effects of Irrigation, types of Irrigation, methods of application of Irrigation water, Indian agricultural soils, methods of improving soil fertility, preparation of land for Irrigation, standards of quality for Irrigation water. Soil-water- plant relationship, vertical distribution of soil moisture, soil moisture constants.

soil moisture tension, consumptive use, estimation of consumptive use, Duty and delta, factors affecting duty- Design discharge for water course. Depth and frequency of Irrigation, irrigation efficiencies – water Logging.

UNIT -V

Classification of canals, design of Irrigation canals by Kennedy's and Lacey's theories, balancing depth of cutting, IS standards for a canal design canal lining. Canal lining- cast in situ cement concrete lining- shot Crete- AC- boulder.

Design Discharge, Computation of design discharge-rational formula, SCS curve number method, flood frequency analysis introductory part only – Stream Gauging – measurement and estimation of stream flow.

TEXT BOOKS:

1. Jayaram Reddy, 'Engineering Hydrology', Laxmi publications pvt. Ltd., New Delhi
2. S K Garg, Irrigation Engineering & Hydraulic Structures, Khanna Publishers
3. P N Modi, Irrigation Engineering & Hydraulic Structures, Standard Book House,2014

REFERENCE BOOKS:

1. G L Asawa, Irrigation Engineering, Wiley Eastern
2. B.C. Punmia and B.B. Lal Pande, Irrigation and Water Power Engg,16 e, Laxmi Publications, 2014.
3. J D Zimmerman, Irrigation, John Wiley & Sons
4. Varshney, Gupta & Gupta, Theory and Design of Irrigation Structures, Nem Chand & Bros.

Department of Civil Engineering

Timetable

III B.Tech. II Semester – WRE

Day/Hour	9.30-10.20	10.20-11.10	11.20-12.10	12.10-01.00	1.40-2.25	2.25-3.10	3.15-4.00
Monday							
Tuesday		WRE					
Wednesday					WRE		
Thursday					WRE		
Friday			WRE				
Saturday				WRE			

Department of Civil Engineering

Vision of the Institute

To be a premier Institute in the country and region for the study of Engineering, Technology and Management by maintaining high academic standards which promotes the analytical thinking and independent judgment among the prime stakeholders, enabling them to function responsibly in the globalized society.

Mission of the Institute

To be a world-class Institute, achieving excellence in teaching, research and consultancy in cutting-edge Technologies and be in the service of society in promoting continued education in Engineering, Technology and Management.

Quality Policy

To ensure high standards in imparting professional education by providing world-class infrastructure, top-quality-faculty and decent work culture to sculpt the students into Socially Responsible Professionals through creative team-work, innovation and research

Vision of the Department

To impart knowledge, skill and excellence in civil engineering with a global perspective to enable the students as competent, qualitative & ethically strong engineers with an intuition to improve quality of life for the benefit of the society.

Mission of the Department

To train the students in the civil engineering domain. To develop knowledge and skill to solve regional and global problems. To transform into qualitative and ethically strong professional engineers through research and Development.

Program Educational Objectives (B.Tech. – CE)
Graduates will be able to

PEO 1: To provide knowledge in mathematics, science and engineering principles for a successful Career in sectors of civil engineering and allied industry and/or higher education.

PEO 2: To develop an ability to identify, formulate, solve problems along with adequate analysis, Design, synthesizing and interpretation skills in civil engineering systems.

PEO 3: To exhibit professionalism, ethics, communication skills and team work in their profession and engaged in lifelong learning of contemporary civil engineering trends.

Program Outcomes (B.Tech. –CE)
At the end of the Program, a graduate will have the ability to

PO 1: An ability to apply knowledge of mathematics, science, and engineering
PO 2: An ability to design and conduct experiments, as well as to analyze and interpret data
PO 3: An ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability
PO 4: An ability to function on multidisciplinary teams
PO 5: An ability to identify, formulates, and solves engineering problems
PO 6: An understanding of professional and ethical responsibility
PO 7: An ability to communicate effectively
PO 8: The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context.
PO 9: A recognition of the need for, and an ability to engage in lifelong learning.
PO 10: A knowledge of contemporary issues.
PO 11: An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice
PO 12: An ability to carry out research in different areas of Civil Engineering including latest technology like GIS/Remote Sensing resulting in design, development, analyse and journal publications and technology development.

COURSE OBJECTIVES

On completion of this Subject/Course the student shall be able to:

S.No	Objectives
1	To provide the knowledge of hydrology and hydrologic cycle and its applications.
2	To provide the knowledge of rain fall measurement methods and its analysis.
3	To provide the knowledge of ground water occurrence and aquifer parameters.
4	To provide the knowledge of the irrigation and Design discharge for water course.
5	To impart the knowledge of design of irrigation canals and also Design Discharge.

COURSE OUTCOMES

The expected outcomes of the Course/Subject are:

S.No	Outcomes
1	To get the knowledge of hydrology and hydrologic cycle and its applications.
2	To gain the knowledge of rain fall measurement methods and its analysis
3	To understand about ground water occurrence and aquifer parameters.
4	To understand about basic knowledge of the irrigation and Design discharge for water course.
5	To get the knowledge of design of irrigation canals and also Design Discharge.

Signature of faculty

Note: Please refer to Bloom's Taxonomy, to know the illustrative verbs that can be used to state the outcomes.

GUIDELINES TO STUDY THE COURSE / SUBJECT

Course Design and Delivery System (CDD):

- The Course syllabus is written into number of learning objectives and outcomes.
- Every student will be given an assessment plan, criteria for assessment, scheme of evaluation and grading method.
- The Learning Process will be carried out through assessments of Knowledge, Skills and Attitude by various methods and the students will be given guidance to refer to the text books, reference books, journals, swayam chapters etc.

The faculty be able to –

- Understand the principles of Learning
- Understand the psychology of students
- Develop instructional objectives for a given topic
- Prepare course, unit and lesson plans
- Understand different methods of teaching and learning
- Use appropriate teaching and learning aids
- Plan and deliver lectures effectively
- Provide feedback to students using various methods of Assessments and tools of Evaluation
- Act as a guide, advisor, counselor, facilitator, motivator and not just as a teacher alone

Signature of HOD Signature of faculty

Date: Date:

Department of Civil Engineering

COURSE SCHEDULE

The Schedule for the whole Course / Subject is:

S. No.	Description	Duration (Date)		Total No. of Periods
		From	To	
1.	**UNIT- I** Introduction to hydrology and its applications, Hydrologic cycle, types and forms of precipitation, rainfall measurement, types of rain gauges, computation of average rainfall over a basin, processing of rainfall data – Adjustment of record – Rainfall double mass curve. Abstraction from rainfall-evaporation, factors affecting evaporation, measurement of evaporation-Eva po transpiration-Infiltration, factors affecting infiltration, measurement of infiltration, infiltration indices.	22.01.2024	14.02.2024	17
2.	**UNIT - II** Runoff – factors affecting Runoff – Runoff over a catchment – Empirical and Rational Formulae. Distribution of Runoff-Hydrograph Analysis Flood Hydrograph – effective Rainfall - base flow separation – Direct Runoff Hydrograph- Unit Hydrograph, definition, and limitations of applications of Unit hydrograph, derivation of Unit Hydrograph, from Direct Runoff Hydrograph and vice versa - S-hydrograph, Synthetic Unit Hydrograph.	15.02.2024	01.03.2024	12
3.	**UNIT- III** Ground water Occurrence, types of aquifers, aquifer parameters, porosity, specific yield, permeability, transmissibility and storage coefficient, Darcy’s law, radial flow to wells in confined and unconfined aquifers. Types of wells – Well Construction – Well Development	05.03.2024	22.03.2024	10

4.	**UNIT- IV** Necessity and Importance of Irrigation, advantages and ill effects of Irrigation, types of Irrigation, methods of application of Irrigation water, Indian agricultural soils, methods of improving soil fertility, preparation of land for Irrigation, standards of quality for Irrigation water. Soil-water- plant relationship, vertical distribution of soil moisture, soil moisture constants. Soil moisture tension, consumptive use, estimation of consumptive use, Duty and delta, factors affecting duty-Design discharge for water course. Depth and frequency of Irrigation, irrigation efficiencies – water Logging.	23.03.2024	23.04.2024	14
5.	**UNIT -V** Classification of canals, design of Irrigation canals by Kennedy's and Lacey's theories,balancing depth of cutting, IS standards for a canal design canal lining. Canal lining- cast in situ cement concrete lining- shot Crete- AC- boulder. Design Discharge, Computation of design discharge-rational formula, SCS curve number method, flood frequency analysis introductory part only – Stream Gauging – measurement and estimation of stream flow. .	24.04.2024	11.06.2024	15

Total No. of Instructional periods available for the course: **68 Hours**

SCHEDULE OF INSTRUCTIONS - COURSE PLAN/UNIT PLAN

Unit No.	Lesson No.	Date	No. of Periods	Topics / Sub-Topics	Objectives & Outcomes Nos.	References (Textbook, Journal)
1.	1	22-Jan-24	1	Introduction to hydrology and its applications	1 1	Jayaram Reddy, ‘EngineeringHydrology’, Laxmi publications pvt. Ltd., New Delhi
	2	23-Jan-24	1	Hydrologic cycle, types and forms of precipitation	1 1	Jayaram Reddy, ‘EngineeringHydrology’, Laxmi publications pvt. Ltd., New Delhi
	3	24-Jan-24	1	Rainfall measurement	1 1	Jayaram Reddy, ‘EngineeringHydrology’, Laxmi publications pvt. Ltd., New Delhi
	4	25-Jan-24	1	Types of rain gauges, Types of rainguages-Weighing buckect,Tipping Buckect,Float type	1 1	Jayaram Reddy, ‘EngineeringHydrology’, Laxmi publications pvt. Ltd., New Delhi
	5	27-Jan-24	1	Construction Details of rainguages and its advantages	1 1	Jayaram Reddy, ‘EngineeringHydrology’, Laxmi publications pvt. Ltd., New Delhi
	6	30-Jan-24	1	Location of rainguages and its network	1 1	Jayaram Reddy, ‘EngineeringHydrology’, Laxmi publications pvt. Ltd., New Delhi
	7	31-Jan-24	1	Computation of average rainfall over a basin Water Losses or Abstraction	1 1	Jayaram Reddy, ‘EngineeringHydrology’, Laxmi publications pvt. Ltd., New Delhi
	8	1-Feb-24	1	Processing of rainfall data Analysis of Rainfall Records - Estimating Missing Rainfall Data	1 1	Jayaram Reddy, ‘EngineeringHydrology’, Laxmi publications pvt. Ltd., New Delhi
	9	2-Feb-24	1	Rainfall double mass curve.	1 1	Jayaram Reddy, ‘EngineeringHydrology’, Laxmi publications pvt. Ltd., New Delhi

	10	3-Feb-24	1	Abstraction from rainfall-evaporation	1 1	Jayaram Reddy, 'EngineeringHydrology', Laxmi publications pvt. Ltd., New Delhi
	11	6-Feb-24	1	Factors affecting evaporation, measurement of evaporation	1 1	Jayaram Reddy, 'EngineeringHydrology', Laxmi publications pvt. Ltd., New Delhi
	12	7-Feb-24	1	Eva po transpiration, Factors affecting Eva po transpiration	1 1	Jayaram Reddy, 'EngineeringHydrology', Laxmi publications pvt. Ltd., New Delhi
	13	8-Feb-24	1	Infiltration, factors affecting infiltration	1 1	Jayaram Reddy, 'EngineeringHydrology', Laxmi publications pvt. Ltd., New Delhi
	14	9-Feb-24	1	Measurement of infiltration, infiltration indices.	1 1	Jayaram Reddy, 'EngineeringHydrology', Laxmi publications pvt. Ltd., New Delhi
	15	12-Feb-24	1	Problems on infiltration	1 1	Jayaram Reddy, 'EngineeringHydrology', Laxmi publications pvt. Ltd., New Delhi
	16	13-Feb-24	1	Design Discharge over a Catchment - Rational Formula	1 1	Jayaram Reddy, 'EngineeringHydrology', Laxmi publications pvt. Ltd., New Delhi
	17	14-Feb-24	1	Infiltration indices and problems	1 1	Jayaram Reddy, 'EngineeringHydrology', Laxmi publications pvt. Ltd., New Delhi
2.	1	15-Feb-24	1	Distribution of Runoff, Hydrograph, Hydrograph Separation	2 2	Jayaram Reddy, 'EngineeringHydrology', Laxmi publications pvt. Ltd., New Delhi
	2	16-Feb-24	1	Unit Hydrograph, Limitations of application of Hydrograph	2 2	Jayaram Reddy, 'EngineeringHydrology', Laxmi publications pvt. Ltd., New Delhi

	3	17-Feb-24	1	Derivation of Unit Hydrograph	2 2	Jayaram Reddy, 'EngineeringHydrology', Laxmi publications pvt. Ltd., New Delhi
	4	19-Feb-24	1	Key terms to describe the storm hydrograph	2 2	Jayaram Reddy, 'EngineeringHydrology', Laxmi publications pvt. Ltd., New Delhi
	5	20-Feb-24	1	Components of the hydrograph	2 2	Jayaram Reddy, 'EngineeringHydrology', Laxmi publications pvt. Ltd., New Delhi
	6	21-Feb-24	1	Factors affecting the hydrograph shape	2 2	Jayaram Reddy, 'EngineeringHydrology', Laxmi publications pvt. Ltd., New Delhi
	7	22-Feb-24	1	Quick-response flow processes, Baseflow processes	2 2	Jayaram Reddy, 'EngineeringHydrology', Laxmi publications pvt. Ltd., New Delhi
	8	23-Feb-24	1	Methods of Baseflow Separation	2 2	Jayaram Reddy, 'EngineeringHydrology', Laxmi publications pvt. Ltd., New Delhi
	9	24-Feb-24	1	Problems on unit hydrograph	2 2	Jayaram Reddy, 'EngineeringHydrology', Laxmi publications pvt. Ltd., New Delhi
	10	27-Feb-24	1	S-hydrograph, Synthetic Unit Hydrograph	2 2	Jayaram Reddy, 'EngineeringHydrology', Laxmi publications pvt. Ltd., New Delhi
	11	28-Feb-24	1	Problems on S-hydrograph	2 2	Jayaram Reddy, 'EngineeringHydrology', Laxmi publications pvt. Ltd., New Delhi
	12	1-Mar-24	1	Problems on Synthetic Unit Hydrograph	2 2	Jayaram Reddy, 'EngineeringHydrology', Laxmi publications pvt. Ltd., New Delhi
3	1	5-Mar-24	1	Ground water Occurrence, Sourses of ground water	3 3	Jayaram Reddy, 'EngineeringHydrology',

				and properties		Laxmi publications pvt. Ltd., New Delhi
	2	6-Mar-24	1	Permeability, Darcy's law	3 3	Jayaram Reddy, 'EngineeringHydrology', Laxmi publications pvt. Ltd., New Delhi
	3	7-Mar-24	1	Problems on permeability, transmissibility, Problems combinations	3 3	Jayaram Reddy, 'EngineeringHydrology', Laxmi publications pvt. Ltd., New Delhi
	4	12-Mar-24	1	Assumptions in Darcy' law, Factors affecting permeability of soil	3 3	Jayaram Reddy, 'EngineeringHydrology', Laxmi publications pvt. Ltd., New Delhi
	5	13-Mar-24	1	limitations of Darcy's law, Measurement of Coefficient of Permeability	3 3	Jayaram Reddy, 'EngineeringHydrology', Laxmi publications pvt. Ltd., New Delhi
	6	14-Mar-24	1	**Field Tests :** Pumping Out Tests Pumping In Tests, Assumptions	3 3	Jayaram Reddy, 'EngineeringHydrology', Laxmi publications pvt. Ltd., New Delhi
	7	15-Mar-24	1	Problems on Pumping Out tests	3 3	Jayaram Reddy, 'EngineeringHydrology', Laxmi publications pvt. Ltd., New Delhi
	8	16-Mar-24	1	Problems on Pumping in tests	3 3	Jayaram Reddy, 'EngineeringHydrology', Laxmi publications pvt. Ltd., New Delhi
	9	21-Mar-24	1	Radial flow in wells, Concept on acquifers and its details	3 3	Jayaram Reddy, 'EngineeringHydrology', Laxmi publications pvt. Ltd., New Delhi
	10	22-Mar-24	1	Types of wells, Concept on Well Construction	3 3	Jayaram Reddy, 'EngineeringHydrology', Laxmi publications pvt. Ltd., New Delhi
4	1	23-Mar-24	1	Necessity and Importance of Irrigation	4 4	S K Garg, Irrigation Engineering & Hydraulic Structures, Khanna Publishers

	2	26-Mar-24	1	Advantages and ill effects of Irrigation	4 4	S K Garg, Irrigation Engineering & Hydraulic Structures, Khanna Publishers
	3	27-Mar-24	1	Types of Irrigation and methods	4 4	S K Garg, Irrigation Engineering & Hydraulic Structures, Khanna Publishers
	4	28-Mar-24	1	Application of Irrigation water	4 4	S K Garg, Irrigation Engineering & Hydraulic Structures, Khanna Publishers
	5	2-Apr-24	1	Agricultural soils, methods of improving soil fertility	4 4	S K Garg, Irrigation Engineering & Hydraulic Structures, Khanna Publishers
	6	3-Apr-24	1	Preparation of land for Irrigation	4 4	S K Garg, Irrigation Engineering & Hydraulic Structures, Khanna Publishers
	7	4-Apr-24	1	Plant growth depends on two important natural resources	4 4	S K Garg, Irrigation Engineering & Hydraulic Structures, Khanna Publishers
	8	6-Apr-24	1	Factors affecting Soil Formation, Factors that retard soil profile development	4 4	S K Garg, Irrigation Engineering & Hydraulic Structures, Khanna Publishers
	9	10-Apr-24	1	Physical Characteristics of Soil, Soil Structure	4 4	S K Garg, Irrigation Engineering & Hydraulic Structures, Khanna Publishers
	10	16-Apr-24	1	Soil Moisture Constants	4 4	S K Garg, Irrigation Engineering & Hydraulic Structures, Khanna Publishers
	11	18-Apr-24	1	Concept on soil moisture tension consumptive use, estimation of consumptive use	4 4	S K Garg, Irrigation Engineering & Hydraulic Structures, Khanna Publishers

	12	19-Apr-24	1	Concept on Duty and delta, factors affecting duty,Problems on Duty and delta	4 4	S K Garg, Irrigation Engineering & Hydraulic Structures, Khanna Publishers
	13	20-Apr-24	1	Concept on irrigation efficiencies – water Logging	4 4	S K Garg, Irrigation Engineering & Hydraulic Structures, Khanna Publishers
	14	23-Apr-24	1	Problems on efficiencies	4 4	S K Garg, Irrigation Engineering & Hydraulic Structures, Khanna Publishers
5	1	24-Apr-24	1	Classification of canals	5 5	S K Garg, Irrigation Engineering & Hydraulic Structures, Khanna Publishers
	2	25-Apr-24	1	Types of canals and its advantages	5 5	S K Garg, Irrigation Engineering & Hydraulic Structures, Khanna Publishers
	3	26-Apr-24	1	Design of Irrigation canals by Kennedy’s	5 5	S K Garg, Irrigation Engineering & Hydraulic Structures, Khanna Publishers
	4	27-Apr-24	1	Assumptions in Kennedy's theory	5 5	S K Garg, Irrigation Engineering & Hydraulic Structures, Khanna Publishers
	5	30-Apr-24	1	Problems on Kennedy's theory	5 5	S K Garg, Irrigation Engineering & Hydraulic Structures, Khanna Publishers
	6	1-May-24	1	Assumptions in Lacey's theory, Problems on lacey's theory	5 5	S K Garg, Irrigation Engineering & Hydraulic Structures, Khanna Publishers
	7	2-May-24	1	Comparision on on Kennedy's theory, lacey's theory	5 5	S K Garg, Irrigation Engineering & Hydraulic Structures, Khanna Publishers
	8		1	Design of Canals by Kennedy’s and Lacey’s	5 5	S K Garg, Irrigation Engineering & Hydraulic

		3-May-24		Theory		Structures, Khanna Publishers
	9	4-May-24	1	Balancing depth of Cutting, IS Standards for Canal Design	5 5	S K Garg, Irrigation Engineering & Hydraulic Structures, Khanna Publishers
	10	7-May-24	1	Different Types of Lining (IS 10430: 2000)	5 5	S K Garg, Irrigation Engineering & Hydraulic Structures, Khanna Publishers
	11	8-May-24	1	SCS Curve Number Method	5 5	S K Garg, Irrigation Engineering & Hydraulic Structures, Khanna Publishers
	12	6-Jun-24	1	Design Discharge, Computation of design discharge	5 5	S K Garg, Irrigation Engineering & Hydraulic Structures, Khanna Publishers
	13	7-Jun-24	1	Canal Lining, Advantages of Canal Lining, Selecting type of Lining	5 5	S K Garg, Irrigation Engineering & Hydraulic Structures, Khanna Publishers
	14	8-Jun-24	1	Stream Gauging – measurement and estimation of stream flow.	5 5	S K Garg, Irrigation Engineering & Hydraulic Structures, Khanna Publishers
	15	11-Jun-24	1	Revision	1,2,3,4,5	Jayaram Reddy, 'EngineeringHydrology', Laxmi publications pvt. Ltd., New Delhi S K Garg, Irrigation Engineering & Hydraulic Structures, Khanna Publishers

Signature of HOD　　　　　　　　Signature of faculty

Date:　　　　　　　　Date:

Note:

1. Ensure that all topics specified in the course are mentioned.
2. Additional topics covered, if any, may also be specified in bold.
3. Mention the corresponding course objective and outcome numbers against each topic

LESSON PLAN (U-I)

Lesson No: 01, 02 Duration of Lesson: 1hr 40 min

Lesson Title: Introduction to hydrology and its applications, Hydrologic cycle, types and forms of precipitation

Instructional / Lesson Objectives:

- Definition of hydrology, basic terms used in hydrology and its applications
- Hydrologic cycle and its formation
- Forms of precipitation

Teaching AIDS : PPT

Time Management of Class :

5 mins for taking attendance
80 min for the lecture delivery
15 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – I & tutorial-I sheets

Signature of faculty

Department of Civil Engineering

LESSON PLAN (U-I)

Lesson No: 03, 04, 05 Duration of Lesson: 2hr 30 min

Lesson Title: Rainfall measurement, Types of rain gauges, -Weighing buckect, Tipping Buckect, Float type, Construction Details of rain guages and its advantages

Instructional / Lesson Objectives:

- Explain the procedure to Rainfall measurement
- Types of rain gauges.
- Construction Details of rainguages and its advantages

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Teaching AIDS : White board, Different colour markers
Time Management of Class :

5 mins for taking attendance 15 for revision of previous class 115 min for lecture delivery 15 min for doubts session

Assignment / Questions: What is a structure?
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – I & tutorial-I sheets

Signature of faculty

LESSON PLAN (U-I)

Lesson No: 06, 07, 08 Duration of Lesson: 2hr 30 min

Lesson Title: Location of rainguages and its network, Computation of average rainfall over a basin Water Losses or Abstraction, Processing of rainfall data Analysis of Rainfall Records - Estimating Missing Rainfall Data

Instructional / Lesson Objectives:

- Location of rainguages and its network
- Calculation of rainfall data
- Analysis of Rainfall Records
- Explain the procedure to Analysis of Rainfall Records

Teaching AIDS : White board, Graph sheets

Time Management of Class :

5 mins for taking attendance
15 for revision of previous class
115 min for lecture delivery
15 min for doubts session

Assignment / Questions: What is a structure?
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – I & tutorial-I sheets

Signature of faculty

LESSON PLAN (U-I)

Lesson No: 09, 10, 11 Duration of Lesson: 2hr 30 min

Lesson Title: Rainfall double mass curve, Abstraction from rainfall-evaporation, Factors affecting evaporation, measurement of evaporation

Instructional / Lesson Objectives:

- To understand students the concept of Rainfall double mass curve
- Calculation of Abstraction from rainfall.
- To understand students the concept of evaporation

Teaching AIDS : White board, Different colour markers

Time Management of Class :

5 mins for taking attendance
15 for revision of previous class
115 min for lecture delivery
15 min for doubts session

Assignment / Questions: What is a structure?
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – I & tutorial-I sheets

Signature of faculty

LESSON PLAN (U-I)

Lesson No: 12, 13, 14 Duration of Lesson: 2hr 30 min

Lesson Title: Eva po transpiration, Factors affecting Eva po transpiration, Infiltration, factors affecting infiltration, Measurement of infiltration, infiltration indices.

Instructional / Lesson Objectives:

- Defination of Eva po transpiration
- Factors affecting Eva po transpiration
- Importance of Infiltration
- Measurement of infiltration,
- How to calculate infiltration indices

Teaching AIDS : White board,

Time Management of Class :

5 mins for taking attendance 15 for revision of previous class 115 min for lecture delivery 15 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – I & tutorial-I sheets

Signature of faculty

Department of Civil Engineering

LESSON PLAN (U-I)

Lesson No: 15, 16, 17 Duration of Lesson: 2hr 30 min

Lesson Title: Problems on infiltration , Design Discharge over a Catchment - Rational Formula

Instructional / Lesson Objectives:

- Design Discharge over a Catchment
- Calculation of infiltration

Teaching AIDS : White board, Different colour markers
Time Management of Class :

5 mins for taking attendance
15 for revision of previous class
115 min for lecture delivery
15 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – I & tutorial-I sheets

Signature of faculty

Department of Civil Engineering

LESSON PLAN (U-II)

Lesson No: 1,2,3 Duration of Lesson: 2hr 30 min

Lesson Title: Distribution of Runoff, Hydrograph, Hydrograph Separation, Unit Hydrograph, Limitations of application of Hydrograph, Derivation of Unit Hydrograph

Instructional / Lesson Objectives:

- To know about runoff and its factors
- Hydrograph, Unit Hydrograph, Limitations and applications.
- Derivation of Unit Hydrograph

Teaching AIDS : White board, Different colour markers
Time Management of Class :

5 mins for taking attendance
15 for revision of previous class
115 min for lecture delivery
15 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – II & tutorial-II sheets

Signature of faculty

Department of Civil Engineering

LESSON PLAN (U-II)

Lesson No:4,5,6 Duration of Lesson: 2hr 30 min

Lesson Title: Key terms to describe the storm hydrograph, Components of the hydrograph, Factors affecting the hydrograph shape

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Instructional / Lesson Objectives:

- Understand the different hydrograph.
- Understand the storm hydrograph.
- Components of the hydrograph
- Differentiate between unit hydrograph and strom hydrograph
- Factors affecting the hydrograph shape

Teaching AIDS : White board, Digital Board

Time Management of Class :

5 min for taking attendance
15 for revision of previous class
115 min for lecture delivery
15 min for doubts session

Assignment / Questions:

(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – II & tutorial-II sheets

Signature of faculty

LESSON PLAN (U-II)

Lesson No: 7,8 Duration of Lesson: 1hr 40 min

Lesson Title: Quick-response flow processes, Baseflow processes,

Instructional / Lesson Objectives:

- Understand the Baseflow processes.
- Methods of Baseflow Separation

Teaching AIDS : White board, Different Colour markers

Time Management of Class :

5 mins for taking attendance
15 for revision of previous class
65 min for lecture delivery
15 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – II & tutorial-II sheets

Signature of faculty

LESSON PLAN (U-II)

Lesson No: 9,10 Duration of Lesson: 1hr 40 min

Lesson Title: Problems on unit hydrograph, S-hydrograph, Synthetic Unit Hydrograph

Instructional / Lesson Objectives:

- Understand the S-hydrograph.
- Construction details about Synthetic Unit Hydrograph

Teaching AIDS : White board, Different Colour markers

Time Management of Class :

5 mins for taking attendance
15 for revision of previous class
65 min for lecture delivery
15 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – II & tutorial-II sheets

Signature of faculty

LESSON PLAN (U-II)

Lesson No: 11,12 Duration of Lesson: 1hr 40 min

Lesson Title: Problems on S-hydrograph and Synthetic Unit Hydrograph

Instructional / Lesson Objectives:

- Problems on S-hydrograph and Synthetic Unit Hydrograph

Teaching AIDS : White board, Different Colour markers

Time Management of Class :

5 mins for taking attendance
15 for revision of previous class
65 min for lecture delivery
15 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – II & tutorial-II sheets

Signature of faculty

LESSON PLAN (U-III)

Lesson No: 1,2,3 Duration of Lesson: 2hr 30 min

Lesson Title: Ground water Occurrence, Sourses of ground water and properties, Permeability, Darcy's law, Problems on permeability and combinations.

Instructional / Lesson Objectives:
On completion of this lesson the student shall be able to:

- Formation of ground water and occurence.
- Understand the ground water and properties.
- Problems on permeability

Teaching AIDS : White board, Different Colour markers
Time Management of Class :

5 mins for taking attendance
15 for revision of previous class
115 min for lecture delivery
15 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – III & tutorial-III sheets

Signature of faculty

LESSON PLAN (U-III)

Lesson No: 4,5,6 Duration of Lesson: 2hr 30 min

Lesson Title: Assumptions in Darcy' law, Factors affecting permeability of soil, limitations of Darcy's law, Measurement of Coefficient of Permeability, Field Tests

Instructional / Lesson Objectives:
On completion of this lesson the student shall be able to:

- Understand the Darcy' law, permeability of soil
- Measurement of Coefficient of Permeability
- To understand about types of tests for ground water

Teaching AIDS : White board, Different Colour markers

Time Management of Class :

5 mins for taking attendance 15 for revision of previous class 115 min for lecture delivery 15 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – III & tutorial-III sheets

Signature of faculty

LESSON PLAN (U-III)

Lesson No: 7,8,9 Duration of Lesson: 2hr 30 min

Lesson Title: Pumping Out Tests Pumping In Tests, Assumptions, Problems on Pumping Out tests and Pumping in tests.

<u>Instructional / Lesson Objectives:</u>
On completion of this lesson the student shall be able to:

- Problems on Pumping Out tests and Pumping in tests.

Teaching AIDS : White board, Digital board
Time Management of Class :

5 mins for taking attendance 15 for revision of previous class 115 min for lecture delivery 15 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – III & tutorial-III sheets

Signature of faculty

LESSON PLAN (U-III)

Lesson No: 10 Duration of Lesson: 50 min

Lesson Title: Types of wells, Concept on Well Construction.

Instructional / Lesson Objectives:
On completion of this lesson the student shall be able to:

- To understand about Types of wells
- Concept on Well Construction

Teaching AIDS : White board, Different Colour markers
Time Management of Class :

5 mins for taking attendance 40 min for lecture delivery 5 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – III & tutorial-III sheets

Signature of faculty

LESSON PLAN (U-IV)

Lesson No: 1,2,3 Duration of Lesson: 2hr 30 min

Lesson Title: Necessity and Importance of Irrigation, Advantages and ill effects of Irrigation, Types of Irrigation and methods.

Instructional / Lesson Objectives:
On completion of this lesson the student shall be able to:

- Necessity and Importance of Irrigation
- Types of Irrigation and methods.

Teaching AIDS : PPT
Time Management of Class :

5 mins for taking attendance 15 for revision of previous class 115 min for lecture delivery 15 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – IV & tutorial-IV sheets

Signature of faculty

LESSON PLAN (U-IV)

Lesson No: 4,5,6 Duration of Lesson: 2hr 30 min

Lesson Title: Application of Irrigation water, Agricultural soils, methods of improving soil fertility, Preparation of land for Irrigation.

Instructional / Lesson Objectives:
On completion of this lesson the student shall be able to:

- Understand the Agricultural soils
- Application of Irrigation water
- To methods of improving soil fertility,
- Preparation of land for Irrigation

Teaching AIDS : PPT

Time Management of Class :

5 mins for taking attendance 15 for revision of previous class 115 min for lecture delivery 15 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – IV & tutorial-IV sheets

Signature of faculty

LESSON PLAN (U-IV)

Lesson No: 7,8,9 Duration of Lesson: 2hr 30 min

Lesson Title: Plant growth depends on two important natural resources, Factors affecting Soil Formation, Factors that retard soil profile development, Physical Characteristics of Soil, Soil Structure

Instructional / Lesson Objectives:
On completion of this lesson the student shall be able to:

- To understand two important natural resources.
- To Factors affecting Soil Formation and its profile

Teaching AIDS : White board, Different Colour markers
Time Management of Class :

5 mins for taking attendance
15 for revision of previous class
115 min for lecture delivery
15 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – IV & tutorial-IV sheets

Signature of faculty

LESSON PLAN (U-IV)

Lesson No: 10,11,12 Duration of Lesson: 2hr 30 min

Lesson Title: Soil Moisture Constants, Concept on soil moisture tension consumptive use, estimation of consumptive use, factors affecting duty, Problems on Duty and delta

Instructional / Lesson Objectives:
On completion of this lesson the student shall be able to:

- Understand the Soil Moisture Constants
- estimation of consumptive use
- Problems on Duty and delta

Teaching AIDS : White board, Different Colour markers
Time Management of Class :

5 mins for taking attendance
15 for revision of previous class
115 min for lecture delivery
15 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – IV & tutorial-IV sheets

Signature of faculty

LESSON PLAN (U-IV)

Lesson No:13,14 Duration of Lesson: 1hr 40 min

Lesson Title: Concept on irrigation efficiencies – water Logging, Problems on efficiencies

Instructional / Lesson Objectives:

On completion of this lesson the student shall be able to:

- Concept on irrigation efficiencies – water Logging
- Problems on efficiencies

Teaching AIDS : White board, Different Colour markers

Time Management of Class :

5 mins for taking attendance
15 for revision of previous class
65 min for lecture delivery
15 min for doubts session

Assignment / Questions:

(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – IV & tutorial-IV sheets

Signature of faculty

LESSON PLAN (U-V)

Lesson No: 1,2 Duration of Lesson: 1hr 40 min

Lesson Title: Classification of canals, Types of canals and its advantages.

Instructional / Lesson Objectives:

On completion of this lesson the student shall be able to:

- Understand the Classification of canals
- Types of canals and its advantages

Teaching AIDS : White board, Different Colour markers

Time Management of Class :

5 mins for taking attendance 80 min for lecture delivery 15 min for doubts session

Assignment / Questions:

(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – V & tutorial-V sheets

Signature of faculty

LESSON PLAN (U-V)

Lesson No: 3,4 Duration of Lesson: 1hr 40 min

Lesson Title: Design of Irrigation canals by Kennedy's, Assumptions in Kennedy's theory

Instructional / Lesson Objectives:

On completion of this lesson the student shall be able to:

- Understand about Kennedy's theory
- Design of Irrigation canals by Kennedy's

Teaching AIDS : White board, Different Colour markers

Time Management of Class :

5 mins for taking attendance
15 min for revision session
65 min for lecture delivery
15 min for doubts session

Assignment / Questions:

(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – V & tutorial-V sheets

Signature of faculty

LESSON PLAN (U-V)

Lesson No: 5,6 Duration of Lesson: 1hr 40 min

Lesson Title: Problems on Kennedy's theory, Assumptions in Lacey's theory, Problems on lacey's theory

Instructional / Lesson Objectives:

On completion of this lesson the student shall be able to:

- Understand about Lacey's theory
- Problems on lacey's theory

Teaching AIDS : White board, Different Colour markers

Time Management of Class :

5 min for taking attendance
15 min for revision session
65 min for lecture delivery
15 min for doubts session

Assignment / Questions:

(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – V & tutorial-V sheets

Signature of faculty

LESSON PLAN (U-V)

Lesson No: 7,8 Duration of Lesson: 1hr 40 min

Lesson Title: Comparision on on Kennedy's theory, lacey's theory, Design of Canals by Kennedy's and Lacey's Theory

Instructional / Lesson Objectives:
On completion of this lesson the student shall be able to:

- Design of Canals by Kennedy's and Lacey's Theory
- Comparision on on Kennedy's theory, lacey's theory

Teaching AIDS : White board, Different Colour markers
Time Management of Class :

5 min for taking attendance 15 min for revision session 65 min for lecture delivery 15 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – V & tutorial-V sheets

Signature of faculty

LESSON PLAN (U-V)

Lesson No: 9,10 Duration of Lesson: 1hr 40 min

Lesson Title: Balancing depth of Cutting, IS Standards for Canal Design, Different Types of Lining (IS 10430: 2000)

Instructional / Lesson Objectives:
On completion of this lesson the student shall be able to:

- Balancing depth of Cutting, IS Standards for Canal Design
- Different Types of Lining (IS 10430: 2000)

Teaching AIDS : White board, Different Colour markers
Time Management of Class :

5 min for taking attendance
15 min for revision session
65 min for lecture delivery
15 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – V & tutorial-V sheets

Signature of faculty

LESSON PLAN (U-V)

Lesson No: 11,12 Duration of Lesson: 1hr 40 min

Lesson Title: SCS Curve Number Method, Design Discharge, Computation of design discharge

Instructional / Lesson Objectives:

On completion of this lesson the student shall be able to:

- Calculatation of discharge in canals
- Computation of design discharge

Teaching AIDS : White board, Different Colour markers

Time Management of Class :

5 min for taking attendance
15 min for revision session
65 min for lecture delivery
15 min for doubts session

Assignment / Questions:

(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – V & tutorial-V sheets

Signature of faculty

LESSON PLAN (U-V)

Lesson No: 13,14 Duration of Lesson: 1hr 40 min

Lesson Title: Concept on irrigation efficiencies – water Logging

Instructional / Lesson Objectives:
On completion of this lesson the student shall be able to:

- Canal Lining, Advantages of Canal Lining, Selecting type of Lining
- Stream Gauging – measurement and estimation of stream flow.

Teaching AIDS : White board, Different Colour markers
Time Management of Class :

5 min for taking attendance 15 min for revision session 65 min for lecture delivery 15 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – V & tutorial-V sheets

Signature of faculty

LESSON PLAN (U-V)

Lesson No: 15 Duration of Lesson: 50 min

Lesson Title: Revision

Instructional / Lesson Objectives:
On completion of this lesson the student shall be able to:

- Previous papers practice and revision

Teaching AIDS : White board, Different Colour markers
Time Management of Class :

5 min for taking attendance
30 min for revision session
15 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – V & tutorial-V sheets

Signature of faculty

ASSIGNMENT – 1

This Assignment corresponds to Unit No. 1

Question No.	Question	Objective No.	Outcome No.
1	Explain About Hydrologic Cycle.	1	1
2	Write A Short On Types Rain guages.	1	1
3	Detailed Discsion On Presentation Of Rainfall.	1	1

Signature of HOD

Date:

Signature of faculty

Date:

ASSIGNMENT – 2

This Assignment corresponds to Unit No. 2

Question No.	Question	Objective No.	Outcome No.
1	Explain in detail about unit hydrograph, it's uses and limitations	2	2
2	Write in detail about S hydrograph	2	2

Signature of HOD

Date:

Signature of faculty

Date:

Department of Civil Engineering

ASSIGNMENT – 3

This Assignment corresponds to Unit No. 3

Question No.	Question	Objective No.	Outcome No.
1	Factors affecting transmissibility in aquifers.	3	3
2	Define the terms porosity, permeability, transmisitivity, specific retention, specific yield, perched water table, confined aquifer and unconfined aquifer	3	3
3	Write briefly about types of wells and its construction details.	3	3

Signature of HOD

Date:

Signature of faculty

Date:

ASSIGNMENT – 4

This Assignment corresponds to Unit No. 4

Question No.	Question	Objective No.	Outcome No.
1	Explain various factors affecting the duty. Discuss methods for improving duty.	4	4
2	Discuss the classification of canals?	4	4
3	Draw neat sketch about sprinkler irrigation and drip irrigation.	4	4

Signature of HOD

Date:

Signature of faculty

Date:

Department of Civil Engineering

ASSIGNMENT – 5

This Assignment corresponds to Unit No. 5

Question No.	Question	Objective No.	Outcome No.
1	a) What is water logging? What are causes of water logging? What are its ill-effects? b) Define sensitivity of an outlet. Find the relation between sensitivity and flexibility of an outlet.	5	5
2	a) Describe with the help of sketches, some of the common types of strainer wells. b) What do you understand by crop rotation? What are its advantages?	5	5

Signature of HOD

Date:

Signature of faculty

Date:

TUTORIAL SHEET – 1

This tutorial corresponds to Unit No. 1 (Objective Nos.: 1, Outcome Nos.: 1)

Q1. ---------These are the regions of high pressure usually of large areal extent

a) Anti cyclone B) Frontal Boundary C) Control Surface D) Hurricanes

Q2. A Mass Curve Plot Between

a) Accumulated Rainfall With Time
b) Rainfall With Time
c) Precipitation With Time
d) Accumulated Rainfall Intensity With Time

Q3. The term used to describe a line on a map that represents equal amounts of precipitations

a) Isohyet b) Isobar c) IsoLine d) Isotherm

Q4. When rain falls through air at subfreezing temperature forms

a)Glaze b) Sleet c) Fog d) Snow

Signature of HOD Signature of faculty

Date: Date:

TUTORIAL SHEET– 2

This tutorial corresponds to Unit No. 2 (Objective Nos.: 2, Outcome Nos.: 2)

Q1. Unit Hydrograph theory was enunciated by

a) Merril Bernard b) Le-Roy K. Shermen
c) Robert E. Horten d) W.W. Horne

Q2. The instrument used for measuring evaporation
a) Hygrometer b) Atmometer c) Lysimeter d) Luxmeter

Q3. Pick up the correct equation from the following
a) Run off = Surface run off + Ground water flow
b) Run off = Surface run off - Ground water flow
c) 1⁄2 NL/Run off = Surface run off / Ground water flow
d) Run off = Surface run off × Ground water flow

Q4. Hydrograph is a graphical representation of ------------------------
a) Ground water flow
b) Rainfall
c) Surface runoff
d) Discharge flowing in the river

Signature of HOD

Date:

Signature of faculty

Date:

Department of Civil Engineering

TUTORIAL SHEET – 3

This tutorial corresponds to Unit No. 3 (Objective Nos.: 3, Outcome Nos.: 3)

Q1. A soil formation through which only seepage is possible being partly permeable and capable of giving insignificant yeild is classified a

a) Aquifuge b) Aquitard c) Aquifer d) Aquiclude

Q2 A leaky aquifer consists of

a) An artesian aquifer confined by aquacludes on its top and bottom
b) An aquitard confined by aquacludes on its top and bottom
c) An aquacludes confined on top by an aquifer and by aquitard on its bottom
d) An artesian aquifer confined by an aquitard either on its top or bottom or both sides

Q3. Water present in soil mantle called as

a) Ground water b) Water table
c) Aquitard d) Aquifer

Signature of HOD

Date:

Signature of faculty

Date:

Department of Civil Engineering

TUTORIAL SHEET – 4

This tutorial corresponds to Unit No. 4 (Objective Nos.: 4, Outcome Nos.: 4)

Q1. Which of the following type of irrigation system is practised on small scale in India,
a) Lift Irrigation b) Flood Irrigation
c) Natural sub-irrigation d) Artificial sub-irrigation

Q2. Construction cost of this mode of irrigation is zero.
a) Sprinkle b) Drip c) Tank d) Well

Q3. Salinity-in-irrigation wate10 is measured by
a) pH-value b) Electrical-conductivity value
c) SAR value d) None of the above

Signature of HOD

Date:

Signature of faculty

Date:

Department of Civil Engineering

TUTORIAL SHEET – 5

This tutorial corresponds to Unit No. 5 (Objective Nos.: 5, Outcome Nos.: 5)

Q1. Which canal is not provided with any headworks for diversion of river water?
a) Permanent canal b) Feeder canal
c) Perennial canal d) Inundation canals

Q2. Loss of canal discharge occurs mainly due to
a) Seepage and Percolation b) Percolation and Absorption
c) Seepage and Evaporation d) Seepage and Absorption

Q3. Which of the following type of irrigation methods uses supply ditch, borders, ridges?
a) Check Flooding b) Basin Flooding
c) Drip Irrigation Method d) Border Flooding

Signature of HOD Signature of faculty

Date: Date:

Department of Civil Engineering

EVALUATION STRATEGY

Target (s)

a. Percentage of Pass : 100%

Assessment Method (s) (Maximum Marks for evaluation are defined in the Academic Regulations)

a. Daily Attendance
b. Assignments
c. Online Quiz (or) Seminars
d. Continuous Internal Assessment
e. Semester / End Examination

List out any new topic(s) or any innovation you would like to introduce in teaching the subjects in this semester

Signature of HOD

Date:

Signature of faculty

Date:

Department of Civil Engineering

COURSE COMPLETION STATUS

Actual Date of Completion & Remarks if any

Units	Remarks	Objective No. Achieved	Outcome No. Achieved
Unit 1	Completed on 14-02-24	1	1
Unit 2	Completed on 1-Mar-24	2	2
Unit 3	Completed on 22-Mar-24	3	3
Unit 4	Completed on 23-Apr-24	4	4
Unit 5	Completed on 11-Jun-24	5	5

Signature of HOD

Date:

Signature of faculty

Date:

Mappings

1. Course Objectives-Course Outcomes Relationship Matrix
(Indicate the relationships by mark "X")

Course-Outcomes / Course-Objectives	1	2	3	4	5
1	H			M	
2		H			
3	M		H		
4				H	
5					H

2. Course Outcomes-Program Outcomes (POs) & PSOs Relationship Matrix
(Indicate the relationships by mark "X")

P-Outcomes / C-Outcomes	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO 1	PSO 2
1	H		M		M				M		M			
2			H						H					
3	H												H	
4											H			
5			H		H				H					

Department of Civil Engineering

Rubric for Evaluation

Performance Criteria	Unsatisfactory	Developing	Satisfactory	Exemplary
	1	**2**	**3**	**4**
Research & Gather Information	Does not collect any information that relates to the topic	Collects very little information some relates to the topic	Collects some basic Information most relates to the topic	Collects a great deal of Information all relates to the topic
Fulfill team role's duty	Does not perform any duties of assigned team role.	Performs very little duties.	Performs nearly all duties.	Performs all duties of assigned team role.
Share Equally	Always relies on others to do the work.	Rarely does the assigned work - often needs reminding.	Usually does the assigned work - rarely needs reminding.	Always does the assigned work without having to be reminded
Listen to other team mates	Is always talking— never allows anyone else to speak.	Usually doing most of the talking-- rarely allows others to speak.	Listens, but sometimes talks too much.	Listens and speaks a fair amount.

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III B.TECH VI SEMESTER I MID EXAMINATIONS - MARCH 2024

Branch : B.Tech. (CE) | **Subject : WATER RESOURCE ENGINEERING,CE604PC** | **Max. Marks : 20M**
Date : 19.03.2024 AN | **Time : 90 Minutes**

PART – A

ANSWER ALL THE QUESTIONS. **5 X 1M = 5M**

Q.No	Question	CO	BTL
1.	What is a rain gauge, and how does it measure rainfall?		
2.	What is mean by the concept of a rainfall double mass curve.		
3.	Define runoff and its significance in hydrology.		
4	Difference between Stream hydrograph and unit hydrograph.		
5.	List out types of aquifer.		

PART - B

ANSWER ALL THE QUESTIONS. **3 X 5M = 15M**

Q.No	Question	CO	BTL
6.	A catchment has five rain gauge stations. In a year, the annual rainfall recorded by the gauges are 78.8 cm, 90.2 cm, 98.6 cm, 102.4 cm and 70.4 cm. For a 6% error in the estimation of the mean rainfall, determine the additional number of gauges needed.		
	OR		
7.	Define hydrology. Discuss the various applications in engineering.		
8.	i) Describe the limitations and applications of unit hydrograph. ii)Distinguish between hyetograph and hydrograph.		
	OR		
9.	Discuss the concept of a synthetic unit hydrograph and its applications.		
10.	Discuss the factors influencing transmissibility in aquifers.		
	OR		
11.	Elaborate on Darcy's law and its significance in groundwater flow.		

III B.TECH VI SEMESTER II MID EXAMINATIONS - JUNE 2024

Branch : B.Tech. (CE) **Max. Marks : 20M**
Date : 19-Jun-2024 **Session : Afternoon** **Time : 90 Min**
Subject : WATER RESOURCE ENGINEERING,CE604PC

PART - A

ANSWER ALL THE QUESTIONS **5 X 1M = 5M**

Q.No	Question	CO	BTL
1.	Define transmissivity, storage coefficient.	CO3	L1
2.	Write about standards of quality for Irrigation water.	CO4	L1
3.	What is crop rotation. What are advantages of crop rotation.	CO4	L2
4.	which type of measures adopted to remove silt from the canal.	CO5	L1
5.	Distinguish between Kennedy's theory and Lacey's theory.	CO5	L1

PART - B

ANSWER ALL THE QUESTIONS **3 X 5M = 15M**

Q.No	Question	CO	BTL
6.	During the recuperation test conducted on an open well in a region, the water level in the well was depressed by 3 m and it was observed to rise by 1.75 m in 75 minutes. What is the specific yield from wells in that region? What could be the yield from a well of 5 m diameter under a depression head of 2.5 m? What should be the diameter of the well to give a yield of 12 lit/s under a depression head of 2 m?	CO3	L4
	OR		
7.	A water course has a culturable commanded area of 1500 hectares. The intensity of irrigation of crop A is 50% and for B is 40%. Crop A is a Kharif crop and crop B is a Rabi crop. Crop A has a kor period of 21 days and crop B has kor period of 14 days. Calculate the discharge of the water course if the kor depth for crop A is 15 cm and for B it is 20 cm.	CO3	L4
8.	a) Explain different types of Irrigation efficiencies. b) A crop requires a total depth of water of 130 cm. Find the duty of water if the base period for the crop is 100 days.	CO4	L3
	OR		
9.	Write notes on the following: (i) Saturation capacity (ii) Field capacity (iii) Wilting point (iv) Optimum water.	CO4	L4
10.	a) Write short notes on the following: (i) Free board in canals, (ii) Permanent land width, (iii) Inspection road, (iv) Dowla. b) The slope of a channel in alluvial soil is 1/6000. Find the channel section and the maximum discharge which can be allowed to flow in it. Take Lacey's silt factor f=1.2. The channel is of trapezoidal section, having side slopes ½:1	CO5	L3
	OR		

11.	a)What are the features of Lacey's method of design of irrigation channels. b)The slope of a channel in alluvial soil is 1/6000. Find the channel section and the maximum discharge which can be allowed to flow in it. Take Lacey's silt factor f=1.2. The channel is of trapezoidal section, having side slopes ½:1	CO5	L3

First Internal Examination Marks

Programme**: BTech** Year: **III** Course: **Theory** **A.Y: 2023-24**

Course: WATER RESOURSE ENGINEERING Section: A Faculty Name: D.VNV LAXMI ALEKHYA

S.No.	H.T.No.	Mid - I	Assignment - I	Mid - I Total	Mid - II	Assignment - II	Mid - II Total	AVG
1	21C11A0101	18	5	23	20	5	25	24
2	21C11A0103	11	5	16	12	5	17	17
3	21C11A0104	AB	AB	AB	AB	AB	AB	AB
4	21C11A0105	15	5	20	14	5	19	20
5	21C11A0106	12	5	17	12	5	17	17
6	21C11A0107	17	5	22	7	5	12	17
7	21C11A0108	19	5	24	19	5	24	24
8	21C11A0110	AB	AB	AB	AB	AB	AB	AB
9	21C11A0111	11	5	16	8	5	13	15
10	21C11A0112	11	5	16	8	5	13	15
11	21C11A0114	18	5	23	20	5	25	24
12	21C11A0115	17	5	22	11	5	16	19
13	21C11A0116	15	5	20	4	5	9	15
14	21C11A0117	14	5	19	10	5	15	17
15	21C11A0118	17	5	22	20	5	25	24
16	22C15A0101	15	5	20	11	5	16	18
17	22C15A0102	18	5	23	19	5	24	24

18	22C15A0103	17	5	22	16	5	21	22
19	22C15A0104	14	5	19	10	5	15	17
20	22C15A0105	14	5	19	11	5	16	18
21	22C15A0106	15	5	20	12	5	17	19
22	22C15A0107	14	5	19	13	5	18	19
23	22C15A0108	17	5	22	12	5	17	20
24	22C15A0109	13	5	18	11	5	16	17
25	22C15A0110	16	5	21	20	5	25	23

No. of Absentees: 02

Total Strength: 25

Signature of Faculty

: **Signature of HoD**

ANURAG ENGINEERING COLLEGE

(An Autonomous Institution)

(Approved by AICTE, New Delhi, Affiliated to JNTUH, Hyderabad, Accredited by NAAC with A+ Grade)

Ananthagiri (V & M), Kodad, Suryapet (Dist), Telangana

Program			YEAR	SEMESTER	MID EXAMINATION
B.Tech. ✓	M.Tech.	M.B.A.	III	II	II

HALL TICKET NO.: 2 1 C 1 1 A 0 1 0 1

Regulation: R-18 Branch or Specialization: Civil

Course: WRE

Signature of Student: K Amulya

Signature of Invigilator with date:

Signature of the Evaluator:

Q.No. and Marks Awarded

1	2	3	4	5	6	7	8	9	10	11
1	1	1	1	1	1	5	5	1		5

Maximum Marks: 20 | Marks Obtained: 20

(Start Writing From Here)

Part-A

1. Transmissivity :- It is defined as the ratio of discharge to the ratio of velocity. It is denoted by T.

$$T = \frac{Q}{V}$$

storage coefficient :- It is defined as the capacity of water required to store in a particular place.

2. * climatic condition :- If the temperature is high, Evaporation is less and humidity also less.
* soil condition :- The soil should be fertile for the crop.
* sub-surface :- The seepage velocity must be present in sub-soil.

3. Crop Rotation means the yielding of crops in a particular Season.

Advantages of crop rotation :-

* ploughing should be done in a systematical manner.

4. Regime canal is measured adopted to remove silt from the canal.
* Furrow type
* Sprinkler

5.

Kennedy's theory	Lacey's theory
* kennedy's theory states that the Eddies are generated from the bed of channel.	* Lacey's theory states that the Eddies are generated through the wetted perimeter
* It is wider and shallower	* It is deeper and thicker
* This Equation involves trial and Error method	* This Equation does not involve trial and Error metho

Part - B

Given data :-

Area (A) = 1500 hectares

Crop A = 50%

Base period B = 21 days

Depth (Δ) = 15 cm

Crop B = 40%

Base period B = 14 days

Depth (Δ) = 20 cm.

we know that,

$$D = 8.64 \frac{B}{\Delta}$$

(or)

$$\Delta = 8.64\left(\frac{B}{D}\right)$$

Crop A :-

$$\Delta = 8.64 \times \left(\frac{21}{15}\right)$$

$$\Delta = 12.09 \text{ cm}$$

we know that, $Q = AV$

$$= 1500 \times 0.5$$

$$Q = 750 \text{ cm}^3/\text{sec}$$

Crop B :-

$$\Delta = 8.64 \times \left(\frac{B}{D}\right)$$

$\Delta = 8.64 \times \frac{14}{20}$

$\boxed{\Delta = 6.048\ cm}$

we know that, $Q = AV$

$= 1500 \times 0.4$

$\boxed{Q = 600\ cm^3/sec}$

∴ The discharge of water course for crop A is

$Q = 750\ cm^3/sec$

∴ The discharge of water course for crop B is

$Q = 600\ cm^3/sec$

(a) Types of irrigation

* Surface irrigation
* sub-surface irrigation
* Sprinkler irrigation

Surface irrigation :-
when the irrigation surface is plain and smooth. The Efficiencies are formed on the Surface of the irrigation system.

Sub-Surface irrigation :-

The irrigation is above the structure the soil layer must be filled with dug, cow dung etc..
when the sub-surface irrigation system is developed it plays a crucial role in our country.

Sprinkler irrigation :-
In this irrigation system, farmers are using different type of chemicals those can be filled in a tank and they can sprinkler all around the field. As a result there is no proper sprinking is adopted.

(b) Given data :-

Depth of water (Δ) = 130 cm

B = 100 days ; D = ?

we know that, $D = 8.64 \frac{B}{\Delta}$

11a) Features of Lacey's theory :-

Some of the features of Lacey's method of design of irrigation channels.

* He states that the Eddies are generated through the wetted perimeter.
* The channel is suitable for irrigation as well as rivers.
* This theory is not measured by mean velocity.
* This theory is not involved for trial and error method.
* There is a relation b/w V & R.
* This method does not measure the slope of the bed.

b) Given data :-

slope = $\frac{1}{6000}$

Silt factor $f = 1.2$

Trapezoidal section,

side slope = $\frac{1}{2} : 1$

* Assume trail depth $D = 1.8$ m
* To calculate critical velocity.

$V = 0.55\, m (D)^{0.64}$

$= 0.55 \times 0.1 \ldots^{0.64}$

* To calculate discharge [∵ A = 1]

$Q = AV$

$= 1 \times 0.128 \times 1000$

$Q = 128\ m^3/sec$

* To calculate area of trapezoidal channel

$A = BD + \frac{D^2}{2}$

$= B(1.8) + \frac{1.8^2}{2}$

$= 1.8B + 1.62$

$A = 1.8 \times 1 + 1.62$

$A = 3.42\ m^2$

* To calculate wetted perimeter

$P = B + D\sqrt{5}$

$= 1 + 1.8 \times \sqrt{5}$

$P = 5.024\ m$

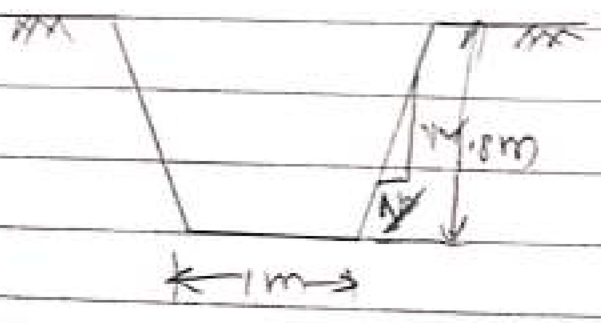
* By chezy's formula

$V = C\sqrt{RS}$

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

$= \frac{3.42}{5.02}$

$R = 0.680$



Hence B = 1m
and depth = 1.8m

Name : Bhukya. prathyusha   Sub : Water resource engineering
Hall ticket No. : 21C11A0114   Branch : civil   Mid : II   Sem : II

1] a) what is water logging ? what are causes of waterlogging ? what are its ill - effects ?

Water Logging :

* The soil whose surface layers are saturated with water is called as waterlogged soil
(or)
* The phenomenon of rising of water table.

Causes of waterlogging :

1] seepage of water from canal system

* The main cause of waterlogging in pakistan is seepage of water from network of canal system 40-50% water is lost from main canals, seeps through soil and rised the ground water.
* In some cases the water table has risen upto root zones or even surface soil.

2] Poor surface runoff and slow drainage :

* The soil surface of pakistan is flat so surface runoff is poor and hence slow drainage, result in accumulation of water on soil surface and move to the water table under the influence of gravity.
* The water table has risen causes water logging.

3] Interruption of surface runoff.

* construction of irrigation networks and housing colonies in the path of natural drains interrupted surface runoff, resulting in accumulation of water in rainy season contributes to waterlogging through seepage.

4] Rainfall :

* After heavy rainfall rain water percolates down the pores b/w soil particles under the action of gravity.

5] Floods

* Flood water spreads on the surface of soil in plains due to inappropriate drainage system, this water percolates in soil and raise water table cause waterlogging.

6] Poor water management

* sometimes farmers use their land unscientifically.
* These are major causes of waterlogging
* Excessive irrigation
* Lack of inadequate drainage system.

7] By Breaking hardpan at a canal bed.

* During cleaning season, the digging of canals breaks the hardpan of the soil at canal bed. it enhances the seepage of water.

8] Railway lines/Roads.

* The construction of railway lines and roads in food plains interrupted the passage of runoff water, water collected in rainy season in the form of ponds, percolates to soil, result in waterlogging.

Effects of water logging

* Absence of areation of soil in the root zone of the plants
* Difficulty in cultivation operations
* Growth of water weeds & wild aquatic plants
* Rise of salts in surface layers
* Restricted root growth
* Lower soil temperature
* plant diseases
* In waterlogged soil transport of gases is reduced disturbing normal growth.

... the width ... of the tube of slot varies from 15/100 to 40/100 b] Define sensitivity of an outlet. find the relation b/w sensitivity & flexibility of an outlet. ②

Sensitivity : it is defined as the ratio of the rate of change of discharge of an outlet to the rate of change of the level of the water surface in the distributing channel.

$$S = \left(\frac{dq/q}{dG/y} \right)$$

Relation between sensitivity & flexibility of an outlet

We know that, $\text{Flexibility} = F = \left[\frac{dq/q}{dQ/Q} \right]$

But $\frac{dQ}{Q} = \frac{n}{y} dy$

equation then becomes

$$F = \left[\frac{dq/q}{(n/y)dy} \right] = \frac{1}{n} \left[\frac{dq/q}{dy/y} \right]$$

But since, $dG = dy$ we get $F = \frac{1}{n} S.$

or $S = n.F$

If $n = \frac{5}{3}$, for wide trapezoidal channels, then,

$$S = (5/3)F.$$

2] a) Describe with the help of sketches, some of the common types of strainer wells.

The following seven common types of strainer wells.

1] Cook strainer.

→ it consists of a solid drawn brass tube. The wedge shaped slots are cut on the surface of the tube. The slots are horizontal.

→ The slots are cut from inside of the tube. thus the openings are wide inside of the tube. The width of the tube. of slot varies from 15/100 to 40/100 of a mm depending upon the coarseness of sand. This strainer is quite good but it is very expensive as the slot cutting is a difficult process.

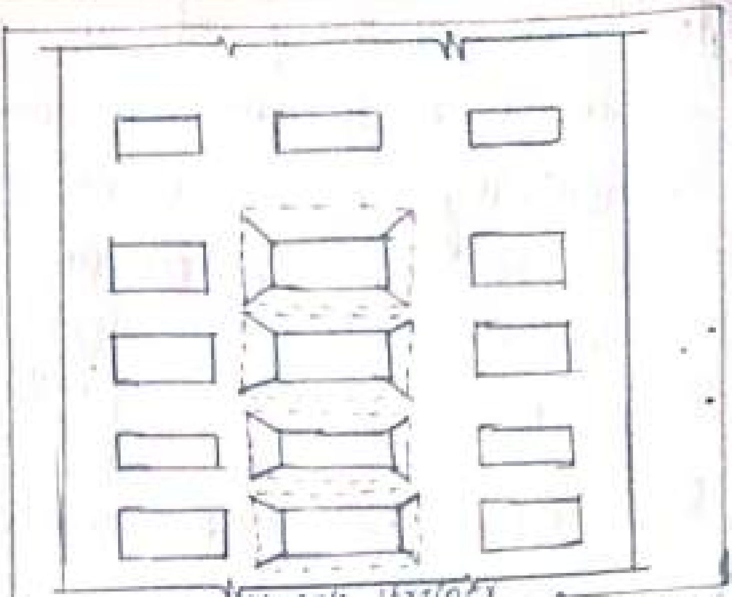


fig: cook strainer

2] Tej strainer

only difference b/w the Tej & cook strainer is in former the brass sheet is first slotted & then bent to form a tube. The tube is then brazed. As there are joints this strainer is weaker. It is cheap & hence widely used.

3] Brownlie strainer

It is made of a convoluted tube of steel. There are perforations in the tube. The wire mesh of in copper surroundings the steel tube. The convolution may be done in various ways. This type is designed in such a way that there is some space left b/w the perforated tube & the surrounding wiremesh.

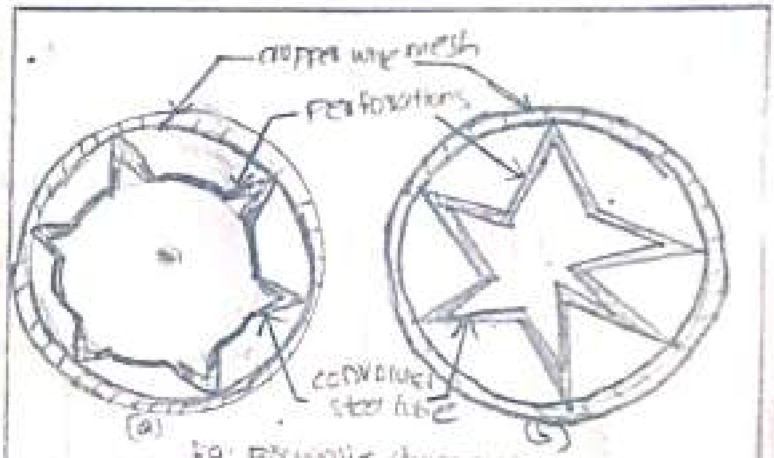


fig Brownlie strainer

4] Ashford strainer

It consists of a perforated tube with a wire mesh surrounding to keep the space b/w the mesh and the tube a wire is wound around the tube. The wire mesh is soldered to this wire. The wire mesh can be protected by a wire net above all. This type is delicate because there are many loose parts.

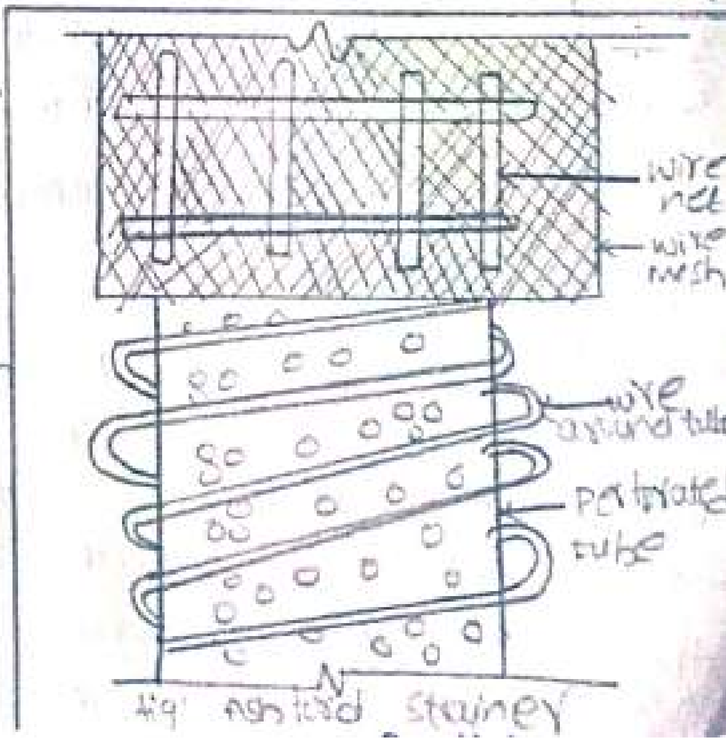


fig Ashford strainer

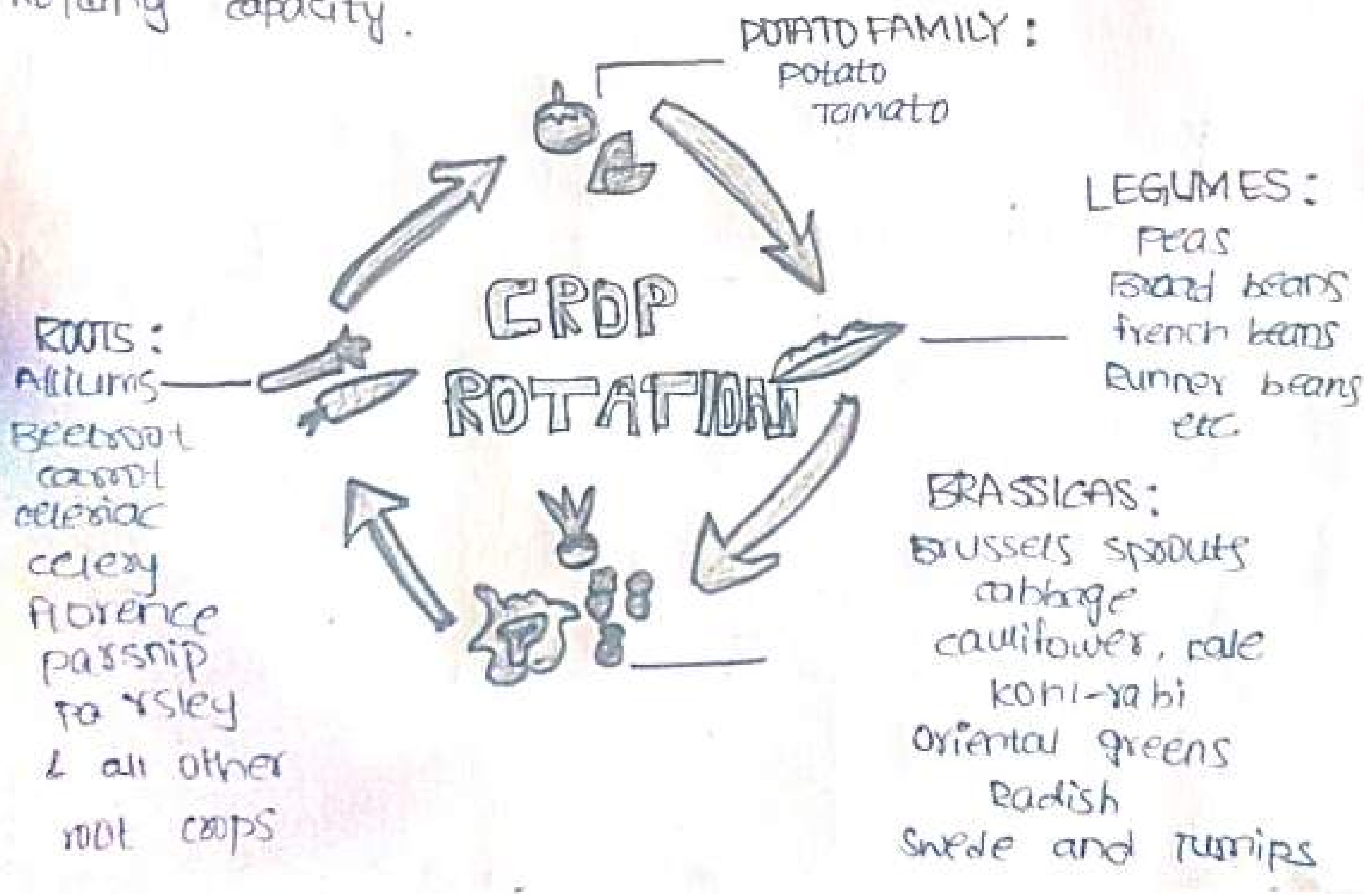
5) Legget strainer: In this type cutters are provided in the tube. By operating the cutters from the ground surface vertically in the tube can be cleaned.

6) Phoenix strainer. It is made of mild steel tube. To avoid corrosion of the tube it is plated with cadmium. The slits are made from inside.

7) Layne & Bowler strainer. It consists of a perforated steel or wrought iron tube. A wedge shaped steel wire is wound over this tube of strainer is robust it is costly.

b) What do you understand by crop rotation? What are its advantages?

Crop rotation: it improves water use efficiency by increasing the amount of organic matter in the soil, which can improve soil structure and water-holding capacity.



Advantages of crops rotation :

1] crop rotation helps in replenishment of soil fertility.

2] It prevents depletion of selective nutrients

3] It prevents building up of diseases & pests of particular crop

4] It enhances the production by increasing the soil fertility.

Water Resources Engineering – I

UNIT 1

- **Abstraction from rainfall**
- Evaporation - Factors affecting evaporation, measurement of evaporation
- Evapotranspiration – Penman and Blaney & Criddle methods
- Infiltration – Factors affecting Infiltration, Measurement of Infiltration, Infiltration Indices

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Water Losses or Abstraction:

Abstraction: The maximum amount of rainfall absorbed without producing runoff.

When there is precipitation, it may or may not result in overland flow into a stream depending upon its intensity and duration. The part of precipitation that is not available as surface runoff is referred to as precipitation loss or abstraction.

The hydrologic equation states that

Rainfall – Losses = Runoff

Hydrologic Abstractions:

- **Interception loss due to surface vegetation, i.e., held by plant leaves.**
  The precipitation intercepted by foliage (plant leaves, forests) and buildings and returned to atmosphere (by evaporation from plant leaves) without reaching the ground surface is called interception loss. Interception loss is high in the beginning of storms and gradually decreases; the loss is of the order of 0.5 to 2 mm per shower and it is greater in the case of light showers than when rain is continuous.
- **Evaporation**
  - from water surface, i.e., reservoirs, lakes, ponds, river channels, etc.
  - from soil surface, appreciably when the ground water table is very near the soil surface.

  Evaporation is the change of the state of water from liquid to vapor as a result of heat addition. Evaporation from a body of water occurs only if the surrounding air is not completely saturated with water vapor, that is, if the relative humidity is less than 100 percent.

- **Transpiration - from plant leaves.**

  Transpiration is the transfer of soil moisture from the soil to the atmosphere by the action of vegetation. Plants transpire water vapor through their foliage. Transpiration has minimal effect on individual storms and is usually only taken into account in long-term hydrologic budgets.

- **Evapotranspiration for consumptive use - from irrigated or cropped land.**

  Evaporation and transpiration are commonly lumped in one variable called evapotranspiration

- **Infiltration - into the soil at the ground surface.**

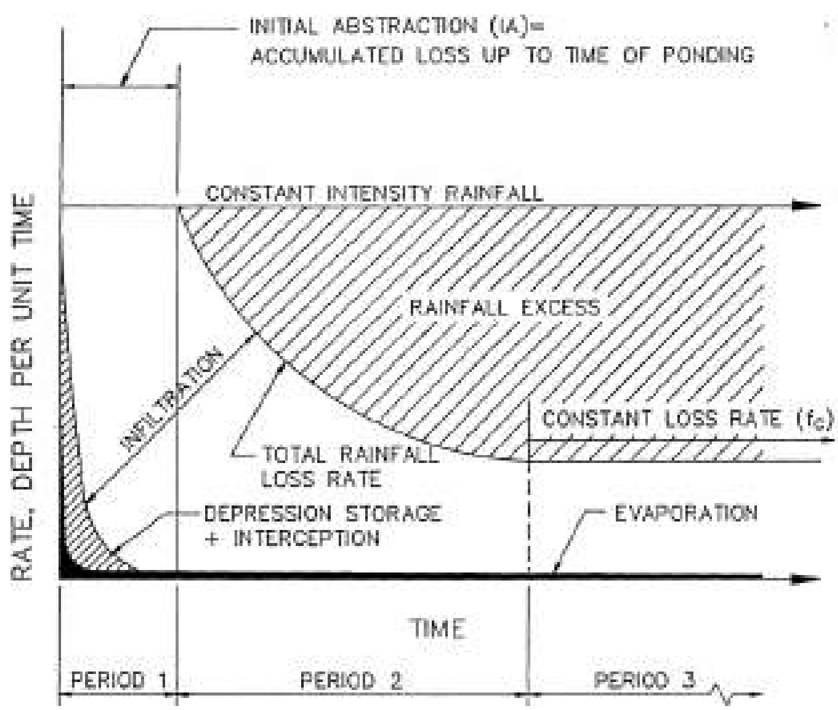
  Infiltration takes place as part of the rain percolates through the soil. The rate of infiltration depends on the soil type, slope, vegetation, soil moisture content, temperature, and the precipitation intensity. Infiltration usually is the largest abstraction and therefore has the most significant effect on runoff. Infiltration rates generally decrease with time as the rainfall proceeds and the soil becomes saturated.

- **Surface Detention**

  Water temporarily detained on the surface. Controlling factors are surface micro-relief, vegetation, surface slope, topography, rainfall excess.

- **Surface Retention**

  Water retained on the ground surface in micro depressions. This water will either evaporate or infiltrate into the soil. Nature of depressions as well as their size is largely a function of the original land form and local land use practices and erosion pattern.



Water Resources Engineering – I

- Hydrology & Hydrology Cycle
- Rainfall Measurement – Rain Gauges
- **Analysis of Rainfall Records - Estimating Missing Rainfall Data**
- Runoff Calculations

Estimating missing rainfall data

Due to the absence of observer or instrumental failure rainfall data record occasionally are incomplete. In such a case one can estimate the missing data by using the nearest station rainfall data. If for example rainfall data at day 1 is missed from station X having mean annual rainfall of N_x and there are three surrounding stations with mean annual rainfall of N1, N2, and N3 then the missing data P_x can be estimated

1. **Arithmetic Mean Method:**

   If N1, N2, and N3 differ within 10% of N_x

   $$P_x = (P1 + P2 + P3)/3$$

2. **Normal Ratio Method:**

   If N1, N2, or N3 differ by more than 10% of N_x

   $$P_x = \frac{1}{3}\left(P_1\frac{N_x}{N_1} + P_2\frac{N_x}{N_2} + P_3\frac{N_x}{N_3}\right)$$

3. **Reciprocal Inverse Weighing Factor**

   $$P_x = \Sigma\, 1/Xn\, [\Sigma Pn/Xn]$$

Where Xn = Distance between the missing data gauge and the other gauges surrounding the missed gauge.

Estimation of average depth of rainfall over a catchment

Several methods are commonly used for estimating average rainfall over a watershed. Choice of method requires judgment in consideration of quality and nature of the data, and the importance, use, and required precision of the result.

Methods of Estimation:

1. **Arithmetic Mean Method**

   The central assumption in the arithmetic mean method is that each rainguage has equal weight and thus the mean depth over a watershed is estimated by:

$$\overline{P} = \sum_{j=1}^{N} \frac{P_j}{N}$$

where: Pj = the station j,

N = the total number of rain gauges in and around the watershed.

It is a simple method, and well applicable if the gages are uniformly distributed over the watershed and individual gage measurements do not vary greatly about their mean.

2. **Thiessen Polygon Method**

   The Thiessen polygon method involves assigning relative weights to the gauges in computing the area average. The assumption in the method is that at any point in the watershed, the rainfall is the same as that at the nearest gauges so the depth recorded at a given gauges is applied out to a distance halfway to the next station in any direction.

The relative weights of each gauge are determined from the corresponding areas of application in a Thiessen polygon network, the boundaries of the polygons being formed by the perpendicular bisectors of the lines joining adjacent gages.

$$\overline{P} = \frac{1}{A} \sum_{j=1}^{J} A_j P_j, \quad A = \sum_{j=1}^{J} A_J$$

Where: Aj = the area of polygon j in the watershed (km^2)

P_j = rainfall amount in polygon j (mm)

P = average rainfall (mm)

The disadvantages of the Thiessen method are its inflexibility that is addition of new station implies construction of new polygon, and it does not directly account for orographic influences of rainfall.

3. **Isohyetal Method**

   The isohyets are drawn between the gauges over a contour base map taking into account exposure and orientation of both gauges and the catchment surface. The rainfall calculation is based on finding the average rainfall P_i between each pair of isohyets, and the area between them in the watershed A_j.

$$\overline{P} = \frac{1}{A}\sum_{j=1}^{J} A_j P_j \,, \quad A = \sum_{j=1}^{J} A_J$$

The method is good where there is a dense network of rain gauges. It is also flexible and considers orographic effect.

Double mass analysis

The double-mass analysis is used to detect if data at a site have been subjected to a significant change in magnitude due to external factors such as problems with instrumentation, observation practices, or recording conditions.

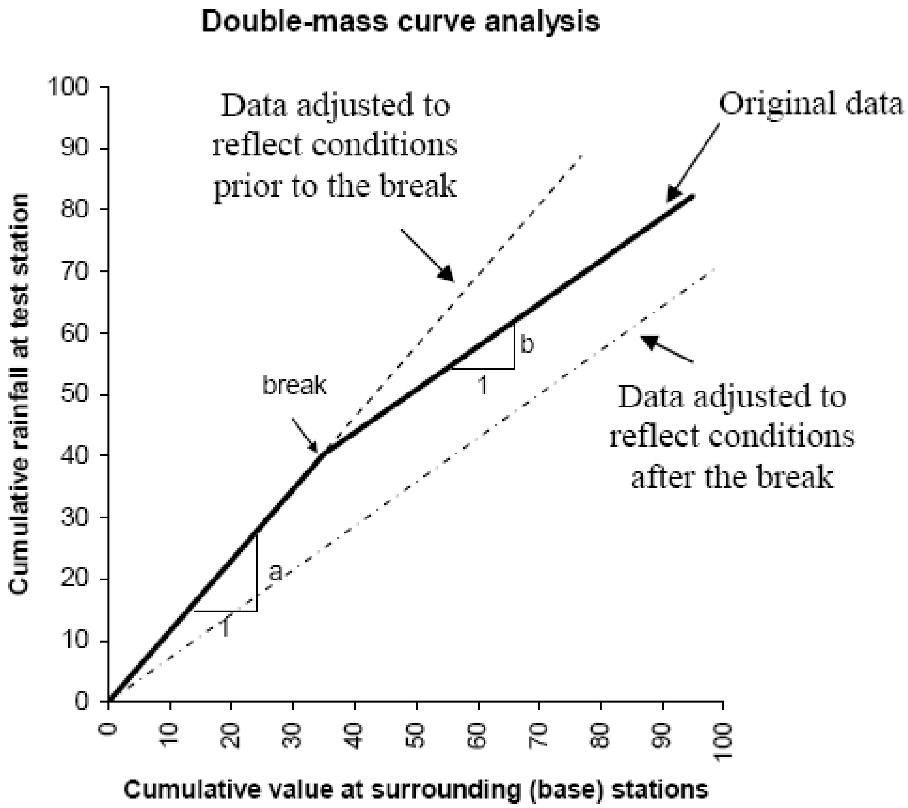
It consists of plotting cumulative rainfall values at a test station against the cumulative mean rainfall values at surrounding (base) stations. It is assumed that changes due to meteorological factors will affect all stations equally and therefore any breaks in the double-mass curve are strictly due to external factors. However, natural variations in the data can produce apparent changes in slope that need to be investigated further by performing statistical hypothesis testing analysis.

If the data are consistent, the double-mass curve will be a straight line of constant slope. If the data is not consistent, a break in the double-mass curve will be apparent. The ratio of the slopes prior ‘a’ and after the break ‘b’ can be used to adjust the data in two ways:

1. The data can be adjusted to reflect conditions prior to the break. This is done by multiplying each precipitation value after the break by the ratio a/b.

OR

2. The data can be adjusted to reflect recent conditions after the break. This is done by multiplying each precipitation value prior to the break by the ratio b/a.



Applicability:

- Base stations should be located relatively close to station being tested.
- Method should not be used in mountainous areas where precipitation can deviate significantly for nearby stations.
- Method should only be used for long-term adjustment of precipitation data but not for adjusting daily or storm precipitation

Water Resources Engineering – I

- **Design Discharge over a Catchment - Rational Formula**
- SCS Curve Number Method
- Introduction to Flood Frequency Analysis
- Stream Gauging – Measurement of estimation of Stream Flow

Introduction

A flood is commonly considered to be an unusually high stage of a river. For a hydraulic structure planned within the river (like a dam or a barrage) or on an adjoining area (like flood control embankments), due consideration should be given to the design of the structure so as to prevent it from collapsing and causing further damage by the force of water released from behind the structure. Hence an estimate of extreme flood flow is required for the design of hydraulic structures.

Methods of Design Discharge

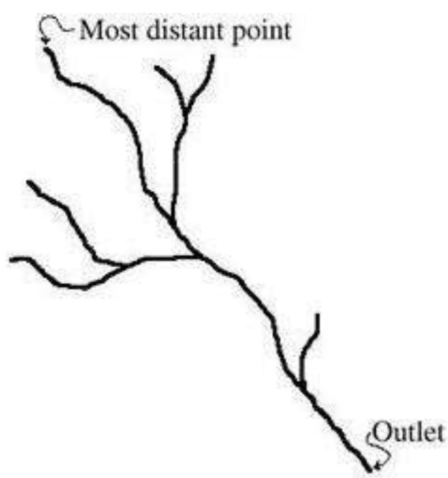
1. Indirect Methods
    a. Rational Method
    b. SCS Curve Number Method
    c. Unit Hydrograph Method
2. Direct Methods
    a. Current Meter
    b. Staff Guage
    c. Crest Stage Guage

Rational Method

Rational Method, which is the most commonly, used method of determining peak discharge from small drainage areas. Peak discharge is the greatest amount of runoff coming out of the watershed at any one time. The Rational Method is most effective in urban areas with drainage areas of less than 15 KM^2. The method is typically used to determine the size of storm sewers, channels, and other drainage structures. This method is not recommended for routing storm water through a basin or for developing a runoff hydrograph. However, for the sake of simplicity, you will use the Rational Method in your project to determine the size of the detention basin required for your construction site.

Limitations that Affect Accuracy of the Rational Method

- The Rational Method assumes that the drainage basin characteristics are fairly homogeneous. If the watershed being considered includes a variety of surfaces, such as paved areas, wooded areas, and agricultural fields, then another method should be selected.
- The type of surface in the drainage basin is also important. The Rational Method becomes more accurate as the amount of impervious surface, such as pavement and rooftops, increases. As a result, the Rational Method is most often used in urban and suburban areas.
- The Rational Method is less accurate for larger areas and is not recommended for drainage areas larger than 200 acres.
- For this method, it is assumed that a rainfall duration equal to the time of concentration results in the greatest peak discharge. The time of concentration is the time required for runoff to travel from the most distant point of the watershed to the outlet. Intuitively, once a rainfall event begins the amount of water flowing out of the watershed will begin to increase until the entire watershed is contributing water, at the time of concentration. If this assumption is not valid for a watershed, then the Rational Method's estimate of peak runoff will not be accurate.



Procedure:

The procedure for determining peak discharge using the Rational Method is as follows.

Step 1: Determine the drainage area (A) in KM^2

Step 2: Determine the runoff coefficient (C).

Step 3: Determine the hydraulic length or flow path that will be used to determine the time of concentration.

Step 4: Determine the types of flow (or flow regimes) that occur along the flow path.

Step 5: Determine the time of concentration (Tc) for the drainage area. (Kirpich Method)

$$tc = 0.00032 * L^{0.77} * S^{-0.385}$$

Where tc is the time of concentration in hours, L is the maximum length of travel of water in meter, and S is the slope equal to H/L, where H is the difference in elevation between the remotest point on the basin and the outlet (m).

Step 6: Use the time of concentration to determine the rainfall intensity (mm/hour)

Step 7: Input the drainage area, C value, and intensity into the formula to determine the peak rate of runoff

$$Q = 0.278CiA$$

Runoff Coefficients, C

The runoff coefficient, C, is a dimensionless ratio intended to indicate the amount of runoff generated by a watershed given a average intensity of precipitation for a storm.

$$C = \frac{R}{P},$$

where:

R = Total depth of runoff (L), and

P = Total depth of precipitation (L).

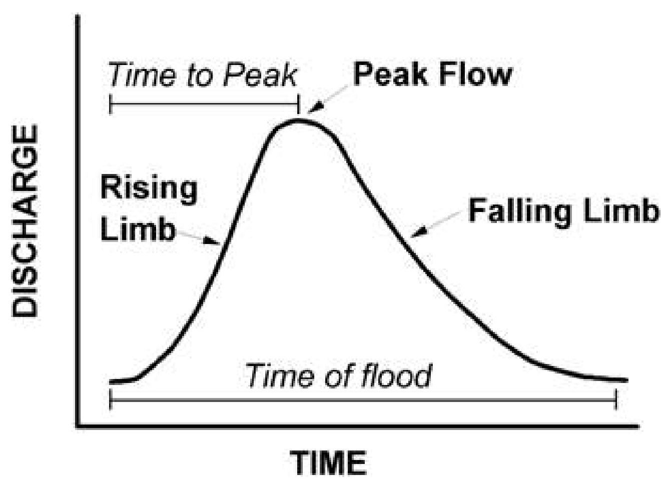
Type of Drainage Area	**Runoff Coefficient, C**
Steep, bare rock	0.90
Rock, steep but wooded	0.80
Plateaus lightly covered, ordinary ground bare	0.70
Densely built up areas of cities with metal led roads & paths	0.70-0.90
Residential areas not densely built up, with metal led roads	0.50-0.70
Residential areas not densely built up, with un-metalled roads	0.20-0.50
Clayey soils, stiff and bare	0.60
Clayey soils lightly covered	0.50
Loam, lightly cultivated or covered	0.40
Loam, lightly, largely cultivated	0.30
Suburbs with gardens, lawns and macadamized roads	0.30
Sandy soil, light growth	0.20

Water Resources Engineering – I

- **Distribution of Runoff, Hydrograph, Hydrograph Separation**
- Unit Hydrograph, Limitations of application of Hydrograph
- Derivation of Unit Hydrograph from Direct Runoff Hydrograph and Vice-versa
- S – Hydrograph, Synthetic Unit Hydrograph

Hydrograph

Hydrograph is the graphical representation of the instantaneous rate of discharge of a stream plotted with respect to time



Key terms to describe the storm hydrograph:

Lag time: The time period between peak rainfall and peak discharge.

Base flow: The constant part of a river's discharge produced by groundwater and slow through flow seeping slowly into the river. It is the main contributor to river flow during dry weather.

The **rising limb** shows the increase of the discharge. The highest flow is shown by the **peak discharge**. This occurs some time after the peak of the input because the water takes time to move through the system to the measuring point of the basin. The **falling or receding limb** shows the fall in the discharge back to the base level.

Surface Runoff or storm flow: Combination of overland flow and rapid through flow.

Components of the hydrograph

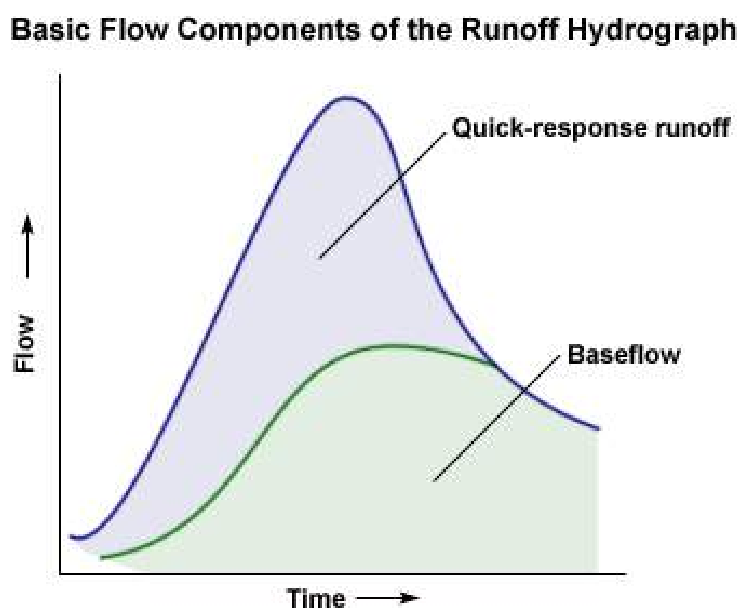
The hydrograph describes flow as a function of time usually known as a time series of flow. The interest may lie in the hydrograph of a long period of several years or only few selected rainfall events of few hours or days. The latter situation frequently occurs in the development of a rainfall-runoff relationship for a watershed.

It is customary to consider two components of the hydrograph:

1. **Direct runoff** the flow that results directly from the rainfall event. Usually after considering the associated losses from the gross rainfall. The volumes of effective rainfall and the volume of direct runoff should be equal.

2. **Base flow** that is unrelated to the rainfall event.

The rainfall-runoff relationship describes the time distribution of direct runoff as a function of excess rainfall (gross rainfall minus losses). Therefore, in developing the rainfall-runoff relationship for a watershed based on observed hyetographs and hydrographs, one must first subtract the Baseflow from the hydrograph. Even after long periods without rain, water still flows in many streams and rivers. This flow is the result of seepage from groundwater aquifers into the stream channel. In larger rivers, Baseflow can be significant. In periods without rain, the Baseflow in a stream will slowly decline as a result of the draw down of the groundwater aquifers. This phenomenon is called Baseflow recession. It is often assumed that Baseflow declines exponentially. Baseflow separation involves dividing the hydrograph into a direct runoff component and a Baseflow component.



Factors affecting the hydrograph shape

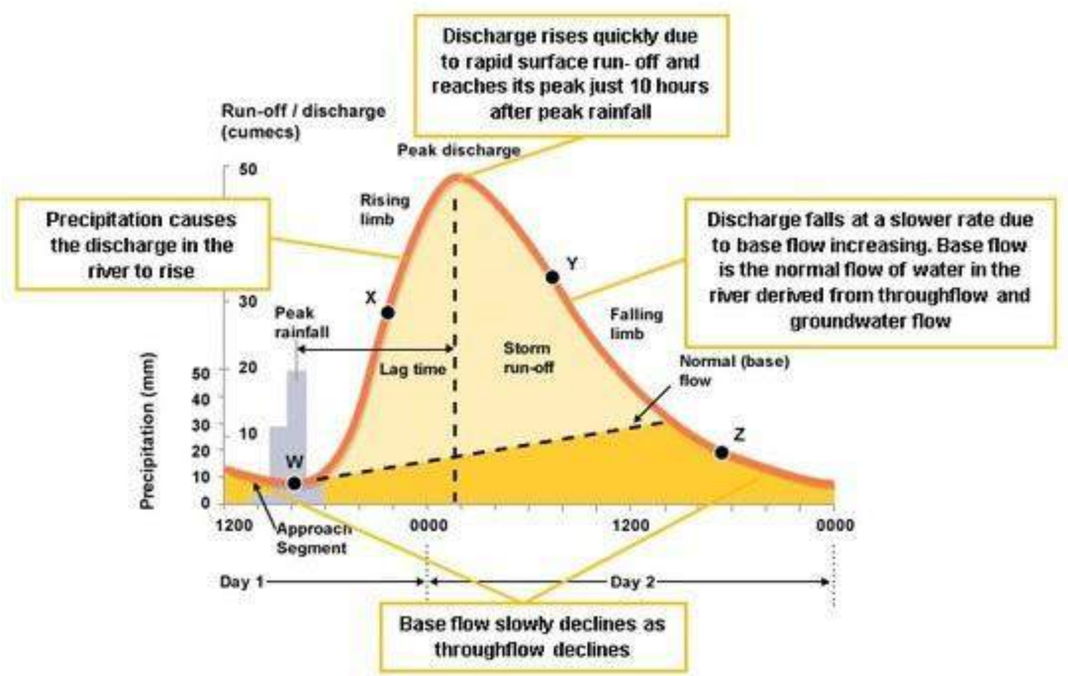
Most hydrographs are controlled by the interaction of several variable factors.

Factor	Hydrograph dominated by Quick-response flow processes*	Hydrograph dominated by Baseflow processes**
Climatic factors		
Precipitation (Intensity and duration of the storm)	High-intensity rainfall which exceeds the infiltration capacity of the soil. Large amount of rainfall	Low-intensity rainfall which is less than the infiltration capacity of the soil Small amounts of rainfall
Snow (Water stored as snow)	Fast snow melt as temperatures suddenly rise above zero	Slow snow melt
Evapotranspiration (temperature)	Low rates of evapotranspiration outputs due to low temperatures	High rates of evapotranspiration outputs due to high temperatures
Soil characteristics		
Soil moisture (Antecedent /pre-existing conditions)	Basin already wet from previous rain, water table high, soils saturated and so low infiltration/percolation	Dry soil-the soil store can hold much more water. Low water table. High infiltration/percolation
Permeability	Impermeable soil	Permeable soil
Drainage basin characteristics		
Drainage density	High drainage density (large number of streams per km).The higher the density the faster the water reaches the main river channel.	Low drainage density (small number of streams per km) means few streams and rivers and so water is more likely to enter the ground and move slowly through the basin.
Size of drainage basin	Small drainage basin tends to respond more rapidly to a storm than larger one, so the lag time is shorter.	
Slopes	Steep slopes promote surface runoff.	Gentle slopes allow infiltration and percolation.
Shape of drainage basin	Rainfall reaches the river more quickly from a round basin than from an elongated basin.	
Rock type	Impermeable rocks e.g. clay, granite, restrict percolation and encourage rapid runoff	Permeable rocks e.g. chalk and limestone, allow infiltration and percolation
Vegetation cover	Little vegetation cover. Lack of interception and root development to open up the soil. Rapid movement through the system. Deciduous trees in winter.	Forest and woodland intercept much rainfall, and root development encourages infiltration. More water lost to evaporation from vegetation surfaces. Deciduous trees in summer.
Soil depth	Thin soil e.g. upland areas allow little infiltration	Deeper soils provide a large soil store e.g. slope bottoms and lowland areas.

Water stores	Lack of lakes and backwater swamps	Lakes and backwater swamps act as water stores, and slow the movement to the channel.
Human activity		
Forests	Deforestation	Reforestation
Urban development	Urban development creates impermeable concrete and tarmac surfaces and water quickly reaches the channel via storms drains. Low infiltration/percolation	Rural land uses intercept more precipitation and have more permeable land surfaces. High infiltration and percolation.
Agricultural practices	Poor agricultural practices – poor soil structure, trampling by animals.	Good agricultural practices which encourage soil aeration and protect the soil surface.

*** Quick-response flow processes:** That component of the rain input which is delivered to the stream by surface runoff/overland flow, or rapid soil transfer. They give a high peak and rapid rise on the hydrograph.

**** Baseflow processes:** Processes such as slow through flow and groundwater flow, which transmit water slowly to the river channel.



Hydrograph Separation

- Discharge not associated with the storm (i.e. from groundwater) is termed Baseflow.
- Hydrograph or Baseflow separation is performed to determine the portion of the hydrograph attributable to Baseflow

Methods of Baseflow Separation:

1. **Constant Discharge Method:**

Assume Baseflow constant regardless of stream height (discharge) project from minimum value immediately prior to beginning of storm hydrograph.

2. **Constant Slope Method:**

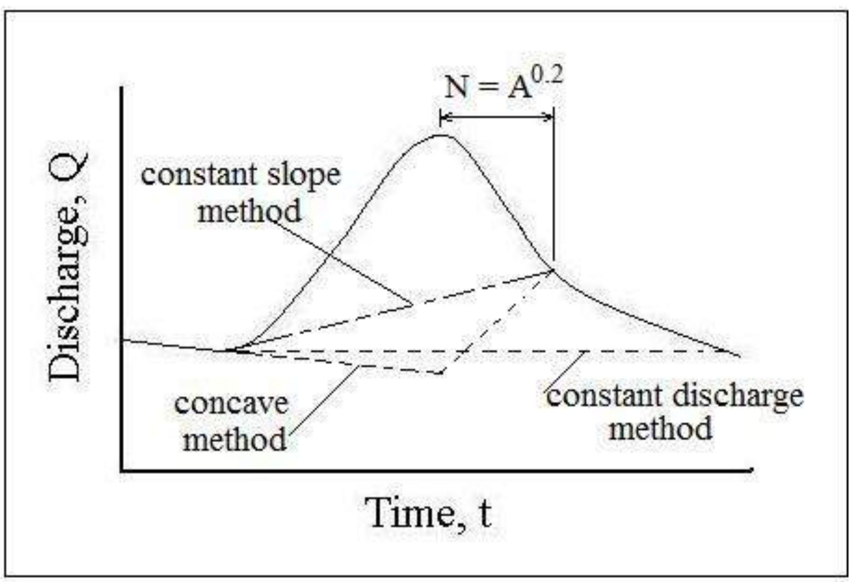
Connect inflection point on Receding limb of storm hydrograph to beginning of storm hydrograph

3. **Concave Method (most realistic):**

Assume Baseflow decreases while stream flow increases (i.e. to peak of storm hydrograph) project hydrograph trend from minimum discharge value immediately prior to beginning of storm hydrograph to directly beneath hydrograph peak connect that point to inflection point on receding limb of storm hydrograph

4. **Master depletion curve method**

Use when the most accurate model of hydrograph recessions is needed combine data from several recessions to make general recession model



Baseflow Separation Methods

2.10 Double mass analysis

Double mass curve technique is often used to test the consistency of rainfall record. The procedure is that accumulated rainfall at the gauge station whose record is in doubt is plotted as ordinate versus the average concurrent accumulated average rainfall of nearby stations whose rainfall data are reliable. The procedure is illustrated in Figure 2.16.

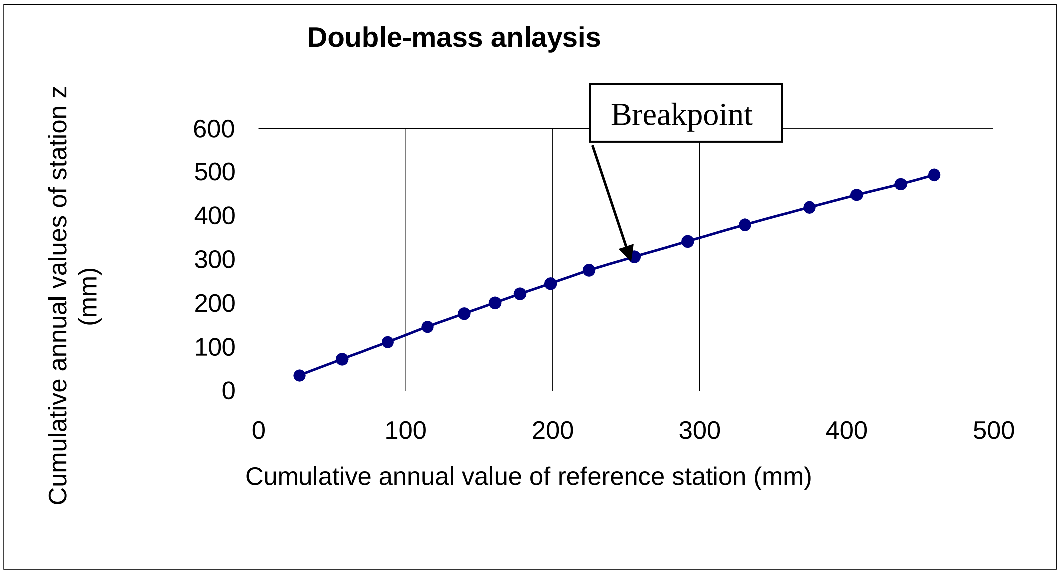


Figure 2.16. Double mass analysis technique

Where there is a break point in the graph is noted, the doubt station data may be adjusted to the previous slope value if the reason for doing so is convincing.

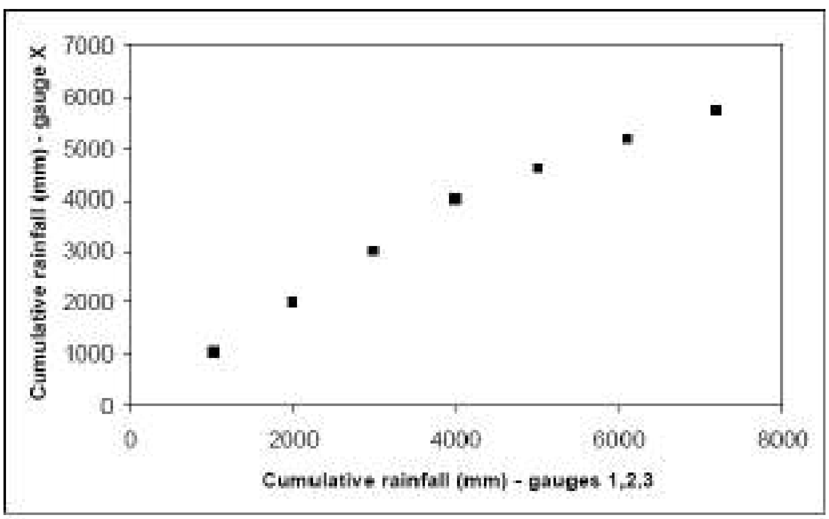
Example 2.5.

In this example the consistency of gauge X will be checked using the double mass curve technique.

Gauge X is the gauge we suspect may have developed a fault. Gauges 1, 2 and 3 are independent rain gauges, each of which has already been tested and are known to be functioning correctly. Gauges 1, 2 and 3 are all located nearby to gauge X.

Table for example mass curve analysis

	Annual rainfall totals (mm)					Cumulative rain (mm)	
	Gauge X	Gauge 1	Gauge 2	Gauge 3	Mean of gauges 1,2,3	Gauge X	Gauges 1,2,3
1988	1020	1020	1030	1040	1030	1020	1030
1989	980	960	980	970	970	2000	2000
1990	995	990	970	980	980	2995	2980
1991	1005	1000	1040	1020	1020	4000	4000
1992	600	1002	1004	1003	1003	4600	5003
1993	550	1080	1095	1110	1095	5150	6098
1994	575	1150	1100	1050	1100	5725	7198



Double mass curve for tabulated data

1. Identifying Erroneous Data

The steps involved in producing the double-mass curve are as follows:

- Compute the cumulative rainfall amounts for the suspect gauge (gauge X)
- Compute the mean of the annual rainfall totals measured by the check gauges (gauges 1,2 and 3)
- Compute the cumulative rainfall amounts for the check gauges (gauges 1, 2 and 3)
- Plot cumulative rainfall for the suspect gauge on the y-axis versus cumulative rainfall for the check gauges
- Attempt to construct a straight-line through the data points.

If there are no errors in the data for the suspect gauge, all points will fall (approximately) on a straight-line Divergence from a straight-line indicates an error in the data for the suspect gauge. If an error is present – the data can be corrected.

In the example, the data appear correct up to an including 1991. From that point on however (i.e. 1992 on), the suspect gauge appears to develop a fault, and begins to underestimate the annual rainfall totals.

2. Correcting the Erroneous Data

Once an error has been identified, the erroneous data can be corrected. This entails the calculation and application of a correction factor (k). The steps are as follows:

Stage 1.

- calculate the gradient of the best-fit line for the period for which no data errors are present. (In the example, the four year period 1988-1991)
- calculate the gradient of the best-fit line for the period for which an error is present. (In the example, the three year period 1992-1994)
- compute a correction factor k where k = *gradient before fault/gradient after fault*

In the example:

Gradient before fault = (4000-0)/(4000-0) = 1.0
Gradient after fault = (5725-4000)/(7198-4000) = 1725/3198 = 0.54

$k = 1.0/0.54 = 1.85$

Stage 2

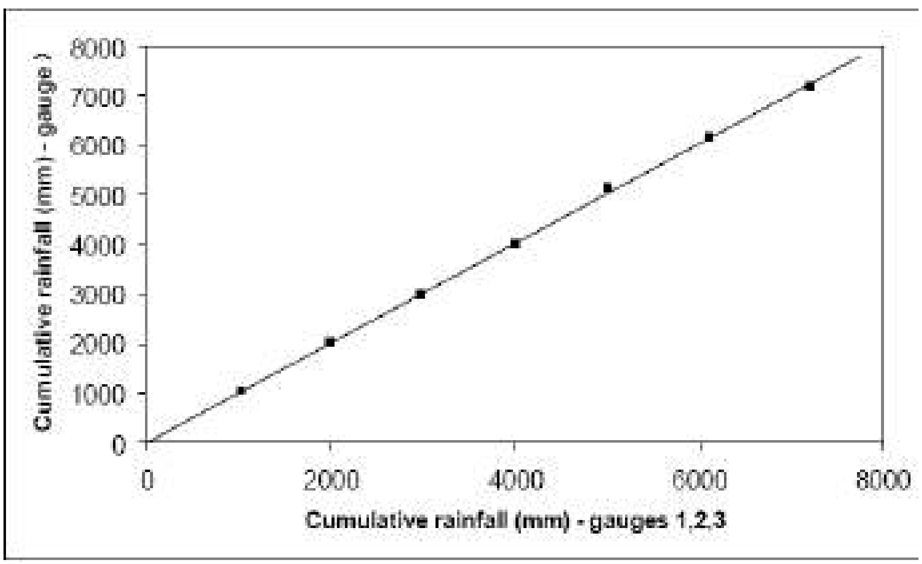
The correction factor is then applied to the erroneous data for gauge X, i.e. the annual rainfall totals for 1992, 1993, and 1994.

Thus the corrected rainfall total for 1992 becomes 600.0*1.85 = 1110.0 mm, 1993 becomes 550*1.85=1017.5 mm, and 1994 becomes 575*1063.75 mm.

Stage 3

If required, the analysis can be repeated for the corrected data to confirm that the procedure has worked satisfactorily.

	Annual depth (mm)		Cumulative rain (mm)	
	Gauge X	Gauge X (corrected)	Gauge X	Gauges 1,2,3
1988	1020	1020	1020	1020
1989	980	980	2000	2000
1990	995	995	2995	2995
1991	1005	1005	4000	4000
1992	600	**1110**	**5110**	5110
1993	550	**1018**	**6128**	6128
1994	575	**1064**	**7191**	7191



Double mass curve for corrected data

Water Resources Engineering – I

- Abstraction from rainfall
- **Evaporation - Factors affecting evaporation, measurement of evaporation**
- Evapotranspiration – Penman and Blaney & Criddle methods
- Infiltration – Factors affecting Infiltration, Measurement of Infiltration, Infiltration Indices

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Evaporation:

Evaporation occurs when water is converted into water vapor at the evaporating surface, the contact between water body and overlapping air. At the evaporative surface, there is a continuous exchange of liquid water molecule into water vapor & vice versa.

Factors affecting Evaporation:

- **Temperature:**

As the temperature of air is increased, its capacity to hold moisture also increases. Any increase in air temperature raises the temperature of water at the evaporation source which means that more energy is available to the water molecules for escaping from liquid to a gaseous state. Hence evaporation is directly proportional to the temperature of evaporating surface. Warmer the evaporating surface, higher the rate of evaporation.

- **Relative humidity:**

The rate of evaporation is closely related with the relative humidity of air. Since the moisture holding capacity of air at a given temperature is limited, drier air evaporates more water than moist air. In other words, higher the vapour pressure, lower the rate of evaporation. It is a common experience that evaporation is greater in summer and at mid-day than in winter and at night.

- **Wind-speed:**

Evaporation depends on the wind speed as well. When the winds are light, a thin layer of air just above the surface gets nearly saturated; under the circumstances the difference between the vapour pressure between ground and air is very small. This results in very low evaporation. On the other hand, when the wind velocity is high, turbulence is set up in the air. Moisture evaporated from the ground is mixed upward and the vapour-pressure difference between the atmosphere and the surface remains large. Thus, the rate of evaporation is accelerated. Wherever there is a combination of high temperature, very low relative humidity and strong wind, the rate of evaporation is exceptionally high. This leads to dehydration of soil to a depth of several inches.

- **Area of the evaporating surface:**

The rate of evaporation is determined by the area of the exposed surface of water. Larger areas of evaporating surface increase the rate of evaporation.

- **Air-pressure:**

Evaporation is also affected by the atmospheric pressure exerted on the evaporating surface. Lower pressure on open surface of the liquid results in the higher rate of evaporation.

- **Composition 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 more slowly than the fresh water.

Rate of Evaporation:

The rate of evaporation is defined as the amount of water evaporated from a unit surface area per unit of time. It can be expressed as the mass or volume of liquid water evaporated per area in unit of time, usually as the equivalent depth of liquid water evaporated per unit of time from the whole area. The unit of time is normally a day. The amount of evaporation should be read in mm. Depending on the type of instrument, the usual measuring accuracy is 0.1 to 0.01 mm.

Methods of measurement of evaporation:

The two methods for measurement of evaporation are:

- **Direct methods**
    - Water Budget Technique
    - Lysimeter
        - Weighing Type
        - Non-weighing Type
- **Indirect methods**
    - Aerodynamic method or Mass Transfer Method
    - Energy Budget Method
    - Penman Equation
    - Blaney & Criddle Method
    - Jensen Haise method
    - Hargreaves method or Pan Evaporation Method

Hargreaves method or Pan Evaporation Method

An evaporation pan is usually used to estimate evaporation from an open water body (e.g. lake or reservoir). The pan evaporation is computed based on the difference in the observed water levels adjusted for any precipitation observed between observations. The actual evaporation from a real open water body is smaller than that measured from a pan. Therefore, a correction coefficient is applied to the measured pan evaporation:

$$E_L = K.E_P$$

Where,

E_L = evaporation from an open water body

K = pan coefficient (0.6-0.8, with an average value of 0.7)

E_P = pan evaporation

Pan coefficient (K)

Evaporation pan data cannot be applied to free water surfaces directly but must be adjusted for the differences in physical and climatological factors. For example, a lake is larger and deeper and may be exposed to different wind speed, as compared to a pan. The small volume of water in the metallic pan is greatly affected by temperature fluctuations in the air or by solar radiations in contrast with large bodies of water (in the reservoir) with little temperature fluctuations. Thus the pan evaporation data have to be corrected to obtain the actual evaporation from water surfaces of lakes and reservoirs, i.e., by multiplying by a coefficient called pan coefficient

Types of Pans

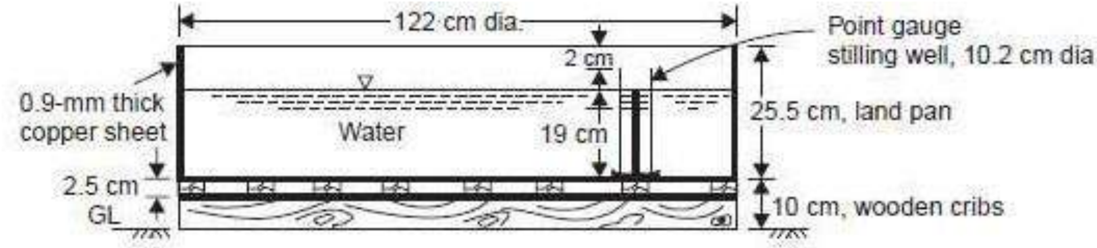
- **Floating Pan**

  A GI Pan of 90 cm square and 45 cm deep are mounted on a raft floating in water. The volume of water lost due to evaporation in the pan is determined by knowing the volume of water required to bring the level of water up to the original mark daily.

- **Land Pan or Class A Evaporation Pan (Recommended by IMD)**

  Evaporation pans are installed in the vicinity of the reservoir or lake to determine the lake evaporation. The IMD Land pan is 122 cm diameter and 25.5 cm deep made of unpainted GI; and set on wood grillage 10 cm above ground to permit circulation of air under the pan. The pan has a stilling well, vernier point gauge, a thermometer with clip and may be covered with a wire screen. The amount of water lost by evaporation from the pan can be directly measured by the point gauge. Readings are taken twice daily at

08.30 and 17.30 hours I.S.T. The air temperature is determined by reading a dry bulb thermometer kept in the Stevenson's screen erected in the same enclosure of the pan. A totalizing anemometer is normally mounted at the level of the instrument to provide the wind speed information required. Allowance has to be made for rainfall, if there has been any. Water is added to the pan from a graduated cylinder to bring the water level to the original mark, i.e., 5 cm below the top of the pan. Experiments have shown that the unscreened pan evaporation is 1.144 times that of the screened one.



- **Colarado sunken pan**

  This is 92 cm square and 42-92 cm deep and is sunk in the ground such that only 5-15 cm depth projects above the ground surface and thus the water level is maintained almost at the ground level. The evaporation is measured by a point gauge.

Applicability:

1. The largest errors in the evaporation pan method are due to the assumed pan coefficient. Therefore, the method is usually useful to provide long-term ballpark estimates of evaporation and to analyze the variability of evaporation.
2. The method is more appropriate for very shallow water bodies. For large water bodies, it may necessary to adjust for heat storage and energy advection.

Water Resources Engineering – I

- Abstraction from rainfall
- Evaporation - Factors affecting evaporation, measurement of evaporation
- **Evapotranspiration – Penman and Blaney & Criddle methods**
- Infiltration – Factors affecting Infiltration, Measurement of Infiltration, Infiltration Indices

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Transpiration:

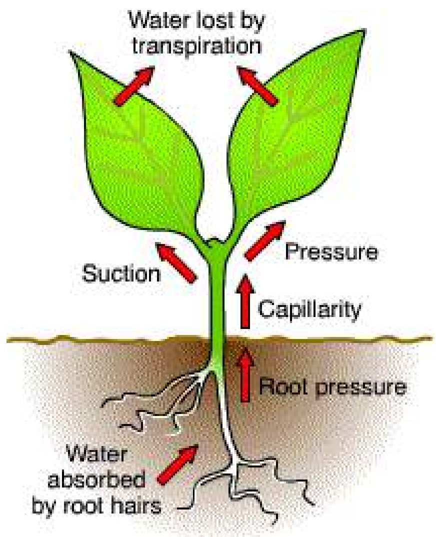
Transpiration is the process by which the water vapour escapes from the living plant leaves and enters the atmosphere.

Various methods are devised by botanists for the measurement of transpiration and one of the widely used methods is by phytometer. It consists of a closed water tight tank with sufficient soil for plant growth with only the plant exposed; water is applied artificially till the plant growth is complete. The equipment is weighed in the beginning (W_1) and at the end of the experiment (W_2). Water applied during the growth (w) is measured and the water consumed by transpiration (W_t) is obtained as

$$\mathbf{W_t = (W_1 + w) - W_2}$$

The experimental values (from the protected growth of the plant in the laboratory) have to be multiplied by a coefficient to obtain the possible field results. Transpiration ratio is the ratio of the weight of water absorbed (through the root system), conveyed through and transpired from a plant during the growing season to the weight of the dry matter produced exclusive of roots.

For the weight of dry matter produced, sometimes, the useful crop such as grains of wheat, gram, etc., is weighed. The values of transpiration ratio for different crops vary from 300 to 800 and for rice it varies from 600 to 800 the average being 700. Evaporation losses are high in arid regions where water is impounded while transpiration is the major water loss in humid regions.



Evapotranspiration

Evapotranspiration is the combined processes by which water is transferred to the atmosphere from open water surfaces and vegetation. It consists of evaporation, which is the amount of water vaporized into the atmosphere from open water surfaces and land areas, and transpiration, which is the amount of water absorbed by plants and crops and eventually discharged into the atmosphere through the plants stomata. The source of water for the plants and crops can be from the unsaturated and saturated zones.

During larger storm events, the intensity of precipitation is much larger than the rate of evapotranspiration. Therefore, evapotranspiration is commonly ignored or lumped with other abstractions when analyzing the water budget during and immediately following a storm event. For longer and drier periods, evapotranspiration becomes a significant component of the water budget.

Potential evapotranspiration is the evapotranspiration from the short green vegetation when the roots are supplied with unlimited water covering the soil. It is usually expressed as a depth (cm, mm) over the area. It is usually higher in the summer, on sunny days, and at latitudes closest to the equator due to the aforementioned reasons.

Potential evapotranspiration is monitored by hydrologists because it is useful in predicting the evapotranspiration of an area and as it usually peaks in the summer, it is helpful in monitoring potential drought situations.

Actual evapotranspiration is the actual amount of evaporation that occurs when water is limited.

Factors affecting evapotranspiration

- Climatological factors like percentage sunshine hours, wind speed, mean monthly temperature and humidity.
- Crop factors like the type of crop and the percentage growing season.
- The moisture level in the soil.

Estimation of evapotranspiration

The following are some of the methods of estimating evapotranspiration:

- Lysimeter
- Class 'A' Pan Method
- Penman Method
- Hargreaves Method
- Blaney & Criddle Method

Penman formula

The penman formula is a semi-empirical equation combining mass transfer (Ea) and energy budget (H) methods. The formula was developed by Penman in 1948 and is still widely used for calculating the potential evaporation using synoptic meteorological data.

According to Penman the potential evaporation E_o (in mm/day) can be calculated as:

$$E_o = \frac{\left(\frac{\Delta}{\gamma} H + E_a\right)}{\frac{\Delta}{\gamma} + 1}$$

where $\frac{\Delta}{\gamma}$ is an empirical parameter depending on temperature

$H = (1-r) R_{in} - R_o$

Where,

r = albedo (0.05 for water) – reflected sunlight

R_{in} = Incoming radiation

R_o = outgoing radiation

Weighting Factor Δ/γ and Temperature

(Ministry of Agriculture, Fisheries and Food (1967) *Potential Transpiration*. Reproduced by permission of the Controller, Her Majesty's Stationery Office, © Crown copyright.)

°C	0	10	20
0	0.69	1.26	2.23
0.5	0.71	1.30	2.28
1.0	0.73	1.34	2.35
1.5	0.76	1.38	2.41
2.0	0.78	1.42	2.48
2.5	0.80	1.47	
3.0	0.83	1.51	
3.5	0.85	1.56	
4.0	0.88	1.60	
4.5	0.91	1.65	
5.0	0.94	1.69	
5.5	0.97	1.74	
6.0	1.00	1.79	
6.5	1.03	1.84	
7.0	1.06	1.89	
7.5	1.09	1.94	
8.0	1.13	1.99	
8.5	1.16	2.04	
9.0	1.19	2.11	
9.5	1.23	2.17	

Blaney & Criddle formula:

This formula, based on another empirical model, requires only mean daily temperatures T (^{0}C) over each month. Then:

$$P_E = p\,(0.46T_{mean} + 8)\ \text{mm/day}$$

where

T_{mean} = mean daily temperature (^{0}C)

p = the mean daily percentage (for the month) of total annual daytime hours

Mean Daily Percentage (p) of Annual Daytime Hours for different Latitudes

Latitude	North	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
	South	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June
35		0.23	0.3	0.27	0.3	0.31	0.32	0.32	0.3	0.28	0.3	0.23	0.22
30		0.24	0.3	0.27	0.3	0.31	0.32	0.31	0.3	0.28	0.3	0.24	0.23
25		0.24	0.3	0.27	0.3	0.3	0.31	0.31	0.3	0.28	0.3	0.25	0.24
20		0.25	0.3	0.27	0.3	0.29	0.3	0.3	0.3	0.28	0.3	0.25	0.25
15		0.26	0.3	0.27	0.3	0.29	0.29	0.29	0.3	0.28	0.3	0.26	0.25
10		0.26	0.3	0.27	0.3	0.28	0.29	0.29	0.3	0.28	0.3	0.26	0.26
5		0.27	0.3	0.27	0.3	0.28	0.28	0.28	0.3	0.28	0.3	0.27	0.27
0		0.27	0.3	0.27	0.3	0.27	0.27	0.27	0.3	0.27	0.3	0.27	0.27

Calculation Example Blaney-Criddle Method

<u>Given</u>

Latitude = 35°North

Mean T max in April = 29.5°C

Mean T min in April = 19.4°C

<u>Question</u>

Determine for the month April the mean P_E in mm/day using the Blaney-Criddle method

<u>Answer</u>

Formula: $P_E = p\,(0.46\,T_{mean} + 8)$

Step 1: determine T mean:

$$T\ mean = \frac{T\ max + Tmin}{2} = \frac{29.5 + 19.4}{2} = 24.5°C$$

Step 2: determine p: Latitude: 35°North

Month: April

p = 0.29 (from table)

Step 3: calculate P_E:

$P_E = 0.29\,(0.46 \times 24.5 + 8) = 5.6$ mm/day

Thus the mean reference crop evapotranspiration P_E =5.6 mm/day during the whole month of April.

Indicative Values of P_E

If only a rough estimate of the P_E value is required, the following Table can be used.

	Mean daily temperature		
Climatic zone	low (less than 15°C)	medium (15-25°C)	high (more than 25°C)
Desert/arid	4-6	7-8	9-10
Semi arid	4-5	6-7	8-9
(Moist) Sub-humid	3-4	5-6	7-8
Humid	1-2	3-4	5-6

Water Resources Engineering – I

- **Hydrology & Hydrology Cycle**
- Rainfall Measurement – Rain Gauges
- Analysis of Rainfall Records - Estimating Missing Rainfall Data
- Runoff Calculations

Aim and Objectives

The overall aim of this lesson is to get familiarize and understanding the sources of water, hydrology and its components. The following are the objectives of the lesson:

- To know the principles behind the sources of water,
- To study about hydrologic cycle in general aspect, and
- To further understand the hydrological components like evaporation, precipitation, infiltration, runoff and subsurface flow.

Introduction

Most of the earth's water sources get their water supplies from precipitation, which may fall in various forms, such as, rain, snow, hail, dew etc. When rain starts falling, it is first of all intercepted by buildings and other objects. When the rainfall rate exceeds the interception rate, water starts reaching the ground and infiltration starts. This is the source of groundwater storage.

Sources of Water

The primary sources of water include: rainwater, surface water (stored in lakes, streams, and ponds), and groundwater. The distribution of water, however, is quite varied; many locations have plenty of it while others have very little. Water exists on earth in three forms solid (ice), liquid or gas (water vapour). Oceans, rivers, clouds, and rain, all of which contain water, are in a frequent state of change (surface water evaporates, cloud water precipitates rainfall infiltrates the ground, etc.). However, the total amount of the earth's water does not change.

Water at the Earth's Surface

Oceans	97.25%
Ice Caps and Glaciers	2.05%
Groundwater	0.68%

Lakes	0.01%
Soil Moisture	0.005%
Atmosphere	0.001%
Streams and Rivers	0.0001%

Definition of Hydrology

Hydrology is a multidisciplinary subject that deals with the occurrence, circulation and distribution of the waters of the Earth. In other words, hydrology is the study of the location and movement of inland water, both frozen and liquid, above and below ground. The domain of hydrology embraces the physical, chemical, and biological reaction of water in natural and manmade environment.

Application of Hydrology

Hydrology is applied to major civil engineering projects such as

- Irrigation schemes,
- Dams and Hydroelectric Power Projects, and
- Water Supply Projects.

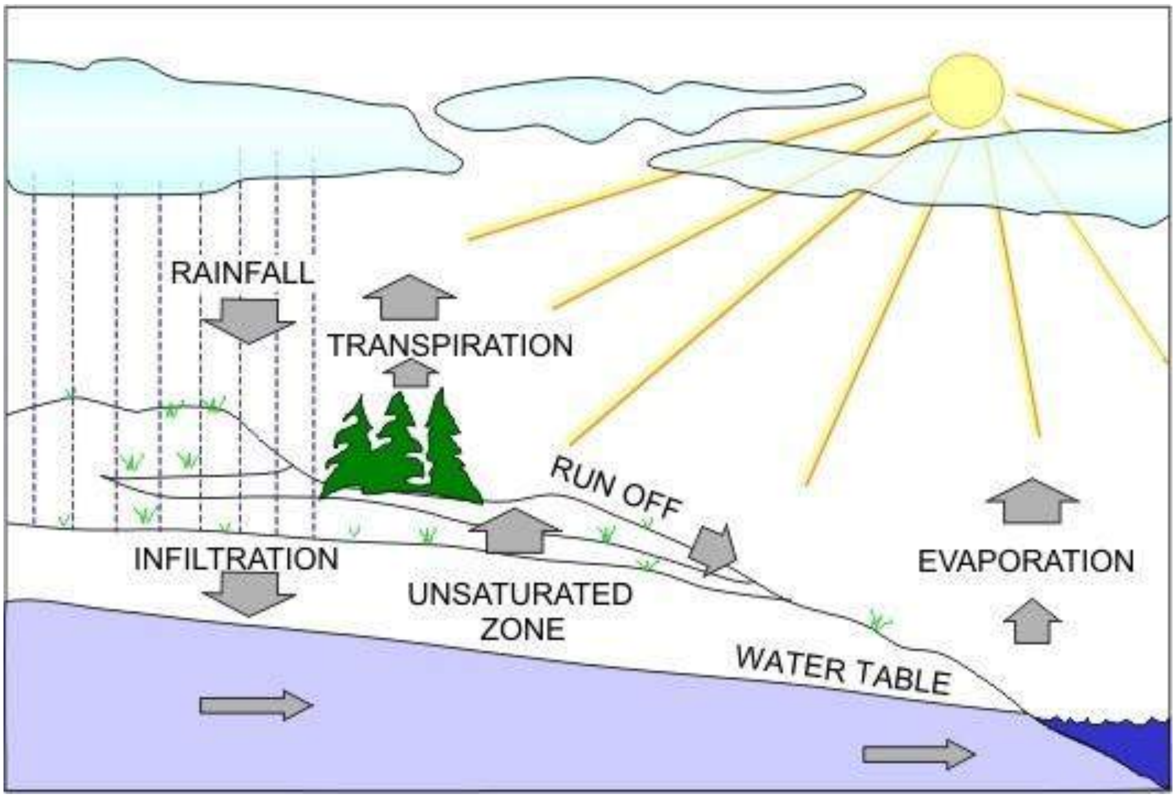
Scope of Hydrology

The study of hydrology helps us to know

1. the maximum probable flood that may occur at a given site and its frequency; this is required for the safe design of drains and culverts, dams and reservoirs, channels and other flood control structures.
2. 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.
3. the ground water development for which a knowledge of the hydrogeology of the area, i.e., of the formation soil, recharge facilities like streams and reservoirs, rainfall pattern, climate, cropping pattern, etc. are required.
4. the maximum intensity of storm and its frequency for the design of a drainage project in the area

Hydrologic Cycle

Journey of water from the ocean to atmosphere and back to the earth and ultimately to the ocean through the processes of evaporation, precipitation, percolation, runoff and return to the ocean is called hydrologic cycle.



The hydrologic cycle can be broadly divided into two phases

- Atmospheric Phase
- Land Phase

Atmospheric Phase of Hydrologic Cycle

Atmospheric phase of hydrologic cycle starts with the formation of clouds after vaporization from water bodies and ends after the occurrence of precipitation.

Land Phase of Hydrologic Cycle

After occurrence of precipitation, water comes in contact with the earth surface and hydrologic cycle enters the land phase. Part of precipitation is infiltrated and a part of it, depending upon circumstances, is intercepted by trees and vegetation. If there are depressions in the surface upon which precipitation falls, a part of precipitation will be stored in the depressions in the form of depression storage. All of these parts are liable to vaporization. Rainwater stands on the surface of earth where it falls, after various losses, depending upon the rate of rainfall when the depth of standing water becomes sufficient it starts flowing over the ground surface in the form of surface runoff.

Components of the Hydrologic Cycle – Storages and Flows

- **Precipitation** – Includes rain, snow and other forms of water falling from the atmosphere in liquid or solid phase into the land and oceans.
- **Evaporation** – Physical process by which water is vaporized into the atmosphere from free water surface and land areas.
- **Transpiration** – Water from the soil is absorbed by plant roots and eventually discharged into the atmosphere through little pores in the leaves called stomata. It is a side effect of the plant needing to open its stomata in order to obtain carbon dioxide from the air for photosynthesis. Transpiration cools plants and allows flow of nutrients from the plants roots to its stems and leaves.
- **Evapotranspiration** – Combined processes by which water is transferred to the atmosphere from open water surfaces and vegetation.
- **Detention storage** – Fraction of precipitation that is stored temporarily on the land surface en route to a stream.
- **Infiltration** – Movement of water from the land surface to the upper layers of the soil. It is usually the major abstraction from rainfall during a significant runoff producing storm.
- **Percolation** – Movement of water through the subsurface down to the water table.
- **Overland flow** – Portion of runoff that travels over the surface of the ground to reach a stream channel and through the channel to the basin outlet. This process occurs relatively quickly.
- **Surface runoff** – Includes all overland flow as well as precipitation falling directly onto stream channels.
- **Subsurface runoff** – Portion of runoff that travels under the ground to reach a stream channel and to the basin outlet. It includes: a) interflow, and b) groundwater runoff.
- **Groundwater runoff** – Portion of subsurface runoff that comes from infiltration and subsequently percolation down to the water table and eventually reaches a stream channel. This process occurs relatively slowly.
- **Baseflow, base runoff, delayed runoff** – Portion of the total runoff hydrograph at a stream location which is composed of contributions from: a) groundwater runoff, and b) delayed interflow. Baseflow is the result of water accumulating from previous storms and being released over an extended period of time.
- **Direct runoff** – Portion of the total runoff hydrograph at a stream which is caused by and directly following a rainfall or snowmelt event. It consists of: a) overland flow, and b) quick interflow

- **Abstractions** – Portion of precipitation that does not contribute to direct runoff. Includes interception, depression storage, and infiltration. Infiltration is usually the major abstraction from rainfall during a significant runoff-producing storm.
- **Initial abstractions** – Abstractions prior to the beginning of runoff including infiltration prior to ponding, depression storage and interception
- **Interception** – Fraction of precipitation that is retained on buildings and plants and is eventually evaporated.
- **Depression storage** – Fraction of precipitation that is trapped in puddles, ditches, and other surface depressions from where it evaporates or infiltrates into the soil.

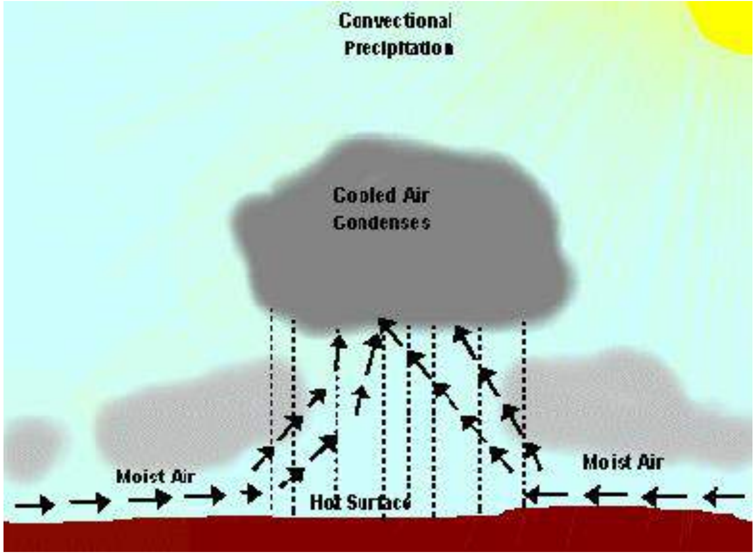
Forms of Precipitation

- **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)
- **Snow flakes** — 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.
- **Dew** — moisture condensed from the atmosphere in small drops upon cool surfaces.
- **Frost** — a feathery deposit of ice formed on the ground or on the surface of exposed objects by dew or water vapour that has frozen
- **Fog** — a thin cloud of varying size formed at the surface of the earth by condensation of atmospheric vapour (interfering with visibility)
- **Mist** — a very thin fog

Types of Precipitation

- **Convectional**

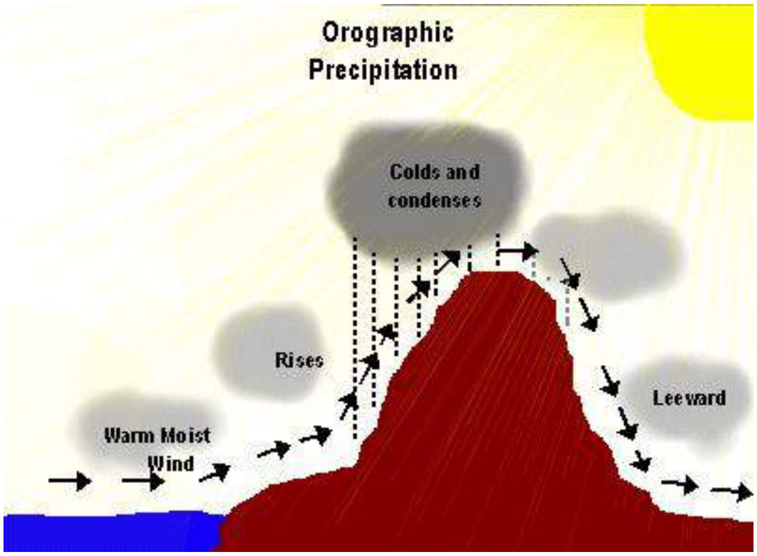
  Convectional precipitation results from the heating of the earth's surface. The warm ground heats the air over it. As the air warms, the air molecules begin to move further apart. With increased distance between molecules, the molecules are less densely packed. Thus, the air becomes “lighter” and rises rapidly into the atmosphere. As the air rises, it cools. Water vapour in the air condenses into clouds and precipitation.



- **Orographic**

  Orographic precipitation results when warm moist air moving across the ocean is forced to rise by large mountains. As the air rises, it cools. Why? A higher elevation results in cooler temperatures

  Cold air cannot hold as much moisture as warm air. As air cools, the water vapour in the air condenses and water droplets form. Clouds forms and precipitation (rain or snow) occurs on the windward side of the mountain (see diagram). The air is now dry and rises over top the mountain. As the air moves back down the mountain, it collects moisture from the ground via evaporation. This side of the mountain is called the leeward side. It receives very little precipitation.

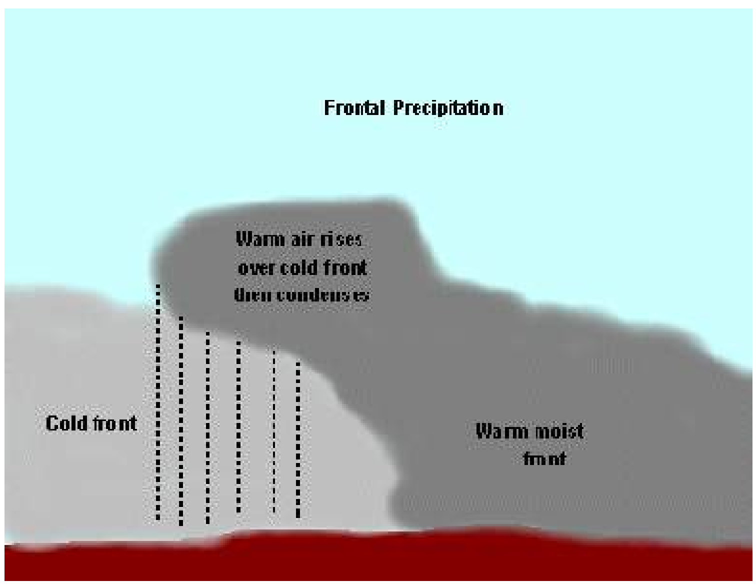


- **Cyclonic**

  Cyclonic or Frontal precipitation results when the leading edge of a warm, moist air mass (warm front) meets a cool and dry air mass (cold front). The molecules in the cold air are more tightly packed together (i.e., more dense), and thus, the cold air is heavier than the warm air. The warmer air mass is forced up over the cool air.

  As it rises, the warm air cools, the water vapour in the air condenses, and clouds and precipitation result. This type of system is called Frontal Precipitation because the moisture tends to occur along the front of the air mass.

  A cyclonic storm is a large, low pressure system that forms when a warm air mass and a cold air mass collide. This collision often occurs under the polar-front jet stream which spreads cold, dry arctic air near warm, moist tropical air. The rotation of the earth causes the air to circulate in a counterclockwise direction around an area of low pressure.



Water Resources Engineering – I

- Abstraction from rainfall
- Evaporation - Factors affecting evaporation, measurement of evaporation
- Evapotranspiration – Penman and Blaney & Criddle methods
- **Infiltration – Factors affecting Infiltration, Measurement of Infiltration, Infiltration Indices**

Infiltration

Infiltration is the process of water entry into a soil from rainfall, or irrigation.

Percolation is the process of water flow from one point to another point within the soil.

Infiltration rate is the rate at which the water actually infiltrates through the soil during a storm and it must be equal the infiltration capacities or the rainfall rate, whichever is lesser.

Infiltration capacity is the maximum rate at which a soil in any given condition is capable of absorbing water. The rate of infiltration is primarily controlled by the rate of soil water movement below the surface and the soil water movement continues after an infiltration event, as the infiltrated water is redistributed.

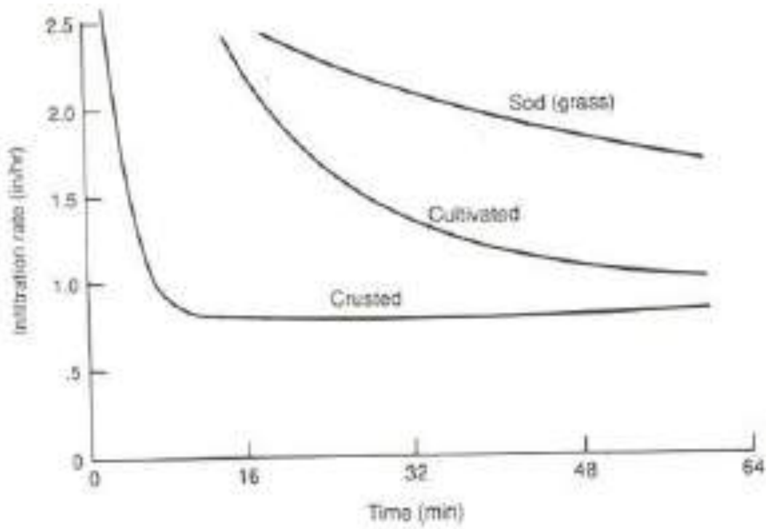
Infiltration and percolation play a key role in surface runoff, groundwater recharge, evapotranspiration, soil erosion, and transport of chemicals in surface and subsurface waters.

Factors affecting infiltration

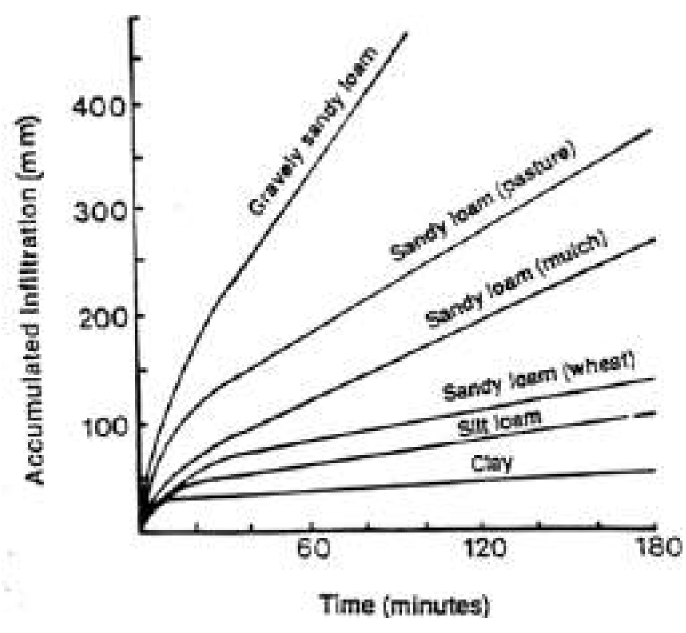
Infiltration rates vary widely. It is dependent on the condition of the land surface (cracked, crusted, compacted etc), land vegetation cover, surface soil characteristics (grain size & gradation), storm characteristics (intensity, duration & magnitude), surface soil and water temperature, chemical properties of the water and soil.

Surface and soil factors

The surface factors are those affect the movement of water through the air-soil interface. Cover material protect the soil surface. A bare soil leads to the formation of a surface crust under the impact of raindrops or other factors, which breakdown the soil structure and move soil fines into the surface or near-surface pores. Once formed, a crust impedes infiltration.



Soil physical properties include particle size properties and morphological properties. Particle-size properties are determined from the size distribution of individual particles in a soil sample. Soil particles smaller than 2 mm are divided into three soil texture groups: sand, silt, and clay. The morphological properties having the greatest effect on soil water properties are bulk density, organic matter, and clay type. These properties are closely related to soil structure and soil surface area. Bulk density is defined as the ratio of the dry solid weight to the soil bulk volume. The bulk volume includes the volume of the solids and the pore space.



Measurement of Infiltration

The rate of infiltration is initially high. It goes on reducing with time and after some time it becomes steady. The rate of infiltration for a soil is measured in the field as well as in the laboratory. These are known as infiltrometers.

The most common types are the following:

- **Flooding-type infiltrometers**

  Used to determine infiltration rates for inundated soils such as flood irrigation or pond seepage.

  These infiltrometers are usually metal rings with a diameter of 30 to 100 cm and a height of 20 cm. The ring is driven into the ground about 5 cm, water is applied inside the ring with a constant-head device, and intake measurements are recorded until a constant rate of infiltration is attained. To help eliminate the effect of lateral spreading use a double-ring infiltrometer, this is a ring infiltrometer with a second larger ring around it.

  Types of Infiltrometers:

  - **Single-tube flooding infiltrometers**

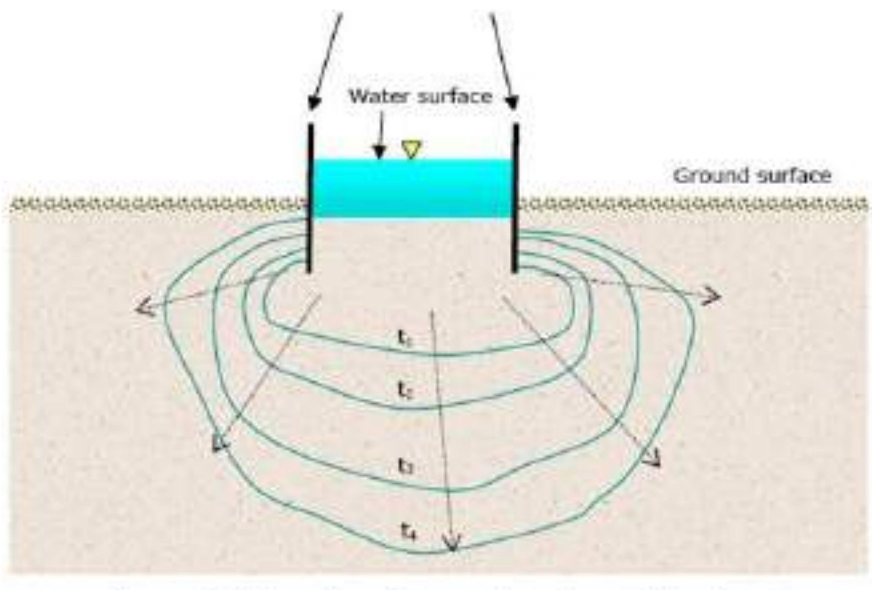


Figure: Infiltrometer diagram showing wetting-front movement from time t_1 to t_4.

  - **Double-tube flooding infiltrometers**

    The double ring infiltrometers is a way of measuring saturated hydraulic conductivity of the surface layer, and consists of an inner and outer ring inserted into the ground. Each ring is supplied with a constant head of water either manually or from mariotte bottles. Hydraulic conductivity can be estimated for the soil when the water flow rate in the inner ring is at a steady state.

It works by directing water onto a known surface area due to the parameters of the inner ring. The rate of infiltration is determined by the amount of water that infiltrates into the soils per surface area, per unit of time. Infiltration can be measured by either a single or double ring infiltrometers, with preference usually lying with the double ring because the outer ring helps in reducing the error that may result from lateral flow in the soil.

- **Sprinkling-type infiltrometers or rain simulators**

  Used where the effect of rainfall on surface conditions influences the infiltration rate.

  With the help of rain simulator, water is sprinkled at a uniform rate in excess of the infiltration capacity, over a certain experimental area. The resultant runoff R is observed, and from that the infiltration f using f = (P-R)/t. Where P = Rain sprinkled, R = runoff collected, and t = duration of rainfall.

  Types of Sprinkling-type infiltrometers:

  - Needle drip systems
  - Stand pipes
  - Sprinkler nozzles
  - Rotating boom

  Experiment Procedure:

  - Before beginning the experiment, select a very gently sloping area about $1m^2$.
  - Determine and mark the lowest point in this area and dig a pit there which is about 30 cm in diameter and in depth.
  - Use the metal flashing to create a tear-drop shaped drainage basin with the hole you dug at the downstream end. Press the flashing into the ground. Use stakes to secure the metal to the ground. Estimate the area of your plot by considering it a series of narrow rectangles.

- o At the down gradient end, secure the funnel to the metal flashing and use plaster to create a good seal so that any run off generated goes into the bucket not under or around the flashing.
- o Fill at least three backpack sprayers with water and have at least three, preferably four, people on hand. Have two people sprinkling, one person taking data, and another reading rain gauges and emptying buckets to measure run off.

- **Tension Type**

  Used to determine the infiltration rates of soil matrix in the presence of macro pores

- **Furrow Type**

  Used when the effect of flowing water is important

- **Average Infiltration Method or Areal infiltration estimation**

  Areal infiltration estimation is accomplished by analysis of rainfall-runoff data from a watershed. For a storm with a single runoff peak, the procedure resembles that of the calculation of φ index. The rainfall hyetograph is integrated to calculate the total rainfall volume. Likewise, the runoff hydrograph is integrated to calculate the runoff volume. The infiltration volume is obtained by subtracting runoff volume from rainfall volume. The average infiltration rate is obtained by dividing infiltration volume by rainfall duration.

- **Soil Surveys**

  Usually report infiltration ranges for various soil types

  Example:

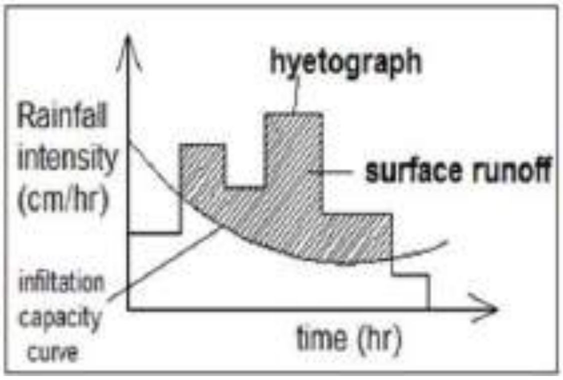
Sand	124 mm/hr
Sandy loam	50 mm/hr
Loam	13.2 mm/hr
Silt loam	1.05 mm/hr
Light clay	0.44 mm/hr

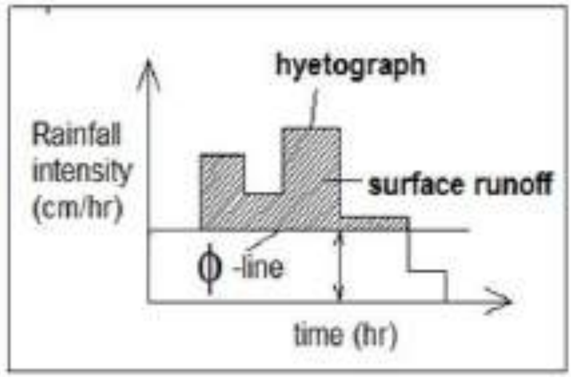
Infiltration indices

The average value of infiltration is called infiltration index.

Two types of infiltration indices

- φ - index
- w – index





The indices are mathematically expressed as:

$$\phi\text{-index} = (P-R)/t_e$$

$$w\text{-index} = (P-R-I_a)/t_e$$

Where,

P=total storm precipitation (cm)

R=total surface runoff (cm)

I_a=Initial losses (cm)

t_e= elapsed time period (in hours)

The w-index is more accurate than the φ-index because it subtracts initial losses

Water Resources Engineering – I

- Hydrology & Hydrology Cycle
- **Rainfall Measurement – Rain Gauges**
- Analysis of Rainfall Records - Estimating Missing Rainfall Data
- Runoff Calculations

Precipitation

Precipitation is one of the most important components of the hydrologic cycle as it connects the atmospheric component of the hydrologic cycle with the land and ocean components. It includes rain, snow and other forms of water falling from the atmosphere in liquid or solid phase into the land and oceans.

Storm (Heavy Rain) Characteristics

The characteristics of a storm, namely depth, duration, intensity and distribution, affect the watershed response to the rainfall event.

- Depth – Amount of precipitation that falls (usually in or cm).
- Duration – Length of a storm (usually min, hr or day)
- Intensity – Depth of rainfall per unit time (usually in/hr or cm/hr). Rainfall intensity changes continuously throughout a storm, but it may be averaged over short time intervals or over the entire storm duration.
- Distribution – Describes how rainfall depth or intensity varies in space over an area or watershed

Rainfall Formation

The formation of rainfall requires the lifting of an air mass in the atmosphere so that it cools and some of its moisture condenses. The three mechanisms of air mass lifting are

- **frontal lifting**, where warm air is lifted over cooler air by frontal passage;
- **orographic lifting**, in which an air mass rises to pass over a mountain range; and
- **convective lifting**, where air is drawn upwards by convective action, such as in the center of a thunderstorm cell.

Measurement of rainfall and optimum number of rain gauges

The basic instrument for rainfall measurement is rain gauge, which samples the incidence of rainfall at a specific point, through an orifice of known area.

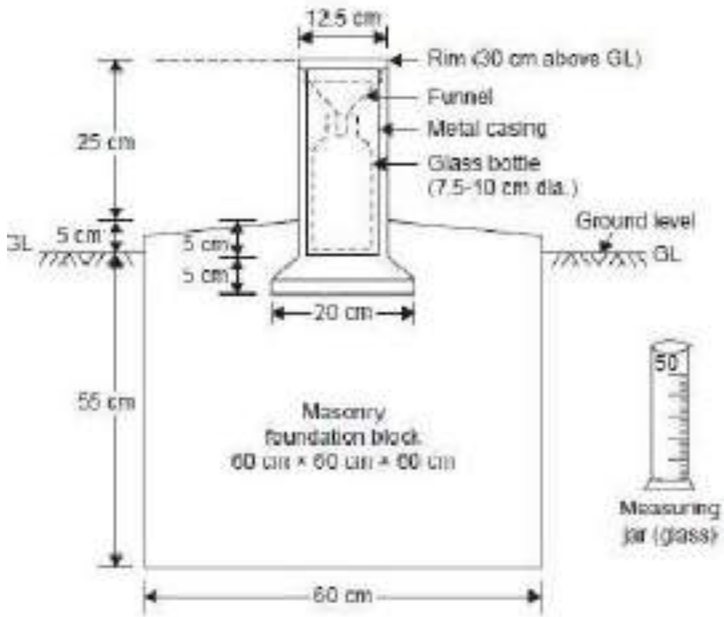
Types of Rain Gauges:

1. **Non-Recording Rain Gauge**

   The non-recording rain gauge used in India is the Symon's rain gauge. It consists of a funnel with a circular rim of 12.7 cm diameter and a glass bottle as a receiver. The cylindrical metal casing is fixed vertically to the masonry foundation with the level rim 30.5 cm 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 full it can measure 1.25 cm of rain.

   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, lest the receiver fill and overflow, but the last measurement should be at 08.30 hours IST and the sum total of all the measurements during the previous 24 hours 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 the 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.



2. 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 a clockwork, a drum with a 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 a storm, time of onset and cessation of rainfall, can be determined.

The gauge is installed on a concrete or masonry platform 45 cm square in the observatory enclosure by the side of the ordinary rain gauge at a distance of 2-3 m from it. The gauge is so installed that the rim of the funnel is horizontal and at a height of exactly 75 cm above 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 the recording rain gauge can be checked and if necessary adjusted.

a) Tipping Bucket Rain Gauge

This consists of a cylindrical receiver 30 cm diameter with a funnel inside. Just below the funnel a 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 of the 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.

b) Weighing Type Rain Gauge

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

c) Floating Type Rain Gauge

In this type, as the rain is collected in a float chamber, the float moves up which makes a pen to move on a 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 used by Indian Meteorological Department (IMD).

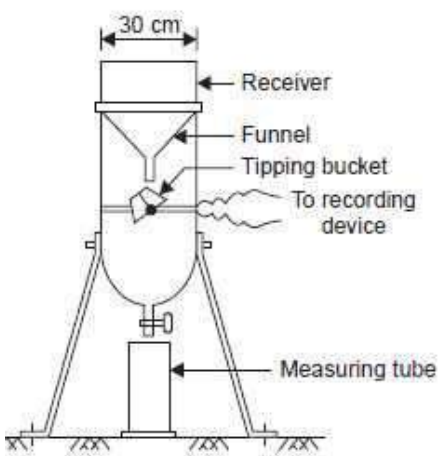


Fig. 2.4 Tipping bucket gauge

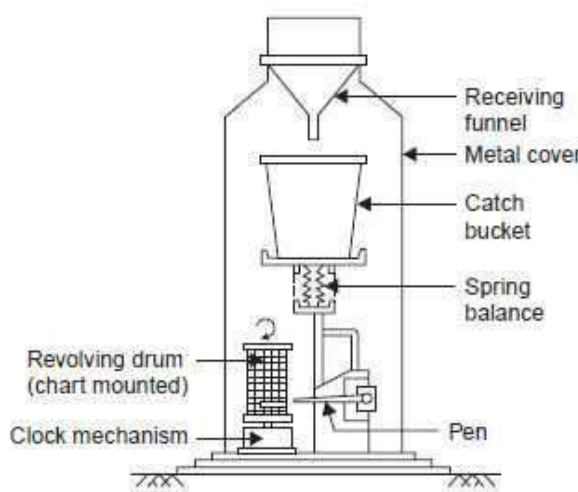


Fig. 2.5 Weighing type rain gauge

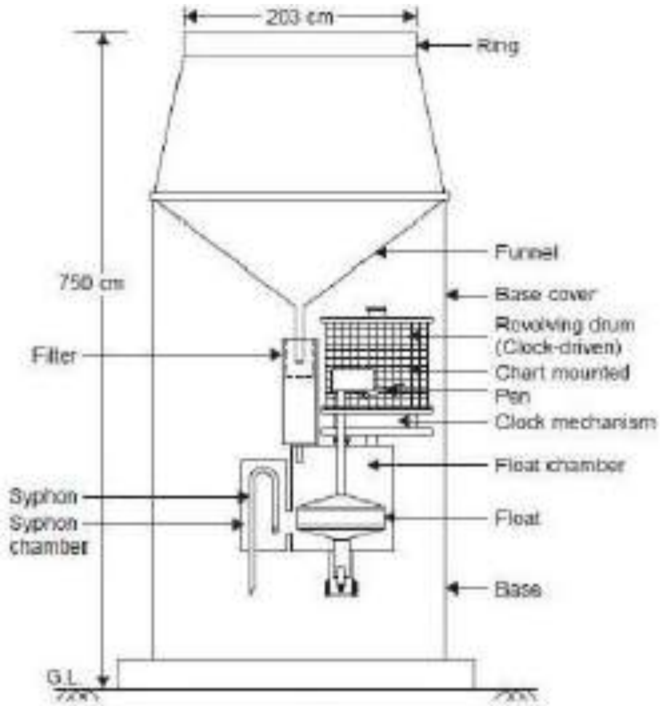


Fig. 2.6 Float type rain gauge

Suitable site for rainfall gauge site

A rainfall gauge site should have some level ground and has ideal shelter. A rain gauge should be placed from a tree or a building at more than two times of the height of the tree or the building. It is to be noted that inconsistencies in rainfall record are often caused by change in the rain gauge site location and surroundings.

Optimum number of rain gauges

Statistics has been used in determining the optimum number of rain gauges required to be installed in a given catchment. The basis behind such statistical calculations is that a certain number of rain gauge stations are necessary to give average rainfall with a certain percentage of error. If the allowable error is more, lesser number of gauges would be required. The optimum number of rain gauges (N) can be obtained using:

$$N = \left[\frac{C_v}{E}\right]^2$$

Where,

Cv = Coefficient of variation of rainfall based on the existing rain gauge stations;

Cv = Mean / Standard Deviation of rainfall

Mean:

$$\mu = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i)}$$

Standard Deviation:

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2}$$

E = Allowable percentage error in the estimate of basic mean rainfall

World Meteorological Organization (WMO) Recommendations:

Region	**Minimum density (km^2 / station)**	
	Non-Recording	**Recording**
Mountainous region	250	2500
Interior plains / Flat regions under difficult conditions	575	5750
Hilly / undulating	575	5750
Arid zones*	10000	100000

*Arid zone herein is defined as annual rainfall < 450 mm, temperature greater than 27^0C, potential evaporation is 20 times greater than annual rainfall.

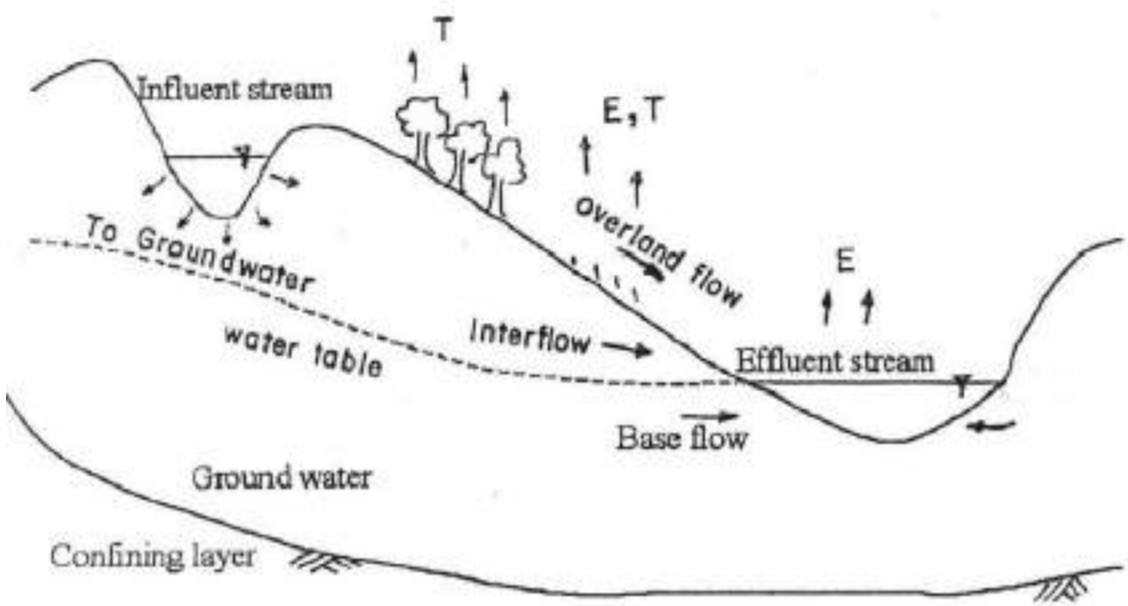
Water Resources Engineering – I

- Hydrology & Hydrology Cycle
- Rainfall Measurement – Rain Gauges
- Analysis of Rainfall Records - Estimating Missing Rainfall Data
- **Runoff Calculations**

Runoff:

Runoff is defined as the portion of precipitation that makes its way towards rivers or oceans as surface or subsurface flow.

Precise estimation of runoff is the basic and foremost input requirement for the design of recharge structures of optimum capacity. Unrealistic runoff estimates of catchments yield often leads to the construction of oversized or undersized structures which must be avoided.



Classification of runoff according to source:

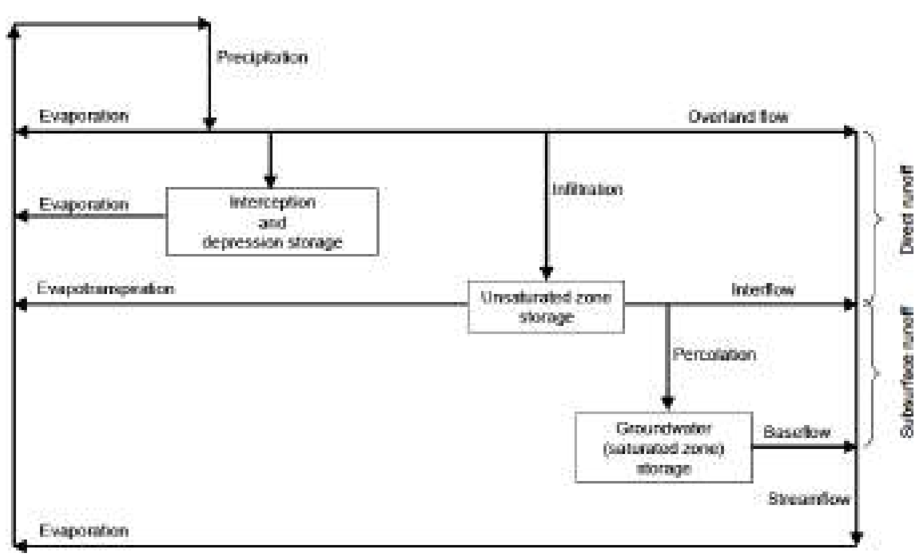
- Surface runoff – Includes all overland flow as well as precipitation falling directly onto stream channels.

- Overland flow – Portion of runoff that travels over the surface of the ground to reach a stream channel and through the channel to the basin outlet. This process occurs relatively quickly.
- Subsurface runoff – Portion of runoff that travels under the ground to reach a stream channel and to the basin outlet. It includes: a) interflow, and b) groundwater runoff.
    - Interflow, through-flow, subsurface storm flow – Portion of subsurface runoff that travels laterally through the unsaturated zone or through a shallow perched saturated zone towards a stream channel. This process is slower than surface runoff.
    - Groundwater runoff – Portion of subsurface runoff that comes from infiltration and subsequently percolation down to the water table and eventually reaches a stream channel. This process occurs relatively slowly

Classification of runoff according to travel time to a stream:

- Direct runoff – Portion of the total runoff hydrograph at a stream which is caused by and directly following a rainfall or snowmelt event. It consists of:
    - Overland flow, and
    - Quick interflow. It contributes rather quickly to stream flow.
- Baseflow, base runoff, delayed runoff – Portion of the total runoff hydrograph at a stream location which is composed of contributions from:
    - groundwater runoff, and
    - Delayed interflow.

Baseflow is the result of water from previous storms accumulating below the water table and being released over an extended period of time.



Factors affecting Runoff:

- Climate factors
  - Type of precipitation
  - Intensity of rainfall
  - Duration of rainfall
  - Area distribution of rainfall
  - Antecedent precipitation
  - Other climatic factors that effect evaporation and transpiration
- Physiographic factors
  - Land use
  - Type of Soil
  - Area of the basin or catchment
  - Shape of the basin
  - Elevation
  - Slope
  - Orientation or Aspect
  - Type of drainage network
  - Indirect drainage
  - Artificial drainage

Estimation of Runoff:

Runoff can be estimated by various methods. These can be classified under the following:

- Empirical Formulae (to find peak runoff)
  - **Dicken's formula**

    This formula was developed in the year 1865. It states that

    $$Q_p = C_d A^{3/4}$$

    Where,

    Q_p = peak discharge rate (m^3/s)

    C_d = a constant (Dickens'), ranging from 6 to 30

    A = Drainage basin area (km^2).

    For Indian conditions, suggested values for C_d are given as below:

Region	Topography	C_d
Northern states	Plains	6
	Hills	11-14
Central states	-	14.28
Coastal area	-	22.28.

- **Ryve's formula**

  Ryve's formula was reported in the year 1884. It states that

  $$Q_p = C_r A^{2/3}$$

  Where,

  Q_p = Peak discharge rate (m^3/s).

  A = Drainage basin area (km^2).

  C_r = A constant (Ryves), as shown below:

Region	C_r
Within 80 km from east coast	6.8
80-160 km from east coast	8.5
Hills	10.2

- **Igles's formula**

  This formula was developed in areas of old Bombay state. It states that

  $$Qp = \frac{123\ A}{\sqrt{A + 10.4}}$$

  Where,

  Q_p = Peak discharge in Cumecs (m^3/s).

  A = Area of the catchment in sq km (km^2).

- **Khosla's formula**

  In this method, the amount of mean annual runoff is calculated by following formula:

  R = P – (T /3.74)

  Where:

  R = mean annual runoff of watershed by cm,

  P = mean annual precipitation by cm, and

  T = mean annual temperature by ˚C.

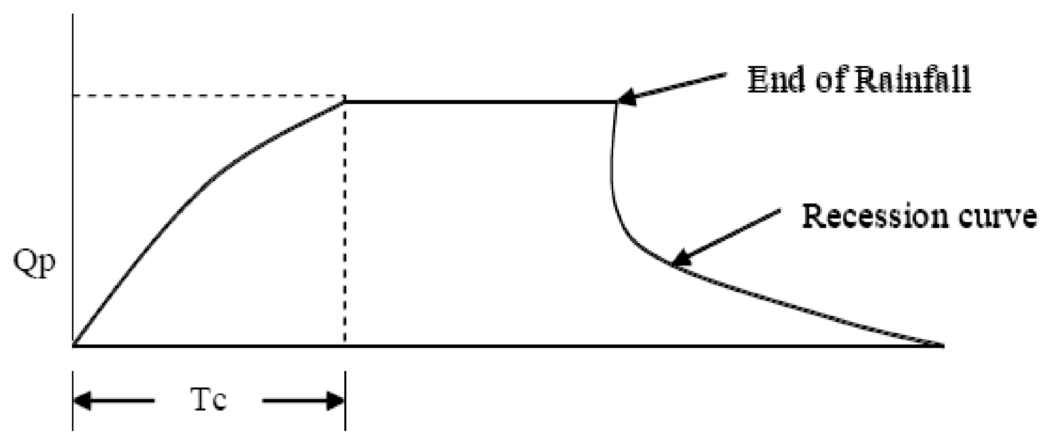
- **Rational Method or Rain-fall Method**

  This method was originally developed for urban catchments. Thus, the basic assumptions for development of this method were made for urban catchments. However, this method is fairly applicable to small agricultural watersheds of 40 to 80 hectares size.

The rational method takes into account the following hydrological characteristics or processes: (1) rainfall intensity, (2) rainfall duration, (3) rainfall frequency, (4) watershed area, (5) hydrologic abstraction, and (6) runoff concentration.

The Rational method is based on the assumption that constant intensity of rainfall is uniformly spread over an area, and the effective rain falling on the most remote part of the basin takes a certain period of time, known as the time of concentration (T_c) to arrive at the basin outlet. If the input rate of excess rainfall on the basin continues for the period of time of concentration, then the part of the excess rain that fell in the most remote part of the basin will just begin its outflow at the basin outlet and with it, the runoff will reach its ultimate and the maximum rate. That is, the maximum rate of outflow will occur when the rainfall duration is equal to the time of concentration.

The above processes are explained below. Consider a drainage basin, which has rainfall of uniform intensity and of longer duration. On plotting the relationship between the cumulative runoff rate Q and time, the rate of runoff shows a gradual increase from zero to a constant value. The runoff increases with increase in flow from remote areas of the basin to its outlet. If the rainfall continues beyond the time of concentration, then there is no further increase in the runoff, and it remains constant at its peak value.



Runoff Hydrograph Due to Uniform Rainfall

The relationship for peak runoff Qp is then expressed as

$$\mathbf{Q_p = 0.278\ C\ I\ A}$$

Where,

Qp = Peak discharge in Cumecs (m^3/s).

C = coefficient of runoff

A = area of the catchment (drainage basin) in Km^2

I = mean intensity of precipitation (mm/h) for a duration equal to time of concentration

Runoff Coefficient Factor (C) for Different Soil Conditions in India:

Type of Vegetation	Slope Range (%)	Runoff Coefficient (C) in		
		Sandy Loam Soil	Loam / Loam Clay Soil	Stiff Clay Soil
Woodland and forests	0-5	0.1	0.3	0.4
	5-10	0.25	0.35	0.5
	10-30	0.3	0.5	0.6
Grassland	0-5	0.1	0.3	0.4
	5-10	0.16	0.36	0.55
	10-30	0.22	0.42	0.6
Agricultural land	0-5	0.3	0.5	0.6
	5-10	0.4	0.6	0.7
	10-30	0.52	0.72	0.82

Intensity of Rainfall: (I = Rainfall depth / $T_{c)}$

The formula for the intensity of rainfall is expresses as.

$$I = \frac{KT_r^{\,a}}{(T_c + b)^n}$$

Where,

I = Intensity of rainfall,

Tr = Recurrence interval,

Tc = Time of concentration, and a, b, n are constants**.**

The values of parameters K, a, b, n for different zones of India have been developed by the ICAR (Indian Council of Agricultural Research) scientists, and are shown as below:

Zone	K	A	b	n
Northern zone	5.92	0.162	0.50	1.013
Central zone	7.47	0.170	0.75	0.960
Western zone	3.98	0.165	0.15	0.733
Southern zone	6.31	0.153	0.50	0.950

Time of Concentration (T_C):

For determination of the time of concentration, the most widely used formula is the equation given by Kirpich (1940). However, for small drainage basins, the lag time for the peak flow can be taken to be equal to the time of concentration. The lag time can be determined by the Snyder's equation.

The Kirpich's equation is given as

$$Tc = 0.01947\ L^{0.77}\ S^{-0.385}$$

Where

T_C = time of concentration (min)

L = maximum length of travel of water (m)

S = slope of the drainage basin

The time of concentration can also be determined as

$$Tc = 0.1947\ (K)^{0.77}$$

$$\text{Where } K = \sqrt{\frac{L^3}{H}}$$

The time of concentration is sometimes also determined by dividing the length of run with the average velocity of flow based on the slope of the channel as given below:

Channel Slope %	Velocity (m/s).
1-2	0.6
2-4	0.9
4-6	1.2
6-10	1.5

- Unit Hydrograph Method

Example

A catchment has an area of 5.0 km². The average slope of the land surface is 0.006 and the maximum travel depth of rainfall in the catchment is approximately 1.95 km. The maximum depth of rainfall in the area with a return period of 25 years is as tabulated in **Table 4.20**.

Table 4.20 Maximum Depth of Rainfall in an Area with a Return Period of 25 Years.

Time duration (min)	5	10	15	20	25	30	40	60
Rain fall depth (mm)	15	25	32	45	50	53	60	65

Consider that 2.0 Km² of the catchment area has cultivated sandy loam soil (c=0.2) and 3.0 Km² has light clay cultivated soil (c = 0.7). Determine the peak flow rate of runoff by using the Rational method.

Solution: The time of concentration is given by Kirpich's equation.

$$Tc = 0.01947\, L^{0.77} S^{-0.385}$$
$$= 0.01947\, (1950)^{0.77}\, (0.006)^{-0.385} \text{ min}$$
$$= 47.65 \text{ min.}$$

The maximum rainfall depth for 47.65 min duration would fall between the periods of 40-60 min and is located at 7.65 min after the 40 min period at which the maximum rainfall depth is 60 mm, as per the available data.

The rainfall depth during the 7.65 min period $= \frac{65-60}{20} \times 7.65 = 1.9$ mm

Therefore, for 47.65 min duration, the rainfall depth = 60 + 1.9 = 61.9 mm.

The average rainfall intensity (During the period of time of concentration) $= \frac{\text{maximum rainfall depth}}{Tc}$

$$= \frac{61.9 \times 60}{47.65} = 77.96 \text{ mm/hr}$$

Runoff coefficient, C $= \frac{(20 \times 0.2) + (3.0 \times 0.7)}{5.0}$

$$= \frac{0.4 + 2.}{5.0} = 0.5$$

Peak runoff rate, Qp $= \frac{CIA}{3.6}$ m³/s

$$= 1/3.6 \times 0.5 \times 77.96 \times 5.0$$

$$= 54.138 \text{ m}^3/\text{s.}$$

UNIT 2

- Distribution of Runoff, Hydrograph, Hydrograph Separation
- Unit Hydrograph, Limitations of application of Hydrograph
- **Derivation of Unit Hydrograph from Direct Runoff Hydrograph and Vice-versa**
- S – Hydrograph, Synthetic Unit Hydrograph

The Unit Hydrograph is best derived from the hydrograph of a storm of reasonably uniform intensity, duration of desired length, and a relatively large runoff volume

Derivation of Unit Hydrograph from a Direct Runoff Hydrograph

Select a storm event for which the rainfall and the total runoff hydrograph have been recorded. The storm should be intense and cover the entire basin

The procedure may be broadly divided into the following steps:

1. Select a storm event for which the rainfall and the total runoff hydrograph have been recorded. The storm should be intense and cover the entire basin.
2. Storms meeting the following criteria are generally preferred and selected out of the uniform storms data collected in Step 1.
3. Storms with rainfall duration of around 20 to 30 % of basin lag,
4. Storms having rainfall excess between 1 cm and 4.5 cm.
5. From the observed total flood hydrograph separate the base flow and plot the direct runoff hydrograph.
6. Measure the total volume of water that has passed the flow measuring point by finding the area under the DRH curve. Since area of the watershed under consideration is known, calculate the average uniform rainfall depth that produced the DRH by dividing the volume of flow (step 3) by the catchment area. This gives the effective rainfall (ER) corresponding to the storm.
7. Express the hydrograph ordinate for the storm at T–hour is the duration of rainfall even. Divide each ordinate of the hydrograph by the storm ER to obtain the UH.

Problem 1:

Given below are observed flows from a storm of 6 hour duration on a stream with a catchment area of 500 km^2

Time(hr)	0	6	12	18	24	30	36	42	48	54	60	66	72
Flow(m^3/s)	20	120	270	220	170	120	90	70	55	45	35	25	20

Assuming a constant base flow of 20 m^3/s, derive the ordinates of a 6 hour unit hydrograph.

Solution

Time Hour	Observed flow cumecs	Base flow cumecs	Direct runoff cumecs	6 hour U.H cumecs	Hour after start
0	20	20	0	0	0
6	120	20	100	23.15	6
12	270	20	250	57.87	12
18	220	20	200	46.30	18
24	170	20	150	34.72	24
30	120	20	100	23.15	30
36	90	20	70	16.20	36
42	70	20	50	11.57	42
48	55	20	35	8.10	48
54	45	20	25	5.79	54
60	35	20	15	3.47	60
66	25	20	5	1.16	66
72	20	20	0	0	72
			1000	231.48	

$\sum$ D. R = 1000 cumecs , drainage area = 500km^2

$$\text{D.R depth} = \frac{1000\times 6\times 60\times 60}{500\times 10^6}\times 100 = 4.32cm$$

Check $\sum$ U.H ordinates = 231.48 cumecs

$$\text{U.H depth} = \frac{231.48\times 6\times 60\times 60}{500\times 10^6}\times 100 = 0.999 \approx 1cm$$

Derivation of a Direct Runoff Hydrograph from Unit Hydrograph:

Once a unit hydrograph for a specific duration (**t_r**) has been developed, it can be used to obtain the direct runoff hydrograph for a storm by convoluting the effective rainfall hyetograph for the storm (defined at **t_r** increments) with the unit hydrograph. In this case, the storm is treated as several individual storms of duration **t_r** and the principle of linearity is applied:

Method of Proportionality: If 5 cm of effective rainfall occurs during a specified unit time (**t_r**), the resulting direct runoff hydrograph will have the same shape as the hydrograph produced by 1 cm effective rainfall of the same duration (**t_r**), but all the ordinates (y-axis) will be five times as large.

Problem 2:

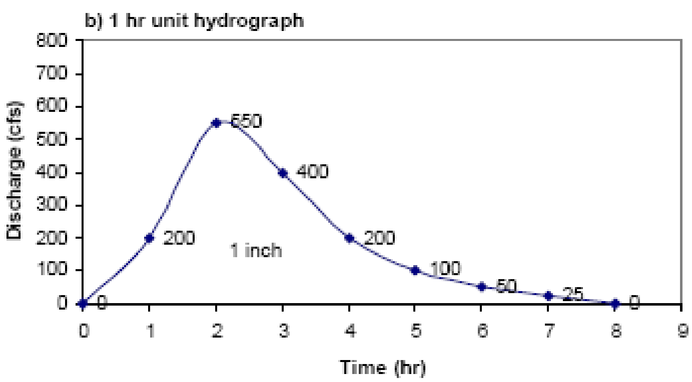
The ordinates of 3 hour unit hydrograph of a basin at 6 hour interval are given below 0,3,5,9,11,7,5,4,2,1,0 cumecs. Derive the storm hydrograph due to a 3 hour storm with a total rainfall of 15 cm. Assume an initial loss of 0.5 cm and φ - index of 1 cm/hr. Take base flow = 4 cumecs.

Solution

Effective rainfall depth R = 15 – 0.5 – 1 x 3 = 11.5 cm

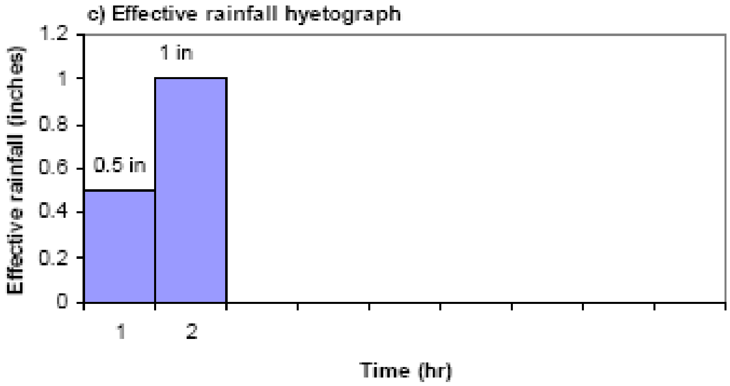
Time (hours)	Unit hydrograph ordinates (cumecs)	Direct runoff ordinates (cumecs)	Base flow	Ordinate of storm hydrograph (cumecs)
0	0	0	4	4
6	3	34.5	4	38.5
12	5	57.5	4	61.5
18	9	103.5	4	107.5
24	11	115.0	4	119.0
30	7	80.5	4	84.5
36	5	57.5	4	61.5
42	4	46.0	4	50.0
48	2	23.0	4	27.0
54	1	11.5	4	15.5
60	0	0	4	4.0

Problem 2:



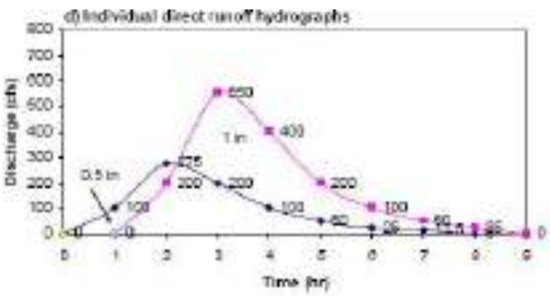
1 hr unit hydrograph

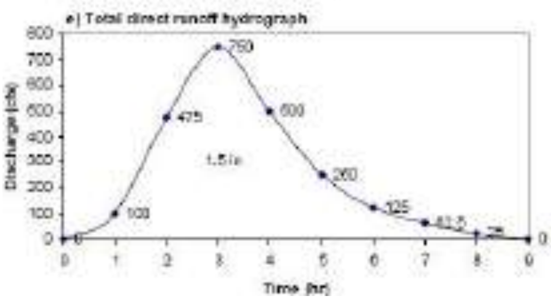
Time (hr)	Q (cfs)
0	0
1	200
2	550
3	400
4	200
5	100
6	50
7	25
8	0



Effective rainfall hyetograph

Time (hr)	Peff (in)
1	0.5
2	1
3	0





Time (hr)	Individual hydrographs (cfs) due to Peff of 0.5 in		1 in		Total DRH (cfs)
0	0			=	0
1	100	+	0	=	100
2	275	+	200	=	475
3	200	+	550	=	750
4	100	+	400	=	500
5	50	+	200	=	250
6	25	+	100	=	125
7	12.5	+	50	=	62.5
8	0	+	25	=	25
9			0	=	0

Water Resources Engineering – I

- **Distribution of Runoff, Hydrograph, Hydrograph Separation**
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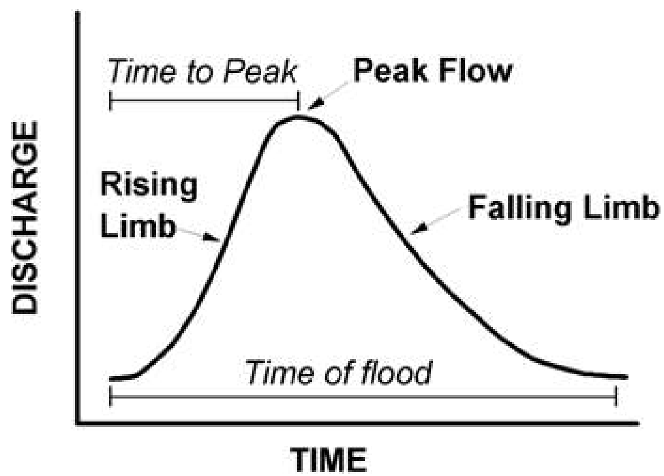
Hydrograph

Hydrograph is the graphical representation of the instantaneous rate of discharge of a stream plotted with respect to time



Key terms to describe the storm hydrograph:

Lag time: The time period between peak rainfall and peak discharge.

Base flow: The constant part of a river's discharge produced by groundwater and slow through flow seeping slowly into the river. It is the main contributor to river flow during dry weather.

The **rising limb** shows the increase of the discharge. The highest flow is shown by the **peak discharge**. This occurs some time after the peak of the input because the water takes time to move through the system to the measuring point of the basin. The **falling or receding limb** shows the fall in the discharge back to the base level.

Surface Runoff or storm flow: Combination of overland flow and rapid through flow.

Components of the hydrograph

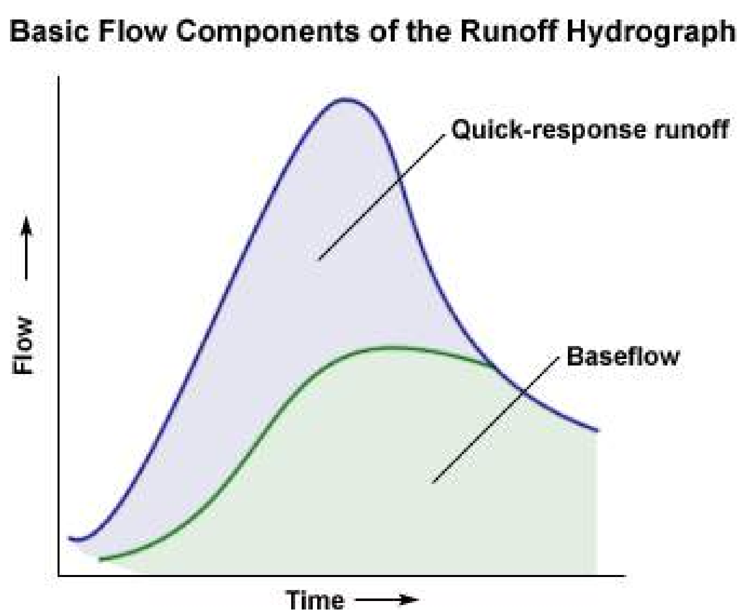
The hydrograph describes flow as a function of time usually known as a time series of flow. The interest may lie in the hydrograph of a long period of several years or only few selected rainfall events of few hours or days. The latter situation frequently occurs in the development of a rainfall-runoff relationship for a watershed.

It is customary to consider two components of the hydrograph:

1. **Direct runoff** the flow that results directly from the rainfall event. Usually after considering the associated losses from the gross rainfall. The volumes of effective rainfall and the volume of direct runoff should be equal.

2. **Base flow** that is unrelated to the rainfall event.

The rainfall-runoff relationship describes the time distribution of direct runoff as a function of excess rainfall (gross rainfall minus losses). Therefore, in developing the rainfall-runoff relationship for a watershed based on observed hyetographs and hydrographs, one must first subtract the Baseflow from the hydrograph. Even after long periods without rain, water still flows in many streams and rivers. This flow is the result of seepage from groundwater aquifers into the stream channel. In larger rivers, Baseflow can be significant. In periods without rain, the Baseflow in a stream will slowly decline as a result of the draw down of the groundwater aquifers. This phenomenon is called Baseflow recession. It is often assumed that Baseflow declines exponentially. Baseflow separation involves dividing the hydrograph into a direct runoff component and a Baseflow component.



Factors affecting the hydrograph shape

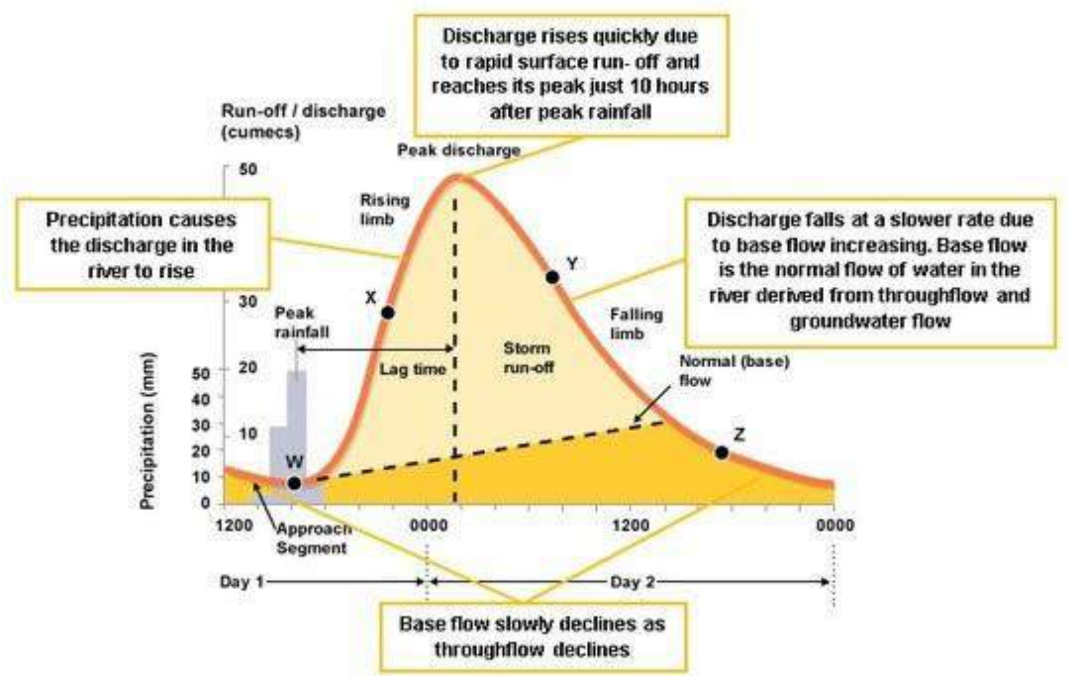
Most hydrographs are controlled by the interaction of several variable factors.

Factor	Hydrograph dominated by Quick-response flow processes*	Hydrograph dominated by Baseflow processes**
Climatic factors		
Precipitation (Intensity and duration of the storm)	High-intensity rainfall which exceeds the infiltration capacity of the soil. Large amount of rainfall	Low-intensity rainfall which is less than the infiltration capacity of the soil Small amounts of rainfall
Snow (Water stored as snow)	Fast snow melt as temperatures suddenly rise above zero	Slow snow melt
Evapotranspiration (temperature)	Low rates of evapotranspiration outputs due to low temperatures	High rates of evapotranspiration outputs due to high temperatures
Soil characteristics		
Soil moisture (Antecedent /pre-existing conditions)	Basin already wet from previous rain, water table high, soils saturated and so low infiltration/percolation	Dry soil-the soil store can hold much more water. Low water table. High infiltration/percolation
Permeability	Impermeable soil	Permeable soil
Drainage basin characteristics		
Drainage density	High drainage density (large number of streams per km).The higher the density the faster the water reaches the main river channel.	Low drainage density (small number of streams per km) means few streams and rivers and so water is more likely to enter the ground and move slowly through the basin.
Size of drainage basin	Small drainage basin tends to respond more rapidly to a storm than larger one, so the lag time is shorter.	
Slopes	Steep slopes promote surface runoff.	Gentle slopes allow infiltration and percolation.
Shape of drainage basin	Rainfall reaches the river more quickly from a round basin than from an elongated basin.	
Rock type	Impermeable rocks e.g. clay, granite, restrict percolation and encourage rapid runoff	Permeable rocks e.g. chalk and limestone, allow infiltration and percolation
Vegetation cover	Little vegetation cover. Lack of interception and root development to open up the soil. Rapid movement through the system. Deciduous trees in winter.	Forest and woodland intercept much rainfall, and root development encourages infiltration. More water lost to evaporation from vegetation surfaces. Deciduous trees in summer.
Soil depth	Thin soil e.g. upland areas allow little infiltration	Deeper soils provide a large soil store e.g. slope bottoms and lowland areas.

Water stores	Lack of lakes and backwater swamps	Lakes and backwater swamps act as water stores, and slow the movement to the channel.
Human activity		
Forests	Deforestation	Reforestation
Urban development	Urban development creates impermeable concrete and tarmac surfaces and water quickly reaches the channel via storms drains. Low infiltration/percolation	Rural land uses intercept more precipitation and have more permeable land surfaces. High infiltration and percolation.
Agricultural practices	Poor agricultural practices – poor soil structure, trampling by animals.	Good agricultural practices which encourage soil aeration and protect the soil surface.

*** Quick-response flow processes:** That component of the rain input which is delivered to the stream by surface runoff/overland flow, or rapid soil transfer. They give a high peak and rapid rise on the hydrograph.

**** Baseflow processes:** Processes such as slow through flow and groundwater flow, which transmit water slowly to the river channel.



Hydrograph Separation

- Discharge not associated with the storm (i.e. from groundwater) is termed Baseflow.
- Hydrograph or Baseflow separation is performed to determine the portion of the hydrograph attributable to Baseflow

Methods of Baseflow Separation:

1. **Constant Discharge Method:**

Assume Baseflow constant regardless of stream height (discharge) project from minimum value immediately prior to beginning of storm hydrograph.

2. **Constant Slope Method:**

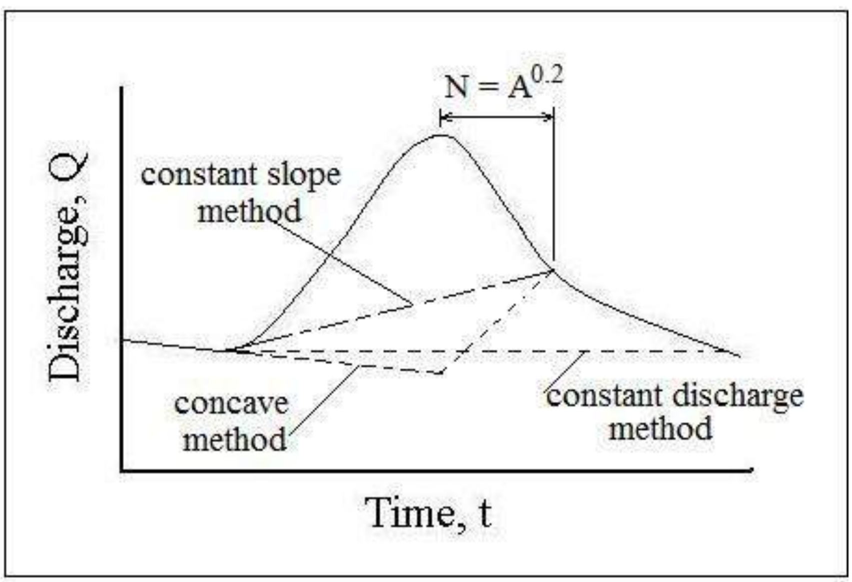
Connect inflection point on Receding limb of storm hydrograph to beginning of storm hydrograph

3. **Concave Method (most realistic):**

Assume Baseflow decreases while stream flow increases (i.e. to peak of storm hydrograph) project hydrograph trend from minimum discharge value immediately prior to beginning of storm hydrograph to directly beneath hydrograph peak connect that point to inflection point on receding limb of storm hydrograph

4. **Master depletion curve method**

Use when the most accurate model of hydrograph recessions is needed combine data from several recessions to make general recession model



Baseflow Separation Methods

Water Resources Engineering – I

- Distribution of Runoff, Hydrograph, Hydrograph Separation
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- **S – Hydrograph, Synthetic Unit Hydrograph**

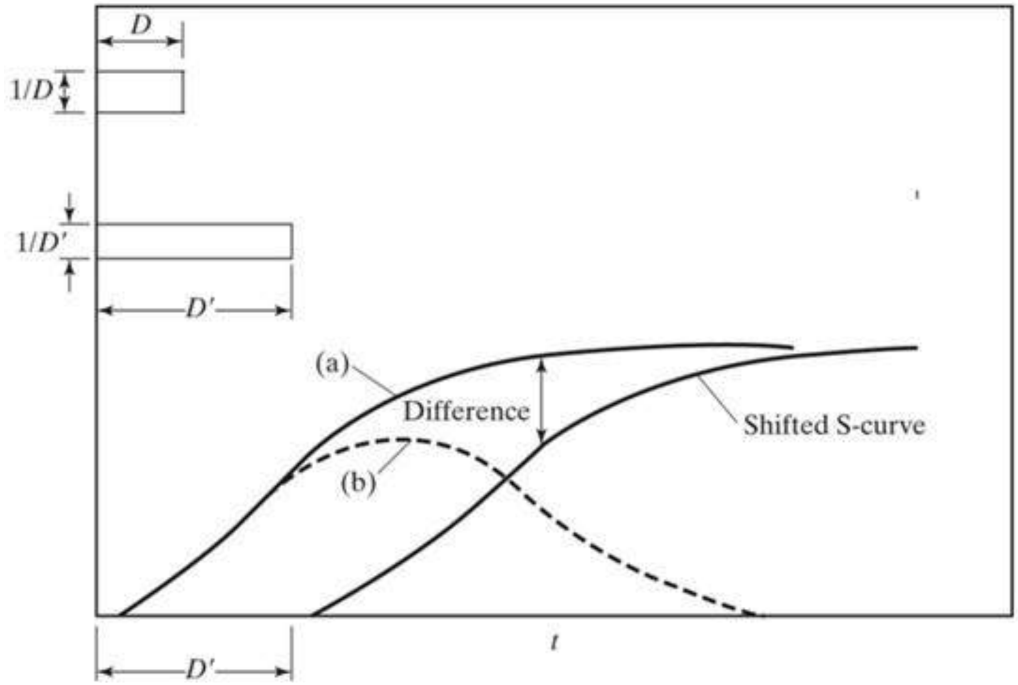
Unit Hydrographs of Different Durations:

Ideally, unit hydrographs are derived from simple isolated storms and if the duration of the various storms do not differ very much, they would all be grouped under one average duration of D hours. Unit hydrographs of different durations, if required, are best derived from field data. Lack of adequate data normally prevents development of unit hydrographs covering a wide range of durations for a given catchment. Under such conditions a D hour unit hydrograph is used to develop unit hydrographs of differing duration's nD.

S- Hydrograph Method: (Effective Rainfall of a Duration > Time of Concentration)

The S-hydrograph method allows the conversion of an X- hour unit hydrograph into a Y-hour unit hydrograph, regardless of the ratio between X and Y. The procedure consists of the following steps:

1. Determine the X hour S-hydrograph. Accumulating the unit hydrograph ordinates at intervals equal to X, thus depriving the X-hour S-hydrograph.
2. Lag the X -hour S-hydrograph by a time interval equal to Y hours.
3. Subtract ordinates of these two S-hydrographs.
4. Multiply the resulting hydrograph ordinates by X/Y to obtain the Y-hour unit hydrograph.
5. The volume under X-hour and Y-hour unit hydrograph is the same. If Tb is the time base of the X-hour unit hydrograph, the time base of the Y-hour unit hydrograph is Tb - X + Y.



By shifting a copy of the S-curve by D' hours, and subtracting the ordinates, the resulting hydrograph (dashed line - - - - - -) must be due to rainfall of intensity 1/D inches/hour that lasts for a duration of D' hours.

To convert the hydrograph (dashed line --------) to a UH, multiply ordinates by D/D', resulting in a UH of duration D'. D' needs NOT be an integral multiple of D.

Problem 1:

- Convert the following 2-hr UH to a 3-hr UH using the S-curve method

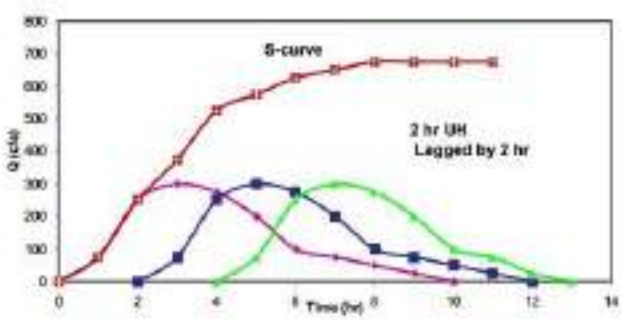
Time (hr)	2-hr UH ordinate (cfs)
0	0
1	75
2	250
3	300
4	275
5	200
6	100
7	75
8	50
9	25
10	0

Solution

Make a spreadsheet with the 2-hr UH ordinates, then copy them in the next column lagged by D=2 hours. Keep adding columns until the row sums are fairly constant. The sums are the ordinates of your S-curve

Time (hr)	2-hr UH	2-HR lagged UH's					Sum
0	0						0
1	75						75
2	250	0					250
3	300	75					375
4	275	250	0				525
5	200	300	75				575
6	100	275	250	0			625
7	75	200	300	75			650
8	50	100	275	250	0		675
9	25	75	200	300	75		675
10	0	50	100	275	250	0	675
11		25	75	200	300	75	675

Draw your S-curve, as shown in figure below



Make a spreadsheet with the 2-hr UH ordinates, then copy them in the next column lagged by D=2 hours. Keep adding columns until the row sums are fairly constant. The sums are the ordinates of your S-curve.

Time (hr)	S-curve ordinate	S-curve lagged 3hr	Difference	3-HR UH ordinate
0	0		0	0
1	75		75	50
2	250		250	166.7
3	375	0	375	250
4	525	75	450	300
5	575	250	352	216
6	625	375	250	166.7
7	650	525	125	83.3
8	675	575	100	66.7
9	675	625	50	33.3
10	675	650	25	16.7
11	675	675	0	0

Problem 2:

A 3 hr duration unit hydrograph has the following ordinates:

Time (hr)	0	3	6	9	12	15	18	21	24	27	30
Q (cumec)	0	3.08	4.94	8.64	9.88	7.41	4.94	3.70	2.47	1.23	0

Develop a unit hydrograph of 6 hour duration

Solution

Time (hr)	Ordinate of 3 hr unit hydrograph	3 hr U.H lagged 3hr	Combined hydrograph	6 hr UH
0	0		0	0
3	3.08	0	3.08	1.54
6	4.94	3.08	8.02	4.01
9	8.64	4.94	13.58	6.79
12	9.88	8.64	18.52	9.26
15	7.41	9.88	17.29	8.65
18	4.94	7.41	12.35	6.18
21	3.70	4.94	8.64	4.32
24	2.47	3.70	6.17	3.09
27	1.23	2.47	3.70	1.85
30	0	1.23	1.23	0.62
33		0	0	0

Synthetic Unit Hydrograph

In India, only a small number of streams are gauged (i.e., stream flows due to single and multiple storms, are measured). There are many drainage basins (catchments) for which no stream flow records are available and unit hydrographs may be required for such basins. In such cases, hydrographs may be synthesized directly from other catchments, which are hydrologically and meteorologically homogeneous, or indirectly from other catchments through the application of empirical relationship.

Methods for synthesizing hydrographs for un-gauged areas have been developed from time to time by Bernard, Clark, McCarthy and Snyder. The best known approach is due to Snyder (1938)

However, the present recommendations of the Central Water Commission (CWC) discourage the use of the Snyder's method. Instead, the Commission recommends the use of the Flood Estimation Reports brought out for the various sub–zones in deriving the unit hydrograph for the region. These sub–zones have been demarcated on the basis of similar hydro–meteorological conditions and a list of the basins may be found. The design flood is estimated by application of the design storm rainfall to the synthetic hydrograph developed by the methods outlined in the reports.

Water Resources Engineering – I

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Unit Hydrograph:

- Very often it is required to predict the flood hydrograph resulting from a known storm
- A large number of methods are available to solve this problem
- Unit Hydrograph Method is the **most popular** and widely used method for predicting flood hydrograph resulting from a known storm
- First suggested by Sherman in 1932

Definition:

The Unit hydrograph (UH) of a catchment is defined as the hydrograph resulting from an effective rainfall of 1mm evenly distributed over the basin during the time (D).

The unit hydrograph is a useful tool in the process of predicting the impact of precipitation on streamflow.

- The term 'unit' refers to a unit depth of rainfall excess which is usually taken as 1mm
- The duration is used as a prefix to a specific unit hydrograph

The definition of a Unit Hydrograph implies the following:

1. The unit hydrograph is the direct runoff hydrograph produced by a storm of given duration such that the total volume of excess rainfall is 1 mm. The total volume of direct runoff is also 1 mm.
2. The ordinates of Unit Hydrograph indicate the direct runoff flow produced by the watershed for every millimeter of excess rainfall; therefore, the units are m^3/sec/mm.
3. A volume of 1 mm is the amount of water in a 1mm layer uniformly distributed over the entire watershed area. This volume is equal to the area under the Unit Hydrograph.
4. Storms of different durations produce different Unit Hydrographs even if the excess rainfall volume is always 1 mm.

5. Longer storms will likely produce smaller peaks and longer duration in the Unit Hydrograph.
6. The duration associated with the Unit Hydrograph that of originating storm and not the base duration of the Unit Hydrograph.

Assumptions:

Unit hydrograph theory assumes that watersheds behave as linear systems. The following are the fundamental assumptions of UH theory.

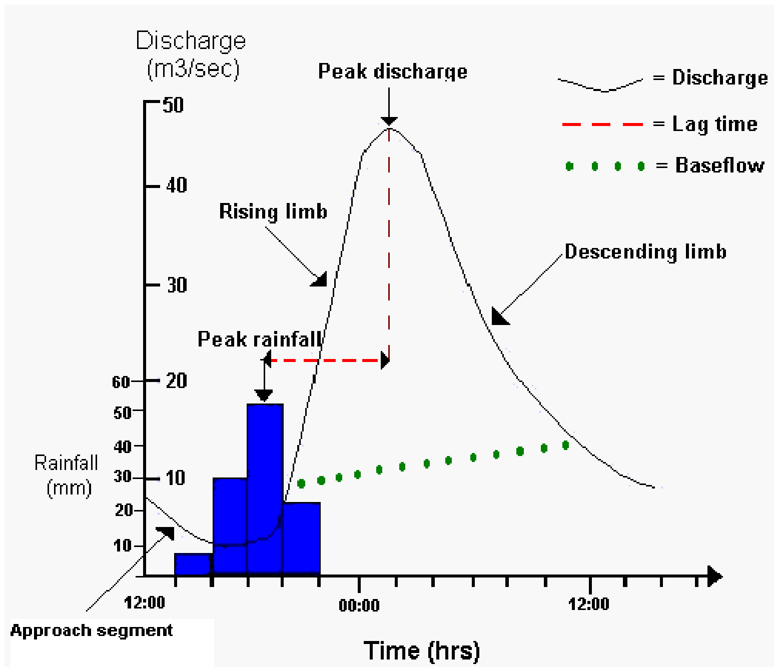
1. The duration of direct runoff is always the same for uniform-intensity storms of the same duration, regardless of the intensity. This means that the time base of the hydrograph does not change and that the intensity only affects the discharge.
2. The direct runoff volumes produced by two different excess rainfall distributions are in the same proportion as the excess rainfall volume. This means that the ordinates of the UH are directly proportional to the storm intensity. If storm A produces a given hydrograph and Storm B is equal to storm A multiplied by a factor, then the hydrograph produced by storm B will be equal to the hydrograph produced by storm A multiplied by the same factor.
3. The time distribution of the direct runoff is independent of concurrent runoff from antecedent storm events. This implies that direct runoff responses can be superposed. If storm C is the result of adding storms A and B, the hydrograph produced by storm c will be equal to the sum of the hydrographs produced by storm A and B.
4. Hydrologic systems are usually nonlinear due to factor such as storm origin and patterns and stream channel hydraulic properties. In other words, if the peak flow produced by a storm of certain intensity is known, the peak corresponding to another storm (of the same duration) with twice the intensity is not necessarily equal to twice the original peak.
5. Despite this nonlinear behavior, the unit hydrograph concept is commonly used because, although it assumes linearity, it is a convenient tool to calculate hydrographs and it gives results within acceptable levels of accuracy.
6. The alternative to UH theory is kinematic wave theory and distributed hydrologic models.

Creating a Unit Hydrograph:

There are six steps in deriving a unit hydrograph from observed precipitation, basin, and streamflow data:

1. Select the appropriate storm (uniform rate and coverage).
2. Separate out the baseflow so you only have effects from quick–response runoff.
3. Calculate the volume of water in the quick–response runoff.

4. Using the volume of water and the basin size, calculate the basin–averaged depth of excess precipitation.
5. Adjust the hydrograph to represent 1 unit of basin–averaged depth.
6. Calculate the duration of excess precipitation.



Application of Unit Hydrograph:

The UHs establish a relationship between the ERH and DRH for a catchment

They are of great use in

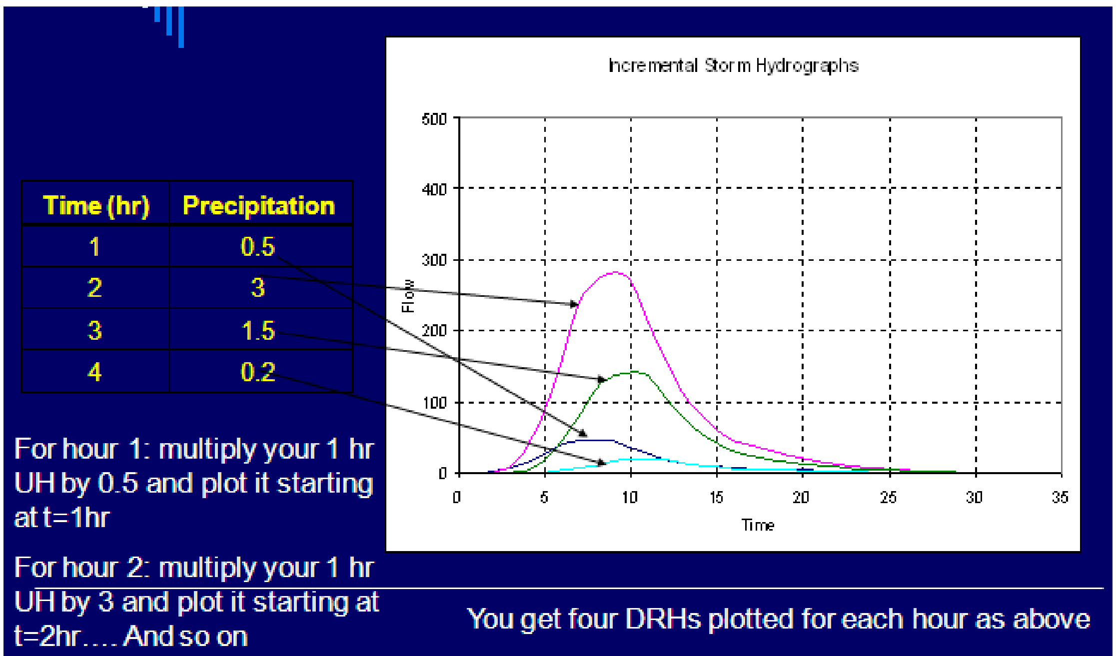
- A unit hydrograph is used to estimate stream flow or discharge given a basin–averaged rainfall.
- The development of flood hydrographs for extreme rainfall magnitudes (for use in the design of hydraulic structures)
- Extension of flood flow records based on rainfall records
- Development of flood forecasting and warning systems based on rainfall

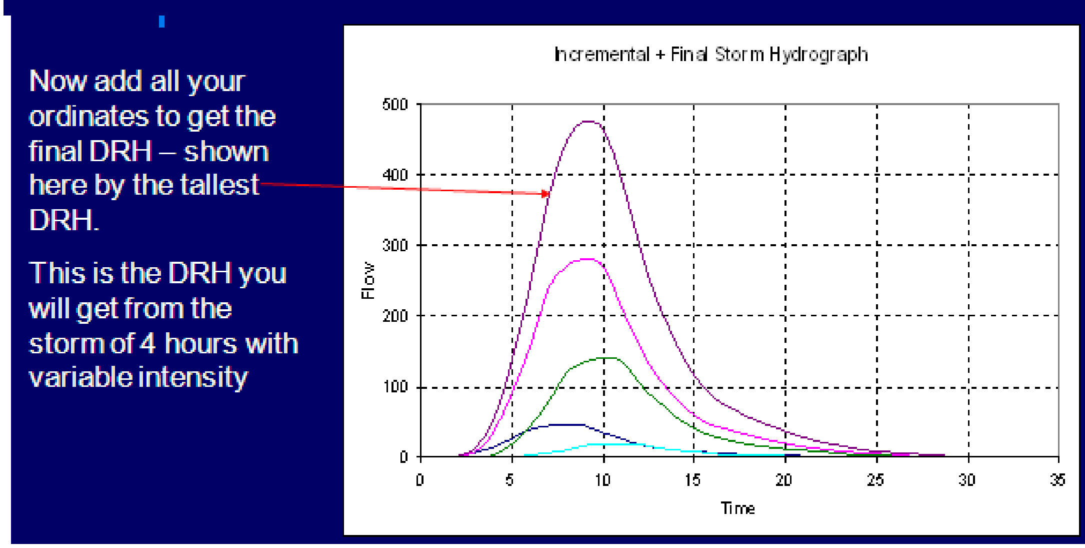
Limitations of application of Unit Hydrograph:

- Unit hydrographs assume uniform distribution of rainfall over the catchment and uniform intensity during the duration of rainfall excess. In practice, these two conditions are never satisfied.
- Under conditions of non-uniform areal distribution and variation of in intensity, the unit hydrograph theory can still be used if the areal distribution is consistent between different storms.

- The size of the catchment imposes an upper limit on the applicability of the unit hydrograph theory (because the centre of the storm can vary from storm to storm and each of these storms can give a different DRH under otherwise identical conditions in very large basins).
- The upper limit for use of the unit hydrograph method is 5000km^2
- In the case of very large basins, the flood hydrographs can be studied by dividing it into a number of smaller sub-basins, developing DRHs for these sub-basins by the UH method, and then routing these DRHs through their respective channels to obtain the composite DRH at the catchment outlet.

Example:





UNIT 3

- Ground water Occurrence, Types of Aquifers
- **Aquifer parameters, porosity, specific yield, permeability, transmissivity and storage coefficient**
- Darcy's law - Radial flow to wells in confined and unconfined aquifers
- Types of wells, Well Construction, and Well Development

Aquifer Parameters:

The following properties of the aquifer are required for study of groundwater hydrology:

1. Porosity
2. Specific Yield
3. Specific Retention
4. Coefficient of permeability
5. Transmissibility
6. Specific Storage
7. Storage Coefficient

1. Porosity:

Porosity (n) is the percentage of rock or soil that is void of material. The larger the pore space or the greater their number, the higher the porosity and the larger the water-holding capacity. It is defined mathematically by the equation:

$$n = \frac{V_v}{V} \times 100\%$$

Where,

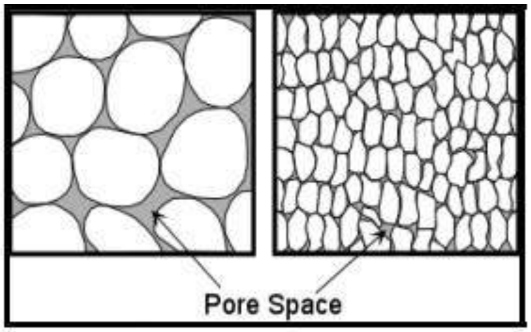
n is the porosity (percentage)

V_v is the volume of void space in a unit volume of earth materials (L^3, cm^3 or m^3)

V is the unit volume of earth material, including both voids and solids (L^3, cm^3 or m^3)

- In sediments or sedimentary rocks the porosity depends on grain size, the shape of the grains, the degree of sorting and the degree of cementation.
- In rocks, the porosity depends upon the extent, spacing and pattern of cracks and fractures.

- Well-rounded coarse-grained sediments usually have higher porosity than fine-grained sediments, because the grains don't fit together well



Porosity of Well-Rounded Coarse-Sediments vs. Fine Grained Sediments

- In igneous and metamorphic rocks porosity is usually low because the minerals tend to be intergrown, leaving little free space. Higher fractured igneous and metamorphic rocks, however, could have high secondary porosity.

Range of Values of Porosity (after Freeze & Cherry, 1979)

Formation	n (%)
Unconsolidated deposits	
Gravel	25 - 40
Sand	25 - 50
Silt	35 - 50
Clay	40 - 70
Rocks	
Fractured basalt	5 - 50
Karst limestone	5 - 50
Sandstone	5 - 30
Limestone, dolomite	0 - 20
Shale	0 – 10
Fractured crystalline rock	0 - 10
Dense crystalline rock	0 – 5

2. Specific Yield:

Specific yield (Sy) is the ratio of the volume of water that drains from a saturated rock owing to the attraction of gravity (or by pumping from wells) to the total volume of the saturated aquifer. It is defined mathematically by the equation:

$$S_y = \frac{V_w}{V} \times 100\%$$

where,

V_w is the volume of water in a unit volume of earth materials (L^3, cm^3 or m^3)

V is the unit volume of earth material, including both voids and solids (L^3, cm^3 or m^3

All the water stored in a water bearing stratum cannot be drained out by gravity or by pumping, because a portion of the water is rigidly held in the voids of the aquifer by molecular and surface tension forces.

Specific Yield in Percent (after Freeze & Cherry, 1979)

Formation	S_y (range)	S_y (average)
Clay	0 - 5	2
Sandy clay	3 - 12	7
Silt	3 - 19	18
Fine sand	10 - 28	21
Medium sand	15 - 32	26
Coarse sand	20 - 35	27
Gravelly sand	20 - 35	25
Fine gravel	21 - 35	25
Medium gravel	13 - 26	23
Coarse gravel	12 - 26	22
Limestone		14

3. Specific Retention:

Specific retention (Sr) is the ratio of the volume of water that cannot be drained out to the total volume of the saturated aquifer. Since the specific yield represents the volume of water that a rock will yield by gravity drainage, hence the specific retention is the remainder. The sum of the two equals porosity.

n = Sr + Sy

- The specific yield and specific retention depend upon the shape and size of particle, distribution of pores (voids), and compaction of the formation.
- The specific retention increases with decreasing grain size.
- It should be noted that it is not necessary that soil with high porosity will have high specific yield because that soil may have low permeability and the water may not easily drain out. For example, clay has a high porosity but low specific yield and its permeability is low.

4. Coefficient of Permeability (Hydraulic conductivity):

Permeability is the ease with which water can flow in a soil mass or a rock. The coefficient of Permeability (K) is equal to the discharge (m^3/s) per unit area (m^2) of soil mass under unit hydraulic gradient. Because the discharge per unit area equals to the velocity, the coefficient of permeability has the dimension of the velocity [L/T]. It is usually expressed as cm/s, m/s, m/day, etc.

The coefficient of permeability is also called hydraulic conductivity

[Hazen method]. The coefficient of permeability (K) depends on the properties of both porous medium and fluid. It can be expressed as,

$$K = \frac{[Cd_m^2]\rho g}{\mu}$$

where,

C is the shape factor which depends upon the shape, particle size and packing of the porous media
d_m is the mean particle size (d_{50}) (L, m)
ρ is the mass density (M/L^3, kg/m^3)
g is the acceleration due to gravity (L/T^2, m/s^2)
μ is the viscosity (M/T.L, kg/s.m)

Typical values of hydraulic conductivity for unconsolidated and hard rocks are given in which are taken from Marsily [1986] are

Hydraulic Conductivity for Unconsolidated and Hard Rocks

Medium	**K (m/day)**
Unconsolidated deposits	
Clay	$10^{-8} - 10^{-2}$
Fine sand	1 - 5
Medium sand	5 - 20
Coarse sand	$20 - 10^2$
Gravel	$10^2 - 10^3$
Sand and gravel mixes	$5 - 10^2$
Clay, sand, gravel mixes (e.g. till)	$10^{-3} - 10^{-1}$
Hard Rocks	
Chalk (very variable according to fissures if not soft)	30.0
Sandstone	3.1
Limestone	0.94
Dolomite	0.001
Granite, weathered	1.4
Schist	0.2

5. Transmissivity:

Transmissivity (T) is the discharge rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient. Thus,

$$T = Kb \quad [confined\ aquifer]$$
$$T = Kh \quad [unconfined\ aquifer]$$

where, b is the saturated thickness of the aquifer. b is equal to the depth of a confined aquifer. It is equal to the **average** thickness of the saturated zone of an unconfined aquifer.

Transmissibility is usually expressed as m^2/s, or m^3/day/m or l/day/m.

Transmissibility of most formations lies between $1*10^4$ -$1*10^6$ l/d/m, with an average value of $1*10^5$ l/d/m.

Classification of Transmissivity

Magnitude (m^2/day)	Class	Designation	Specific Capacity (m^2/day)	Groundwater supply potential	Expected Q (m^3/day) if s=5m
> 1000	I	Very high	> 864	Regional Importance	> 4320
100-1000	II	High	86.4 – 864	Lesser regional importance	432 – 4320
10-100	III	Intermediate	8.64 – 86.4	Local water supply	43.2 – 432
1-10	IV	Low	0.864 – 8.64	Private consumption	4.32 – 43.2
0.1-1	V	Very low	0.0864 – 0.864	Limited consumption	0.423 – 4.32
<0.1	VI	Imperceptible	< 0.0864	Very difficult to utilize for local water supply	< 0.432

6. Specific Storage:

Specific Storage (Ss) is the amount of water per unit volume of a saturated formation that is stored or expelled from storage owing to compressibility of the mineral skeleton and the pore water per unit change in head. This is also called the elastic storage coefficient. The concept can be applied to both aquifers and confining units.

The specific storage is given by the expression (Jacob 1940, 1950; cooper 1966):

$$S_s = \rho_w g(\alpha + n\beta)$$

where ρ_w is the density of the water (M/L^3; Kg/m^3)

g is the acceleration of gravity (L/T^2; m/s^2)

α is the compressibility of the aquifer skeleton ($1/(M/LT^2)$; m^2/N)

n is the porosity

β is the compressibility of water ($1/(M/LT^2)$; m^2/N)

The specific storage is usually expressed as cm^{-1} or m^{-1}. For most aquifers, the specific storage is about $3*10^{-7}$ m^{-1}

Values of Specific Storage Assuming Porosity Equal to 15 %

Typical Lithologies	Specific Storage (m^{-1})
Clay	9.81×10^{-3}
Silt, fine sand	9.82×10^{-4}
Medium sand, fine	9.87×10^{-5}
Coarse sand, medium gravel, highly fissured	1.05×10^{-5}
Coarse gravel, moderately fissured rock	1.63×10^{-6}
Unfissured rock	7.46×10^{-7}

SOURCE: (Younger, 1993)

7. Storage Coefficient:

Storage coefficient (S) is the volume of water released from storage, or taken into storage, per unit of aquifer storage area per unit change in head. The storage coefficient is also called Storativity.

- The storage coefficient is a dimensionless as it is the ratio of the volume of water released from original unit volume.
- The water-yielding capacity of an aquifer can be expressed in terms of its storage coefficient.
- In unconfined aquifers, Storativity is the same as the specific yield of the aquifer.
- In confined aquifer, Storativity is the result of compression of the aquifer and expansion of the confined water when the head (pressure) is reduced during pumping.

For a vertical column of unit area extending through a confined aquifer, the storage coefficient equals the volume of water released from the aquifer when the piezometric surface declines a unit distance.

In most confined aquifers, values fall in the range $0.00005 < S < 0.005$, indicating that large pressure changes over extensive areas are required to produce substantial water yields. Storage coefficients can best be determined from pumping tests of wells or from groundwater fluctuation in response to atmospheric pressure or ocean tide variation.

Storativity of **unconfined aquifers** ranges from 0.02 to 0.30.

Water Resources Engineering – I

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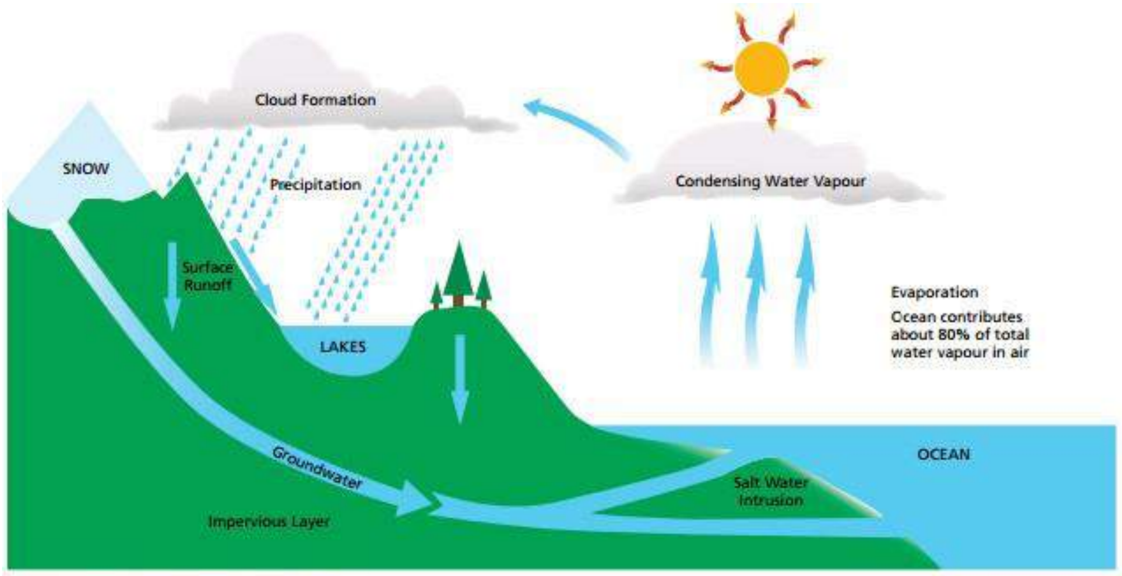
Introduction:

Groundwater is water that exists in the pore spaces and fractures in rocks and sediments beneath the Earth's surface.

Groundwater scientists typically restrict the use of the term "groundwater" to underground water that can flow freely into a well, tunnel, spring, etc. This definition excludes underground water in the unsaturated zone. The unsaturated zone is the area between the land surface and the top of the groundwater system. The unsaturated zone is made up of earth materials and open spaces that contain some moisture but, for the most part, this zone is not saturated with water. Groundwater is found beneath the unsaturated zone where all the open spaces between sedimentary materials or in fractured rocks are filled with water and the water has a pressure greater than atmospheric pressure.

To understand the ways in which groundwater occurs, it is needed to think about the ground and the water properties.

- Porosity, which is the property of a rock possessing pores or voids.
- Saturated and unsaturated zones.
- Permeability, which is the ease with which water can flow through the rock.
- Aquifer, which is a geologic formation sufficiently porous to store water and permeable enough to allow water to flow through them in economic quantities.
- Storage coefficient, which is the volume of water that an aquifer releases from or takes into storage per unit surface area of aquifer per unit change in the component of area normal to surface.



Groundwater is part of the water cycle.

Types of Geological Formations:

There are basically four types of geological formations

1. Aquifers
2. Aquitard
3. Aquiclude
4. Aquifuge

1. Aquifer

An aquifer is a ground-water reservoir composed of geologic units that are saturated with water and sufficiently permeable to yield water in a usable quantity to wells and springs. Sand and gravel deposits, sandstone, limestone, and fractured, crystalline rocks are examples of geological units that form aquifers.

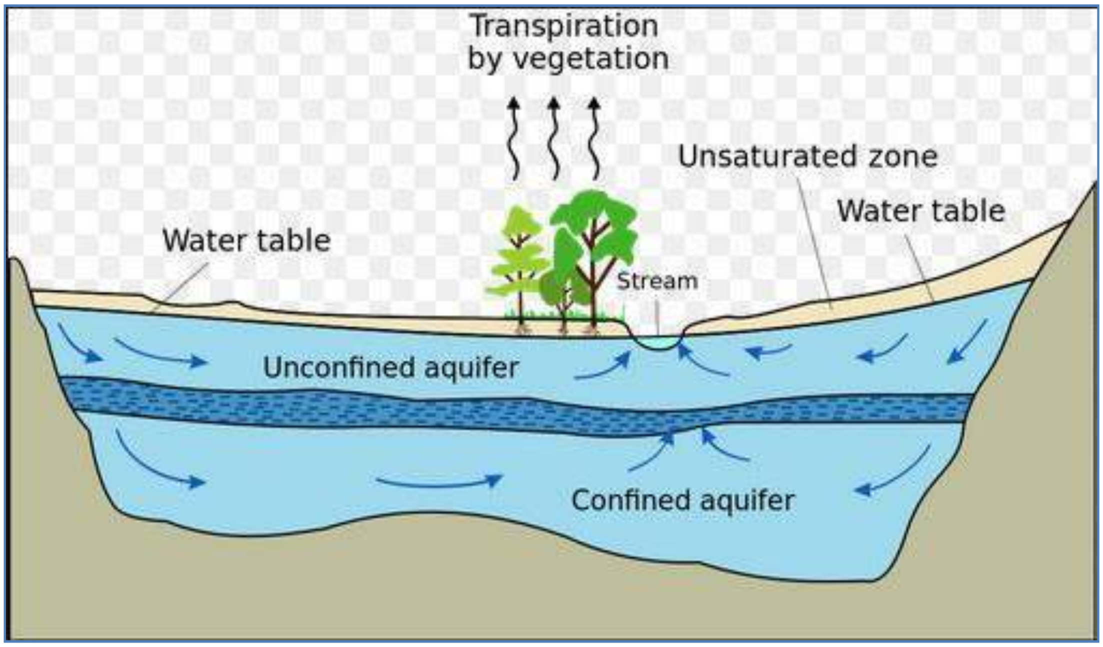
Aquifers provide two important functions:

a) They transmit ground water from areas of recharge to areas of discharge, and
b) They provide a storage medium for useable quantities of ground water. The amount of water a material can hold depends upon its porosity. The size and degree of interconnection of those openings (permeability) determine the materials' ability to transmit fluid.

Types of Aquifers

Most aquifers are of large areal extent and may be visualized as underground storage reservoirs. Water enters a reservoir from natural or artificial recharge; it flows out under the action of gravity or is extracted by wells. Ordinarily, the annual volume of water removed or replaced represents only a small fraction of the total storage capacity. Aquifers may be classed as

1. Unconfined Aquifer
2. Confined Aquifer



Unconfined Aquifer:

An unconfined aquifer is one in which a water table varies in undulating form and in slope, depending on areas of recharge and discharge, pumpage from wells, and permeability. Rises and falls in the water table correspond to changes in the volume of water in storage within an aquifer. Contour maps and profiles of the water table can be prepared from elevations of water in wells that tap the aquifer to determine the quantities of water available and their distribution and movement.

This occurs wherever a groundwater body is separated from the main groundwater by a relatively impermeable stratum of small areal extent and by the zone of aeration above the main body of groundwater. Clay lenses in sedimentary deposits often have shallow perched water bodies overlying them. Wells tapping these sources yield only temporary or small quantities of water.

Confined Aquifers:

Confined aquifers, also known as artesian or pressure aquifers, occur where groundwater is confined under pressure greater than atmospheric by overlying relatively impermeable strata. In a well penetrating such an aquifer, the water level will rise above the bottom of the confining bed. Water enters a confined aquifer in an area where the confining bed rises to the surface; where the confining bed ends underground, the aquifer becomes unconfined. A region supplying water to a confined area is known as a recharge area; water may also enter by leakage through a confining bed. Rises and falls of water in wells penetrating confined aquifers result primarily from changes in pressure rather than changes in storage volumes. Hence, confined aquifers display only small changes in storage and serve primarily as conduits for conveying water from recharge areas to locations of natural or artificial discharge.

2. Aquitard:

An aquitard is a partly permeable geologic formation. It transmits water at such a slow rate that the yield is insufficient. Pumping by wells is not possible. For example, sand lenses in a clay formation will form an aquitard. Also known as a leaky confining layer

3. Aquiclude

Impermeable layer of soil that may absorb water slowly but does not transmit it. A body of relatively impermeable rock that is capable of absorbing water slowly but does not transmit it rapidly enough to supply a well or spring

4. Aquifuge

An aquifuge is a geologic formation which doesn’t have interconnected pores. It is neither porous nor permeable. Thus, it can neither store water nor transmit it. Examples of aquifuge are rocks like basalt, granite, etc. without fissures.

Water Resources Engineering – I

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Introduction:

A water wells is a hole or shaft, usually vertical, excavated in the earth for bringing ground water to the surface.

Uses of wells are for irrigation purpose, livestock watering, industrial supplies, geothermal or ground-source energy, construction, dewatering, brine mining, water injection to oil reservoirs, aquifer clean up, river support and artificial recharge of aquifers. Wells also used extensively for monitoring water levels and groundwater quality.

Types of Water Wells:

Diverse geological formations require different types of wells for tapping ground water for irrigation and water supply. The choice of type of well for irrigation is influenced by the size of farm holdings and the relative preference given to private, cooperative and public wells.

There are two broad classes of Wells:

1. Dug well / Open wells
2. Tube wells

1. **Dug Well or Open Well:**

   Open wells have been the major means of domestic water supply throughout the span of the recorded history of mankind. They are also used extensively in small-scale irrigation. Compared to tube wells, open wells are shallow and usually used to tap water table aquifers

   - Larger diameter (3' to 4')
   - Curbing material is usually concrete crocks with loose joints.

- Water enters well through loose casing joints.
- Low well yield
- Highly vulnerable to contamination

Types of Open wells:

- Unlined wells
- Wells with pervious lining
- Wells with impervious lining
- Dug-cum-Bore wells

2. Tube Wells:

Tube well is a hole drilled in the ground for the purpose of extracting ground water. Tube wells are classified on the basis of the entry of water into the well, the method of construction, the depth and the type of aquifer tapped.

Classification based on Entry of water:

1) Screen wells

Several types of well screens are used to suit the specific requirements of the aquifer and economic status of the farmer.

- Openings in the form of slots which are continues and uninterrupted around the circumstance of the screen.
- Close spacing of slot openings to provide the maximum percentage of open area.
- V-shaped slot openings that widen inward.
- Single metal construction to avoid galvanic corrosion.
- Adaptability to different ground water and aquifer conditions by the use of various materials.
- Maximum open area consistent with adequate strength

a) Strainer wells

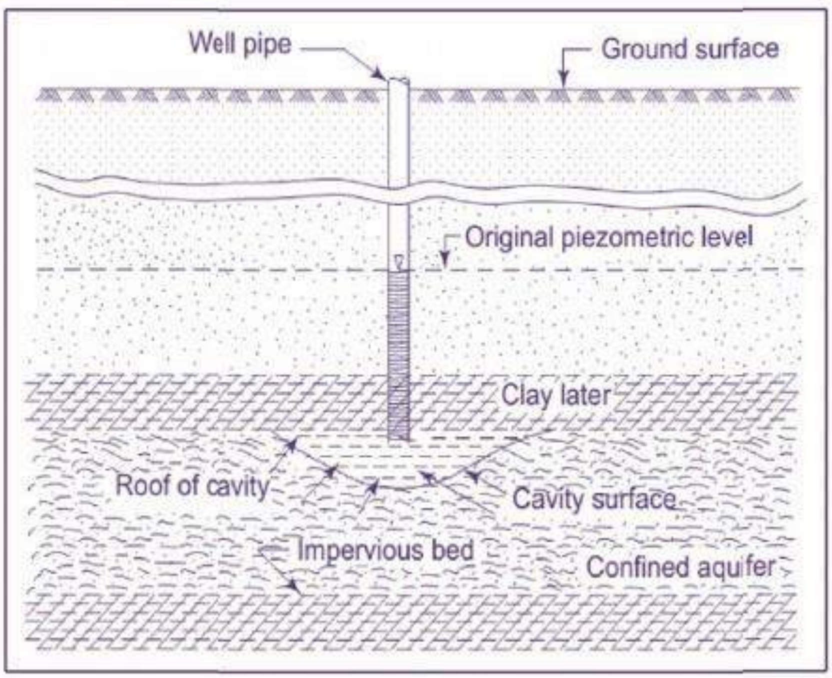
It essentially consists of a perforated or a slotted pipe with a wire mesh wrapped around the pipe with smaller annular space between the two. In this type of tube well a screen is placed against the water bearing stratum. The wire screen prevents sand particles from entering the well pipe through the fine mesh (screen) and the sand particles of size larger than the size of mesh are kept away from entering the pipe.

b) Slotted pipe gravel pack wells

It uses a slotted pipe without being covered by any wire mesh. If proper depth of water bearing strata is not available even at deep depths of 85 to 100 m, so as to obtain the required discharge from a strainer well. After placing the assembly of plain and slotted pipes in the bore hole, gravel is poured into the bore hole between the well pipe assembly and the casing pipe. Gravel packs are highly perforated for deep wells and tap more than one aquifer.

2) Cavity wells

A cavity well is the shallow tube well drilled in alluvial formation .A cavity type tube well draws water from bottom of the well and not from the sides. The difference in flow pattern of a screen well and cavity well is that whereas in a strainer well, the flow is radial, the flow in a cavity well s spherical.



Classification based Method of Construction:

1) Drilled wells

- Constructed using rotary, cable tool, jetting, hollow rod, or auger rigs.
- Casing material can be steel or PVC plastic.
- More common than driven or dug wells.
- Most are greater than 15m deep.

2) Driven wells

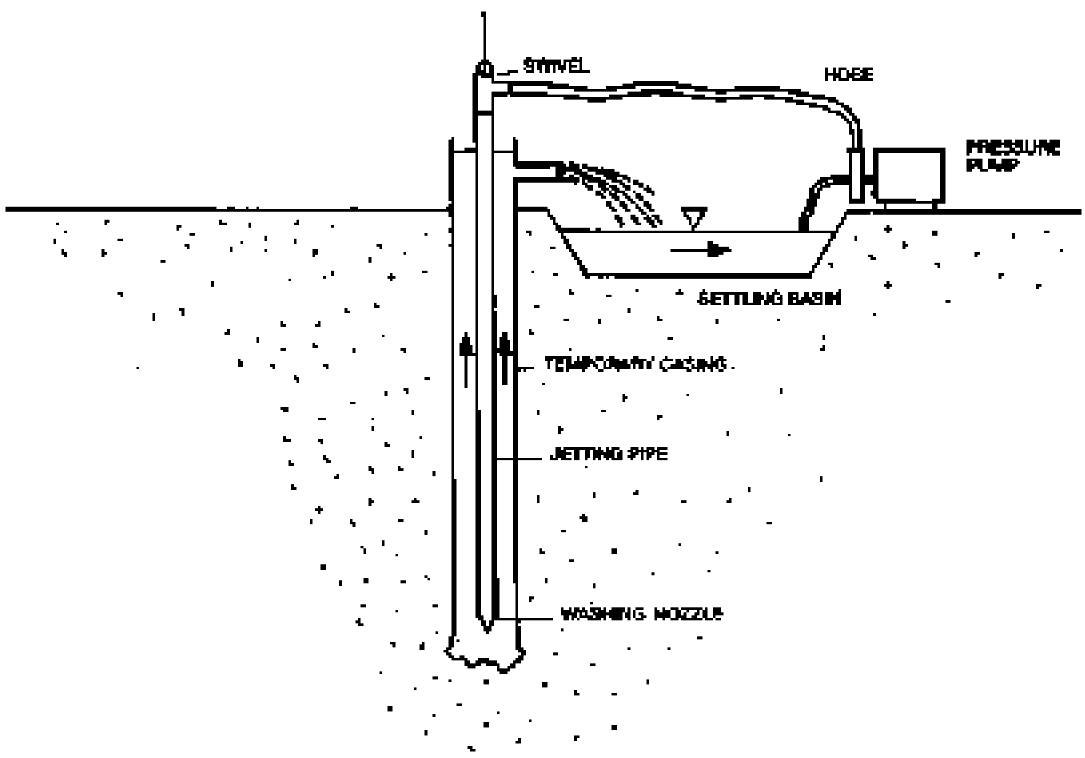
- Cannot be driven into bedrock.
- Well point driven into ground with post driver, tripod with weight or sledge hammer.
- Common around lakes and high water table areas.

- Most are less than 10 m deep and have a limited yield (less than 7gpm).
- More susceptible to contamination than drilled wells.

3) Jetted wells

Jetted wells are constructed by employing the erosive action of a stream of water to cut a hole, inside which a well screen and rising pipe can be inserted after completion. The water required for this process is conveyed to the hole by a jetting pipe, of relatively small diameter. At the top, this pipe is connected by a flexible hose to a pressure pump, while a washing nozzle at the lower end assures the outflow of water under high pressure. This water squirts at high speed against the bottom of the hole, loosens the material and carries the disintegrated fragments upwards and out of the hole; to prevent the hole from collapsing, temporary casing is commonly sunk as jetting proceeds.

This type of wells may only be constructed in places where subsoil formations are soft enough to allow the technique to work; sandy alluvial formations are among the most suitable aquifers for these wells. Sands are easily displaced and, in such formations, wells may be constructed quicker by jetting than by any other method. The presence of clays, hardpan or coarse gravel beds may slow down or impede drilling to continue. Well jetting requires large amounts of water, limiting its application in arid regions.



Well Construction:

A variety of methods are used to construct water wells, depending on the geologic conditions and the intended use of the well. Two general types of well construction are

- Extending casing down the borehole through the upper loose sediment or rocks, but leaving the bottom portion of the borehole uncased. This type of well construction is usually used in hard, fractured rock. (Partial Casing)
- Extending casing down the borehole through sediment or rock and placing a well screen in the aquifer. This type of well construction is commonly used in unconsolidated sediment, such as sand and gravel (Full Casing).

Typical well construction procedure:

1. Drilling Operations

Drilling methods vary widely and range from digging by hand to the use of very technical and expensive drilling rigs. All drilling methods accomplish the same task, creating a borehole. Most drilling operations are completed by the use of some sort of drilling rig. The rig is set up over the prospective well location and drilling continues until the desired depth has been reached.

2. Installing the Casing and Screen

Once the desired depth of the borehole has been reached, the drill crew can then install the casing and screen. Casing can be made of different materials, such as steel or plastic, and comes in various diameters and lengths. Well screens are also available in various material types, diameters, and lengths, and have slots or holes cut in them. The slots or holes are sized to allow water to flow into the well and keep unwanted materials, such as sand, out. Well screens are usually attached to the first piece of casing to be put down the borehole and successive pieces of casing are then added until the entire length of the borehole has been screened or cased.

3. Installing an Artificial Filter Pack

For some well designs, it is necessary for an artificial filter pack to be placed around the screen. This operation takes place before grouting or sealing the well. The filter pack consists of graded sand or gravel, which is placed around the well screen. The filter pack removes or filters unwanted fine particles from the formation that would otherwise find a way into the well. These fine particles could cause the well water to appear cloudy.

4. Grouting the Well

Grouting a well involves filling the space between the casing and borehole wall with slurry of cement or clay. This is done to seal the area between the casing and borehole wall to prevent downward leakage of contaminants from the surface, or to prevent intermixing of ground water between water-bearing zones encountered while drilling.

Grouting can be accomplished by several methods, but all involve the mixing and placement of either a bentonite clay slurry or neat cement slurry in the annular space between the borehole and the casing. The most common type of grout used in the water well industry today is neat cement. The section of the borehole to be grouted varies according to geologic conditions, the type of water well being constructed, and water well codes. Once the grouting process is completed, the well is ready to be developed for its intended use.

Well Development:

Well development is a procedure intended to maximize the well yield. During the drilling operation, damage to the formation or aquifer occurs. This happens when the drill bit cuts through the rock or sediment leaving behind small pieces of rock or sediment that may plug the well screen and reduce the yield of the well. Also, during the drilling operation, different fluids may be introduced to the borehole to remove cuttings and to prevent it from collapsing.

There are two main reasons for well development:

- Repair damage done to the formation during drilling, and to remove unwanted fluids, so that the natural properties of the aquifer are restored; and
- Change the physical properties (porosity and permeability) of the aquifer near the borehole so that water will flow more freely into the well

A variety of techniques are used to develop wells. Some are as simple as bailing the well and others may involve a complex operation of high capacity pumping and jetting. The screened area of the well, or the uncased unscreened portion of a borehole, is where the development takes place because this is the area where water will enter the well. All of the techniques have their advantages and achieve the same goal. This is to increase the amount of water that can be delivered to the surface for use. With development complete, a permanent pump can be installed, if necessary, and the well can be put to use.

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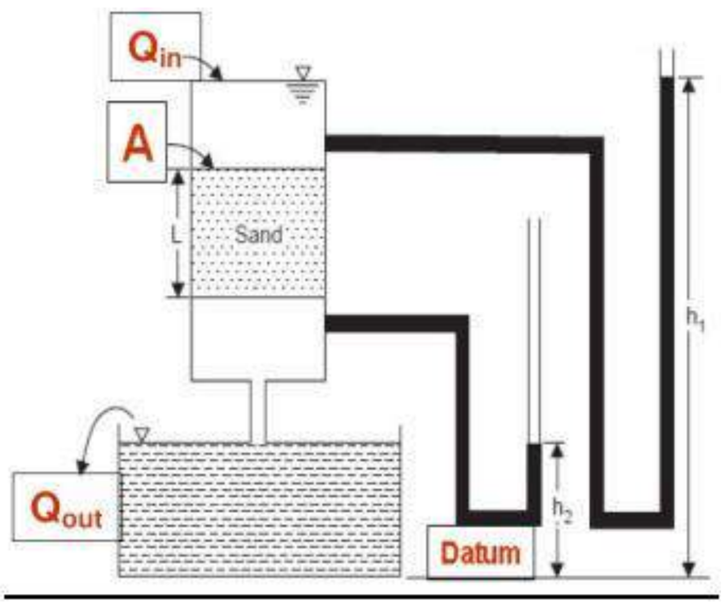
Permeability is the measure of the soil's ability to permit water to flow through its pores or voids. Knowledge of the permeability properties of soil is necessary to:

- Estimating the quantity of underground seepage
- Solving problems involving pumping seepage water from construction excavation

Darcy's law:

In 1856, H.P.G. Darcy (1803-1858) constructed the first experimental apparatus to study the flow characteristics of water through the soil medium. From his experiments, he derived the equation that governs the laminar (non-turbulent) flow of fluids in homogeneous porous media which became to be known as Darcy's law.



Schematic diagram depicting Darcy's experiment

The schematic diagram representing Darcy’s experiment is depicted in Figure above. By measuring the value of the rate of flow, Q for various values of the length of the sample, L, and pressure of water at top and bottom the sample, h1 and h2, Darcy found that Q is proportional to (h1 – h2)/L or the hydraulic gradient, i, that is,

$$Q = k\frac{h_1 - h_2}{L}A = k\frac{\Delta h}{L}A$$

$$Q = kiA$$

The loss of head of Δh units is affected as the water flows from h_1 to h_2. The hydraulic gradient defined as loss of head per unit length of flow may be expressed as,

$$i = \frac{\Delta h}{L}$$

k is coefficient of permeability or hydraulic conductivity with units of velocity, such as mm/sec or m/sec. Thus the theory of seepage flow in porous media is based on a generalization of **Darcy's Law which is stated as, “Velocity of flow in porous soil media is proportional to the hydraulic gradient”** where, flow is assumed to be laminar. That is,

v = k i

Where,

k = coefficient of permeability

v = velocity of flow

i = the hydraulic gradient.

Typical values of coefficient of permeability for various soils are as follows,

Soil type	*Coefficient of permeability (mm/s)*
Coarse	$10 - 10^3$
Fine gravel, coarse, and medium sand	$10^{-2} - 10$
Fine sand, loose silt	$10^{-4} - 10{-}2$
Dense silt, clayey silt	$10^{-5} - 10^{-4}$
Silty clay, clay	$10^{-8} - 10^{-5}$

Assumptions made defining Darcy’ law.

- The flow is laminar that is, flow of fluids is described as laminar if a fluid particles flow follows a definite path and does not cross the path of other particles.
- Water & soil are incompressible that is, continuity equation is assumed to be valid
- The soil is saturated
- The flow is steady state that is, flow condition do not change with time.

Factors affecting permeability of soil:

- Grain-size
    - Shape and size of the soil particles.
    - Smaller the grain-size the smaller the voids and thus the lower the permeability.
    - A relationship between permeability and grain-size is more appropriate in case of sands and silts.
- Void ratio
    - Increase in the porosity leads to an increase in the permeability. It causes an increase in the percentage of cross-sectional area available for flow.
- Composition
    - The influence of soil composition on permeability is generally insignificant in the case of gravels, sands, and silts, unless mica and organic matter are present.
    - Soil composition has major influence in the case of clays.
- Soil structural
    - Fine-grained soils with a flocculated structure have a higher coefficient of permeability than those with a dispersed structure.
    - Remoulding of a natural soil reduces the permeability
    - Permeability parallel to stratification is much more than that perpendicular to stratification
- Degree of saturation
    - Higher the degree of saturation, higher is the permeability.
    - In the case of certain sands the permeability may increase three-fold when the degree of saturation increases from 80% to 100%.
- Presence of entrapped air and other foreign matter.
    - Entrapped air reduces the permeability of a soil.
    - Organic foreign matter may choke flow channels thus decreasing the permeability

Validity or limitations of Darcy's law:

Darcy's law given by v = k i is true for laminar flow through the void spaces. A criterion for investigating the range can be furnished by the Reynolds number. For flow through soils, Reynolds number Rn can be given by the relation,

$$R_n = \frac{vD\rho}{\mu g}$$

Where, v=discharge (superficial) velocity in cm/s, D = average diameter of the soil particle in cm, ρ= density of the fluid in g/cm^3, μ= coefficient of viscosity in g/cm·s, g = acceleration due to gravity, cm/s^2

For laminar flow conditions in soils, experimental results show that,

$$R_n = \frac{vD\rho}{\mu g} \leq 1$$

with coarse sand, assuming $D = 0.47$ mm and $k \approx 100D^2 = 100(0.047)2 = 0.2209$ cm/s.
Assuming $i = 1$, then $v = ki = 0.2209$ cm/s.
Also, water $\approx$ 1g/cm^3, and (μ at 20^{0}C) g = 10–5 (980) g/cm·s. Gives, $\boldsymbol{R_n = 1.059} \approx 1$

From the above calculations, we can conclude that, *for flow of water through all types of soil (sand, silt, and clay), the flow is laminar and Darcy's law is valid.*

With coarse sands, gravels, and boulders, turbulent flow of water can be expected.

Measurement of Coefficient of Permeability:

- Laboratory Tests **(using Darcy's Law)**
  - Constant-head permeability test - suitable for coarse grained soils,
  - Falling or Variable -head permeability test - suitable for fine grained soils
- Field Tests
  - **Pumping Out Tests**
  - Pumping In Tests
- Indirect Methods
  - Computation from the particle size
  - Computation from consolidation test

Pumping out Tests:

The coefficient of permeability of the permeable layer can be determined by pumping from a well at a constant rate and observing the steady-state water table in nearby observation wells. The steady-state is established when the water levels in the test well and the observation wells become constant. When water is pumped out from the well, the aquifer gets depleted of water, and the water table is lowered resulting in a circular depression in the phreatic surface. This is referred to as the 'Drawdown curve' or 'Cone of depression'. The analysis of flow towards such a well was given by Dupuit (1863).

Assumptions

1. The aquifer is homogeneous.
2. Darcy's law is valid.
3. The flow is horizontal.
4. The well penetrates the entire thickness of the aquifer.

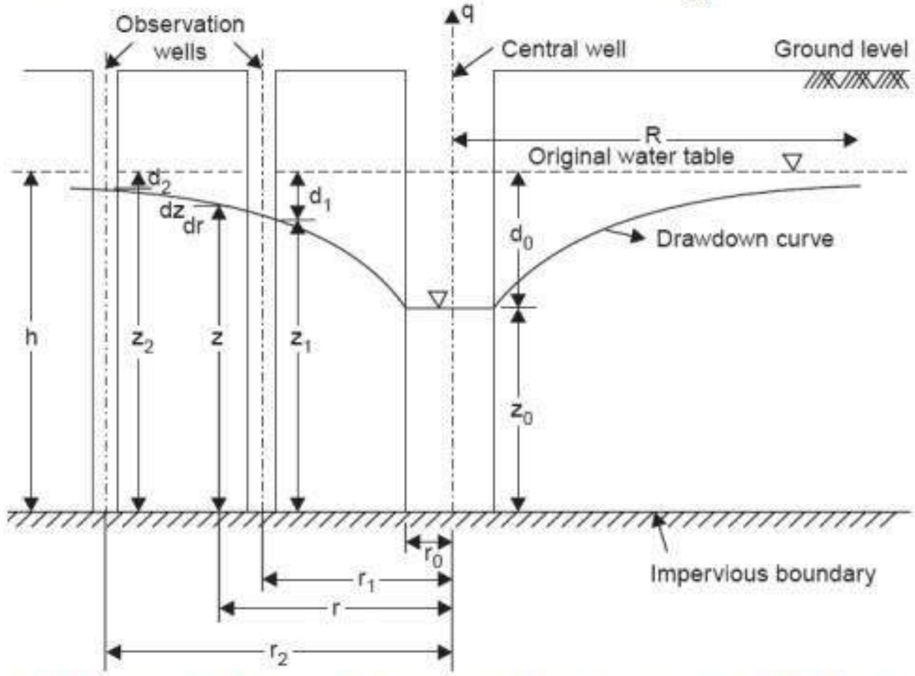
5. Natural groundwater regime remains constant with time.

6. Dupuit's theory is valid that is, i = dz/dr

Case 1: Unconfined Aquifer

Let r and z be the radial distance and height above the impervious boundary at any point on the drawdown curve as shown in Figure 4.6. At steady state, the rate of discharge due to pumping can be expressed as, $q = kiA$

Hydraulic gradient at any point is given by Dupuit's theory, $i = \frac{dz}{dr}$



Field permeability test – Pumping out test in an unconfined aquifer

$$\therefore q = k\frac{dz}{dr}2\pi rz \qquad (\because A = 2\pi rz)$$

$$\frac{dr}{r} = \frac{2\pi k}{q}(z.dz), \quad \text{integrating both sides} \int_{r_1}^{r_2}\frac{dr}{r} = \frac{2\pi k}{q}\int_{z_1}^{z_2} z.dz$$

$$\Rightarrow k = \frac{2.303q}{\pi(z_2^2 - z_1^2)}\left[\log_{10}\frac{r_2}{r_1}\right]$$

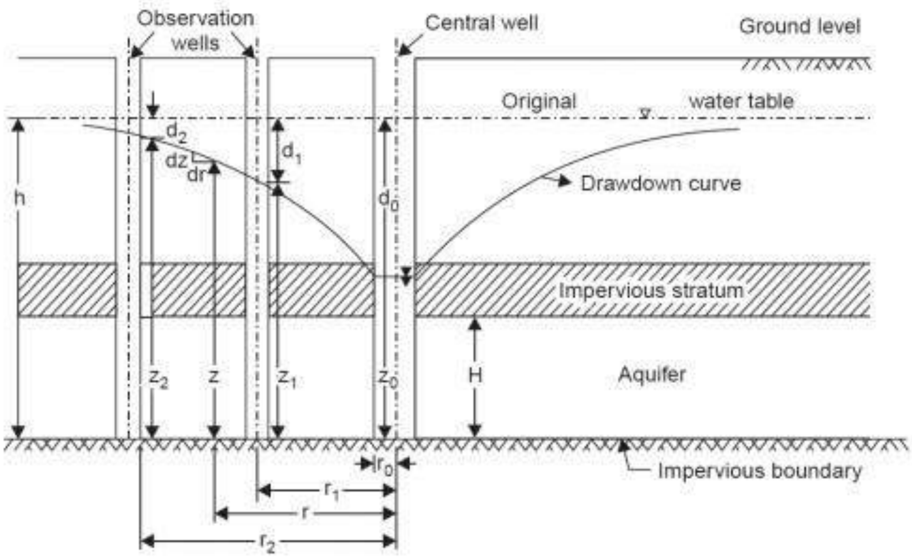
Note: $z_1 = (h - d_1)$ & $z2 = (h - d_2)$

$$\therefore k = \frac{2.303q}{\pi[(d_1 - d_2)(2h - d_1 - d_2)]}\left[\log_{10}\frac{r_2}{r_1}\right]$$

If the values of r_1, r_2, z_1, z_2, and q are known from field measurements, the coefficient of Permeability can be calculated using the above relationship for k.

Case 2: Confined Aquifer

Let r and z be the radial distance and height above the impervious boundary at any point on the drawdown curve as shown in Figure 4.7. At steady state, the rate of discharge due to pumping can be expressed as, $q = kiA$



Field permeability test – Pumping out test in confined aquifer

$$\therefore q = k\frac{dz}{dr}2\pi rH \qquad (\because A = 2\pi rH)$$

H is depth of confined aquifer

$$kdz = \frac{q}{2\pi H}\frac{dr}{r} \text{ integrating both sides, } k\int_{z_1}^{z_2} dz = \frac{q}{2\pi H}\int_{r_1}^{r_2}\frac{dr}{r}$$

$$\Rightarrow k[z]_{z_1}^{z_2} = \frac{q}{2\pi H}\Big[\log_e r\Big]_{r_1}^{r_2}$$

$$\Rightarrow k = \frac{2.303q}{2\pi H(z_2 - z_1)}\left(\log_{10}\frac{r_2}{r_1}\right); \qquad \Rightarrow k = \frac{q}{2.7283 \times H(z_2 - z_1)}\left(\log_{10}\frac{r_2}{r_1}\right)$$

Note: $z_1 = (h - d_1)$ & $z2 = (h - d_2)$

$$\therefore k = \frac{q}{2.7283 \times H(d_1 - d_1)}\left(\log_{10}\frac{r_2}{r_1}\right)$$

If the values of r_1, r_2, z_1, z_2, and q are known from field measurements, the coefficient of Permeability can be calculated using the above relationship for k.

UNIT 4

- **Soil-Water-Plant Relationship, Vertical Distribution of Soil Moisture, Soil Moisture Constants, Soil Moisture Tension**
- Consumptive Use, Duty and Delta, Factors affecting Duty
- Design Discharge for a Water Course, Depth and Frequency of Irrigation
- Irrigation Efficiencies, Water Logging

Introduction:

Plant growth depends on two important natural resources:

- Soil € Provides mechanical and nutrient support necessary for plant growth
- Water € Essential for Plant Life Processes

Effective management of the above resources for crop production requires the understanding of relationships between soil, water, and plants.

Soil:

A dynamic natural body composed of mineral and organic matter and living forms in which plants grow. Dynamic body means that its composition and properties change with time.

Factors affecting Soil Formation:

- Climate
- Living Organisms
- Relief
- Parent Material
- Time

Factors that retard soil profile development:

- Low Rainfall & Humidity
- High Lime & Clay Content, Quartz, Water Table
- Hard Rock
- Steep Slopes & Severe Erosion
- Cold Temperature

What happens to a soil with time?

- Loss of nutrients (bases) – lower pH or soil becomes more acid
- Increase in concentration of iron
- Increase in clay content
- Deeper weathering into material

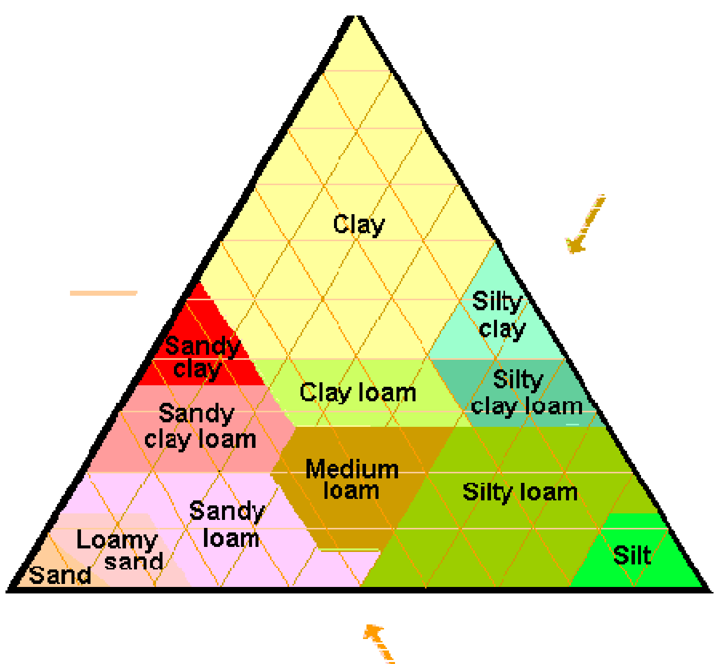
Physical Characteristics of Soil:

- **Soil Texture**

  Soil texture is determined by the size of the particles that make up the soil

  According to textural gradations a soil may be broadly classified as:

  - Open or light textural soils: these are mainly coarse or sandy with low content of silt and clay.
  - Medium textured soils: these contain sand, silt and clay in sizeable proportions, like loamy soil.
  - Tight or heavy textured soils: these contain high proportion of clay



- **Soil Structure**

  Soil structure is the shape and arrangement of soil particles into aggregates.

  The classification of soil structure is done according to three indicators as:-

  - **Type**: structures-platy, prism-like, block like and spheroidal.
  - **Class:** very fine, fine, medium, coarse and very coarse.

- **Grade:** this represents the degree of aggradation that is the proportion between aggregate and unaggregated material that results when the aggregates are displaced or gently crushed. Grades are termed as structure less, weak, moderate, strong and very strong depending on the stability of the aggregates when disturbed.

  Soil structure is unstable and can change with climate, biological activity, and soil management practices.

- **Bulk Density €** Weight of Soils to its Volume. Total volume includes solids and pore spaces.
- **Soil Porosity €** Volume of pores in a soil. Compacted soils have less porosity and higher bulk density.

The above all impact how soil, water, and air interact.

Soil Composition:

- Air - 25%
  - More CO_2 and Less O_2 than the atmosphere
  - Soil has relative humidity near 100%
- Water - 25%
- Mineral Matter - 45% to 49%
- Organic Matter - 1% to 5%
  - Fresh Residue (<10%)
  - Decomposing Organic Matter (33-50%)
  - Stable Organic Matter (33-50%)
  - Living Organisms (<5%)

Soil and Water Interactions:

It is important to understand the following interactions:

- Soil Moisture Content or Vertical Distribution of Soil Moisture
- Soil Moisture Storage Capacity or Soil Moisture Constants
- Soil Moisture Tension

Soil Moisture Content or Vertical Distribution of Soil Moisture

As stated earlier, water may occur in the soil pores in varying proportions. Some of the definitions related to the water held in the soil pores are as follows:

- **Gravitational water:** A soil sample saturated with water and left to drain the excess out by gravity holds on to a certain amount of water. The volume of water that could easily drain off is termed as the gravitational water. This water is not available for plants use as it drains off rapidly from the root zone. Drains out of the soil in 2-3 days after a rain.

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

Soil Moisture Constants:

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

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

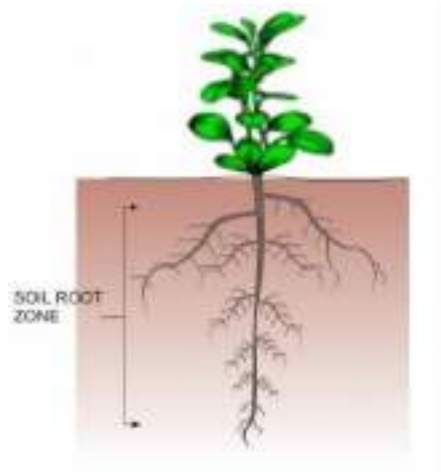
  Two stages of wilting points are recognized and they are:

  - **Temporary wilting point:** this denotes the soil water content at which the plant wilts at day time, but recovers during night or when water is added to the soil.
  - **Ultimate wilting point:** at such a soil water content, the plant wilts and fails to regain life even after addition of water to soil.

It must be noted that the above water contents are expressed as percentage of water held in the soil pores, compared to a fully saturated soil.

Important Definitions:

Root Zone: The soil root zone is the area of the soil around the plant that comes in contact with the plant root.



Definition of soil root zone

Wilts: Wilting is drooping of plants. Plants bend or hang downwards through tiredness or weakness due to lack of water.

Soil Moisture Tension:

It is the measurement of how strongly water is held in the soil. Water is held in the soil by capillary forces as well as the attraction of the water molecule to itself and to electrically charged clay particles. Soil moisture tension is measured in units of pressure (centibars or kilopascals). The tension at which irrigation is recommended depends on the soil and crop, but typically falls somewhere between 30 and 50 centibars (1 centibar = 1 kPa)

Summary:

Basic knowledge of soil-plant-water relationship makes possible to better manage and conserver irrigation water. Some important points are:

1. Soil water holding capacity varies with soil texture. It is high for medium and medium and fine textured soils but low for sandy soils.
2. Plant roots can use only available soil moisture which is stored in between field capacity and permanent wilting point.
3. Although plant roots may grow to deep depths, most of the water and nutrients are taken from upper half of the root zone.

Water Resources Engineering – I

- Necessity, Importance, Advantages, ill effects of Irrigation, Types of Irrigation
- **Methods of Irrigation**
- Indian Agricultural Soils, Methods of Improving Soil fertility
- Crop rotation, Preparation of land for irrigation, Standard quality for Irrigation water

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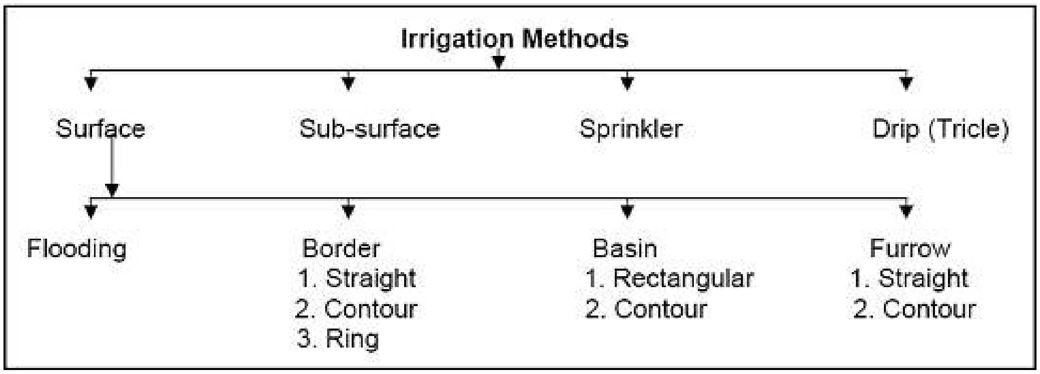
Methods of Irrigation:

Irrigation water can be applied to crop lands one of the following irrigation methods:



Surface Irrigation

a) Uncontrolled or Wild Flooding:

It is the primitive and most inefficient method of irrigation. In this method water is spread over the smooth or flat field without much control over the flow or prior preparation. The water is spread into the field from the ditch excavated either on the contour or up and down the slope. This method is applicable to inundation irrigation system or for pastures or forage crops where water is available in abundance at the highest elevation and is inexpensive or the crop values do not justify adoption of better method. The water distribution is quite uneven. The method is suitable for all medium to fine texture soils. It has low cost and does not interfere with tillage.

Disadvantages:

1. wasteful use of water,
2. non-uniform distribution of water,
3. excessive soil erosion on steeper slopes,
4. Require drainage arrangement to reduce ponding.

b) Border irrigation:

- The land is divided into number of long parallel strips called borders.
- These borders are separated by low ridges.
- The border strip has a uniform gentle slope in the direction of irrigation.
- Each strip is irrigated independently by turning the water in the upper end.
- The water spreads and flows down the strip in a sheet confined by the border ridges.

Suitability:

To soils having moderately low to moderately high infiltration rates. It is not used in coarse sandy soils that have very high infiltration rates and also in heavy soils having very low infiltration rate. Suitable to irrigate all close growing crops like wheat, barley, fodder crops and legumes and not suitable for rice.

Advantages:

1. Border ridges can be constructed with simple farm implements like bullock drawn “A” frame ridger or bund former.
2. Labour requirement in irrigation is reduced as compared to conventional check basin method.
3. Uniform distribution of water and high water application efficiencies are possible.
4. Large irrigation streams can be efficiently used.
5. Adequate surface drainage is provided if outlets are available.

Width of border strip: It varies from 3-15 m

Border length

Slope	Soil	Length
0.25 - 0.60%	Sandy and sandy loam	60-120 m
0.20 - 0.40%	Medium loam soil	100-180 m
0.05 – 0.20%	Clay loam and clay soil	150-300 m

c) Check basin irrigation

- It is the most common method.
- Field is divided into smaller unit areas so that each has a nearly level surface.
- Bunds or ridges are constructed around the area forming basins within which the irrigation water can be controlled.
- The water applied to a desired depth can be retained until it infiltrates into the soil.
- The size of the basin varies from 10m^2 to 25 m^2 depending upon soil type, topography, stream size and crop.

Adaptability

- Small gentle and uniform land slopes
- Soils having moderate to slow infiltration rates.
- Adapted to grain and fodder crops in heavy soils.
- Suitable to permeable soils.

Advantages

1. Check basins are useful when leaching is required to remove salts from the soil profile.
2. Rainfall can be conserved and soil erosion is reduced by retaining large part of rain
3. High water application and distribution efficiency.

Limitations

1. The ridges interfere with the movement of implements.
2. More area occupied by ridges and field channels.
3. The method impedes surface drainage
4. Precise land grading and shaping are required
5. Labour requirement is higher.
6. Not suitable for crops which are sensitive to wet soil conditions around the stem.

d) Furrow irrigation

- Used in the irrigation of row crops.
- The furrows are formed between crop rows.
- The dimension of furrows depend on the crop grown, equipment used and soil type.
- Water is applied by small running streams in furrows between the crop rows.
- Water infiltrates into soil and spreads laterally to wet the area between the furrows.
- In heavy soils furrows can be used to dispose the excess water.

Adaptability

1. Wide spaced row crops including vegetables.
2. Suitable for maize, sorghum, sugarcane, cotton, tobacco, groundnut, potatoes
3. Suitable to most soils except sand.

Advantages

1. Water in furrows contacts only one half to one fifth of the land surface.
2. Labour requirement for land preparation and irrigation is reduced.
3. Compared to check basins there is less wastage of land in field ditches.

Types of furrow irrigation

Based on alignment of furrows

1. Straight furrows
2. Contour furrows

Based on size and spacing

1. Deep furrows
2. Corrugations

Based on irrigation:

1. All furrow irrigation: Water is applied evenly in all the furrows and are called furrow system or uniform furrow system.
2. Alternate furrow irrigation: It is not an irrigation layout but a technique for water saving. Water is applied in alternate furrows for eg. During first irrigation if the even numbers of furrows are irrigated, during next irrigation, the odd number of furrows will be irrigated.
3. Skip furrow irrigation: They are normally adopted during the period of water scarcity and to accommodate intercrops. In the skip furrow irrigation, a set of furrows are completely skipped out from irrigation permanently. The skipped furrow will be utilized for raising intercrop. The system ensures water saving of 30-35 per cent. By this method, the available water is economically used without much field reduction.
4. Surge irrigation: Surge irrigation is the application of water in to the furrows intermittently in a series of relatively short ON and OFF times of irrigation cycle. It has been found that intermittent application of water reduces the infiltration tare over surges thereby the water front advances quickly. Hence, reduced net irrigation water requirement. This also results in more uniform soil moisture distribution and storage in the crop root zone compared to continuous flow. The irrigation efficiency is in between 85 and 90%.

Sub-surface irrigation

- In subsurface irrigation, water is applied beneath the ground by creating and maintaining an artificial water table at some depth, usually 30-75 cm below the ground surface.
- Moisture moves upwards towards the land surface through capillary action
- Water is applied through underground field trenches laid 15-30 m apart.
- Open ditches are preferred because they are relatively cheaper and suitable to all types of soil.
- The irrigation water should be of good quality to prevent soil salinity.

Advantages

1. Minimum water requirement for raising crops
2. Minimum evaporation and deep percolation losses
3. No wastage of land
4. No interference to movement of farm machinery
5. Cultivation operations can be carried out without concern for the irrigation period.

Disadvantages

1. Requires a special combination of natural conditions.
2. There is danger of water logging
3. Possibility of choking of the pipes lay underground.
4. High cost.

Sprinkler Irrigation System

- The sprinkler (overhead or pressure) irrigation system conveys water to the field through pipes (aluminium or PVC) under pressure with a system of nozzles.
- This system is designed to distribute the required depth of water uniformly, which is not possible in surface irrigation.
- Water is applied at a rate less than the infiltration rate of the soil hence the runoff from irrigation is avoided.

A sprinkler system usually consists of the following parts.

1. A pumping unit
2. Debris removal equipment
3. Pressure gauge / water-meter
4. Pipelines (mains – sub-mains and laterals)
5. Couplers
6. Raiser pipes
7. Sprinklers
8. Other accessories such as valves, bends, plugs, etc.

Pumping unit

A high speed centrifugal or turbine pump can be installed for operating the system for individual farm holdings. The pumping plants usually consist of a centrifugal or a turbine type pump, a driving unit, a suction line and a foot valve.

Pipe lines

Pipelines are generally of two types. They are main and lateral. Main pipelines carry water from the pumping plant to many parts of the field. In some cases sub main lines are provided to take water from the mains to laterals. The lateral pipelines carry the water from the main or sub main pipe to the sprinklers. The pipelines may be either permanent, semi permanent or portable.

Couplers

A coupler provides connection between two tubing and between tubing and fittings.

Sprinklers

Sprinklers may rotate or remain fixed. The rotating sprinklers can be adapted for a wide range of application rates and spacing. They are effective with pressure of about 10 to 70 m head at the sprinkler. Pressures ranging from 16-40 m head are considered the most practical for most farms. Fixed head sprinklers are commonly used to irrigate small lawns and gardens.

Other accessories / fittings

1. Water meters - It is used to measure the volume of water delivered.
2. Pressure gauge - It is necessary to know whether the sprinkler is working with the desired pressure in order to deliver the water uniformly.
3. Bends, tees, reducers, elbows, hydrants, butterfly valves, end plugs and risers
4. Debris removal equipment: This is needed when water is obtained from streams, ponds, canals or other surface supplies. It helps to keep the sprinkler system clear of sand, weed seeds, leaves, sticks, moss and other trash that may otherwise plug the sprinklers.
5. Fertilizer applicators. These are available in various sizes. They inject fertilizers in liquid form to the sprinkler system at a desired rate.

Types of sprinkler system

On the basis of arrangement for spraying irrigation water

1. Rotating head (or) revolving sprinkler system
2. Perforated pipe system

Based on the portability

1. Portable system: It has portable mainlines and laterals and a portable pumping unit
2. Semi portable system: A semi portable system is similar to a fully portable system except that the location of the water source and pumping plant are fixed.

3. Semi permanent system: A semi permanent system has portable lateral lines, permanent main lines and sub mains and a stationery water source and pumping plant. The mainlines and sub-mains are usually buried, with risers for nozzles located at suitable intervals.
4. Solid set system: A solid set system has enough laterals to eliminate their movement. The laterals are placed in the field early in the crop season and remain for the season.
5. Permanent system: It consists of permanently laid mains, sub-mains and laterals and a stationary water source and pumping plant. Mains, sub-mains and laterals are usually buried below plough depth. Sprinklers are permanently located on each riser.

Advantages

1. Water saving to an extent of 35-40% compared to surface irrigation methods.
2. Saving in fertilizers - even distribution and avoids wastage.
3. Suitable for undulating topography (sloppy lands)
4. Reduces erosion
5. Suitable for coarse textured soils (sandy soils)
6. Frost control - protect crops against frost and high temperature
7. Drainage problems eliminated
8. Saving in land
9. Fertilisers and other chemicals can be applied through irrigation water

Disadvantages

- High initial cost
- Efficiency is affected by wind
- Higher evaporation losses in spraying water
- Not suitable for tall crops like sugarcane
- Not suitable for heavy clay soils
- Poor quality water cannot be used (Sensitivity of crop to saline water and clogging of nozzles)

Steps to be taken for reducing the salt deposits on leaves and fruits during sprinkler irrigation

- Irrigate at night
- Increase the speed of the sprinkler rotation
- Decrease the frequency of irrigation

Trickler or Drip Irrigation System

- Drip or trickle irrigation is one of the latest methods of irrigation.
- It is suitable for water scarcity and salt affected soils.
- Water is applied in the root zone of the crop
- Standard water quality test needed for design and operation of drip irrigation system.

(Major inorganic salts, hardeners, suspended solids, total dissolved solids, biological oxygen demand, chemical oxygen demand, organic, and organic matter, micro-organisms, iron, dissolved oxygen, H_2S, iron bacteria, sulphur reducing bacteria etc have to be tested)

Components

- .A drip irrigation system consists of a pump or overhead tank, main line, sub-mains, laterals and emitters.
- .The mainline delivers water to the sub-mains and the sub-mains into the laterals.
- The emitters which are attached to the laterals distribute water for irrigation.
- The mains, sub-mains and laterals are usually made of black PVC (poly vinyl chloride) tubing. The emitters are also made of PVC material
- .The other components include regulator, filters, valves, water meter, fertilizer application components, etc.

Pump

The pump creates the pressure necessary to force water through the components of the system including the fertilizer tank, filter unit, mainline, lateral and the emitters and drippers. Centrifugal pump operated by engines or electric motors are commonly used. The laterals may be designed to operate under pressures as low as 0.15 to 0.2 kg/cm^2 and as large as 1 to 1.75 kg/cm2. The water coming out of the emitters is almost at atmospheric pressure.

Chemical tank

A tank may be provided at the head of the drip irrigation systems for applying fertilizers, herbicides and other chemicals in solution directly to the field along with irrigation water.

Filter

It is an essential part of drip irrigation system. It prevents the blockage of pipes and drippers/emitters. The filter system consists of valves and a pressure gauge for regulation and control.

Emitters

Drip nozzles commonly called drippers or emitters are provided at regular intervals on the laterals. They allow water to emit at very low rates usually in trickles. The amount of water dripping out of each emitters in a unit time will depend mainly upon the pressure and size of the opening. The discharge rate of emitters usually ranges from 2 to 10 litres per hour.

Micro-tubes are also used in a drip lateral. They are used mainly in the following ways
(1) as emitters (2) as connectors, (3) as pressure regulators

Advantages

1. Water saving - losses due to deep percolation, surface runoff and transmission are avoided. Evaporation losses occurring in sprinkler irrigation do not occur in drip irrigation.
2. Uniform water distribution
3. Application rates can be adjusted by using different size of drippers
4. Suitable for wide spaced row crops, particularly coconut and other horticultural tree crops
5. Soil erosion is reduced
6. Better weed control
7. Land saving
8. Less labour cost

Disadvantages

1. High initial cost
2. Drippers are susceptible to blockage
3. Interferes with farm operations and movement of implements and machineries
4. Frequent maintenance
5. Trees grown may develop shallow confined root zones resulting in poor anchorage.

Water Resources Engineering – I

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Soils:

- Loose material and upper most layer of earth's crust
- Important natural resource
- Formed due to weathering of rocks
- Providing nutrients and water to plants

Factors affecting soil formation:

- Climate
- Vegetation
- Age of rock
- Relief
- Parent Rock

Types of soils:

Eight major types according to Indian Council of Agricultural Research (ICAR)

- Alluvial soils
- Black soils
- Red soils
- Laterite soils
- Desert soils
- Mountain soils
- Saline and Alkaline soils
- Peaty and Marshy soils

Alluvial soils

- Formed by depositor of alluvium by rivers
- Contribute greatly in agricultural development

Types:

a) Khadar
    - Newer Alluvium
    - Sandy, Pale Brown composition
    - Found in lower areas
    - Flooded by every year

b) Bhangar
    - Older Alluvium
    - Clayey and dark in color
    - Coarse in nature
    - Contains Kankar, Pebbles and Gravel
    - Represents Riverine alluvium of Himalyan Rivers
    - The regions of alluvial soils are thickly populated and intensively cultivated

Characteristics:

- Transported soils
- Coarser in upper section and finer in delta
- Light to dark in colour
- Rich in Potash & Humus
- Poor in Phosphorous and Nitrogen
- Highly fertile. Good for all crops (Kharif & Rabi)
- **Crops:** Rice, Wheat, Sugarcane, Cotton, Jute
- **Areas:** Punjab, Haryana, U.P., Bihar, West Bengal, Assam, Parts of Orissa, Deltra regions of South India

Black Soil:

- Also known as Regur or Black Cotton Soil
- Dark Grey to Black in color
- High Clay Content
- Highly moist retentive
- Develops cracks in summer
- Highly suitable for Cotton
- Rich in iron, lime, calcium, magnesium, carbonates, and alumina
- Poor in Phosphorous, Nitrogen, and Organic matter
- The soil is black in color because it is in volcanic in origin

- Created from igneous rocks
- **Areas:** Deccan trap which includes Maharastra, Parts of Andhra Pradesh, Parts of Karnataka & Tamilnadu and Rajasthan
- **Crops:** Cotton, Sugarcane, Groundnut, Millets, Rice, Wheat, Oilseeds

Red Soil:

- Formed due to weathering of old crystalline rocks in the areas of low rainfall
- More sandy and less clayey
- Rich in iron and small amount of Humus
- Poor in Phosphorous, Nitrogen, and Lime
- Slightly acidic and do not retain moisture
- Porous and Friable
- **Areas:** Tamilnadu, Southern Karnataka, Parts of Madhya Pradesh, Maharashtra, West Bengal, Eastern Rajasthan, North Eastern States
- **Crops:** Ragi, Groundnut, Millet, Tobocco, Potato, Rice, Wheat, Sugercane

Laterite Soil

- Formed under high temperature and rainfall with wet and dry spell
- Silica is leached to high rainfall
- Remnants of iron and aluminum oxides left behind is known as Laterite
- Brown to Yellowish Color
- Becomes hard when exposed to atmosphere
- Used as building material
- Rich in Iron
- Poor in Lime, Potash, and Magnesium
- The humus content is less because the microorganisms and decomposers get destroyed under high temperature
- **Areas:** Parts of Assam, Karnataka, Tamilnadu, Andhra Pradesh, Madhya Pradesh , Kerala
- **Crops:** After taking soil conservation measures, the soil is suitable for Tea, Coffee, Cashew, Rubber and Coconut

Desert Soil:

- Contains soluble salts
- Red to brown in colour
- Originated by mechanical disintegration & wind deposit
- Porous and Coarse

- 90% of Sand and 10% of Clay
- Rich in Nitrates and Phosphates
- Poor in Nitrogen and Humus
- Friable, Sandy & Low moisture content
- **Areas:** Arid and Semi-arid Regions of Rajasthan, South Haryana, Punjab, North Gujarat
- **Crops:** Drought resistant crops like millets and barley

Mountain Soils:

- Found in hilly slopes
- Formed by deposition of organic matter from forest
- Rich in Humus
- Poor in Potash and Lime
- **Areas:** Assam, Kashmir, Sikkim, and Arunachal Pradesh
- **Crops:** Tea, Coffee, Spices, and Tropical Fruits

Saline and Alkaline Soils:

- Contains Salts like Sodium, Magnesium, Calcium
- Infertile. Unfit for Cultivation
- Sandy to Loamy in texture
- **Areas:** Parts of Gujarat, Rajasthan, Punjab, Haryana, U.P. and Maharastra

Peaty and Marshy Soils

- Occur in Humid region
- Formed by accumulation of organic matter
- Black in Color
- Highly acidic
- **Areas:** Kottayam & Alleppey in Kerala, Coastal Orissa, Sundarbans of West Bengal

Methods of Improving soil fertility:

Fertility is the term used to describe the potential capacity of a soil to grow crops. This is a combined effect of the natural fertility and the conditions of the soil at the time. The natural fertility of soil depends on

- composition of the soil
- the slope of the land which affects drainage
- climate and local weather
- ease of cultivation

A healthy soil, loaded with compost, will be naturally fertile. Underground, plant roots are mining the soil, turning organic minerals into leaves, flowers, and fruit. While light and water are essential for this process, there are also some major nutrients that must be in place for proper growth.

- Nitrogen is needed for green leafy growth.
- Phosphorus helps with strong root and healthy fruit and seed formation.
- Potassium is needed for vigorous growth and disease resistance.

Although healthy soils may have plenty of these nutrients available, on less-than-ideal soil plants may need supplemental feeding. And even plants on healthy soils can sometimes benefit from additional nutrients.

The form in which the nutrients are applied is of utmost importance. Although synthetic fertilizers provide precise amounts of specific nutrients, they lack micronutrients and soil-building microorganisms, and because they release nutrients all at once, they promote a flush of growth that is weak and susceptible to disease. Also, the excess nutrients leach away, polluting nearby waterways. The opposite is true of compost. It provides a slow, sustained release of nutrients that plants use as needed.

Compost provides so many benefits that every gardener should consider taking advantage of this easy-to-make soil improver.

Compost and Other Organic Matter

Leaves, grass clippings, pine straw, and vegetable wastes from your kitchen are examples of organic matter. Organic matter will decompose and provide nutrients to plants. An even better way to add organic matter is with compost.

Compost is organic matter that has been decomposed and recycled as a fertilizer and soil amendment. Compost helps break up clay particles, allowing water to drain better. In sandy soils, it binds the grains together to retain moisture and fertility. Compost can be applied as mulch to perennial plantings.

The organic matter provided in compost provides food for microorganisms, which keeps the soil in a healthy, balanced condition. Nitrogen, potassium, and phosphorus will be produced naturally by the feeding of microorganisms.

Water Resources Engineering – I

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Not all water taken from a source (river, well) reaches the root zone of the plants. Part of the water is lost during transport through the canals and in the fields. The remaining part is stored in the root zone and eventually used by the plants. In other words, only part of the water is used efficiently, the rest of the water is lost for the crops on the fields that were to be irrigated.

Irrigation water losses in canals are due to:

1. Evaporation from the water surface
2. Deep percolation to soil layers underneath the canals
3. Seepage through the bunds of the canals
4. Overtopping the bunds
5. Bund breaks
6. Runoff in the drain
7. Rat holes in the canal bunds

Irrigation water losses in the field; these are due to:

1. Surface runoff, whereby water ends up in the drain
2. Deep percolation to soil layers below the root zone

Irrigation Efficiency:

Irrigation efficiency (e in %) is that part of the water pumped or diverted through the scheme inlet which is used effectively by the plants. The scheme irrigation efficiency can be sub-divided into:

1. Conveyance Efficiency (ec) - which represents the efficiency of water transport in canals
2. Field Application Efficiency (ea) - which represents the efficiency of water application in the field.

Conveyance Efficiency:

it mainly depends on the length of the canals, the soil type or permeability of the canal banks and the condition of the canals.

In large irrigation schemes more water is lost than in small schemes, due to a longer canal system. From canals in sandy soils more water is lost than from canals in heavy clay soils. When canals are lined with bricks, plastic or concrete, only very little water is lost. If canals are badly maintained, bund breaks are not repaired properly and rats dig holes, a lot of water is lost.

Soil Type	**Earthen Canals**			**Lined Canals**
	Sand	**Loam**	**Clay**	
Canal Length				
Long (> 2000m)	60%	70%	80%	95%
Medium (200 -2000m)	70%	75%	85%	95%
Short (< 200m)	80%	85%	90%	95%

Application Efficiency:

It refers to the amount of water applied that is stored in the crop root zone. This value is determined by water distribution characteristics, system management, soil conditions, the crop, and weather conditions. Water application efficiency pertains to an individual irrigation event.

Ea = (Water applied that is used by crop / Water delivered to irrigation field) x 100

Some indicative values of the average field application efficiency (ea) are given below:

Attainable Efficiencies	
Surface Irrigation	
Basin	80 - 90%
Border	70 - 85%
Furrow	60 - 75%
Sprinkler Irrigation	
Hand Move or Portable	65 - 75%
Traveling Gun	60 - 70%

Center Pivot & Linear Move	75 - 90%
Solid Set or Permanent	70 - 80%
Trickle Irrigation	
With Point Source Emitters	75 - 90%
With Line Source Products	70 - 85%

Irrigation efficiency (e) can be calculated, using the following formula:

$$e = \frac{ec \times ea}{100}$$

Where, ec = conveyance efficiency (%)

ea = field application efficiency (%)

A scheme irrigation efficiency of 50-60% is good; 40% is reasonable, while a scheme Irrigation efficiency of 20-30% is poor.

Water Logging and Salinity

Excess water in the plant root zone restricts the aeration required for optimum plant growth. It may affect the availability of several nutrients by changing the environment around the roots.

Excess salts in the root zone inhibit water uptake by plants, affect nutrient uptake and may result in toxicities due to individual salts in the soil solution. Excess exchangeable sodium in the soil may destroy the soil structure to a point where water penetration and aeration of the roots become impossible. Sodium is also toxic to many plants.

Water Logging and salinity in the soil profile are most often the result of high water tables resulting from inadequate drainage or poor quality irrigation water. Adequate surface drainage allows excess irrigation and rain water to be evacuated before excess soil saturation occurs or before the water is added to the water table. Adequate subsurface drainage insures that water tables are maintained at a sufficient depth below the soil surface to prevent water logging and salt accumulation in the root zone.

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Irrigation:

The process of supplying water to crops by artificial means such as canals, wells, tube-wells, tanks, etc. from the sources of water such as rivers, tanks, ponds or underground water is called Irrigation.

The primary objective of irrigation is to provide plants with sufficient water to obtain optimum yields and a high quality harvested product. Indian farmers gain access to irrigation from two sources:

- surface water (that is, water from surface flows or water storage reservoirs) and
- groundwater (that is, water extracted by pumps from the groundwater aquifers through wells, tube wells and so on).

Surface irrigation is largely provided through large and small dams and canal networks, run-off from river lift irrigation schemes and small tanks and ponds. Canal networks are largely gravity-fed while lift irrigation schemes require electrical power.

Groundwater irrigation is accessed by dug wells, bore wells, tube wells and is powered by electric pumps or diesel engines.

Importance of Irrigation:

1. Irrigation maintains moisture in the soil. Moisture is necessary for the germination of seeds. Seeds do not grow in dry soil. That is why irrigation is done before tilling.
2. Irrigation is essential for the growth of the roots of the crop plants. Roots of the plants do not grow well in dry soil.
3. Irrigation is necessary for the absorption of mineral nutrients by the plants from the soil. Thus, irrigation is essential for the general growth of the plants.
4. Water supplies two essential elements hydrogen and oxygen to the crop.

Need for Irrigation:

1. India is a big country and stands next to China when we talk about population and so irrigation facilities are needed to grow more food to feed our teaming millions.
2. The distribution in rainfall is uneven and uncertain which either causes famines or drought. By means of irrigation we can check both the problems.
3. Different water requirements of different crops can only be met through irrigation facilities.
4. India, being a tropical country the temperature is high and evaporation more rapid, so, artificial irrigation is necessary for ample supply of water and also to prevent water scarcity in the long dry winter season.

Advantages of Irrigation:

Some of the advantages of irrigation are as follows.

1. Increase of food production.
2. Modify soil or climate environment – leaching.
3. Lessen risk of catastrophic damage caused by drought.
4. Increase income & national cash flow.
5. Increase labor employment.
6. Increase standard of living.
7. Increase value of land.
8. National security thus self sufficiency.
9. Improve communication and navigation facilities.
10. Domestic and industrial water supply.
11. Improve ground water storage.
12. Generation of hydro-electric power.

Disadvantages or ill Effects of Irrigation:

The following are the disadvantages of irrigation.

1. Water logging.
2. Salinity and alkalinity of land.
3. Ill aeration of soil.
4. Pollution of underground water.
5. Results in colder and damper climate causing outbreak of diseases like malaria.

Types of Irrigation:

Depending upon the availability of surface or ground water, topography, soil and rivers, various types of irrigation practiced in India are as follows:

- Tanks
- Wells
  - Open Wells
  - Tube Wells
- Canals
  - Inundation Canals
  - Perennial Canals
- Multi-purpose River Valley Projects

Tanks:

It is prevalent in the uneven and relatively rocky plateau of Peninsular India. Tanks are commonly used in Deccan Plateau, Andhra Pradesh, Karnataka, Tamil Nadu and Maharashtra. About 8% of total irrigated area is irrigated by tanks.

Most of the tanks are small in size and built by individuals or group of farmers by raising bunds across seasonal streams. But there are some drawbacks: Tanks cover a large area of cultivable land. Evaporation of water is rapid due to large expanse of shallow water of tanks; do not ensure perennial supply of water.

Well:

It is more widespread in plains, coasts and some regions of peninsular India. It is less costly and more flexible as water can be drawn whenever needed and 'evaporation loss' is minimized and no fear of "over irrigation". Uttar Pradesh leads in well irrigation and is followed by Punjab, Haryana, Bihar, Gujarat and Andhra Pradesh.

Wells are of two types:

- Open wells
- Tube wells

Open wells are shallow and irrigate a small area because water available is limited.

Tube wells are deep and have the capacity to draw a large volume of water. It has increased in recent years.

Canals:

Canals are the main source of irrigation in India. Canals are big water channels taken out from rivers to carry water to places far away from the river.

It is of two types:

- Canals taken out from rivers without any regulating system like weirs etc. at their head are called inundation canals. In many places during the rainy season, there is flood in the rivers. The flood water is carried to the field through canals. These canals are found in West Bengal., Bihar, Orissa, etc. They supply water only when there is flood in the rivers, and therefore, are of no use during the dry season when water is required most.
- Canals taking off from perennial rivers with a weir system to regulate flow of water are called perennial canals. In order to supply water throughout the year, reservoirs are constructed for storing water. From these reservoirs, water can be supplied to the fields whenever there is demand for it. So this system of irrigation ensures supply of water in all season. This type of perennial canal is found mostly in Punjab, Utter Pradesh, and Tamil Nadu.

Multi Purpose River Valley Projects:

In recent years, multi-purpose river valley projects are helping agriculture. The most important are

- Damodar Project and the Mor Project in West Bengal,
- Mahanadi (Hirakud) Project in Orissa,
- Kosi Project in Bihar,
- Bhakra Nangal Project in Punjab,
- Srisailam and Nagarjuna Sagar Project in Andhra Pradesh

These projects offer facilities for irrigation, flood control, soil conservation etc.

Irrigation Sector Terminology:

The terms used by the Ministry of Water Resources (MoWR), Ministry of Rural Development (MoRD), and the Ministry of Agriculture (MoA), the three ministries within the government responsible for irrigation are as follows:

1. Major irrigation (cultivable command area above 10,000 ha).
2. Medium irrigation (cultivable command area between 2000 ha to 10,000 ha).
3. Minor irrigation (cultivable command area less than 2000 ha)

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Consumptive Use:

Consumptive use for a particular crop may be defined as the total amount of water used by the plants in transpiration (building of plant tissues etc.) and evaporation from the adjacent soils, in any specified time. The values of consumptive use (Cu) may be different for different crops and may be different for the same crop at different times and places.

It is expressed in hectare-meter or as depth of water in m

Estimation of consumptive use:

Commonly used methods are

- Blaney-Criddle equation
- Hargreaves class A pan evaporation method
- Penman's equation

Factors affecting Consumptive Use:

1. **Evaporation affected by:** The degree of saturation of soil surface, Temperature of air and soil, Humidity, Wind velocity, Extent of vegetative cover

2. Transpiration affected by:
   Climate factors: Temperature, Humidity, Wind speed, Duration & intensity of light, Atmospheric vapor pressure
   Soil factors: Texture, Structure, Moisture content, Hydraulic conductivity
   Plant factors: Efficiency of root systems in moisture absorption, Leaf arrangement and structure, Stomatal behavior

Water Requirements of Crops:

Water requirements of a crop mean the total quantity and the way in which a crop requires water from the time it is sown to the time it is harvested.

Water requirements depend on:

- water table
- crop
- ground slope
- intensity of irrigation
- method of application of water
- place
- climate
- type of soil
- method of cultivation
- useful rainfall

Crop Period or Base Period

- The time period that elapses from the instant of its sowing to the instant of its harvesting is called the **crop period**.
- The time between the first watering of a crop at the time of its sowing to its last watering before harvesting is called the **base period.**

Crop	Base in days
Rice	120
Wheat	120
Maize	100
Cotton	200
Sugarcane	320

Duty:

The duty of water is the relationship between the volume of water and the area of the crop it matures. It may be defined as the number of hectares of land irrigated for full growth of a given crop by supply of 1 m^3/sec of water continuously during the entire base period (B) of the crop.

Duty represents the irrigation capacity of unit water (ha/m^3/s)

$D = A/Q$

Where, A command area and Q continuous discharge required for the base period.

If $3m^3/s$ of water is required for a crop sown in area of 5100ha continuously, the duty of irrigation water will be $5100/3=1700ha/m^3/s$, and a discharge of $3m^3/s$ is required throughout the base period.

Duty is generally expressed by D.

In a large canals irrigation system, the water from its source, first of all flows into the main canal, then it flows into primary canal; from the primary it flows into secondary canals and from secondary to tertiary canals and finally in to the field. During the passage of water from those irrigation channels, the water is lost due to evaporation and percolation. Those losses are called transit loss or transmission or conveyance losses. Duty of water, therefore, varies from one place to another and increases as we move downstream from the head of the main canal towards the head of branches or water courses.

Crop	Duty in hectares/cumec
Rice	900
Wheat	1800
Cotton	1400
Sugarcane	800

Delta (∆):

Each crop requires certain amount of water depending up on the area to be cultivated. If the area to be cultivated is large, the amount of water required will be more; on the other hand if area is small the amount of water required will be less. The total quantity of water required by the crop for its full growth may be expresses in ha-m. Thus the total depth of water (in cm) required by a crop to come to maturity is called Delta.

Suppose certain amount of water is applied to a crop from a time of sowing till the crop matures and if the applied water is not lost or used up by any means then there will be a thick layer of water standing all over the field. The depth or height of this water layer is known as delta for the crop.

$\Delta = V / A$

Where, V is total volume of water required for the base period and A is command area.

Example:

If rice required about 8cm depth of water at an average interval of about 12days, and the crop period for rice is 120days. Find out the delta of rice?

Solution:

8cm of water at an average of 12 days

Water requirement = 8cm/12days = 0.6667cm/day

For 120 days =120day*0.6667cm/day

Delta (Δ) = 80cm

The average values of delta for certain crops are shown below. Those values represent the total water requirement of the crop on the field; actually can be less depending upon the useful rainfall.

Crop	Delta on field cm
Sugarcane	120
Rice	120
Tobacco	75
Garden fruit	60
Cotton	50
Vegetables	45
Wheat	40
Barly	30
Maize	25
Fodder	22.5
Peas	15

Relation between Duty and Delta:

Assume a crop of base period B in days, D duty of water in hectare per cubic meters per second and Δ be the delta or depth of water for a crop in meter. From the definition of delta, duty and base period $1m^3/s$ flowing continuously for B days mature D hectares of land under the crop or $1m^3/s$ continuously for B days gives a depth Δ, over D hectares of land.

The total amount of water applied to this crop during B days. By definition of duty:

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

$$V = 86{,}400 * Bm^3$$

The depth of water applied on this land 1ha = $10^4 m^2$

$$\Delta = \frac{V}{A} = \frac{86400B}{D * 10^4} m = \frac{8.46B}{D} m$$

Where: B in days, Δ delta in m and D in $ha/m^3/s$

Factors affecting Duty:

- Type of crop
- Climate and season
- Useful rainfall
- Type of soil
- Method of Ploughing
- Method of Irrigation
- Base Period
- Topography of Agricultural Land

Importance of Duty:

It helps us in designing an efficient canal irrigation system. Knowing the total available water at the head of a main canal, and the overall duty for all the crops required to be irrigated in different seasons of the year, the area which can be irrigated can be worked out. Inversely, if we know the crops are required to be irrigated and their duties, we can work out the discharge required for designing the channel.

Methods of Improving Duty of water:

The duty of canal water can certainly be improved by effecting economy in the use of water by resorting to the following precautions and practices:

- **Proper Ploughing:** Ploughing should be done properly and deeply so that water retaining capacity is increased.
- **Methods of Supplying Water: (**based on field and soil conditions)
    - Furrow Method - Crops in row
    - Contour Method - Hilly Area
    - Basic Method - for Orchards
    - Flooding Method - Plain Lands
- **Canal Lining:** Reduces percolation losses
- **Transmission Loss:** to reduce this canals should be taken close to the fields
- **Crop Rotation:** to increase the moisture retaining capacity and fertility of the soil

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Crop rotation:

Crop rotation is one of the oldest and most effective cultural control strategies. It means the planned order of specific crops planted on the same field. It also means that the succeeding crop belongs to a different family than the previous one. The planned rotation may vary from 2 or 3 year or longer period.

Some insect pests and disease-causing organisms are hosts' specific. For example, rice stem borer feeds mostly on rice. If you don't rotate rice with other crops belonging to a different family, the problem continues as food is always available to the pest. However, if you plant corn as the next crop, then beans, the insect pest will likely die due to absence of food.

Advantages of crop rotation

- Prevents soil depletion
- Maintains soil fertility
- Reduces soil erosion
- Controls insect/mite pests. Crop rotation as a means to control to insect pests is most effective when the pests are present before the crop is planted have no wide range of host crops; attack only annual/biennial crops; and do not have the ability to fly from one field to another.
- Reduces reliance on synthetic chemicals
- Reduces the pests' build-up
- Prevents diseases
- Helps control weeds

Different sequences of crop rotation

Rotation of two crops within a year i.e.:

Year 1: Wheat

Year 2: Barley

Year 3: Wheat again

Rotation of three crops within a year i.e.:

Year 1: Wheat

Year 2: Barley

Year 3: Mustard

Year 4: Wheat again

Under Network Project on Organic Farming (NPOF of ICAR) important cropping systems, which were found economically better or at par with conventional system at different experimental stations in the country are as follows:

- Soybean - Berseem/ Mustard/ chickpea at Raipur, Chattisgarh
- Tomato/ Cabbage – cauliflower – pea and maize – garlic at Bajaura, Himachal Pradesh
- Rice – wheat/ potato/ mustard/ lentil at Ranchi, Jharkhand
- Groundnut – rabi Sorghum, soybean – durum wheat, potato – chick pea, chilli + Cotton and maize – chick pea at Dharwad, Karnataka
- Soybean – durum wheat/ mustard/ chick pea/ isabgol at Bhopal, M.P.
- Rice – durum wheat/ berseem, rice – potato – Okra and rice – garlic, sorghum – berseem, maize – berseem – maize + cowpea and sorghum + cluster bean – oats-cowpea at Ludhiana, Punjab
- Maize – cotton, chillies – onion and brinjal – sunflower at Coimbatore
- Sorghum – pea – okra at Modipuram, Uttar Pradesh
- Carrot/ rice (pre kharif) – rice (kharif), potato/rice (pre kharif) – rice (kharif), tomato/ rice (pre kharif) – rice (kharif), French bean/ rice (pre kharif) – rice (kharif) at Umiam, Meghalaya

Preparation of land for irrigation:

Land preparation covers a wide range of practices from zero-tillage or minimum tillage which minimizes soil disturbance through to a totally 'puddled' soil which actually destroys soil structure. It typically involves

1. plowing to "till" or dig-up, mix, and overturn the soil;
2. harrowing to break the soil clods into smaller mass and incorporate plant residue, and
3. leveling the field.

Initial land preparation begins after your last harvest or during fallow period. This is important for effective weed control and for enriching the soil. Generally, it will take 3−4 weeks to prepare the field before planting. Tillage is the preparation of soil for planting. It is used for the process of keeping the soil loose, porous, to free from weeds during the growth of crops.

The primary objectives of tillage are:

1. Preparation of a suitable seed bed.

   A good seed bed is considered to imply finer soil particles at greater fineness soil in the vicinity of seeds. A fine soil structure is desirable to allow rapid infiltration, provide adequate air capacity to exchange with in the soil and to minimize resistant to root penetration.

2. To control weeds:

   During tillage different weeds are cut down. There stem, uprooting and then mixed into the soil. Tillage disturbs the growth process of weeds.

3. To improve the physical condition of soil.

   Tillage incorporating to mix crop residue helps for controlling of soil moistur

Standard quality for Irrigation water: (IS: 11624-1986)

The following chemical properties shall be considered for developing water quality criteria for irrigation:

1. Total salt concentration,
2. Sodium adsorption ratio,
3. Residual sodium carbonate or bicarbonate ion concentration, and
4. Boron content.

1. Total Salt Concentration:

It is expressed as Electrical Conductivity (EC). In relation to hazardous effects of the total salt concentration, the irrigation water can be classified into four major groups.

WATER QUALITY RATING BASED ON THE TOTAL SALT CONCENTRATION

Sl No.	Class	Range of EC (Micromhos/cm)
(1)	(2)	(3)
i)	Low	Below 1 500
ii)	Medium	1 500-3 000
iii)	High	3 000-6 000
iv)	Very high	Above 6 000

2. Sodium Adsorption Ratio (SAR):

In relation to the hazardous effects of Sodium Adsorption Ratio, the irrigation water quality rating is given below:

WATER QUALITY RATING BASED ON SODIUM ADSORPTION RATIO

SL No.	CLASS	SAR RANGE $\sqrt{(\text{millimole/litre})}$
(1)	(2)	(3)
i)	Low	Below 10
ii)	Medium	10-18
iii)	High	18-26
iv)	Very high	Above 26

3. Residual sodium carbonate or bicarbonate ion concentration

In relation to the hazardous effects of High Bicarbonate Ion Concentration expressed as Residual Sodium Carbonate, the irrigation water quality rating is given below:

WATER QUALITY RATING BASED ON RESIDUAL SODIUM CARBONATE

SL No.	CLASS	RSC RANGE (mg/l)
(1)	(2)	(3)
i)	Low	Below 1·5
ii)	Medium	1·5-3·0
iii)	High	3·0-6·0
iv)	Very high	Above 6·0

4. Boron content

Boron, though a nutrient, becomes toxic if present in water beyond a particular level. In relation to boron toxicity, the irrigation water quality rating is given below:

WATER QUALITY RATING BASED ON BORON CONTENT

SL No.	CLASS	BORON (ppm)
(1)	(2)	(3)
i)	Low	Below 1·0
ii)	Medium	1·0-2·0
iii)	High	2·0-4·0
iv)	Very high	Above 4·0

Water Resources Engineering – I

- Soil-Water-Plant Relationship, Vertical Distribution of Soil Moisture, Soil Moisture Constants, Soil Moisture Tension
- Consumptive Use, Duty and Delta, Factors affecting Duty
- **Design Discharge for a Water Course, Depth and Frequency of Irrigation**
- Irrigation Efficiencies, Water Logging

Water Course:

It is a small channel to deliver water to each and every field in the command area of an outlet which is approximately 40 Ha for a delivery system of one cusec. The length of water course is generally limited to 3 Kms.

Longitudinal slope: A minimum slope of 1 in 2000 is ordinarily adopted for earthen water courses. A slope of 1/1000 to 1/1500 should be preferred. However, natural slope of the land is deciding factor. For lined water courses, steeper slope like 1/1000 may be generally adopted.

Transit losses: Generally transit losses in main canal, branches & distributaries and field channels are 17%, 8%, & 20% respectively in Indo-Gangetic plains as given by ICRD.

Transit losses in a water course are due to

a) Leakage
b) spillage
c) Evaporation and
d) Seepage.

Seepage losses can be accurately measured by Ponding method. Normally the transit losses are considered @ 2.5 cumec / million Square metre of wetted perimeter.

Section:

S. No.	Type of water course	Minimum bottom width	Minimum full supply depth	Free board	Water surface slope	Minimum bank width
1	Earthen	30 cm	25 cm	15 cm	1/2000 to 1/500	30 cm
2	Lined	25 cm	30 cm	7.5 cm	1/666 to 1/200	38 cm

Field layout

After fixing the minimum chak size and normal chak size, the command area of a canal is divided into chaks, so that capacity of the water course is 14 lts/sec (minimum) and 28 lts/sec (average).

For this purpose contour plan of the command area of canal is prepared by surveying the command area by grid system. Grid size as generally kept 30 m x 30 m. The contour interval should be kept 15 cm (for lands up to 1/100 slope) and at 25 cm (for lands above 1/100 slope). The grid and contours should be marked on a village map and thus sheet should be prepared. Chak boundaries are kept so that length of water course does not exceed 3 kms. The alignment of water course is generally kept along the ridge line.

Requirements of good distribution network

A good distribution system should satisfy the following requirements:

- It should provide desired quantity of water economically and efficiently to each part of the chak.
- It should have enough capacity to meet crop water requirements during peak use periods.
- The system should be large enough to allow delivery of water in the time allotted when water is supplied on rotation or turn basis.

Design capacity of water courses

The capacity of water course has to be decided taking into consideration the requirement as per water allowance, chak area and the losses in transit like seepage losses etc.

Discharge, Q = Area / Duty

Where,

Q= Design capacity of water course in cumec.

A= Area to be irrigated in Hectares.

Duty, D = **8.64 B /** Δ in hectare/cumecs

Δ = Total depth of water required for a crop

Base Period, B = Whole period of cultivation time from first watering to last watering before harvesting.

Often an extra capacity up to 25% is added to provide for unexpected requirement of irrigation.

Irrigation Scheduling

Proper irrigation management demands application of water at the time of actual need of crop with just enough water to wet the effective root zone soil. On the other hand, delayed irrigation causes plant water stress that depresses the growth activities and yield.

The interval between irrigations and the amount of water to apply at each irrigation depend on how much water is held in the root zone and how fast it is used by the crop. Proper irrigation scheduling will improve profitability and water use efficiency by:

1. maximizing crop yield and quality;
2. decreasing water lost through deep percolation and runoff; and
3. Optimizing pumping costs.

To effectively schedule irrigation applications, four key pieces of information need to be known:

1. soil texture;

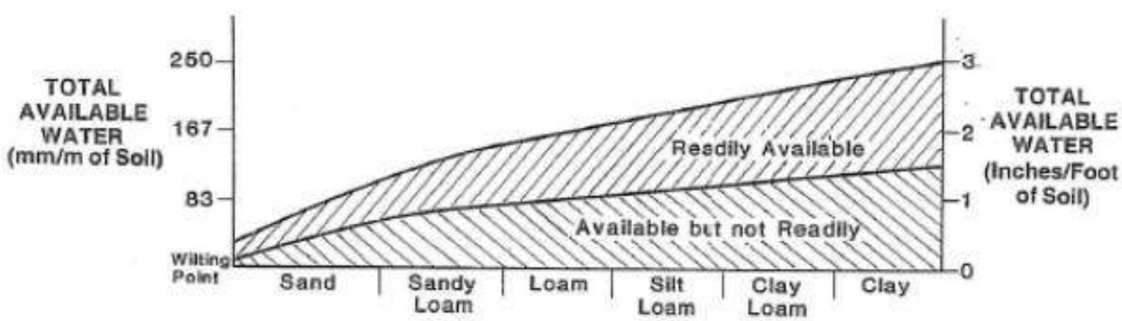


Figure 1. Estimated available moisture for various soil textures

2. water holding capacity of the soil;
3. soil moisture content;

Texture	% Field Capacity *	% Wilting Point *	% Available Moisture Holding Capacity *
Loamy Sand (LS)	10	5	5
Sandy Loam (SL)	18	8	10
Fine Sandy Loam (FSL)	20	9	11
Very Fine Sandy Loam (VL)	22	10	12
Silt Loam (SiL)	22	10	12
Loam (L)	24	12	12
Clay Loam (CL)	26	13	13
Clay (C)	40	22	18

4. Crop water use at the specific development stage.

   Crops may be allowed to stand water stress to some extent during certain periods of life excepting at critical stages to save water under situations of water scarcity.

Depth and Frequency of Irrigation

The depth of water to be applied in each irrigation to bring the soil to the desired moisture content level will be governed by

- Root Zone Depth
- Available Moisture Content (AMC)
- Maximum permissible depletion of AMC

  AMC = Field Capacity – Wilting Point
- Effective Rainfall
- Losses in the field

Depth of soil moisture which can be safely depleted,

D_W = AMC x relative soil density x root zone depth

The frequency of irrigation which is defined as the time interval in days in between consecutive irrigation is governed by

- Depth of moisture which can be safely depleted
- Consumptive rate
- Distribution of rain fall

Frequency of irrigation in days = Depth of moisture depleted / Daily consumption rate

Example:

The following data were collected from a field growing wheat during the rabi:

(*i*) field capacity–22%;

(*ii*) wilting point–10%;

(*iii*) root zone depth–100 cm;

(*iv*) dry unit weight of soil–1400 kg/m^3;

(*v*) maximum permissible depletion of moisture–60% of AMC;

(*vi*) class A pan evaporation–5 mm/day;

(*vii*) rainfall–nil; and

(*ix*) losses in field application–20% of water applied.

Calculate the depth and frequency of irrigation required

$$AMC = FC - WP = 22 - 10 = 12\,\%$$

$$\therefore \quad P_w = \frac{60}{100} \times 12 = 7.2\%$$

$$A_s = \frac{\gamma_s}{\gamma_w} = \frac{1400}{1000} = 1.4$$

$$D = 1.0\text{ m}$$

∴ Depth of soil moisture which can be safely depleted,

$$d = P_w A_s D = 7.2 \times 1.4 \times 1.0 = 10\text{ cm} = 100\text{ mm (approx)}$$

∴ NIR = 100 mm (as effective rainfall is nil)

$$\therefore \text{ FIR} = 100 \times \frac{1}{0.8} = 125\text{ mm} \text{ (as 20\% losses occur in field)}$$

Consumptive rate = $K \times$ Evaporation rate = $0.8 \times 5 = 4$ mm/day

$$\therefore \text{ Frequency of Irrigation} = \frac{\text{Depth of moisture depleted}}{\text{Consumptive rate}}$$

$$= \frac{100}{4} = 25\text{ days.}$$

UNIT 5

- **Classification of Canals**
- Design of Canals by Kennedy's and Lacey's Theory
- Balancing depth of Cutting, IS Standards for Canal Design
- Canal Lining

Canal Irrigation System

A canal is an artificial channel, generally trapezoidal in shape constructed on the ground to carry water to the fields either from the river or from a tank or a reservoir.

Classification of Canals

a) Based on nature of source of supply
   a. Permanent Canal – when it is fed by a permanent source of supply
   b. Inundation Canal – usually draw their supplies from rivers whenever there is a high stage in the river.

b) Based on function of the canal
   a. Irrigation Canal

      These are the canals which carry water to the fields. The canals having outlets are called irrigation canals. The entire system of main canals, branch canals, distributaries and minors is to be designed properly for a certain realistic value of peak discharge that must pass through them so as to provide sufficient irrigation to command areas. These canals have to aligned and excavated either alluvial soils or non alluvial soils; depending upon which they are called alluvial canals or non alluvial canals.

   b. Carrier Canal

      These canals not only serve for irrigation but also provide the link between two channels and serve to provide water to other conveyance structure. The total flow through carrier canals is more than the flow required for input to the other conveyance structure. The excessive water is used to serve irrigation purposes.

   c. Feeder Canal

      A feeder canal is constructed with the idea of feeding two or more canals. When main canal is divided into two canals then it is called as feeder canal. These are constructed to provide water to other conveyance structures and are not used for irrigation.

d. Link Canal

The canal that is from river to river is known as link canal. These are the canals which are constructed to transfer water to the other conveyance structure which contains in-sufficient quantity of water. These transfer water from river to river system.

e. Navigation Canal

These are the canals which are used to provide transport and voyage facility from one city to the other or from one country to the other. Main canal is navigation canal.

f. Power Canal

The canals which are constructed to supply water with very high force to the hydro electric power station for the purpose of moving turbine to generate electric power is known as power canal. Main canal is also used as power canal.

c) Based on boundary of surface of canal

a. Alluvial Canals – excavated on alluvial soils such as silt.

b. Non-alluvial Canals – excavated on non-alluvial soils such as loam, clay, hard soil (murram), rock etc.

c. Rigid Boundary Canals – have rigid sides and base such as lined canals

d) Based on the Discharge

a. Main Canal

It generally carries water directly from the river or reservoir

b. Branch Canal

It usually carries a discharge of 5 m^3/s. It feed supplies to major and minor distributaries.

c. Major Distributory

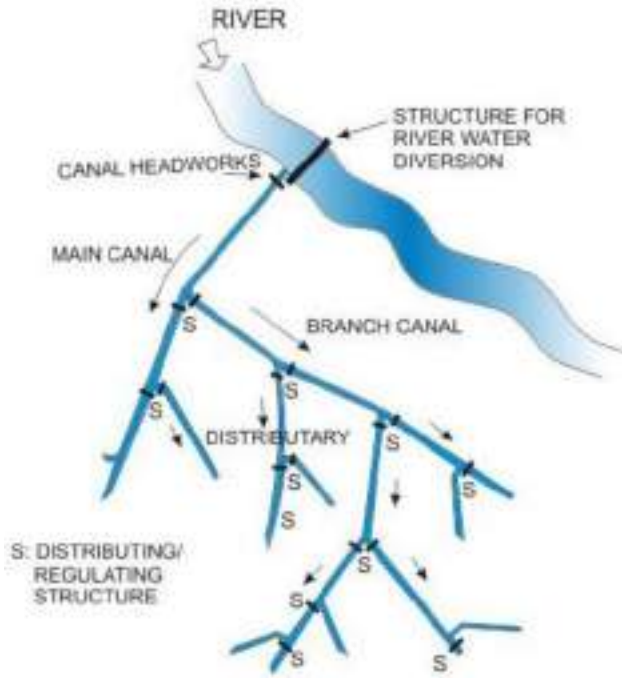
The discharge varies from 0.25 to 5 m^3/s

d. Minor Distributory

The discharge is usually less than 0.25 m^3/s

e. Water Course

It is a smallest which ultimately feeds the water to irrigation fields.

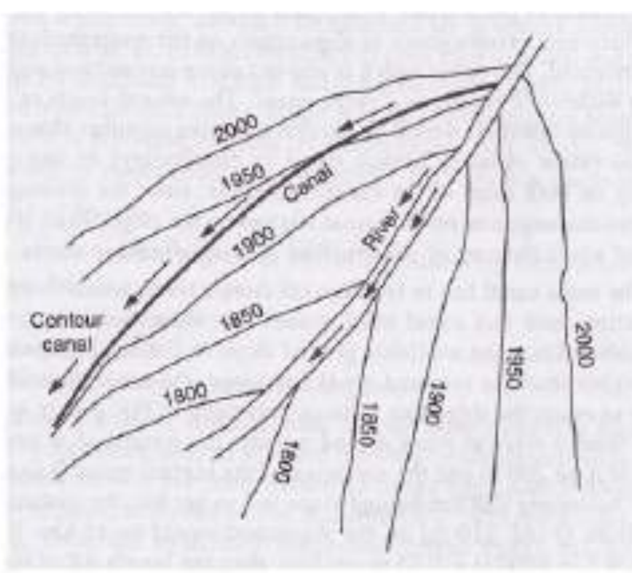


Typical layout of an irrigation canal system

e) Based on Canal Alignment

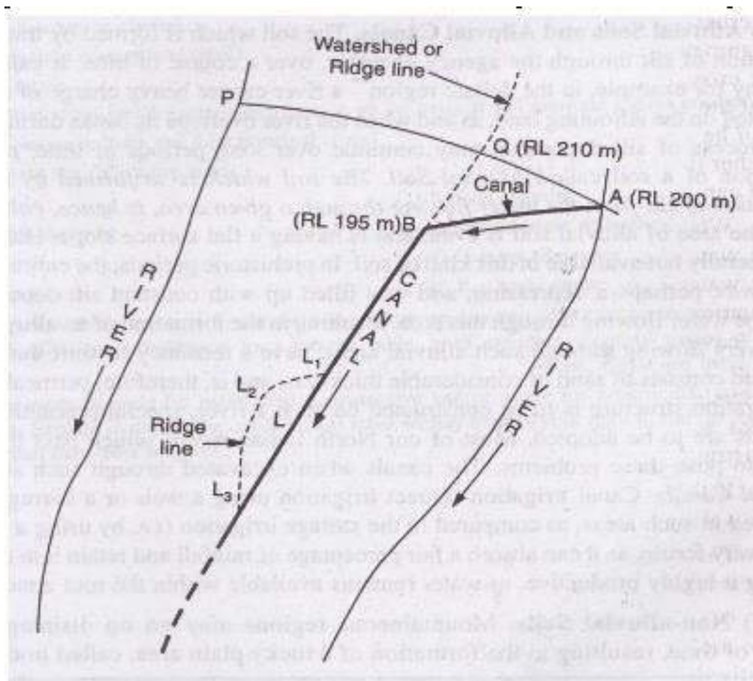
   a. Contour Canal

      - Contour channels follow a contour, except for giving the required longitudinal slope to the canal.
      - Since the river slope is much steeper than the canal bed slope, the canal encompasses more and more area between itself and the river.
      - A contour canal irrigates only on one side because the area on the other side is higher



b. Watershed or Ridge Canal

The dividing ridge line between the catchment areas of two streams (drains) is called the watershed or ridge canal. Thus between two major streams, there is the main watershed (ridge line), which divides the drainage area of the two streams, as shown in figure below.

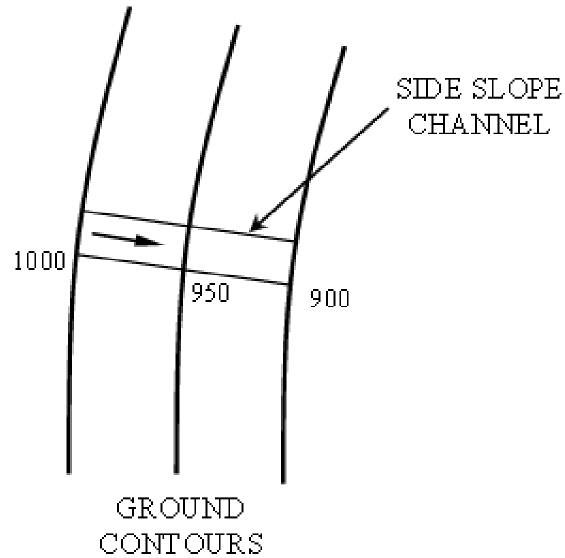


Similarly, between a main stream and any of its tributary, there are subsidiary watersheds (ridge lines), dividing the drainage between the two streams on either side. The canal which is aligned along any natural watershed (ridge line) is called a watershed canal, or a ridge canal. Aligning a canal (main canal or branch canal or distributory) on the ridge ensures gravity irrigation on both sides of the canal.

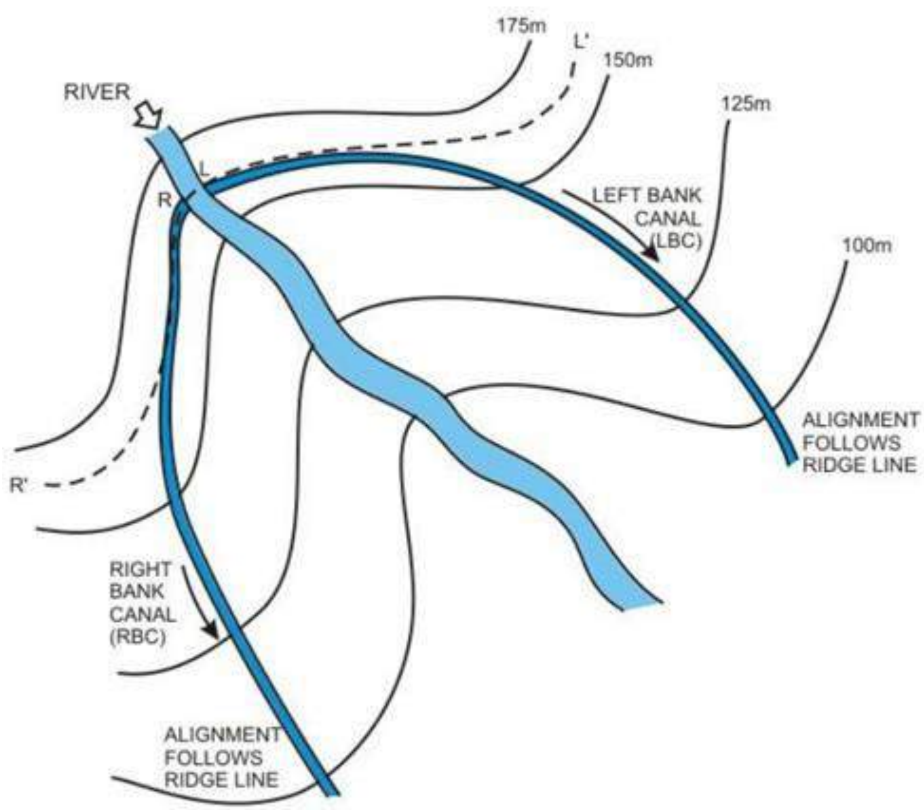
Since the drainage flows away from the ridge, no drainage can cross a canal aligned on the ridge. Thus, a canal aligned on the watershed saves the cost of construction of cross drainage works

c. Slide Slope Canal

A side slope canal is that which is aligned at right angles to the contours; i.e. along the side slopes, as shown in figure below. Since such a canal runs parallel to the natural drainage flow, it usually does not intercept drainage channels, thus avoiding the construction of cross drainage structures.



It is a canal which is aligned roughly at right angle to contours of the country but not on watershed or valley. The side slope channel has the advantage of not intercepting cross drainage works but its course must follow the shortest route the nearest valley and such channel shall be along a line of steepest possible slope except in very flat areas.



Water Resources Engineering – I

- Classification of Canals
- Design of Canals by Kennedy’s and Lacey’s Theory
- Balancing depth of Cutting, IS Standards for Canal Design
- **Canal Lining**

Canal Lining

Canal Lining is a resistant layer protecting the canal bed and its sides in order to have a sufficient strength to resist water pressure. The layer advantage is to save water for extension of irrigation, to minimize filtration losses, improve duty, and minimize maintenance cost and to prevent growth of wild plants.

Lining is a resistant layer made of concrete, protecting the canal bed and its sides in order to have a sufficient strength to resist water pressure. The layer advantage is to save water for extension of irrigation, to minimize filtration losses, improve duty, minimize maintenance cost and to prevent growth of wild plants.

Advantages of Canal Lining

Before the decision is made to line a canal, the costs and benefits of lining have to be compared. By lining the canal, the velocity of the flow can increase because of the smooth canal surface. Possible benefits of lining a canal include:

- water conservation

  An important reason for lining a canal can be the reduction in water losses, as water losses in unlined irrigation canals can be high. Lining a canal will not completely eliminate these losses, but roughly 60 to 80% of the water that is lost in unlined irrigation canals can be saved by a hard-surface lining.
- no seepage of water into adjacent land or roads

  If canal banks are highly permeable, the seepage of water will cause very wet or waterlogged conditions, or even standing water on adjacent fields or roads. Lining of such a canal can solve this problem, since the permeability of a lined canal bank is far less than that of an unlined bank, or may even be zero, depending on the lining material.

- reduced canal dimensions

  The roughness-resistance to flow of a lined canal is less than that of an unlined canal, and thus the flow velocity will be higher in the lined canal when the canal bed slope is the same.

- reduced maintenance

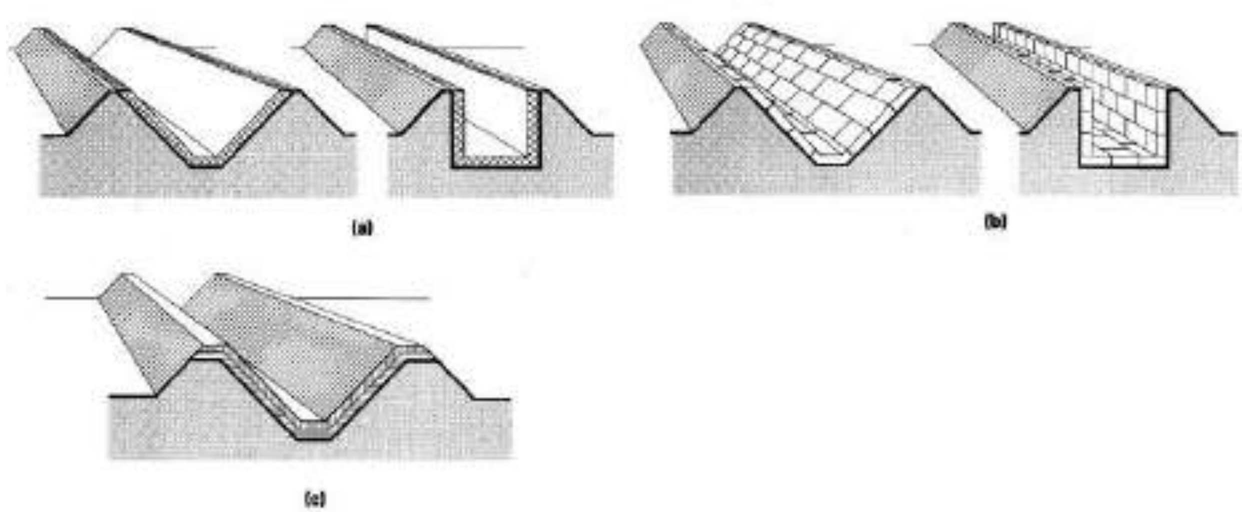
  A surface lining, such as concrete, brick or plastic, on the canal prevents the growth of plants and discourages hole-making by rats or termites, and so the maintenance of a lined canal can be easier and quicker than that of an unlined canal. Moreover, the higher velocity that can safely be allowed in the lined canal prevents the small particles of soil carried in the water from settling out, accumulating and causing siltation. The bed and sides of lined canals are more stable than those of unlined canals and are thus less susceptible to erosion.

Selecting type of Lining

The most commonly used types of lining are:

- concrete;
- concrete blocks, bricks or stone masonry;
- sand cement;
- plastic; and
- compacted clay.

Different types of lining: (a) concrete lining; (b) masonry lining; (c) compacted clay or soil (sand) cement lining



The choice of lining material depends primarily on:

- local costs;
- availability of materials; and
- availability of local skills (local craftsmen)

Different Types of Lining (IS 10430: 2000)

1. Rigid Ling
    a. Stone-pitched lining;
    b. Burnt clay tile or brick lining;
    c. Precast cement concrete/stone slab lining;
    d. In-situ cement lime/concrete lining;
    e. Stone masonry lining;
    f. Soil cement lining;
    g. Shotcrete lining; and
    h. Asphaltic cement/concrete.
2. Flexible Lining
    a. Geomembrane like HDPE, PVC, LDPE cover comprising layer
    b. Bituminous or bituminous/asphaltic felt lining,
    c. Fibre reinforced plastic tissue as phallic membrane, and
    d. Composite membrane/rubber lining
3. Combination Lining (membrane in the bed and brick/tile or concrete lining on sides)

Water Resources Engineering – I

- Design Discharge over a Catchment - Rational Formula
- **SCS Curve Number Method**
- Introduction to Flood Frequency Analysis
- Stream Gauging – Measurement of estimation of Stream Flow

The SCS Runoff Curve Number method is developed by the United States Department of Agriculture (USDA) Soil Conservation Service (SCS). The SCS curve number method is a simple, widely used and efficient method for determining the approximate amount of runoff from a rainfall even in a particular area. Although the method is designed for a single storm event, it can be scaled to find average annual runoff values.

The SCS method originally was developed for agricultural watersheds in the mid-western United States; however it has been used throughout the world far beyond its original developers would have imagined.

The general equation for the SCS curve number method is as follows:

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \qquad (1)$$

Q = runoff (in)
P = rainfall (in)
S = potential maximum retention after runoff begins
I_a = initial abstratctions

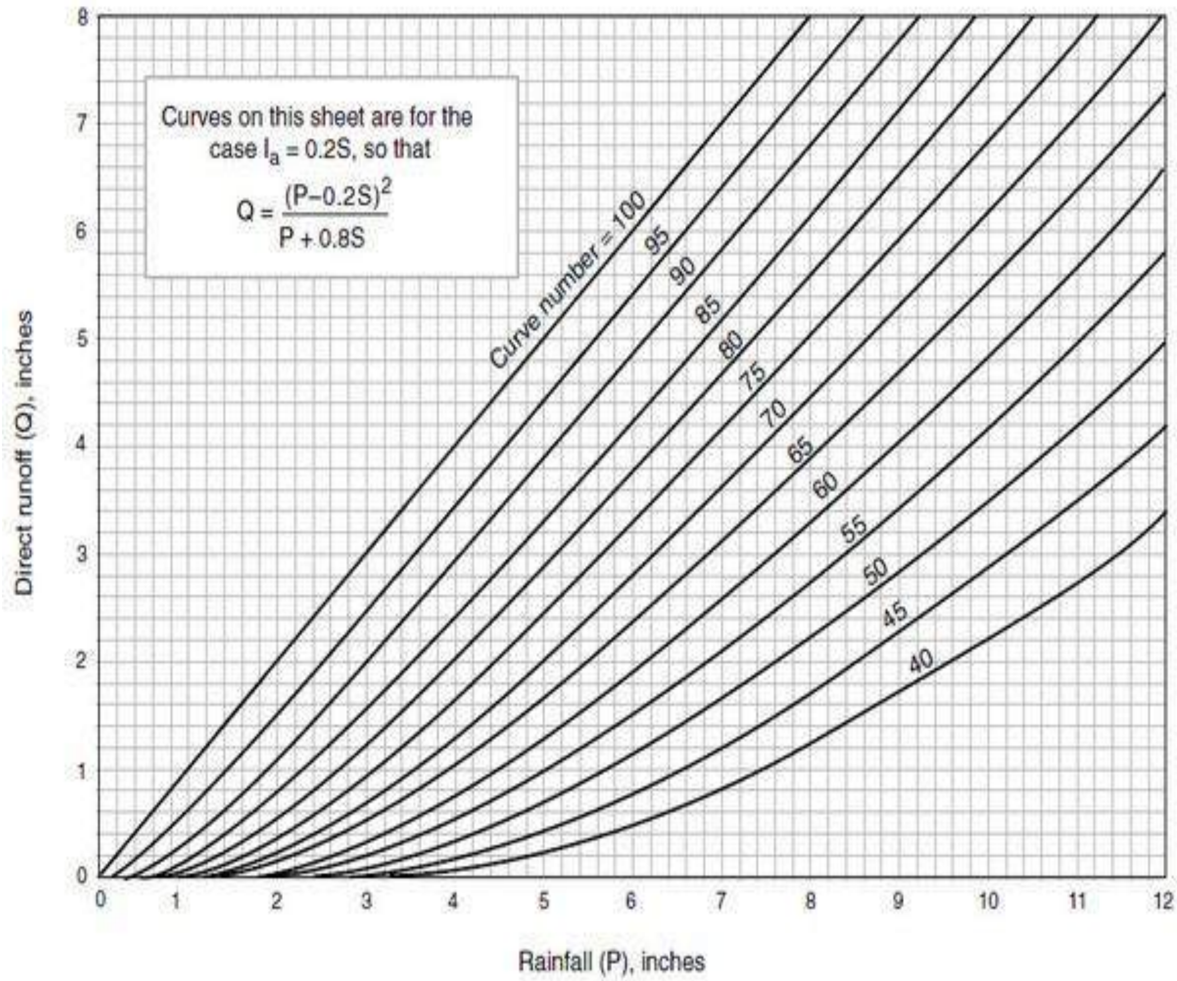
$$I_a = 0.2\,S \qquad (2)$$

$$Q = \frac{(P - 0.2\,S)^2}{(P + 0.8\,S)} \qquad (3)$$

$$S = \frac{1000}{CN} - 10 \qquad (4)$$

The initial equation (1) is based on trends observed in data from collected sites; therefore it is an empirical equation instead of a physically based equation. After further empirical evaluation of the trends in the data base, the initial abstractions, I_a, could be defined as a percentage of S (equation 2). With this assumption, the equation (3) could be written in a more simplified form with only 3 variables. The parameter CN is a transformation of S, and it is used to make interpolating, averaging, and weighting operations more linear equation (4).

With the following chart, the amount of runoff can be found if the rainfall amount (in inches) and curve number is known.



Factors considered in determining runoff curve numbers

The major factors that determine CN are

- hydrologic soil group (HSG),
- cover type,
- treatment,
- hydrologic condition, and
- antecedent runoff condition (ARC).

Land Use Description on Input Screen	Description and Curve Numbers					
	Cover Description		Curve Number for Hydrologic Soil Group			
	Cover Type and Hydrologic Condition	% Impervious Areas	A	B	C	D
Agricultural	Row Crops - Straight Rows + Crop Residue Cover- Good Condition (1)		64	75	82	85
Commercial	Urban Districts: Commercial and Business	85	89	92	94	95
Forest	Woods(2) - Good Condition		30	55	70	77
Grass/Pasture	Pasture, Grassland, or Range(3) - Good Condition		39	61	74	80
High Density Residential	Residential districts by average lot size: 1/8 acre or less	65	77	85	90	92
Industrial	Urban district: Industrial	72	81	88	91	93
Low Density Residential	Residential districts by average lot size: 1/2 acre lot	25	54	70	80	85
Open Spaces	Open Space (lawns, parks, golf courses, cemeteries, etc.)(4) Fair Condition (grass cover 50% to 70%)		49	69	79	84
Parking and Paved Spaces	Impervious areas: Paved parking lots, roofs, drives ways, etc. (excluding right-of-way)	100	98	98	98	98
Residential 1 acre	Residential districts by average lot size: 1 acre	20	51	68	79	84
Residential 2 acres	Residential districts by average lot size: 2 acre	12	46	65	77	82
Water/ Wetlands		0	0	0	0	0

Notes:

(1) Hydraulic condition is based on combination factors that affect infiltration and runoff, including (a) density and canopy of vegetative areas, (b) amount of year-round cover, (c) amount of grass or close-seeded legumes, (d) percent of residue on the land surface (good>=20%), and (e) degree of surface roughness.

(2) Good: Woods are protected form grazing, and litter and brush adequately cover the soil.

(3) Good: >75% ground cover and lightly or only occasionally grazed.

(4) CN's shown sre equivalent to those of pasture. Composite CN's may be computed for other combinations of open space cover type.

Water Resources Engineering – I

- Classification of Canals
- Design of Canals by Kennedy's and Lacey's Theory
- **Balancing depth of Cutting, IS Standards for Canal Design**
- Canal Lining

Balancing depth of Cutting

For a given canal section, the depth of cutting for which area cutting is equal to area of filling is called balancing depth.

Example: Refer the canal section as given below:-

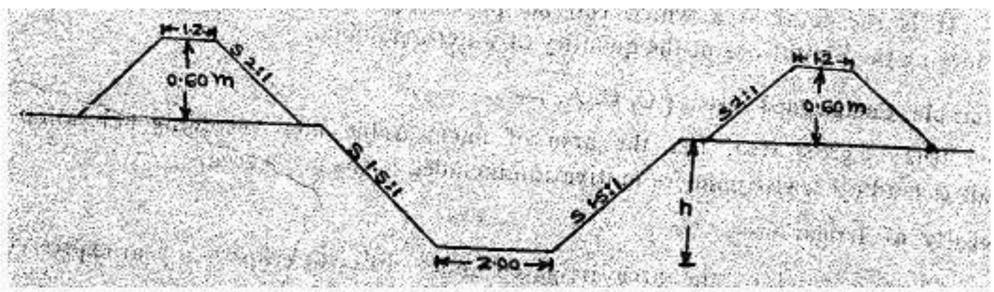


Figure 1.1

Area of cutting = (2+1.5 x h) h ---------------(I)

Area of Filling = (1.2+2x0.6) 0.6 x 2 ---------------(II)

For balancing depth,

Area of cutting = Area of filling

Therefore, (2+1.5 x h) h = (1.2+2 x 0.6) 0.6 x 2

or $2h + 1.5h^2 = 1.44 + 1.44$

or $1.5h^2 + 2h - 2.88 = 0$

or $h = -2 \pm \sqrt{\frac{4+4\times1.5\times2.88}{2\times1.5}}$

$= \frac{-2\pm4.61}{3}$

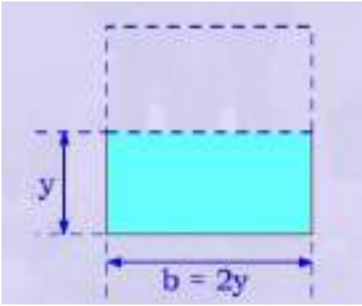
$=$ 0.87m

I S Standards for Canal Design

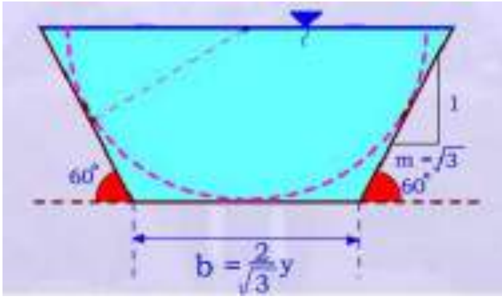
1. Shape of Cross Section of Canal

   From the Manning and Chezy equation, it is obvious that the conveyance of a channel increases as the hydraulic radius increases or as the wetted perimeter decreases

Rectangular Canal:



Trapezoidal Canal:



General Guideline for Width-to-Depth Ratio: (as per CWC recommendations)

$Q (m^3/s)$	0.30	3.0	14.0	28.0	140	285
B/D	2.0	4.0	6.0	7.5	14.0	18.0

2. Side Slope of Canal

   The side slopes of a channel depend primarily on the engineering properties of the material through which the channel is excavated.

Indian standards for canal in cutting and embankment

	Side slope (Horizontal to Vertical m:1)	
Material (soil)	Cutting	Embankment
Hard clay or gravel	0.75 : 1	1.5 to 1.0
Soft Clay and alluvial soils	1.0 to 1.0	2.0 to 1.0
Sandy loam	1.5 to 1.0	2.0 to 1.0
Light sand	2.0 to 1.0	2.0 to 1.0 to 3.0 to 1.0
Soft rock	0.25 to 1.0 to 0.5 to 1.0	-
Hard rock	0.125 to 1 to 0.25 to 1.0	-

3. Longitudinal Slope

   The longitudinal slope of the channel is influenced by topography, the head required to carry the design flow, and the purpose of the channel. The slopes adopted in the irrigation channel should be as minimum as possible in order to achieve the highest command. Generally, the slopes vary from 1: 4000 to 1: 20000 in canal.

4. Permissible Velocities – Maximum and Minimum

It may be noted that canals carrying water with higher velocities may scour the bed and the sides of the channel leading to the collapse of the canal. On the other hand the weeds and plants grow in the channel when the nutrients are available in the water. Therefore, the minimum permissible velocity should not allow the growth of vegetation such as weed, hycinth as well you should not be permitting the settlement of suspended material (non silting velocity). The designer should look into these aspects before finalizing the minimum permissible velocity.

"Minimum permissible velocity" refers to the smallest velocity which will prevent both sedimentation and vegetative growth in general. an average velocity of (0.60 to 0.90 m/s) will prevent sedimentation when the silt load of the flow is low.

A velocity of 0.75 m /s is usually sufficient to prevent the growth of vegetation which significantly affects the conveyance of the channel. It should be noted that these values are only general guidelines. Maximum permissible velocities entirely depend on the material that is used and the bed slope of the channel. For example: in case of chutes, spillways the velocity may reach as high as 25 m/s. As the dam heights are increasing the expected velocities of the flows are also increasing and it can reach as high as 70 m/s in exceptional cases. Thus, when one refers to maximum permissible velocity, it is for the normal canals built for irrigation purposes and Power canals in which the energy loss must be minimized.

Hence, following table gives the maximum permissible velocity for some selected materials:

material	V (m / s)
Fine sand	0.5
vertical Sandy loam	0.58
Silt loam	0.67
Firm loam	0.83
Stiff clay	1.25
Fine gravel	0.83
Coarse gravel	1.33
Gravel	1.2
Disintegrated Rock	1.5
Hard Rock	4.0
Brick masonry with cement pointing	2.5
Brick masonry with cement plaster	4.0
Concrete	6.0
Steel lining	10.0

5. Roughness Coefficient or Resistance to flow

In a given channel the rate of flow is inversely proportional to the surface roughness.

Manning roughness for the design of several types of linings

Surface Characteristics	Value of n
Concrete with surface as indicated below	
(a) Trowel finish	0.012 - 0.014
(b) Flat finish	0.013 - 0.015
(c) Float finish some gravel on bottom	0.015 - 0.017
(d) Gunite, good section	0.016 - 0.017
Concrete bottom float finished sides as indicated below	
(a) Dressed stone in mortar	0.015 - 0.017
(b) Random stone in mortar	0.017 - 0.020
(c) Cement rubble masonry plastered	0.016 - 0.020
Brick lining	0.014 - 0.017
Asphalt lining	
(a) Smooth	0.013
(b) Rough	0.016
Concrete lined excavated rock with	
(a) Good section	0.017 - 0.020
(b) Irregular section	0.022 - 0.027

6. Free Board

The term freeboard refers to the vertical distance between either the top of the channel or the top of the channel is carrying the design flow at normal depth. The purpose of freeboard is to prevent the overtopping of either the lining or the top of the channel fluctuations in the water surface caused by

a) wind-driven waves,
b) hydraulic jumps,
c) super elevation of the water surface as the flow goes round curves at high velocities,
d) the occurrence of greater than design depths of flow caused by canal sedimentation or an increased coefficient of friction

Free boards varying from less than 5% to 30% of the depth are commonly used in design. In semi-circular channels, when the velocities are less than 0.8 times the critical velocity then 6% of the diameter as free board have been proved to be adequate.

Free board as per Indian Standards (IS 4745 - 1968), (IS 7112 - 1973)

Discharge Q (m^3/s)	Free board (m)	
	Unlined	Lined
< 10.0	0.50	0.60
> 10.0	0.75	0.75

Water Resources Engineering – I

- Classification of Canals
- **Design of Canals by Kennedy's and Lacey's Theory**
- Balancing depth of Cutting, IS Standards for Canal Design
- Canal Lining

The preparation of a canal irrigation project involves the

1. Fixing of the canal alignment,
2. Discharge,
3. Longitudinal slope and
4. Cross section.

Canal Alignment

- While many factors play a role in fixing canal alignment, one important consideration is to have an alignment which runs mostly along the watershed (the ridge line dividing the catchment of two drainages). This ensures that the channel can provide flow irrigation to its command and does not have to cross too much drainage, thereby reducing the number of cross drainage works.
- It may also be mentioned that the river being the lowest elevation in the vicinity, the canal takes off from a low elevation and must mount the watershed in as little a distance as possible. It will thus cross some drainage in this reach and some cross drainage works will be required till the canal mounts the watershed.
- Avoid too many curves, populated areas and other important structures.
- The alignment should be such that the cutting and filling of earth or rock should be balanced, as far as possible.
- The alignment should be such that the canal crosses the natural stream at its narrowest point in the vicinity.

According to the Bureau of Indian Standard code IS: 5968-1970 "Guide for planning and layout of canal system for irrigation", the radii of curves should usually be 3 to 7 times the water surface width subject to the minimum values as given in the following table.

Type of canal	Capacity of canal (m^3/s)	Minimum radius (m)
Unlined canals	80 and above	1500
	30 to 80	1000
	15 to 30	600
	3 to 15	300
	0.3 to 3	150
	Less than 3	90
Lined canals	280 and above	900
	200 to 280	750
	140 to 200	600
	70 to 140	450
	40 to 70	300
	10 to 40	200
	3 to 10	150
	0.3 to 3	100
	Less than 0.3	50

In order to finalize the layout of canal network for an irrigation project, the alignment of channels should be marked on topo-sheets, until an optimum is reached. This alignment is then transferred to the field by fixing marking posts along the centerline of the canal. Formal guidelines for canal layout may be had from Bureau of Indian Standard IS: 5968-1987 "Guide for planning and layout of canal system for irrigation".

Discharge

Q = Area x Velocity

Determination of Longitudinal Slope:

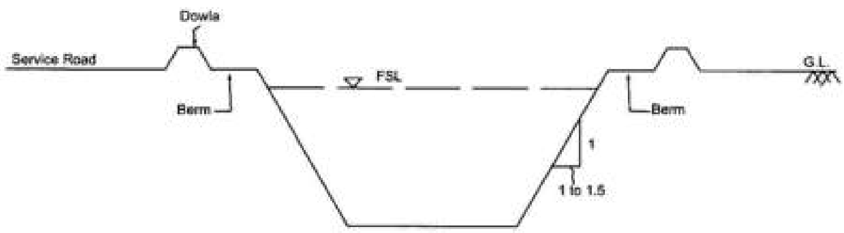
The slope of the canal is governed by the ground slope to a large extent. For a stable channel, the slope should be close to the regime slope. These two considerations are used in deciding the slope. The ground profile is drawn all along the canal length and the regime slope computed. A trial water surface is drawn with a slope nearly equal to the regime slope, keeping in mind the following:

- The water surface is kept slightly (15-30cm) higher than the ground level to permit flow irrigation

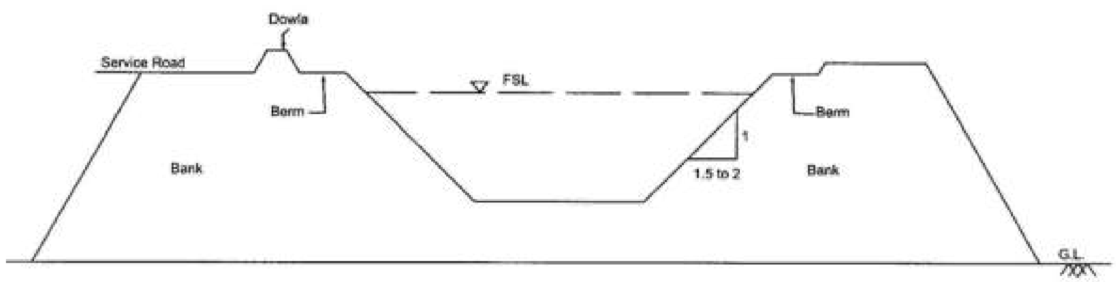
- There should be balanced earthwork i.e. the amount of cutting should be nearly equal to the filling for achieving economy.
- If the water surface goes very much above the ground level, a fall can be provided at that location.

Cross sections of Irrigation Channels

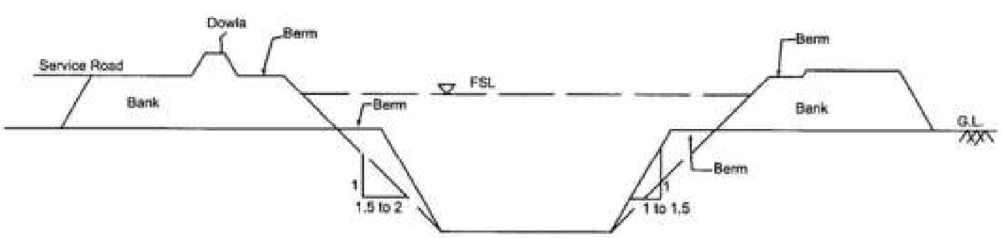
An irrigation channel may be fully in cutting, fully in filling or partially in cutting and partially in filling. Balanced earthwork requires the canal to be partly in filling and partly in cutting, but this may not always be possible all along the length of the canal.



(a) Fully in cutting



(b) Fully in filling



(c) Partly in cutting and partlry in filling

Typical cross-sections of irrigation canals

The following points need mention as far as the canal cross sections are concerned:

- The side slope in cutting is usually kept 1H: 1V and in filling 1.5H: 1V. This may however vary depending upon the soil characteristics

- A horizontal strip of land, known as “berm” is provided between the inner toe of the bank and the top edge of cutting
- The banks are provided such that there is adequate freeboard from the full supply level to the top of the bank
- A service road is provided on the bank of the canal is provided for safety

Objective of Channel Design

Transport water between two points in a safe and cost-effective manner includes economical, safety, and esthetics aspects. Here, mainly hydraulic aspects are considered.

General observations:

- Conveyance of a channel increases with the hydraulic radius (wetted perimeter deceases).
- The best hydraulic section is a semicircle (for a given area it has the minimum wetted perimeter).

Design of Canals:

The canals may be for irrigation or power generation purposes. While the former may be unlined (mobile boundaries) or lined (rigid boundaries), the later are almost invariably lined. Further, they may be taking off from diversion head works or from storage works. While canals taking off from diversion works will carry sediment laden water, those taking off from storage works will be carrying relatively sediment free water.

Thus from the design point of view, channels can be classified into the following:

1. Channels with unlined boundaries and carrying sediment laden water
2. Channels with unlined boundaries and carrying relatively clear water
3. Channels with rigid (lined) boundaries and carrying sediment laden water
4. Channels with rigid (lined) boundaries and carrying relatively clear water

Concrete-lined channel

Unlined channel

Channels with unlined boundaries and carrying sediment laden water

Such channels have to be designed so as to transport the sediment entering the channel without deposition or scour. Since the boundaries are mobile, the bed or sides could be scoured if the sediment carrying capacity of the channel is more than the quantity entering the same. On the other hand if the sediment carrying capacity is less than the quantity of sediment entering the channel, there could be objectionable deposits. There have been a large number of studies on design of stable channels for such conditions, but only two such approaches which have been used in designs are

1. Kennedy's Theory

R.G. Kennedy established a relation between non scouring, non silting velocity, termed as "critical velocity" of flow and the stage of flow on the basis of experimental work done by him on the upper BARI-DOAB canal system in Punjab. For any given channel having a particular soil condition, the critical velocity ratio which is a function of silt charge and grade and rugosity coefficient is uniquely fixed. Kutter's equation was used for the calculation of mean velocity in the channel. Though the use of Kutter's equation by Kennedy in theory of channel design made the design procedure tedious and complicated, Garret had given graphical solutions in the form of charts for relatively easy design procedures. The design procedures still involved trial and error.

The reasons behind selection of Kutter equation for determination of mean velocity instead of Manning's equation is not available, however, hydraulic engineers have now started preferring Manning's equation in determining the mean velocity of flow. Manning's roughness coefficient and Kutter's rugosity coefficient are generally identical within practical ranges, the Manning's roughness coefficient is better known, therefore, the use of Manning's equation which is much simpler in application is suggested for determine the mean velocity flow in a channel.

Kennedy had suggested a general form of equation for critical velocity

$V_C = C\ m\ D^n$

Where D = Depth of Flow in metres

The value of 'm' (critical velocity ratio) depends upon the silt charge and silt grade.

The coefficient C and the power index "n" are not constant and change from site to site. The most prevalent values of C and n as worked out by Kennedy are 0.546 and 0.64 respectively. The popular form of Kennedy's equation for regime channel designs is

$V_C = 0.546\ m\ D^{0.64}$

C	Material
0.56	extremely fine soil
0.84	fine, light sandy soil
0.92	coarse, light sandy soil
1.01	sandy, loamy silt
1.09	coarse silt or hard silt debris
n	**Sediment Load**
0.64	water containing very fine silt
0.50	clear water

Velocity Ratio, m = 1.1 to 1.2 for sands coarser than standard
0.9 to 0.8 for sands finer than standard

For design of stable channel in alluvial soils graphical solutions by developing hydraulic diagram using Kennedy theory with Manning's equation is suggested for general application. Taking a trapezoidal section, the area, wetted perimeter and hydraulic mean depth can be described in terms of bed width and depth of flow. The mean velocity of flow can be written in terms of rugosity coefficient n, bed width, and depth and slope parameter. Equating the velocity obtained from Manning's equation to the critical velocity as per Kennedy theory a

chart can be developed between and depth of flow for various values of B/D and Q/m. These hydraulic charts can be used for design of channels.

2. Lacey's Theory

Lacey made a study of channels which had remained stable i.e. which were neither getting silted up nor were scouring – a condition termed as "Regime Condition" by him and came out with what is called Lacey's Regime Theory.

For regime conditions to be established, Lacey postulated that the channel should be carrying a constant discharge and sediment load and flowing through an unlimited Incoherent alluvium of the same grade and character as the sediment being transported. This implies that the bed and sides of the channel should be equally amenable to deposition and scour. He further stipulated that if these conditions are satisfied, the channel will have a unique slope and size which is related only to the discharge and the silt grade.

The aforesaid conditions are hardly met with fully in any situation. However, in most cases of alluvial channels, Lacey's theory can be used to a reasonable extent. The situation in rivers is quite different in as much as there is a large variation in the discharge as well as the sediment load. It is only during the high floods that conditions approaching the regime may be attained partially and hence rivers can at best attain what is called quasi regime conditions only during floods.

In the case of canals, Lacey also differentiated between "initial" and "final" regime. A canal constructed with dimensions different from the regime dimensions will adjust the slope and attain a working equilibrium, which was called the initial regime. With time however, the canal will adjust the dimensions and slope to attain the final regime. In cases where such adjustment is not possible, say because of the sides being non-erodable, the canal will continue to flow in the initial regime. Lacey also considered that the sediment size is an important parameter in determining the dimensions of regime channels and introduced what he called the silt factor f, related to the median sediment size as below:

$$f = 1.76 \sqrt{d}$$

where 'd' is the sediment diameter in millimeters.

Plotting all the available data, he obtained the following equations for a regime channel:

$$V = 10.8\, R^{2/3}\, S^{1/3}$$

$$P = 4.75 \sqrt{Q}$$

$$R = 0.48\, (Q/f)^{1/3}$$

$$S = 0.0003\, f^{5/3} / Q^{1/6}$$

The aforesaid equations, known as Lacey's regime equations, define completely the slope and dimensions of a channel once the discharge Q and sediment size d are specified and hence can be used for design. It may be mentioned, however that the Lacey's theory is empirical in nature and hence expected to yield appropriate results for channels with the same kind of parameters – viz. sediment size and sediment load - as those from which the data was obtained. The theory thus cannot be applied to channels carrying large sediment loads or to rivers flowing through gravel or boulder regions.

Channels with mobile boundaries and carrying relatively clear water

Such conditions arise mostly in channels taking off from reservoirs. In such a case most of the sediment settles down in the reservoir and only relatively clear water enters the channel. The design therefore has to be such as to ensure that there is no scouring in the channel bed or sides. The procedure for such designs is known as the USBR method and is based on ensuring that the tractive force on the bed and sides is within specified limits.

Channels with rigid boundaries and carrying sediment laden water

Since the boundaries are rigid, as would be the case with lined channels or channels cut through hard rock, there is no problem of scour. The only consideration in design of such channels is to ensure that the sediment entering the channel does not settle down. This can be done by ensuring that the velocity of flow in the channel is sufficient to transport the sediment. Generally velocities of the order of 1.0 m/s will be adequate unless the sediment load is very high. In case the sediment load is very high, the transporting capacity of the channel will have to be checked with some of the transport relationships available.

Channels with rigid boundaries and carrying relatively clear water

The flow of water in an open channel is generally defined by Chezy's equation

V = mean velocity of flow in m/sec

C= a coefficient, its value depends upon the shape and surface of the channel

R = Hydraulic mean depth in m

S = Slope of channel

With a view to arrive at stable channel dimensions attempts have been made from time to time by various authors in the field of open channel flow to define the value of C in the above equation. The most widely accepted values are those suggested by Kutter and Manning as given herein below:

- Kutter's Equation

- Manning's Equation