



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.

IRRIGATION ENGINEERING



N N Basak

Information contained in this work has been obtained by Tata McGraw-Hill, from sources believed to be reliable. However, neither Tata McGraw-Hill nor its authors guarantee the accuracy or completeness of any information published herein, and neither Tata McGraw-Hill nor its authors shall be responsible for any errors, omissions, or damages arising out of use of this information. This work is published with the understanding that Tata McGraw-Hill and its authors are supplying information but are not attempting to render engineering or other professional services. If such services are required, the assistance of an appropriate professional should be sought.



Tata McGraw-Hill

© 1999, Tata McGraw-Hill Publishing Company Limited

Tenth reprint 2007
RXDCRRXYRXALA

No part of this publication may be reproduced in any form or by any means without the prior written permission of the publishers

This edition can be exported from India by the publishers,
Tata McGraw-Hill Publishing Company Limited

ISBN 0-07-463538-7

Published by Tata McGraw-Hill Publishing Company Limited,
7 West Patel Nagar, New Delhi 110 008, and typeset in Times at
Anvi Composers, New Delhi 110 063, and printed at
Gopaljee Enterprises, Maujpur, Delhi

Cover: De-Unique

The McGraw-Hill Companies

CONTENTS

Preface

vii

1. Introduction **1**

- 1.1 Definition of Irrigation 1
- 1.2 Necessity of Irrigation 1
- 1.3 Benefits of Irrigation 2
- 1.4 Ill-Effects of Irrigation 2
- 1.5 Systems of Irrigation 3
- 1.6 Difference Between Weir, Barrage and Dam 6
- 1.7 Methods of Distribution of Water 7
- 1.8 Irrigation Project Surveying 11
- 1.9 Irrigation Project Report 15
- 1.10 Important Irrigation Projects in India 16
- Review Questions 19
- Answers 20

2. Water Requirement of Crops and Soil-Water Relationship **21**

- 2.1 Introduction 21
- 2.2 Factors Affecting the Water Requirement 21
- 2.3 Definition of Important Terms 22
- 2.4 Base, Delta and Duty 26
- 2.5 Factors Affecting Duty 27
- 2.6 Methods of Improving Duty 28
- 2.7 Relation between Base, Delta and Duty 29
- 2.8 Numerical Problems on Base, Delta and Duty 29
- 2.9 Types of Soils 34
- 2.10 Types of Soil Water 34
- 2.11 Consumptive Use of Water 36
- 2.12 Methods of Determining Consumptive Use 36
- 2.13 Frequency of Irrigation 37
- 2.14 Standard of Irrigation Water 38
- 2.15 Irrigation Efficiency. 39
- Review Questions 40
- Answers 41

3. Hydrology	42
3.1 Definition	42
3.2 Importance of Hydrology	42
3.3 Some Terms Related to Hydrology	42
3.4 Hydrologic Cycle	43
3.5 Hydrograph	43
3.6 Hyetograph	44
3.7 Unit Hydrograph	44
3.8 Base Flow	48
3.9 Precipitation and Its Measurement	49
3.10 Average Depth of Precipitation	53
3.11 Water Losses	55
3.12 Infiltration Indices	58
3.13 Factors Affecting Run-off	60
3.14 Estimation of Run-off	61
3.15 S-hydrograph	63
3.16 Estimation of Peak Flow (Flood Discharge)	64
3.17 Flood Routing	67
<i>Review Questions</i>	68
<i>Answers</i>	69
4. Lift Irrigation	70
4.1 Introduction	70
4.2 Lift Irrigation (By Man or Animal Power)	70
4.3 Lift Irrigation (By Mechanical or Electrical Power)	74
4.4 Explanation of Different Terms	75
4.5 Classification of Well	80
4.6 Construction of Open Well	82
4.7 Determination of Yield of Open Well	84
4.8 Problems on Yield of Open Well	86
4.9 Sinking of Tube Wells	87
4.10 Yield of Tube Well in Unconfined Aquifer	89
4.11 Yield of Tube Well in Confined Aquifer	90
4.12 Problems on Yield of Tube Well	92
4.13 Types of Strainers	94
4.14 Shrouding of Well	95
4.15 Development of Well	96
4.16 Maintenance of Tube Well	97
4.17 Failure of Tube Well	98
4.18 Pumps	98
4.19 Centrifugal Pump	99
4.20 Reciprocating Pump	100
4.21 Rotary Pump	101

- 4.22 Air Lift Pump 101
- 4.23 Horse Power of Pump 101
- 4.24 Methods of Lifting Water From Wells 103
- 4.25 Section of Deep Tube Well 105
- Review Questions* 105
- Answer* 106

5. Flow Irrigation 107

- 5.1 Introduction 107
- 5.2 Types of Canals 107
- 5.3 Selection of Barrage or Dam Site 110
- 5.4 Selection of Alignment of Perennial Canal 111
- 5.5 Selection of Site for Inundation Canal 112
- 5.6 Maintenance of Inundation Canal 112
- 5.7 Advantages and Disadvantages of Inundation Irrigation 114
- 5.8 Comparison Between Inundation and Perennial Irrigation 114
- 5.9 System of Bandhara Irrigation 115
- 5.10 Advantages and Disadvantages of Bandhara Irrigation System 116
- Review Questions* 116
- Answers* 117

6. Canal Section 118

- 6.1 Terms Relating to Canal Section 118
- 6.2 Canal Bank 119
- 6.3 Berm 119
- 6.4 Hydraulic Gradient 120
- 6.5 Counter Berm 120
- 6.6 Free Board 121
- 6.7 Side Slope 121
- 6.8 Service Road 122
- 6.9 Dowel or Dowla 122
- 6.10 Spoil Bank 122
- 6.11 Borrowpit 122
- 6.12 Land Width 123
- 6.13 Balancing Depth 124
- 6.14 Canal in Full Cutting 125
- 6.15 Canal in Full Banking 125
- 6.16 Canal in Partial Cutting and Partial Banking 126
- Review Questions* 126
- Answers* 127

7. Canal Lining 128

- 7.1 Object of Canal Lining 128
- 7.2 Types of Lining 129

7.3	Cement Concrete Lining	129
7.4	Pre-Cast Concrete Lining	130
7.5	Cement Mortar Lining	130
7.6	Lime Concrete Lining	131
7.7	Brick Lining	131
7.8	Boulder Lining	131
7.9	Shot Crete Lining	132
7.10	Asphalt Lining	132
7.11	Bentonite and Clay Lining	132
7.12	Soil-Cement Lining	133
7.13	Advantages and Disadvantages of Canal Lining	133
7.14	Selection of Type of Lining	133
7.15	Justification of Lining	134
7.16	Economics of Canal Lining	135
	<i>Review Questions</i>	136
	<i>Answers</i>	137

8. Drainage Channel Design 138

8.1	<u>Introduction</u>	138
8.2	<u>Value of Run-off Coefficient (K)</u>	138
8.3	Value of Impermeability Factor (p)	139
8.4	Determination of Run-off Coefficient (K)	139
8.5	Determination of Rainfall Intensity (i)	139
8.6	Estimation of run-off by Rational Method	140
8.7	Determination of Run-off by Empirical Formulae	141
8.8	Computation of Volume of Water Collected in a Water Logged Area	141
8.9	Channel Design Formulae	142
8.10	Problems on Drainage Channel Design	143
	<i>Review Questions</i>	147

9. Design of Irrigation Canal 149

9.1	<u>Introduction</u>	149
9.2	<u>Definition of Different Terms Related to Canal Design</u>	149
9.3	<u>Unlined Canal Design on Non-alluvial Soil</u>	152
9.4	<u>Unlined Canal Design on Alluvial Soil by Kennedy's Theory</u>	157
9.5	<u>Unlined Canal Design on Alluvial Soil by Lacey's Theory</u>	162
9.6	<u>Comparison Between Kennedy's Theory and Lacey's Theory</u>	165
9.7	Design of Lined Canal	166
	<i>Review Questions</i>	168

10. Canal Head Works 170

10.1	<u>Introduction</u>	170
10.2	<u>Object of Diversion Head Works</u>	170

10.3	<u>Selection of Site for Storage Head Works</u>	170
10.4	<u>Selection of Site for Diversion Head Works</u>	171
10.5	<u>Components Parts of Diversion Head Works</u>	171
10.6	<u>Weir or Barrage</u>	171
10.7	Divide Wall	172
10.8	Scouring Sluices or Under Sluices	173
10.9	Fish Ladder	173
10.10	Canal Head Regulator	174
10.11	Silt Excluder	174
10.12	Marginal Embankment or Dyke	175
10.13	Guide Bank	176
	<u>Review Questions</u>	178
	<u>Answers</u>	179

11. Weir and Barrage **180**

11.1	<u>Introduction</u>	180
11.2	<u>Theory of Seepage Flow</u>	180
11.3	<u>Hydraulic Gradient or Exit Gradient</u>	181
11.4	Causes of Failure of Weir or Barrage on Permeable Foundation	182
11.5	<u>Precautions Against Failure</u>	183
11.6	<u>Bligh's Creep Theory</u>	183
11.7	Limitations of Bligh's Creep Theory	185
11.8	Khosla's Theory	185
11.9	Types of Weirs	186
11.10	Component Parts of Weir	187
11.11	<u>Component Parts of Barrage</u>	189
	<u>Review Questions</u>	193
	<u>Answers</u>	193

12. Spill Ways **194**

12.1	<u>Necessity of Spill Ways</u>	194
12.2	<u>Location of Spill Way</u>	194
12.3	<u>Determination of Discharge Capacity and Number of Spill Ways</u>	195
12.4	<u>Types of Spill Ways</u>	195
12.5	<u>Energy Dissipation</u>	201
	<u>Review Questions</u>	204
	<u>Answers</u>	204

13. Cross-Drainage Works **205**

13.1	<u>Introduction</u>	205
13.2	<u>Necessity of Cross-Drainage Works</u>	205
13.3	<u>Types of Cross-Drainage Works</u>	206

13.4	Selection of Type of Cross-Drainage Works	207
13.5	Aqueduct	208
13.6	Siphon Aqueduct	208
13.7	Super Passage	209
13.8	Siphon Super Passage	209
13.9	Level Crossing	209
13.10	<u>Inlet and Outlet</u>	<u>210</u>
	<u>Review Questions</u>	<u>210</u>
	<u>Answers</u>	<u>211</u>

14. Canal Falls **212**

14.1	<u>Introduction</u>	<u>212</u>
14.2	<u>Necessity of Canal Falls</u>	<u>212</u>
14.3	<u>Types of Canal Falls</u>	<u>213</u>
	<u>Review Questions</u>	<u>216</u>
	<u>Answers</u>	<u>217</u>

15. Inland Navigation **218**

15.1	<u>Introduction</u>	<u>218</u>
15.2	<u>Requirements of Navigable Water Ways</u>	<u>219</u>
15.3	<u>Types of Inland Navigation</u>	<u>220</u>
15.4	<u>Methods of River Navigation</u>	<u>220</u>
15.5	<u>Methods of Canal Navigation</u>	<u>223</u>
15.6	<u>Navigation Locks or Lock Gates</u>	<u>224</u>
	<u>Review Questions</u>	<u>226</u>
	<u>Answers</u>	<u>226</u>

16. Dam **227**

16.1	<u>Introduction</u>	<u>227</u>
16.2	<u>Selection of Site for Dam</u>	<u>227</u>
16.3	<u>Investigation Works for Dam Site</u>	<u>228</u>
16.4	<u>Classification of Dam</u>	<u>229</u>
16.5	<u>Solid Gravity Dam</u>	<u>231</u>
16.6	<u>Forces Acting on Gravity Dam</u>	<u>231</u>
16.7	<u>Causes of Failure of Gravity Dam</u>	<u>236</u>
16.8	<u>Precautions Against Failure</u>	<u>236</u>
16.9	<u>Elementary or Theoretical Profile of the Gravity Dam</u>	<u>237</u>
16.10	<u>Practical Profile of a Gravity Dam</u>	<u>238</u>
16.11	<u>Economical Height of Dam</u>	<u>239</u>
16.12	<u>Low Dam and High Dam</u>	<u>240</u>
16.13	<u>Temperature Control in Concrete Dam</u>	<u>242</u>
16.14	<u>Stability Analysis of Dam</u>	<u>242</u>
16.15	<u>Arch Dam</u>	<u>245</u>
16.16	<u>Forces on Arch Dam</u>	<u>246</u>

- 16.17 Types of Arch Dams 246
- 16.18 Buttress Dam 247
- 16.19 Types of Buttress Dam 248
- 16.20 Merits and Demerits of Buttress Dam 249
- 16.21 Earthen Dam 250
- 16.22 Causes of Failure of Earthen Dam 251
- 16.23 Rock-fill Dam 252
- 16.24 Composite Dam 253
- 16.25 Steel Dam 253
- 16.26 Timber Dam 253
- Review Questions 254*
- Answers 255*

17. Reservoir Planning, Water Management and Water Laws 256

- 17.1 Purpose of Reservoir 256
- 17.2 Classification of Reservoir 256
- 17.3 Selection of Site For Reservoir 257
- 17.4 Investigation Works for Reservoir 258
- 17.5 Yield and Capacity of Reservoir 259
- 17.6 Mass Curve and Demand Curve 259
- 17.7 Zones of Storage Reservoir 260
- 17.8 Useful Life of Reservoir 261
- 17.9 Water Losses from Reservoir 262
- 17.10 Control of Water Losses 262
- 17.11 Causes of Sedimentation in Reservoir 263
- 17.12 Effect of Sedimentation 263
- 17.13 Control of Sedimentation 264
- 17.14 Flood Routing 265
- 17.15 Water Management 266
- 17.16 Water Laws 268
- Review Questions 268*
- Answers 269*

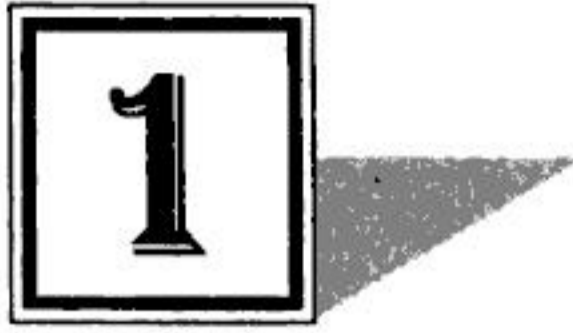
18. Water Logging and Watershed Management 270

- 18.1 Introduction 270
- 18.2 Causes of Water Logging 270
- 18.3 Effects of Water Logging 271
- 18.4 Control of Water Logging (i.e. anti water logging measures) 272
- 18.5 Land Reclamation 273
- 18.6 Watershed Management 274
- Review Questions 276*
- Answers 276*

19. River Gauging 277

- 19.1 Introduction 277

19.2	Necessity of River Gauging	277
19.3	Selection of Gauge Site	277
19.4	Fixing of Gauge Post	278
19.5	Selection of Discharge Site	278
19.6	Measurement of Discharge by Area-velocity Method	278
19.7	Measurement of Depth of Water	279
19.8	Determination of Area of Water Section	280
19.9	Measurement of Velocity of Flow	282
	<i>Review Questions</i>	285
	<i>Answer</i>	286
20.	River Training Works	287
20.1	Introduction	287
20.2	Stages of River Flow	287
20.3	Necessity of River Training Works	288
20.4	Meandering of River	288
20.5	Components of River training Works	289
20.6	Marginal Embankment (Dyke or Levee)	289
20.7	Guide Bank	290
20.8	Spurs	290
20.9	Groynes	291
20.10	Comparison Between Spur and Groyne	294
20.11	Bank Protection	294
	<i>Review Questions</i>	295
	<i>Answers</i>	297
21.	Flood Control Works	298
21.1	Introduction	298
21.2	Causes of Flood	298
21.3	Effects of Flood	300
21.4	Benefits of Flood Control (Economics of Flood Control)	301
21.5	Flood Forecasting	301
21.6	Methods of Flood Control or Flood Mitigation Works	303
21.7	Evacuation and Flood Proofing	305
21.8	Land Management	306
	<i>Review Questions</i>	306
	<i>Answers</i>	306
	Appendix A: Objective-type Questions with Answers	307
	Appendix B: Model Questions with Hints	316
	References	325
	Index	326



INTRODUCTION

1.1 DEFINITION OF IRRIGATION

The process of artificial application of water to the soil for the growth of agricultural crops is termed as irrigation. It is practically a science of planning and designing a water supply system for the agricultural land to protect the crops from bad effect of drought or low rainfall. It includes the construction of weirs, dams, barrages and canal systems for the regular supply of water to the culturable (i.e. cultivable) lands.

1.2 NECESSITY OF IRRIGATION

Throughout the crop period adequate quantities of water is required near the root zone of the plants for their growth. At times during the crop period the rainfall may not be adequate to fulfil the water requirement. The intensity of rainfall is practically uncertain and beyond the control of human power and it may not be well distributed throughout the crop season or the culturable area. So, irrigation becomes absolutely necessary to fulfil the water requirement of crops. The following are the factors which govern the necessity of irrigation.

(a) Insufficient Rainfall When the seasonal rainfall is less than the minimum requirement for the satisfactory growth of crops, the irrigation system is essential.

(b) Uneven Distribution of Rainfall When the rainfall is not evenly distributed during the crop period or throughout the culturable area, the irrigation is extremely necessary.

(c) Improvement of Perennial Crops Some perennial crops like sugarcane, cotton, etc. require water throughout the major part of the year. But the rainfall may fulfil the water requirement in rainy season only. So, for the remaining part of the year, irrigation becomes necessary.

2 Irrigation Engineering

(d) Development of Agriculture in Desert Area In desert area where the rainfall is very scanty, irrigation is required for the development of agriculture.

1.3 BENEFITS OF IRRIGATION

The following are the important benefits of irrigation:

(a) Yield of Crops In the period of low rainfall or drought, the yield of crop may be increased by the irrigation system.

(b) Protection from Famine The food production of a country can be improved by ensuring the growth of crops by availing the irrigation facilities. This helps a country to prevent famine situation.

(c) Improvement of Cash Crops Irrigation helps to improve the cultivation of cash crops like vegetables, fruits, tobacco, etc.

(d) Prosperity of Farmers When the supply of irrigation water is assured, the farmers can grow two or more crops in a year on the same land. Thus the farmers may earn more money and improve their living standard.

(e) Source of Revenue When irrigation water is supplied to the cultivators in lieu of some taxes, it helps to earn revenue which may be spent on other development schemes.

(f) Navigation The irrigation canals may be utilised for inland navigation which is further useful for communication and transportation of agricultural goods.

(g) Hydroelectric Power Generation In some river valley projects, multi-purpose reservoirs are formed by constructing high dams where hydroelectric power may be generated along with the irrigation system.

(h) Water Supply The irrigation canals may be the source of water supply for domestic and industrial purposes.

(i) General Communication The inspection road along the canal banks may serve as a communication link with the otherwise remote villages.

(k) Development of Fishery The reservoir and the canals can be utilised for the development of fisher projects.

1.4 ILL-EFFECTS OF IRRIGATION

The following are the ill-effects of irrigation:

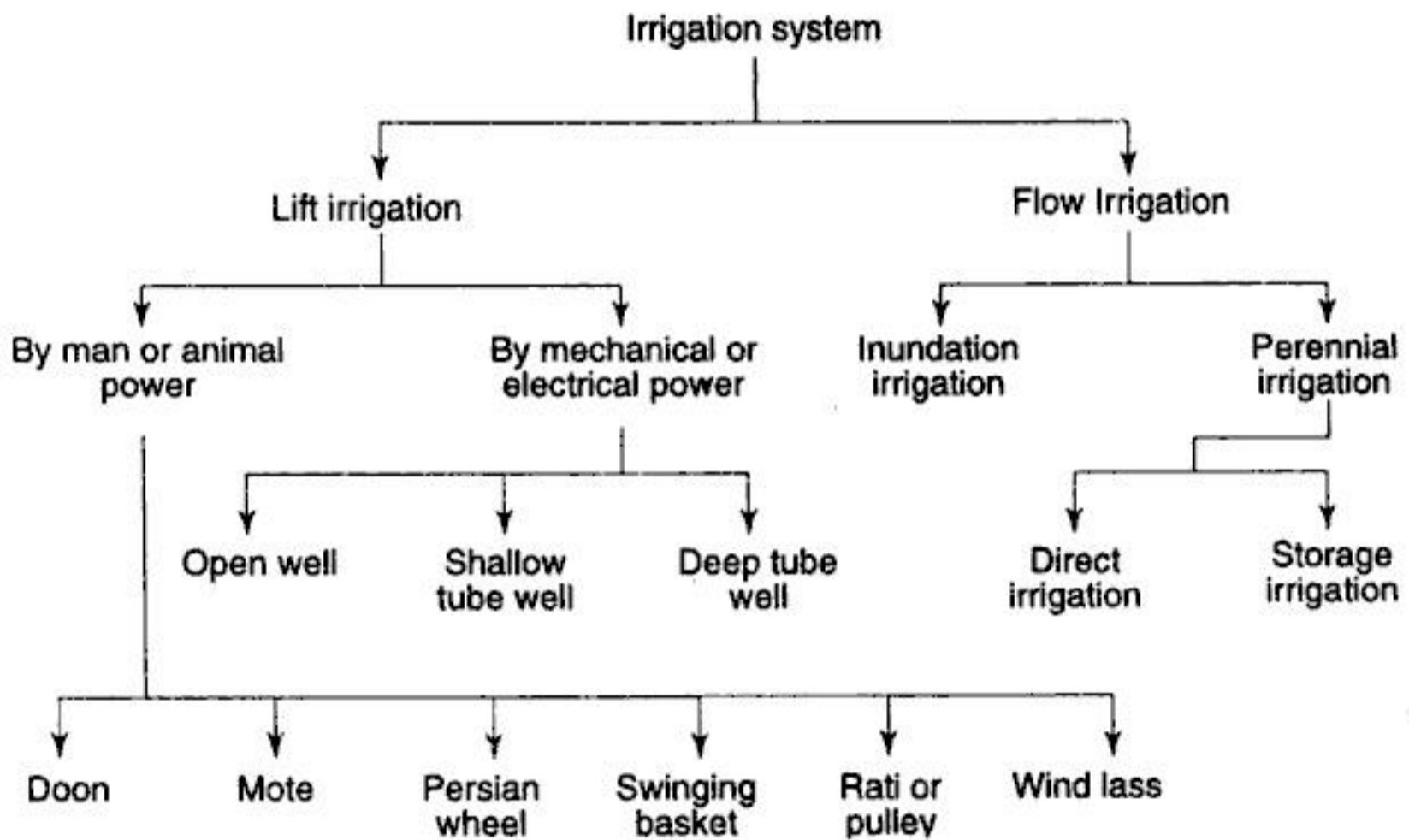
(a) Rising of Water Table Due to the excessive seepage of water through the bed and banks of the canals, the water table in the surrounding area may be raised which may constantly saturate the root zone of the crops and the soil may develop alkaline property which is harmful to the crops.

(b) Formation of Marshy Land Excessive seepage and leakage of water from the irrigation canals may lead to formation of marshy lands along the course of the canals. These marshy lands form the colonies of mosquitos which may be responsible for diseases.

(c) Dampness in Weather The temperature of the commanded area of an irrigation project may be lowered considerably and the area may become damp. Due to dampness, the people residing around the area may suffer from cold, cough and other such diseases originating from dampness.

(d) Loss of Valuable Lands Valuable land may get submerged when storage reservoirs are formed by constructing barrages or dams and, it also may be lost while constructing irrigation canals.

1.5 SYSTEMS OF IRRIGATION



A. Lift Irrigation

When water is lifted from surface sources or underground sources by man or animal power, mechanical or electrical power and directly supplied to the agricultural land, then it is known as *lift irrigation*. In this method isolated small areas can be irrigated. The vast areas cannot be included in this system. Lift irrigation can be divided into two groups:

- (a) Lifting of water by man or animal power.
- (b) Lifting of water by mechanical or electrical power.

When mechanical or electrical powers are not available in villages or the economic condition of the farmers is not good enough to afford this expensive method, the lifting of water is done by the following method from the surface sources (like ponds, lakes, rivers, etc):

4 Irrigation Engineering

- (i) Doon
- (ii) Mote
- (iii) Persian wheel
- (iv) Swinging basket
- (v) Dhenkli
- (vi) Rati or pulley
- (vii) Wind lass

When mechanical or electrical power is available in villages or the farmers can afford the expenditure for the installation of the same, the underground water is lifted by pumps (diesel pumpset or electrical pump set) and directly supplied to the agricultural land. The underground water may be available from the following sources:

- (i) Open well
- (ii) Shallow tube well
- (iii) Deep tube well.

Now-a-days, the pumping system of lift irrigation from shallow or deep tube well is widely practised.

(Details of lift irrigation systems will be studied in Chapter 4.)

Advantages of Lift Irrigation

The following are the advantages of lift irrigation

- (i) The farmers can supply water to their fields according to the requirement, and hence there is no possibility of over irrigation.
- (ii) The water table is lowered when water is lifted from the wells thereby reducing chances of water logging in the area.
- (iii) As water is supplied directly to the fields, there is no water loss due to conveyance.
- (iv) Initial cost is low as there is no necessity of constructing hydraulic structures.
- (v) As the loss of water is low, the duty of water is high.
- (vi) The maintenance cost is low.
- (vii) More than one crop can be grown in a year on the same land.
- (viii) Loss of valuable land is prevented as there is no necessity of constructing the network of canals.
- (ix) The water of the well is cooler in hot season and warmer in cold season. This phenomenon is favourable for the crops.

Disadvantages of Lift Irrigation

The following are the disadvantages of lift irrigation

- (i) In summer the surface water may be dried up and the water table may go down below the suction head. Hence, the lift irrigation from the surface source and from the shallow tube well may fail in summer.
- (ii) If the lifting mechanism (i.e. pump) fails due to mechanical or electrical failure, then water cannot be supplied until the mechanism is restored.

- (iii) The well water has no silt content. The yield of crop therefore depends on chemical fertiliser, which is costly.
- (iv) The lift irrigation in consideration with the yield of crop is not cost effective.

B. Flow Irrigation

When water flows under gravitational pull through the artificial canal towards the agricultural land, it is termed as *flow irrigation*. In this system, the head of the canal should always be at higher elevation than the land to be irrigated. The following are the different systems of flow irrigation.

1. Inundation Irrigation System

In this system, a canal is excavated from the bank of the inundation river (i.e. the river which overflows in rainy season but nearly dried up in summer and winter) [Fig. 1.1 (a)].

In this case water flows to the agricultural land in rainy season only. There is no regulator at the head of the canal to control the flow of water. The bed level of the canal is fixed at such level that the water can flow through the canal only when the water level of the river rises above the canal bed [Fig. 1.1(b)].

Again, the flow of water through the canal stops automatically when the water level of the river falls below the canal bed [Fig. 1.1(c)]

So, this system of irrigation depends completely on the water level of the river. As there is no regulator at the head of the canal, over irrigation is possible resulting in damaging the crops.

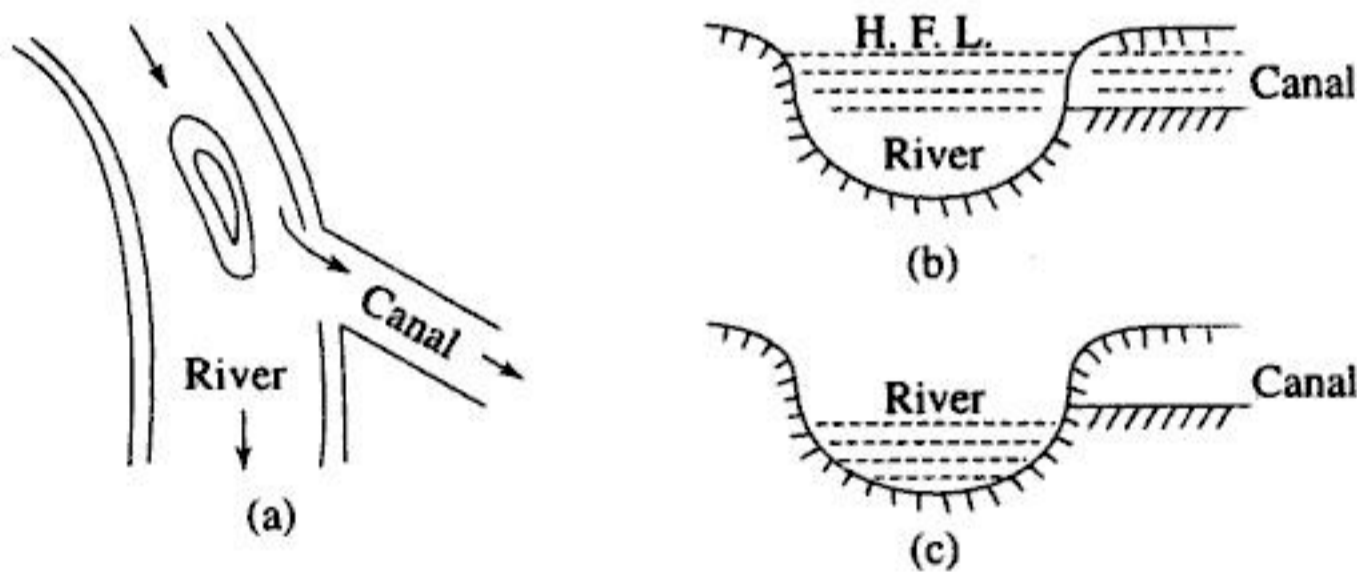


Fig. 1.1 Inundation canal

2. Perennial System of Irrigation

In this system, a weir or a barrage is constructed across the perennial river (i.e., the river which flows throughout the year in its full capacity) to raise the water level on the up stream side or a dam is constructed to form a storage reservoir. Then main canal is constructed on either or both the banks of the river. Regulator is constructed at the head of the canal to control the flow of water through the canal towards the agricultural land. This system is reliable as water is available throughout the year. The perennial system of irrigation may be of the following types:

(a) Direct Irrigation System In this system, a weir is generally constructed across a perennial river to raise the water level on the up stream side up to a certain limit, so that the water can flow through the canal. Here, the water level on the up stream side will remain at a constant height and the excess water flows over the weir. Sometimes, a barrage is constructed, in place of weir, to regulate the water level on the upstream side. The hydraulic structure which is constructed in direct irrigation system is known as Diversion Head Works (Fig. 1.2).

(b) Storage Irrigation System In this system a dam is constructed across a river valley to form a storage reservoir (Fig. 1.3). The main canals may be taken from both sides of the dam. The flow of water through the canal is controlled by head regulator. This storage reservoir is also known as multipurpose reservoir as it serves the following purposes:

- (a) Irrigation
- (b) Water supply
- (c) Hydro-electric power generation
- (d) Fishery
- (e) Flood control.

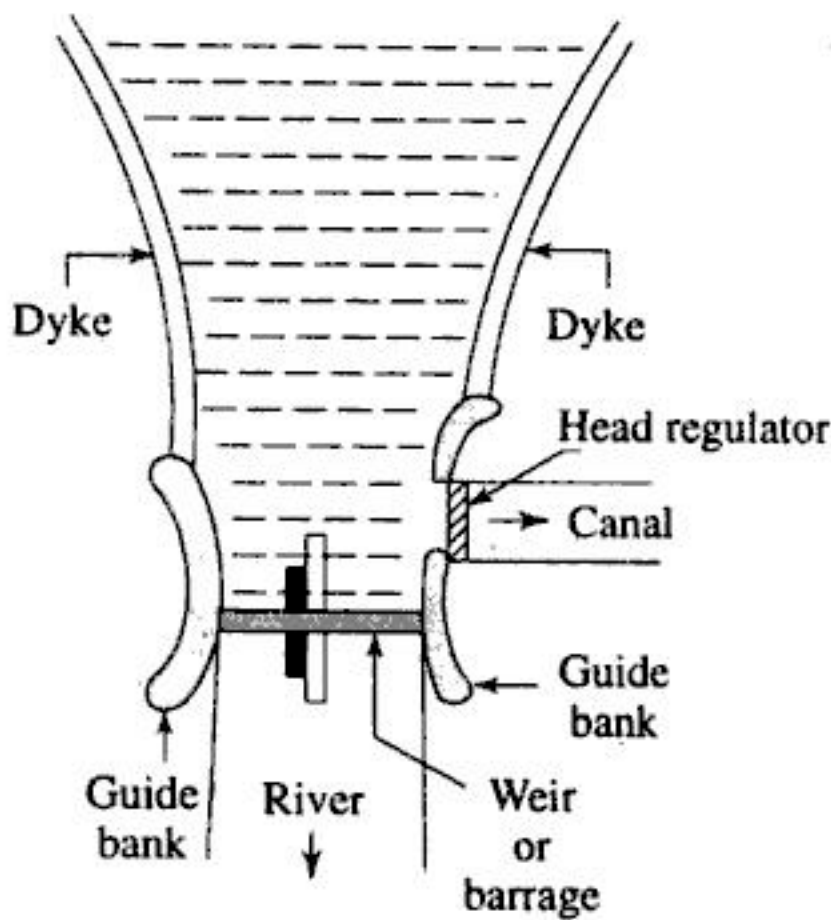


Fig. 1.2 Diversion head works

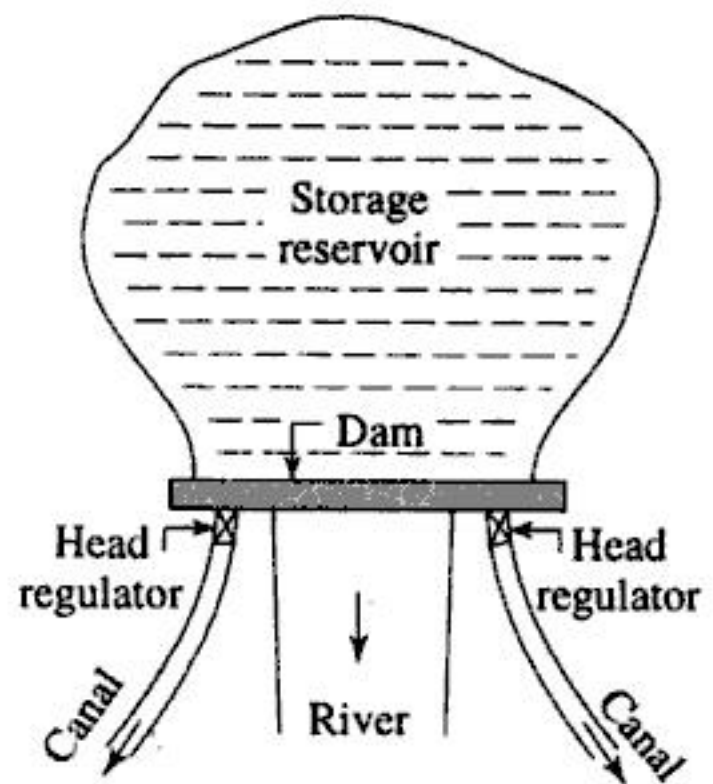


Fig. 1.3 Storage reservoir

1.6 DIFFERENCE BETWEEN WEIR, BARRAGE AND DAM

Weir An impervious barrier which is constructed across a river to raise the water level on the up stream side is known as weir. Here the water level is raised up to the required height and the surplus water is allowed to flow over the weir. Generally it is constructed across a inundation river (Fig. 1.4).

Barrage When adjustable gates are installed over a weir to maintain the

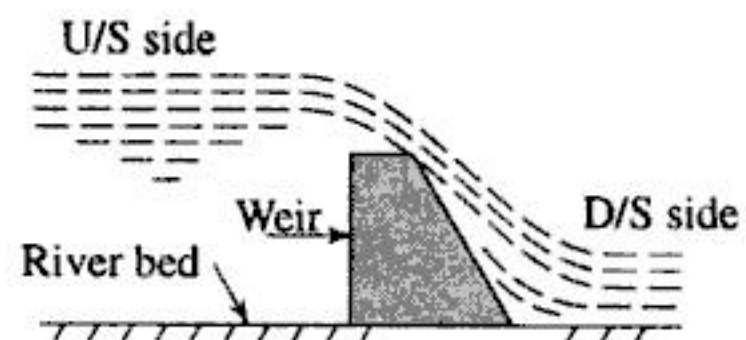


Fig. 1.4 Weir

water surface at different levels at different times, then it is known as barrage. The water level is adjusted by operating the adjustable gates or shutters. The gates are placed at different tiers and these are operated by cables from the cabin. The gates are supported on the piers at both ends. The distance between pier to pier is known as Bay (Fig. 1.5).

Dam The high impervious barrier constructed across a river valley to form a deep storage reservoir is known as *dam*. The surplus water is not allowed to flow over the dam, but it flows through the spillways provided at some designed level (Fig. 1.6).

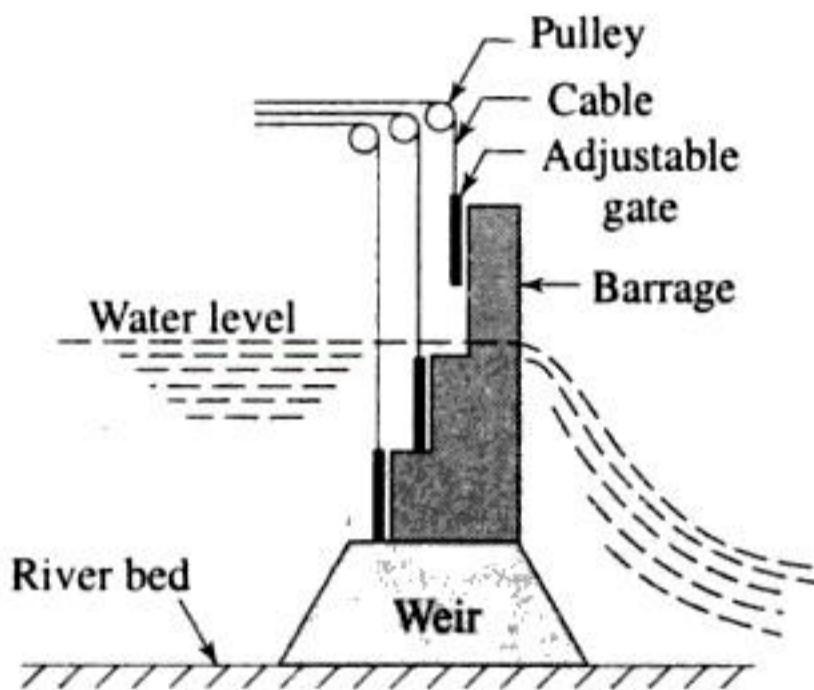


Fig. 1.5 Barrage

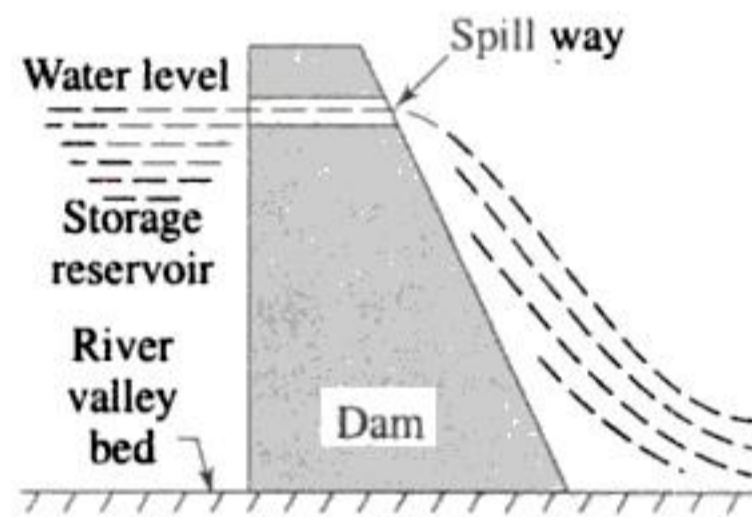
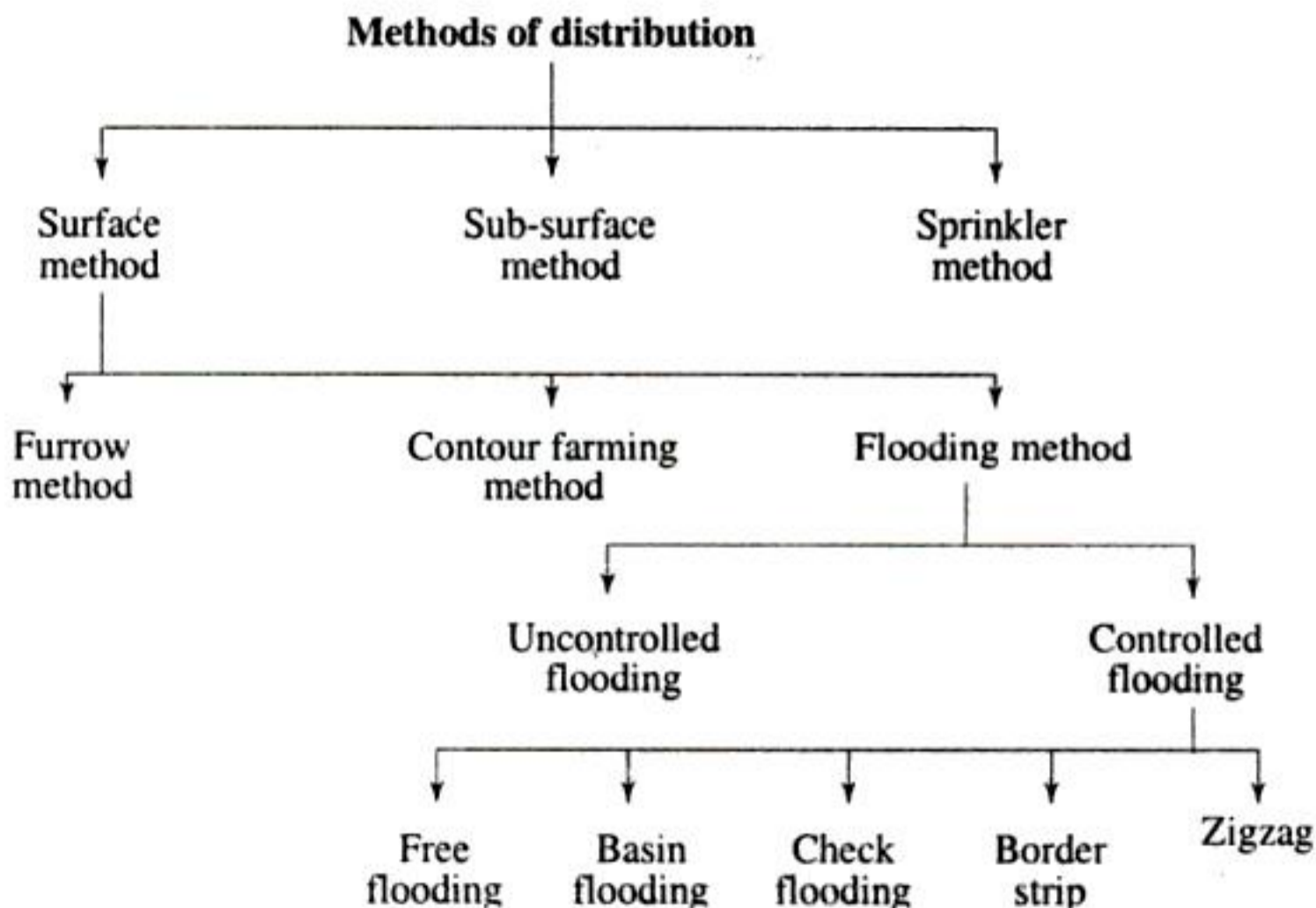


Fig. 1.6 Dam

1.7 METHODS OF DISTRIBUTION OF WATER



A. Surface Method

In this method, the irrigation water is distributed to the agricultural land through the small channels which flood the area up to the required depth. The surface method is again sub-divided into three categories:

(a) Furrow Method

In this method, the irrigation water is supplied to the land by digging narrow channels known as furrows at regular intervals. The water flows through the furrows and infiltrates into the soil and spreads laterally to saturate the root zone of the crops. This method is suitable for the crops which are sown in rows. The crops are potato, ground nut, tobacco, sugarcane, etc (Fig. 1.7).

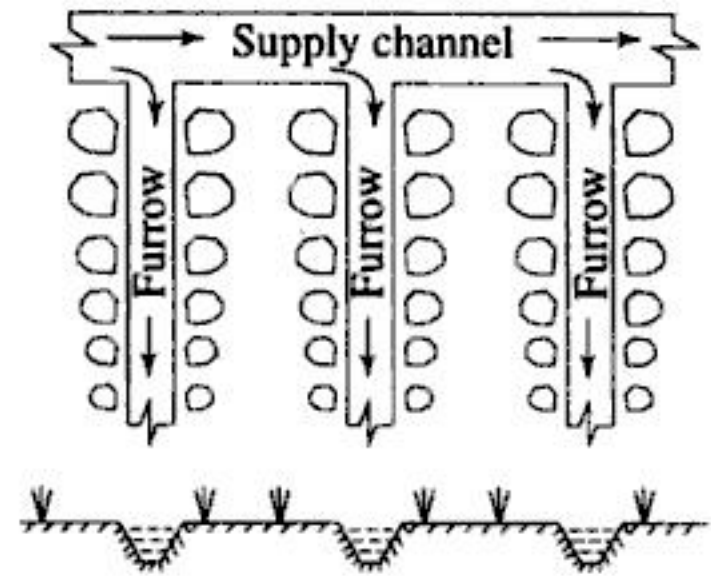


Fig. 1.7 Furrow method

(b) Contour Farming

This method is adopted in hilly areas where the land has steep slope. Here, the land is divided into series of horizontal strips which are known as terraces. Small bunds are provided at the end of each terrace to hold water upto the required depth.

This method serves also the purpose of flood control and soil erosion (Fig. 1.8).

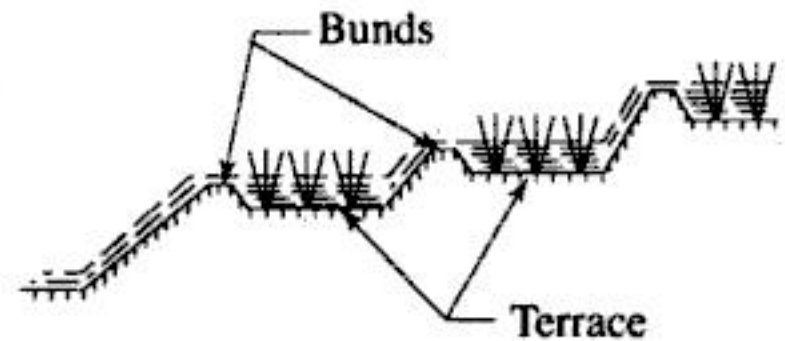


Fig.1.8 Contour farming

(c) Flooding Method

This method is suitable for the agricultural land which exists in flat topography. In this method, the field is flooded with water with the help of field channels. The flooding method may be of two types.

(1) Uncontrolled flooding This method is applicable in inundation irrigation system. Here, the land is flooded with water by inundation canal. As there is no controlling system in inundation canal, this type of distribution of water is known as uncontrolled flooding. This method results in wastage of water and over irrigation.

(2) Controlled Flooding This method is applicable in perennial irrigation system. In this method, the agricultural area is flooded with water through the canals which are provided with regulators. It is again sub-divided into following types-

- (a) Free flooding
- (b) Basin method
- (c) Check flooding

- (d) Border flooding
- (e) Zig-zag method

(a) Free Flooding In this method, the agricultural land is divided into small strips by a series of field channels which are connected to the supply channel. The strips of land are flooded with water by opening the field regulators (F.R.) the surplus water flows through the waste water channel and is discharged into the river or drainage (Fig. 1.9).

(b) Basin Method This method is employed for watering orchards. In this method, each tree or a group of trees are enclosed by circular channel through which water flows. The circular channel is known as basin. Each basin is connected to field channel. The field channel is again connected to the supply channel. When all the basins are filled with water, the supply of water is stopped (Fig. 1.10).

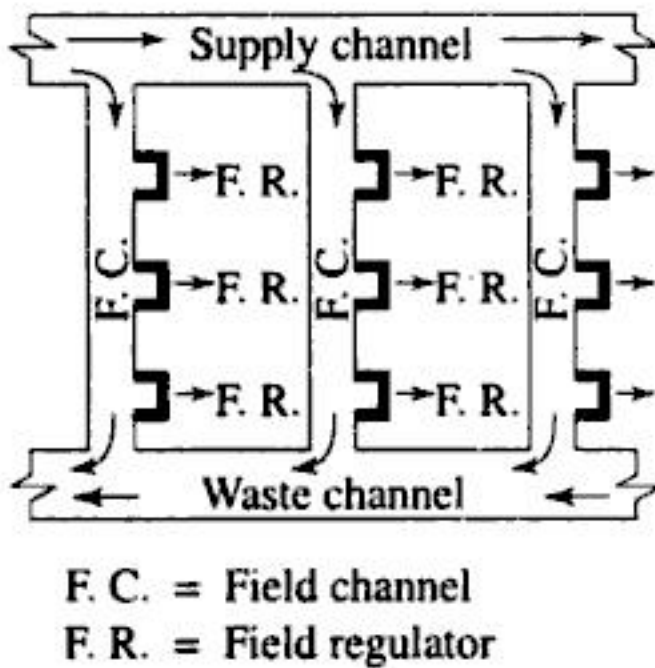


Fig. 1.9 Free flooding

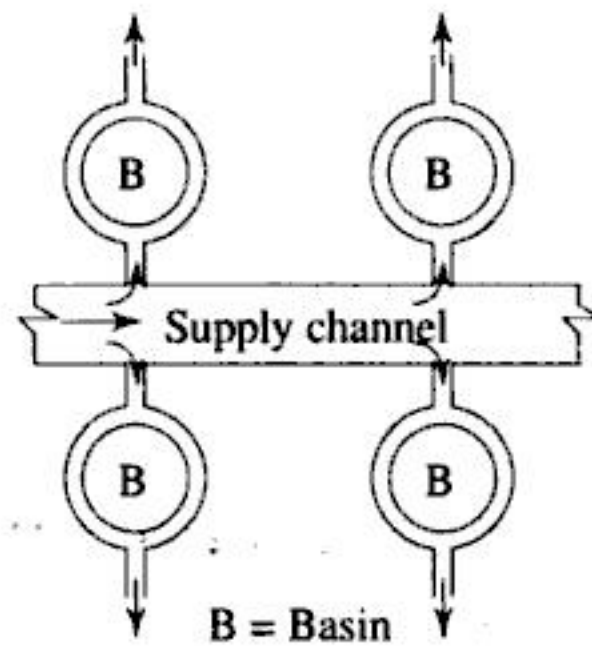


Fig. 1.10 Basin method

(c) Check Flooding In this method, the agricultural area is divided into small plots (known as check basins) by check bunds. The water is supplied to the check basins through the field channels which are connected with the supply channel. Each basin is flooded with water to the desired depth and the water is retained for some hours so that it can infiltrate into the soil (Fig. 1.11).

(d) Border Strips In this method, the agricultural area is divided into series of long narrow strips (known as Border strips) by levees, i.e. small bunds. The strips are aligned along the country slope so that the water can flow easily throughout the area. This method is suitable when the area is at level with gentle country slope.

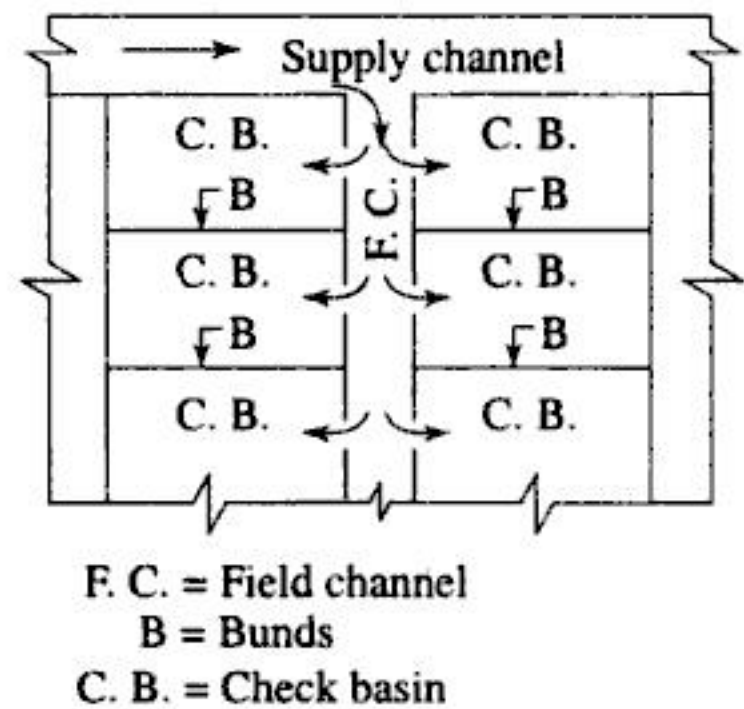
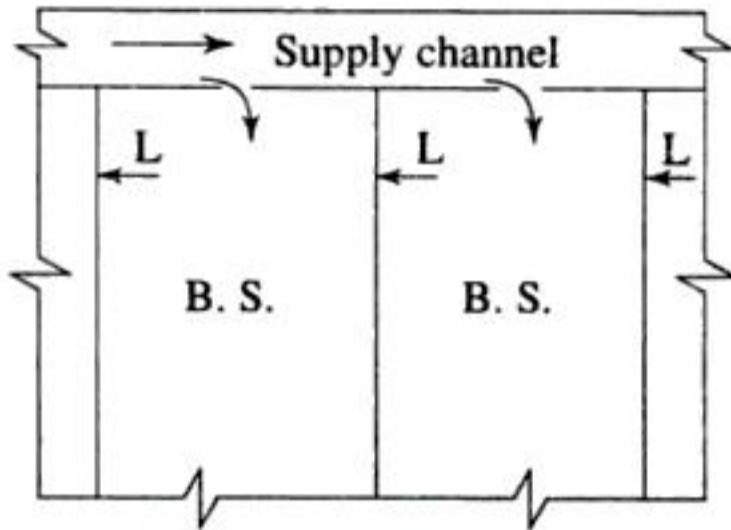


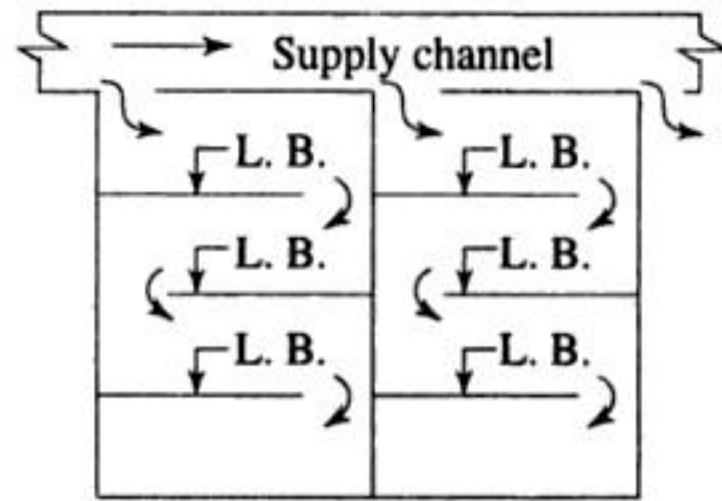
Fig. 1.11 Check Flooding

(e) Zig-zag Method In this method, the agricultural area is sub-divided into small plots by low bunds in a zig-zag manner. The water is supplied to the plots from the field channel through the openings. The water flows in a zig-zag way to cover the entire area. When the desired depth is attained, the openings are closed (Fig. 1.13).



B. S. = Border strips
L = Levees

Fig. 1.12 Border strips



L. B. = Low bunds

Fig. 1.13 Zig-zag method

B. Sub-Surface Method

In this method, the water is applied to the root zone of the crops by underground network of pipes. The network consists of main pipe, sub-main pipes, and lateral perforated pipes. The perforated pipes allow the water to drip out slowly and thus the soil below the root zone of the crops absorbs water continuously. This method is suitable for permeable soil like sandy soil. This method is also known as drip method or trickle method of irrigation (Fig. 1.14).

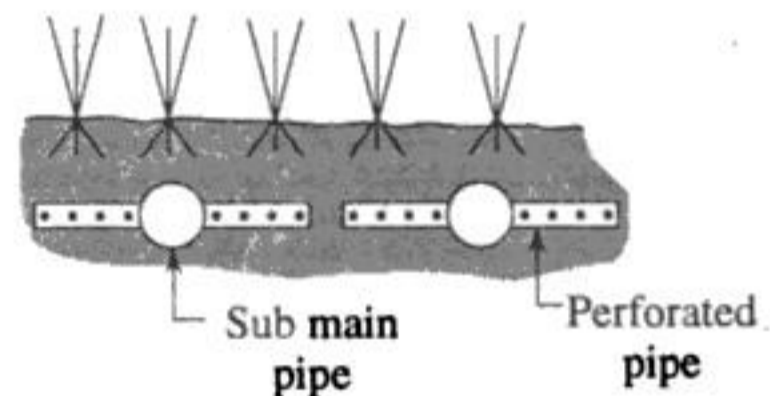


Fig. 1.14 Sub-surface method

C. Sprinkler Method

In this method, the water is applied to the land in the form of spray like rain. The spraying of water is achieved by the network of main pipe, sub-main pipes and lateral pipes.

The lateral pipes may be perforated at the top and sides through which the water comes out in the form of spray and spreads over the crop in a particular area. Again, the lateral pipes may contain series of nozzles through which the water comes out as fountain and spreads over in a particular area.

Now-a-days, the lateral pipes consists of riser pipes with rotating arms at the top. The arms are fitted with nozzles. So, the water gets distributed on a circular area when the arms are rotated on the vertical axis by electrical motor coupled with belt and Pulley System. The network of pipe lines are supported on pillars and the water is forced through the pipe lines by pumping unit. The following are different forms of sprinklers

- (a) Perforation on lateral pipes
- (b) Fixed nozzles on lateral pipes
- (c) Rotating sprinklers.

(a) Perforation on Lateral Pipes

In this type, the lateral pipes are perforated along the top and sides. The water is sent under pressure by a pumping unit through the main pipe, sub-main pipes and lateral pipes. The water comes out through the perforations in all directions in the form of spray. The spacing of lateral pipes should be such that the whole area may be evenly sprayed with water. The lateral pipes are supported on pillars (Fig. 1.15).

(b) Fixed Nozzles on Lateral Pipes

In this type, a series of nozzles are fixed along the lateral pipes. The spacings of the nozzles are such that the water may cover the whole area evenly. The lateral pipes are supported on pillars. When the water is forced under pressure through the network of pipes, it comes out as fountain through the nozzles and spreads over the land (Fig. 1.16).

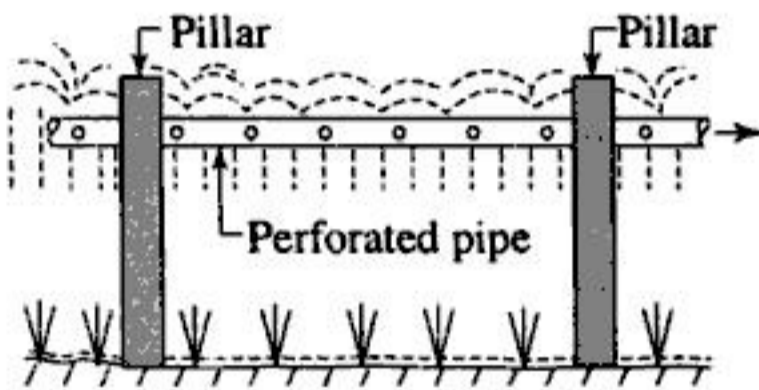


Fig. 1.15 Perforated lateral pipes

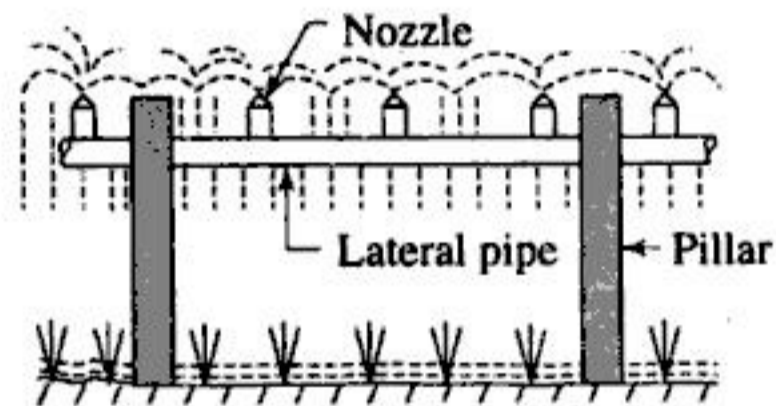


Fig. 1.16 Fixed nozzles

(c) Rotating Sprinklers

In this type, the riser pipes are fixed on the lateral pipes at a regular intervals. On the top of the riser pipe are two arms which can rotate about a vertical axis. The upper ends of the arms consists of nozzles. When the water is forced under pressure through the main, sub-main and lateral pipes, it rises up and comes out through the nozzles in the form of spray. As the arms rotate, a circular area is covered by each riser (Fig. 1.17).

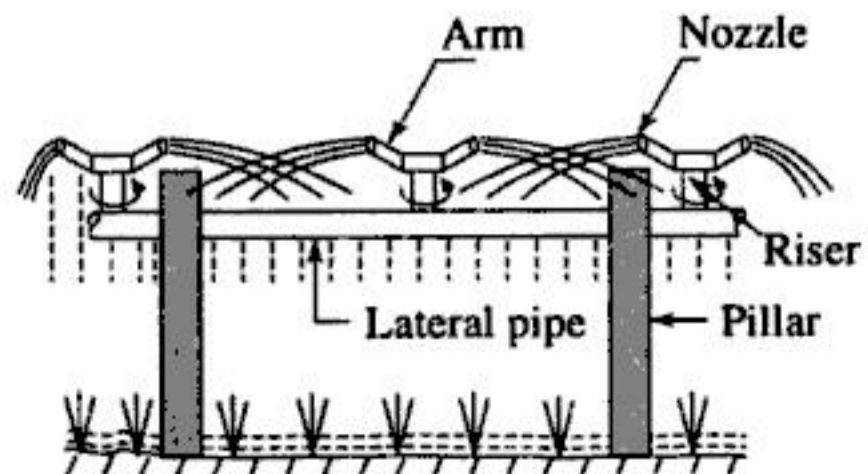


Fig. 1.17 Rotary sprinklers

1.8 IRRIGATION PROJECT SURVEYING

1. Availability of Irrigation Water

When it is found necessary to take up an irrigation project, the availability of required water should be investigated. The following points should be considered

12 Irrigation Engineering

- (a) Whether any perennial river is available near the command area or not.
- (b) If an inundation river is available, the maximum discharge of that river is to be ascertained from the highest flood level mark (as indicated by the villagers residing near the bank of the river).
- (c) From various investigations (i.e. maximum discharge, rainfall etc.) it is necessary to ascertain whether the river will be able to meet the total water requirement or not.

2. Selection of Probable Site for Barrage or Dam

When the source of water is available, the suitable site for the barrage or dam should be found out considering the following points,

- (a) The course of the river should be straight at least for a distance of about one kilometre both on the upstream and down-stream side of the site.
- (b) The width of the river should be minimum and the section of the river should be well-defined.
- (c) A suitable basin should be available for the storage reservoir.
- (d) The elevation of the site should be higher than that of the culturable command area.
- (e) The storage reservoir should not submerge much valuable land.
- (f) The capacity of the reservoir should fulfil the total water requirement.

3. Discharge Observation for the River

The gauge and discharge observation station should be established at the proposed site to collect the following data,

- (a) The daily discharge, maximum discharge and minimum discharge of the river throughout the year should be recorded.
- (b) Silt analysis should be carried out in rainy season (when the river carries much silt) to determine the nature of sedimentation in river or reservoir.
- (c) Discharge observations should also be carried out for all the rivers crossing the proposed canal. This is required for designing cross-drainage works.

4. Marking of Gross Command Area and Culturable Area

When it is decided to take up the project, the gross command area should be marked on the topographical map. The culturable areas should be defined on the map to find the culturable command area that is to be included in the project.

5. Marking of Alignment of Main Canal

The alignment should be marked on the topographical map of the concerned area. While marking the alignment the following points should be kept in mind

- (a) The alignment of the main canal should be taken in such a way so that unnecessary cutting and banking is avoided.
- (b) The alignment of the main canal should be such that the branch canals can be taken suitably to cover the whole culturable area.

- (c) The alignment should cross the rivers, roads, railways lines etc. perpendicularly as much as possible.
- (d) The alignment should not be taken through the valuable agricultural land.
- (e) The alignment should not pass through the thickly populated areas, religious places, burial grounds, etc.

6. Preliminary Location Survey

The reconnaissance survey should be carried out along the alignment to record necessary data such as obstacles, road crossings, railway crossings, river crossings, etc. This survey involves the following procedures.

- (i) The approximate distance along the alignment should be measured by pacing and the magnetic bearings of the traverse legs (open traverse) and it should be noted in the field book.
- (ii) The objects and the nature of the ground on both sides of the alignment should also be noted in the field book.
- (iii) The alignment may be diverted to avoid religious places, valuable structures, etc.
- (iv) The alignment should be made to cross the rivers perpendicularly.
- (v) An index map should be prepared for the alignment.

7. Final Survey

(a) Final Location of Barrage or Dam Site The final location of the barrage or dam site involves the following steps.

- (i) The centre line of the barrage or dam site should be marked with pillars on both banks of the river.
- (ii) The cross-section of the barrage site should be taken very precisely.
- (iii) Cross-sections should be taken at regular interval on the upstream side of the barrage site to ascertain the storage capacity of the reservoir.
- (iv) Boring test should be carried out along the centre line of the barrage site to determine the depth and nature of foundation.

(b) Route Survey A prismatic compass survey or planetable survey should be conducted along the alignment of the main canal to prepare a route survey map of the area covering a distance of about 30 m on both sides of the alignment.

(c) Longitudinal Levelling The longitudinal levelling should be done along the alignment of the main canal. Generally, the staff readings are taken at an interval of 20 m along the centre line of the main canal. The magnetic bearings of the lines (traverse legs) should also be noted in the level book. Longitudinal levelling for the branch canals should also be done.

(d) Cross-Sectional Levelling The cross-sectional levelling at regular intervals along the alignment of the main canal should be taken. The cross-sections for the branch canals also should be taken. These cross-sections are required for the computation of volume of earth work.

(e) Data for Cross-Drainage Work At the places of river crossings, road crossings, railway crossings etc. additional data should be collected for designing cross-drainage works. At the sites of river crossings the gauge and discharge observation stations should be established.

(f) Soil Survey The soil survey should be conducted along the alignment. It consists of collecting the sample of soil by boring up to the depth until impervious layer is obtained.

(g) Well Observation Well observation should be carried out along the alignment. This operation consists of measuring the water level of the wells existing on both sides (within 50 m) of the alignment. This is done to know the nature of water table along the course of the canal.

8. Preparation of Drawings

- (i) Route survey map (to suitable scale).
- (ii) Longitudinal sections for the main and branch canals with formation level (to suitable scale)
- (iii) Cross-sections of main and branch canals with formation level (to suitable scale).
- (iv) Contour map along the alignment.
- (v) Design of curves with setting out table.

9. Office Works

- (i) The sections of the canals should be designed.
- (ii) The detailed estimate should be prepared to know the volume of earth work in cutting or banking along the main canal and branch canals.
- (iii) The total land width required should be marked on the route survey map.
- (iv) The design of the barrage or dam, cross-drainage works and other allied structures should be completed.
- (v) The detailed report should be prepared for the compensation. It includes the names of owners, location, amount of properties, valuation of the land, etc.
- (vi) The total cost of the project should be ascertained by considering all the aspects.

10. Justification of the Selection of Final Alignment

After preliminary survey, the estimates for the tentative alignments (if taken) are prepared. Then by comparing the total costs, working feasibility, etc. with the alignments the final alignment is selected.

11. Final Location Survey

The final location survey of the approved alignment of the canal should be carried out for the execution of the project works. It includes the following:

- (i) The centre line of the main and branch canals should be marked with concrete pillars at an intervals of 30 m or 50 m.

- (ii) The total land width required for the main and branch canals should be marked with pillars at suitable intervals.

1.9 IRRIGATION PROJECT REPORT

1. Introduction

The introduction of the project includes the following points:

- (a) Aim of the project.
- (b) Location of the project.
- (c) Total area to be covered within the project.
- (d) Total population to be benefitted by the project.
- (e) Future prospect if irrigation is practised.
- (f) Stages of future development.
- (g) Total cost of the project.

2. Necessity and Economic Justification of the Project

To justify the necessity and economical development of the area, the following points should be clearly illustrated

- (a) Amount of yearly rainfall.
- (b) Nature of distribution of rainfall during the crop season.
- (c) Types of major crops grown in the area.
- (d) Total water requirement of the crops.
- (e) Amount of water requirement by irrigation system.
- (f) Expected increase in yield of crops, if irrigation is practised.
- (g) Total revenue expected.

3. Report on Land Acquisition and Compensation

A detailed statement should be prepared showing the names of owners, types of properties, quantity, amount of compensation, etc. The procedure adopted for the land acquisition should be clearly mentioned.

4. Details of Design and Drawing of Hydraulic Structures

The detailed design procedure and drawing of hydraulic structures, canals and other allied structures should be incorporated.

5. Detailed Estimate

The detailed estimate for all the works of the project should be incorporated.

6. Specification

The specifications of the construction materials and different works should be clearly mentioned.

7. Availability of Materials and Labourers

The source of construction materials and places of recruitment of labourers should be mentioned.

8. Communication

The existing communication to the selected barrage or dam site should be pointed out. If new communication is required for inaccessible site, the possible route should be pointed out and the expenditure for the new route should be included in the project.

9. Maps to be Submitted

- (a) Topographical map of the area showing the canal alignment and barrage or dam site.
- (b) Route survey map.
- (c) Longitudinal sections.
- (d) Cross-sections.
- (e) Contour map of alignment.
- (f) Detailed drawing of barrage or dam, cross-drainage works, etc.

10. Conclusion and Recommendation

After furnishing all the aspects of the project, the proposal is forwarded to the higher authority with proper recommendation for the necessary approval.

1.10 IMPORTANT IRRIGATION PROJECTS IN INDIA

1. Bhakra Nangal Project

It is a multipurpose project for irrigation and hydro-electric power generation. It consists of Bhakra dam which is 518 m long and 226 m high. The dam is constructed across the river Sutlej in Bilaspur district of Himachal Pradesh. The storage reservoir is known as Govind Sagar reservoir. The area of the reservoir is about 150 sq. km. A barrage is constructed at Nangal which is 305 m long and 29 m high. The main canal is of length 174 km and the culturable command area is 15 lakh hectares in Punjab, Haryana and Rajasthan. The project consists of four hydro-electric power generation stations. Two at the toe of the dam and other two at Gangwal and Kotla. The total power generation capacity of the project is about 1200 MW.

2. Damodar Valley Project

This project is situated in West Bengal. It is a multipurpose project for irrigation, navigation, flood control and hydro-electric power generation. The overall development of the Damodar Valley is achieved by the components described here.

(a) Tilaiya Dam It is about 365 m long and 30 m high constructed across the river Barakar.

(b) Konar Dam It is about 3550 m long and 49 m high constructed across the river Konar.

(c) Maithan Dam It is also constructed across the river Barakar. The length of the dam is about 1005 m and the height is about 35 m.

(d) Panchet Dam It is constructed across the river Damodar. The height and the length of the dam is about 30 m and 2570 m respectively.

(e) Durgapur Barrage It is 672 m long and 12 m high constructed across the river Damodar. An irrigation cum navigation canal of length 137 km is taken off from the left bank. A canal of length 88 km is taken off from the right bank for irrigation only.

The power generation capacity of the project was initially 105 MW. Now, the capacity has been increased stage by stage. The total culturable command area is about 3.75 lakh hectares.

3. Farakka Barrage Project

This barrage is situated in West Bengal. It is constructed across the river Ganges at Farakka in Murshidabad district. It is a part of the main project "Ganga-Brahmaputra navigation cum irrigation project." A right bank feeder canal has been taken off from the barrage to connect the river Bhagirathi to keep it navigable throughout the year. This barrage serves an important role for roadway and railway communication with West Bengal, Bihar and Assam. The proposed link canal will be excavated from Mahananda barrage (at Sonapur) to Farakka barrage for the purpose of irrigation and Navigation.

4. Gandak Project

This is situated in Champaran district of Bihar just close to India-Nepal border. A barrage of length 740 m and height 10 m has been constructed across the river Gandak. It is a multipurpose project for irrigation and hydro-electric power generation. The total culturable area is about 15 lakh hectares. The hydro-electric power generation capacity is 15 MW.

5. Godavari Barrage Project

This project is situated in Andhra Pradesh. A barrage of length 3600 m with 174 number of bays has been constructed across the river Godavari. A feeder canal has been taken from the barrage to feed Godavari delta canal system to irrigate an area of about 5 lakh hectares.

6. Hirakud Project

The project is situated in Orissa. It consists of a dam of length 4800 m and height 60 m constructed across the river Mahanadi at Sambalpur district. The culturable area of the project is about 2.5 lakh hectare The hydro-electric power generation capacity is about 270 MW.

7. Mahanadi Delta Project

This project is situated in Orissa. It is executed in two stages.

First Stage It consists of the remodelling work of the following

- (a) A barrage has been constructed across the river Mahanadi near Cuttack. This is a remodelling work of an old weir.

18 Irrigation Engineering

- (b) Another barrage has been constructed across the river Birupa which is also a remodelling work of an old weir.
- (c) A link canal has been taken off from the barrage to connect existing canal system to irrigate an area of about 3 lakh hectares.

Second Stage It is completely a new project. In this stage a weir is constructed across the river Mahanadi at Mundali to irrigate an area of about 5.50 lakh hectares.

8. Mayurakshi Project

This project is situated in West Bengal. It consists of a dam of length 640 m and height 47 m constructed across the river Mayurakshi. A barrage has been constructed across the same river a few kilometre down stream of the dam. The total culturable area of the project is about 3 lakh hectares.

9. Kangsabati Project

This project is situated in West Bengal. It consists of two dams. One has been constructed across the river Kangsabati and the other has been constructed across the river Kumari both in Bankura district. These two dams have been connected by a dyke to form a single reservoir. The total culturable area of this project is about 4 lakh hectares.

10. Kosi Project

The project is situated in Bihar. A barrage of length about 1144 m has been constructed across the river Kosi on India–Nepal border. Eastern Kosi canal system irrigates a vast area of India and Nepal. A hydro-electric power generation station of capacity 25 MW has been installed. Western Kosi canal system has been included in this project at a later stage.

11. Tungabhadra Project

It is situated in Karnataka. A masonry dam of length 2440 m and height 50 m has been constructed across the river Tungabhadra in Bellary district. It is a multi-purpose project for irrigation and hydro-electric power generation. The total culturable area is about 3.5 lakh hectares. The total power generation capacity is about 100 MW.

12. Ukai Project

It is situated in Gujarat. A composite dam of length 4928 m and height 69 m has been constructed across the river Tapi near Ukai village in Surat district. It is a multipurpose project for irrigation, flood control and hydro-electric power generation. The total culturable area is 2 lakh hectares. The hydro-electric power generation capacity is 75 MW.

REVIEW QUESTIONS

1. Fill up the blanks with appropriate word/words
 - (i) For the growth of the crops _____ of water should always be required.
 - (ii) When the seasonal rainfall _____ the minimum requirement for the growth of crops, the irrigation is necessary.
 - (iii) When the seasonal rainfall is _____ distributed during the crop period, the irrigation is necessary.
 - (iv) In desert area the rainfall is very _____.
 - (v) Vegetable, fruits, tobacco, etc. are known as _____.
 - (vi) The root zone of crops and the soil may get _____ due to excessive seepage of water through canal banks.
 - (vii) Seepage and leakage of water from the irrigation canal may form _____.
 - (viii) In lift irrigation _____ areas can be irrigated.
 - (ix) When the water level of a river is to be raised to some required height, then a _____ is constructed.
 - (x) When the water of the river is required to be fixed at different levels at different times, then a _____ is constructed.
 - (xi) When a storage reservoir is to be formed, then a _____ is constructed.
 - (xii) For the irrigation of potato, groundnut, sugarcane the _____ of distribution of water is adopted.
 - (xiii) In hilly area, the _____ method of distribution of water is adopted.
 - (xiv) For the irrigation of orchard, the _____ is adopted.
 - (xv) The sub-surface method of distribution of water is suitable for the lands consisting of _____.
2. Define irrigation, state the points to be considered while recommending the necessity of irrigation.
3. State the advantages and disadvantages of irrigation.
4. Differentiate between the lift irrigation and flow irrigation.
5. Name the methods of distribution of water adopted for the following crops and describe the methods with sketch
 - (a) Potato
 - (b) Orchard
 - (c) Paddy (in plane terrain)
6. What are the different types of sprinkler method of distribution of water? Describe briefly, with a neat sketch.
7. Write short notes on any four of the major irrigation projects in West Bengal.
8. Write short notes on any five of the major irrigation projects in India.

9. Enumerate the procedure of irrigation project survey.
10. State, briefly, the procedure of preparation of irrigation project report.

ANSWERS

1. (i) adequate quantities (ii) is less than
(iii) not evenly (iv) scanty
(v) cash crops (vi) alkaline property
(vii) marshy lands (viii) isolated small
(ix) weir (x) barrage
(xi) dam (xii) furrow method
(xiii) contour farming (xiv) Basin method
(xv) sandy soil



WATER REQUIREMENT OF CROPS AND SOIL-WATER RELATIONSHIP

2.1 INTRODUCTION

For proper growth and maturity of the crops, water is of vital importance throughout the crop period. The water requirement may vary from crop to crop, from soil to soil and from period to period. Again, the total water requirement for a crop is not supplied at a time, but at a fixed interval so that the root zone of the crop may remain saturated throughout the crop period. Generally, the seasonal rainfall cannot meet the total water requirement. Hence, the additional requirement is fulfilled by the irrigation system.

The irrigation engineer should be acquainted with the type of soil, characteristics of soil moisture, quality of irrigation water, frequency of irrigation etc. for the proper implementation of irrigation system.

2.2 FACTORS AFFECTING THE WATER REQUIREMENT

The following are the factors that affect the water requirement of crops

(a) Water Table If the water table is nearer to the ground surface, the water requirement will be less. If it is much below the ground surface, the water requirement will be more.

(b) Climate In hot climate, the evaporation loss is more and hence the water requirement will be more and *vice versa*.

(c) Ground Slope If the slope of the ground is steep, the water flows down very quickly and the soil gets little time to absorb requisite moisture resulting in water loss. So, the water requirement will be more. But if the ground is flat, the water flows slowly and the soil gets sufficient time to absorb the requisite moisture. So, the water requirement is less.

(d) Intensity of Irrigation If the intensity of irrigation for a particular crop is high, then more area comes under the irrigation system and the water requirement is more and *vice versa*.

(e) Type of Soil In sandy soil water percolates very quickly and cannot be retained. So, water requirement is more. But the clayey soil can retain water near the root zone of crops. So, it requires less water.

(f) Method of Application of Water In surface method more water is required to meet up evaporation loss. In sub-surface method less water is required as the soil just absorbs the optimum moisture. In sprinkler method also less water is required as it just moistens the soil like rainwater.

(g) Method of Ploughing In deep ploughing (by tractor) less water is required, because the soil can retain moisture for longer period. But in shallow ploughing (by bullocks) more water is required as the soil cannot retain moisture for a longer period due to evaporation.

2.3 DEFINITION OF IMPORTANT TERMS

1. Gross Command Area (G.C.A.)

The whole area enclosed between an imaginary boundary line which can be included in an irrigation project for supplying water to agricultural land by the network of canals is known as Gross Command Area (G.C.A.). It includes both the culturable and unculturable areas (Fig. 2.1).

2. Unculturable Area

The area where the agriculture cannot be done and crops cannot be grown is known as unculturable area. The marshy lands, barren lands, lakes, ponds, forests, villages, etc. are considered as unculturable area.

3. Culturable Area

The area where the agriculture can be done satisfactorily is known as culturable area.

4. Culturable Command Area (C.C.A.)

The total area within an irrigation project where the cultivation can be done and crops can be grown is known as Culturable Command Area (C.C.A.). Again C.C.A. may be of two categories.

(a) Culturable Cultivated Area It is the area within C.C.A. where the cultivation has been actually done at present.

(b) Culturable Uncultivated Area It is the area within the C.C.A. where cultivation is possible but it is not being cultivated at present due to some reasons.

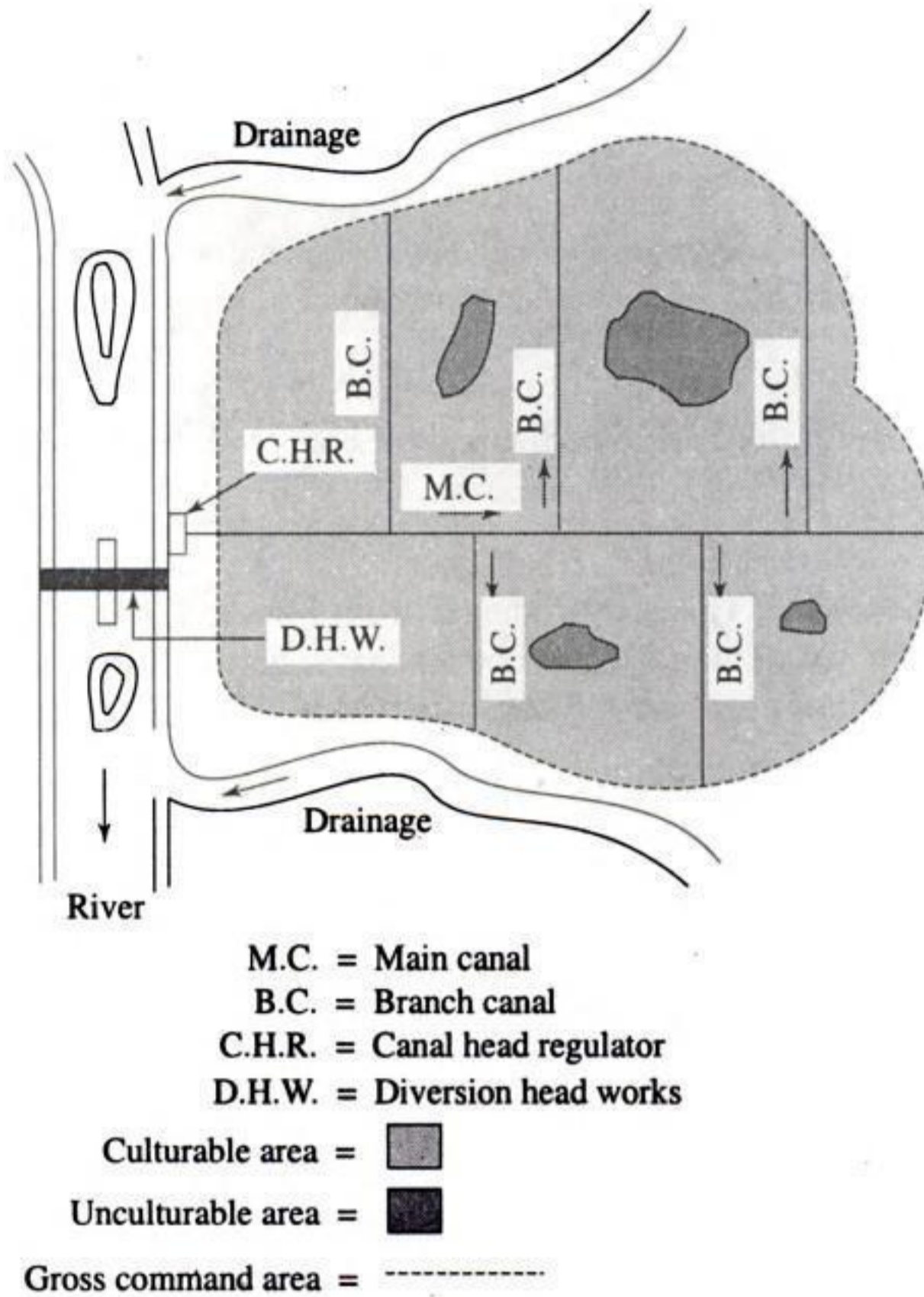


Fig. 2.1 Gross command area

5. Intensity of Irrigation

The total culturable command area may not be cultivated at the same time in a year due to various reasons. Some area may remain vacant every year. Again, various crops may be cultivated in the culturable command area. So, the intensity of irrigation may be defined as a ratio of cultivated land for a particular crop to the total culturable command area. It is expressed as a percentage of C.C.A. For example, if total culturable command area is 1000 hectares where wheat is cultivated in 250 hectares, then,

$$\text{Intensity of irrigation for wheat} = \frac{250}{1000} \times 100 = 25\%.$$

So, area to be irrigated = C.C.A. × Intensity of irrigation.

6. Crop Ratio

It is defined as the ratio of the areas of the two main crop seasons, e.g. *Kharif* and *Rabi*.

For example, if the area under Kharif crop is 2500 hectares and the area under Rabi crop is 5000 hectares then, crop ratio of *Kharif* to *Rabi* is 1 : 2 (i.e. C.R. = $\frac{2500}{5000} = 1:2$)

The crop ratio should be so selected that the discharge of the canal for supplying water to *Kharif* and *Rabi* may be nearly equal.

7. Crop Season

The period during which some particular types of crops can be grown every year on the same land is known as crop season. The following are the main crop seasons.

(a) Kharif Season This season ranges from June to October. The crops are sown in the very beginning of monsoon and harvested at the end of autumn.

The major kharif crops are—Rice, Millet, Maize, Jute, Groundnut, etc.

(b) Rabi Season This season ranges from October to March. The crops are sown in the very beginning of winter and harvested at the end of spring. The major *Rabi* crops are—Wheat, Gram, Mustard, Rapeseed, Linseed, Pulses, Onion, etc.

Again there are several crops which are not included in *Kharif* and *Rabi* as they require more time and they cover both the main seasons.

As for example, cotton requires eight months to mature and sugarcane requires about whole year to mature. Hence, they are designated as follows,

- (i) Cotton—eight month's crop.
- (ii) Sugarcane—perennial crop.

8. Cash Crop

The crops which are cultivated by the farmers to sell in the market to meet their current financial requirements are known as cash crops. The crops like vegetables, fruits, etc. are considered as cash crops.

9. Crop Rotation

The process of changing the type of crop for the cultivation on the same land is known as crop rotation. It is found that if same crop is cultivated on the same land every year, the fertility of the land gets reduced and the yield of crop also gradually reduces. This is so because the necessary salts required for the growth of a particular crop get exhausted. It is found by experiment that if the principle of crop rotation is practised, the fertility of the soil can be restored.

Few crop rotation possible are

- (i) Rice—Gram.
- (ii) Wheat—Millet—Gram.
- (iii) Rice—Gram—Wheat.

10. Crop Period

The crop period is defined as the total period from the time of sowing a crop to the time of harvesting it. That means, it is the period in which the crop remains in the field.

11. Overlap Allowance

Sometimes a crop of one season may overlap the next crop season by a few days more which it requires to mature. During this period of overlapping the irrigation water is to be supplied simultaneously to the crops of both the seasons. Due to the extra demand of water during this period, the discharge of the canal has to be increased. So, for the purpose of canal design, a provision should be made for this extra demand. This provision is termed as *overlap allowance*. This is expressed in percentage.

12. Time Factor

The ratio of the number of days the canal has actually been kept open to the number of days the canal was designed to remain open during the base period is known as *Time factor*.

For example, a canal was designed to be kept open for 15 days, but it was practically kept open for 10 days for supplying water to the culturable area. Then

the time factor is $\frac{10}{15}$.

So,

$$\begin{aligned} \text{Time factor} &= \frac{\text{No. of days the canal practically kept open}}{\text{No. of days the canal was designed to keep open}} \\ &= \frac{\text{Actual discharge}}{\text{designed discharge}} \end{aligned}$$

13. Capacity Factor

Generally, a canal is designed for a maximum discharge capacity. But, actually it is not required that the canal runs to that maximum capacity all the time of the base period. So, the ratio of the average discharge to the maximum discharge (designed discharge) is known as capacity factor.

For example, a canal was designed for the maximum discharge of 50 cumec, but the average discharge is 40 cumec.

So, Capacity factor = $\frac{40}{50} = 0.8$.

14. Number of Watering

The total depth of water required by a crop is not supplied at one time. But, it is supplied over the base period by stages depending upon the requirement.

The initial watering which is done on the land to provide moisture to the soil just before sowing any crop is known as paleo or paleva.

The first watering is done when the crop has grown to about three centimetres. This watering is known as *Kor* watering and the period is known as *Kor* period.

Subsequent watering is done at some regular intervals during the base period till the crop attains maturity.

The number of watering depends on the type of soil, base period, soil condition, climatic condition etc.

15. Cumec Day

The quantity of water flowing continuously for one day at the rate of one cumec is known as cumec-day.

$$\begin{aligned} 1 \text{ cumec-day} &= \frac{1 \text{ m}^3}{\text{sec.}} \times 24 \times 60 \times 60 \text{ secs.} \\ &= 24 \times 60 \times 60 \text{ m}^3 \\ &= \frac{24 \times 60 \times 60}{10,000} \times 1 \text{ m (1 hectare = 10 000 m}^2\text{)} \\ &= 8.64 \text{ hectare-metre.} \end{aligned}$$

16. Arid Region

The area where the rainfall is very scanty and occurs irregularly and where the agriculture is not at all possible is known as arid region.

2.4 BASE, DELTA AND DUTY

Base The base is defined as the period from the first to the last watering of the crop just before its maturity. It is also known as base period. It is denoted by 'B' and expressed in number of days. The base period for some common crops are given in Table 2.1.

Table 2.1

<i>Crop</i>	<i>Base in days</i>
Rice	120
Wheat	120
Maize	100
Cotton	200
Sugarcane	320

Delta Each crop requires certain amount of water per hectare for its maturity. If the total amount of water supplied to the crop (from first to last watering) is stored on the land without any loss, then there will be a thick layer of water standing on that land. This depth of water layer is known as Delta for the crop. It is denoted by 'Δ' and expressed in cm. Delta for some common crops is given in Table 2.2.

Table 2.2

<i>Kharif crop</i>	<i>Delta in cm</i>
Rice	125
Maize	45
Ground nut	30
Millet	30
<i>Rabi crop</i>	<i>Delta in cm</i>
Wheat	40
Mustard	45
Gram	30
Potato	75

Duty The duty of water is defined as number of hectares that can be irrigated by constant supply of water at the rate of one cumec throughout the base period. It is expressed in hectares/cumec. and is denoted by 'D'. The duty of water is not constant, but it varies with various factors like soil condition, method of ploughing, method of application of water, etc. The duties of some common crops are given in Table 2.3.

Table 2.3

<i>Crop</i>	<i>Duty in hectares/cumec</i>
Rice	900
Wheat	1800
Cotton	1400
Sugarcane	800

2.5 FACTORS AFFECTING DUTY

The factors that affect the duty are described below.

1. Soil Characteristics If the soil of the canal bed is porous and coarse grained, it leads to more seepage loss and consequently low duty. If the soil is compact and closed grained, the seepage loss will be less and the duty will be high.

If the agricultural land consists of sandy soil, the percolation loss will be high causing the duty to be low. If it consists of alluvial soil, the percolation loss will be less and the soil retains the moisture for longer period and consequently the duty will be high.

2. Climatic Condition When the atmospheric temperature of the command area becomes high, the evaporation loss is more and the duty becomes low and *vice versa*.

3. Rainfall If the rainfall is sufficient during the crop period, less quantity of irrigation water shall be required and therefore the duty will be more and *vice versa*.

4. Base Period When the base period is longer, the water requirement will be more and the duty will be low and *vice versa*.

5. Type of Crop The water requirement of various crops are different. So, the duty varies from crop to crop.

6. Topography of Agricultural Land If the agricultural land is uneven, the water requirement will be more and hence the duty will be low. If the land has slight slope, the duty will be high as water requirement is optimum. As the ground slope increases the duty decreases because there is wastage of water.

7. Method of Ploughing Proper deep ploughing which is done by tractors requires overall less quantity of water and hence the duty is high. But, shallow ploughing with bullocks requires overall more quantity of water, and hence the duty is low.

8. Methods of Irrigation The duty of water is high in case of perennial irrigation system as compared to that in inundation irrigation system. It is so because in Perennial system head regulator is used whereas in inundation system there is no regulator.

9. Water Tax If some tax is imposed on the basis of the volume of water consumption, the farmer will use the water economically, and thus the duty will be high.

2.6 METHODS OF IMPROVING DUTY

The following points should be remembered for improving the duty of water.

1. Proper Ploughing Ploughing should be done properly and deeply so that the moisture retaining capacity of the soil is increased.

2. Methods of Supplying Water The method of supplying water to the agricultural land should be decided according to the field and soil conditions. For example,

Furrow method—for crops sown in rows.

Contour method—for hilly areas.

Basin method—for orchards.

Flooding method—for plain lands.

3. Canal Lining To reduce percolation loss the canals should be lined according to site condition.

4. Transmission Loss To reduce transmission loss the canals should be taken close to the irrigable lands as far as possible.

5. Crop Rotation The principle of crop rotation should be adopted to increase the moisture retaining capacity and fertility of the soil.

6. Implementation of Tax The water tax should be imposed on the basis of volume of water consumption.

2.7 RELATION BETWEEN BASE, DELTA AND DUTY

Let,

D = Duty of water in hectares/cumec

B = Base in days,

Δ = Delta in m

From definition, one cumec of water flowing continuously for ' B ' days gives a depth of water Δ over an area ' D ' hectares. That is,

1 cumec for B days gives Δ over D hectares

or 1 cumec for 1 days gives Δ over $\frac{D}{B}$ hectares

or 1 cumec for 1 day = $\frac{D}{B} \times \Delta$ hectare-metre

So, 1 cumec-day = $\frac{D}{B} \times \Delta$ hectare-metre (1)

Again, 1 cumec-day = $1 \times 24 \times 60 \times 60 = 86400 \text{ m}^3$
 = 8.64 hectare-metre (2)
 (1 hectare = $10,000 \text{ m}^2$)

From (1) and (2)

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

$$\therefore \Delta = \frac{8.64 \times B}{D} = \text{in m.}$$

2.8 NUMERICAL PROBLEMS ON BASE, DELTA AND DUTY

Problem 1 A channel is to be designed for irrigating 5000 hectares in *Kharif* crop and 4000 hectares in *Rabi* crop. The water requirement for *Kharif* and *Rabi* are 60 cm and 25 cm, respectively. The *Kor* period for *Kharif* is 3 weeks and for *Rabi* is 4 weeks. Determine the discharge of the channel for which it is to be designed.

Solution Using the relation.

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

Discharge for Kharif Crop

Here, $\Delta = 60 \text{ cm} = 0.60 \text{ m}$

$B = 3 \text{ weeks} = 21 \text{ days}$

$$\therefore \text{Duty} = \frac{8.64 \times 21}{0.60} = 302.4 \text{ hectares/cumec}$$

Area to be irrigated = 5000 hectares

$$\text{Required discharge of channel} = \frac{5000}{302.4} = 16.53 \text{ cumec}$$

Discharge for Rabi Crop

Here, $\Delta = 25 \text{ cm} = 0.25 \text{ m}$

$B = 4 \text{ weeks} = 28 \text{ days}$,

$$\therefore \text{Duty} = \frac{8.64 \times 28}{0.25} = 967.68 \text{ hectares/cumec},$$

Area to be irrigated = 4000 hectares.

$$\text{Required discharge of channel} = \frac{4000}{967.68} = 4.13 \text{ cumec}$$

So, the channel is to be designed for the maximum discharge of 16.53 cumec, because this discharge capacity of the channel will be able to supply water to both the seasons.

Problem 2 The gross command area of an irrigation project is 1.5 lakh hectares, where 7,500 hectare are unculturable. The area of kharif crop is 60,000 hectares and that of *Rabi* crop is 40,000 hectares. The duty of *Kharif* is 3000 hectares/cumec and the duty of *Rabi* is 4000 hectares/cumec.

Find (a) The design discharge of channel assuming 10% transmission loss.

(b) Intensity of irrigation for *Kharif* and *Rabi*.

Solution Culturable command area = 1,50,000 – 7500 = 142500 hectares.

Discharge for Kharif Crop,

Area of *Kharif* crop = 60,000 hectares.

Duty of *Kharif* crop = 3000 hectares/cumec

$$\text{Required discharge of channel} = \frac{60,000}{3000} = 20 \text{ cumec}$$

Considering 10% loss

$$\text{Design discharge} = 20 \times \frac{110}{100} = 22 \text{ cumec}$$

Discharge for Rabi Crop

Area of *Rabi* crop = 40,000 hectares

Duty of *Rabi* crop = 4000 hectares/cumec

$$\text{Required discharge of channel} = \frac{40000}{4000} = 10 \text{ cumec}$$

Considering 10% loss

$$\text{Design discharge} = 10 \times \frac{110}{100} = 11 \text{ cumec}$$

(a) So, the design discharge of the channel should be 22 cumec, as it is maximum.

$$(b) \text{ Intensity of irrigation for } Kharif = \frac{60,000}{142500} \times 100 = 42.11\%$$

$$\text{Intensity of irrigation for } Rabi = \frac{40,000}{142500} \times 100 = 28.07\%$$

Problem 3 The gross command area of an irrigation project is 1 lakh hectares. The culturable command area is 75% of G.C.A. The intensities of irrigation for *Kharif* and *Rabi* are 50% and 55% respectively. If the duties for *Kharif* and *Rabi* are 1200 hectare/cumec and 1400 hectares/cumec respectively, determine the discharge at the head of the canal considering 20% provisions for transmission loss, overlap allowance, evaporation loss etc.

Solution Culturable command area = $100000 \times \frac{75}{100} = 75,000$ hectares

For *Kharif* crop,

$$\text{Area under } Kharif = 75,000 \times \frac{50}{100} = 37500 \text{ hectares}$$

$$\text{Duty for } Kharif = 1200 \text{ hectares/cumec}$$

$$\text{Required discharge for } Kharif = \frac{37500}{1200} = 31.25 \text{ cumec}$$

For *Rabi* crop,

$$\text{Area under } Rabi = 75,000 \times \frac{55}{100} = 41250 \text{ hectares}$$

$$\text{Duty for } Rabi = 1400 \text{ hectares/cumec}$$

$$\text{Required discharge for } Rabi = \frac{41250}{1400} = 29.46 \text{ cumec}$$

So, to meet up the actual water requirement of the crops, the discharge of the canal at the head of the field should be 31.25 cumec (as it is maximum). Now considering 20% provision for losses,

$$\begin{aligned} \text{Required discharge at the head of canal} &= 31.25 \times \frac{120}{100} \\ &= 37.5 \text{ cumec} \end{aligned}$$

Problem 4 Determine the head discharge of a canal from the following data. The value of time factor may be assumed as 0.75.

Crop	Base period in days	Area in hectare	Duty in hectares/cumec
Rice	120	4000	1500
Wheat	120	3500	2000
Sugarcane	310	3000	1200

Solution Discharge of canal required

$$(a) \text{ For rice} = \frac{4000}{1500} = 2.667 \text{ cumec (Kharif)}$$

$$(b) \text{ For wheat} = \frac{3500}{2000} = 1.750 \text{ cumec (Rabi)}$$

$$(c) \text{ For sugarcane} = \frac{3000}{1200} = 2.500 \text{ cumec (perennial)}$$

As, the base period of sugarcane is 310 days, it will require water both in *Kharif* and *Rabi* seasons.

Now, actual discharge required in *Kharif* season = $2.667 + 2.500 = 5.167$ cumec.

Actual discharge required in *Rabi* season = $1.750 + 2.500 = 4.250$ cumec.

So, the maximum discharge in *Kharif* season (i.e. 5.167 cumec) should be taken into consideration as it will be able to serve both the seasons.

$$\text{Time factor} = 0.75 = \frac{\text{Actual discharge}}{\text{Design discharge}} = \frac{5.167}{\text{Design discharge}}$$

$$\text{Design discharge} = \frac{5.167}{0.75} = 6.889 \text{ cumec}$$

Therefore, the required head discharge of the canal is 6.889 cumec.

Problem 5 Find out the capacity of a reservoir from the following data. The culturable command area is 80,000 hectares.

<i>Crop</i>	<i>Base in days</i>	<i>Duty in hect/cumec</i>	<i>Intensity of irrigation in percentage</i>
Rice	120	1800	25
Wheat	120	2000	30
Sugarcane	320	2500	20

Assume the canal and reservoir losses as 5% and 10% respectively.

Solution Using relation

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

Calculation of delta for each crop

$$\text{delta for rice} = \frac{8.64 \times 120}{1800} = 0.576 \text{ m}$$

$$\text{delta for wheat} = \frac{8.64 \times 120}{2000} = 0.518 \text{ m}$$

$$\text{delta for sugarcane} = \frac{8.64 \times 320}{2500} = 1.106 \text{ m}$$

Calculation of area for each crop

$$\text{Area for rice} = \frac{80,000 \times 25}{100} = 20,000 \text{ hectare}$$

$$\text{Area for wheat} = \frac{80,000 \times 30}{100} = 24000 \text{ hectare}$$

$$\text{Area for sugarcane} = \frac{80,000 \times 20}{100} = 16,000 \text{ hectare}$$

Volume of water required for each crop

We know, volume = area \times delta

$$\therefore \text{Volume for rice} = 20,000 \times 0.576 = 11520.00 \text{ ha-m.}$$

$$\text{Volume for wheat} = 24,000 \times 0.518 = 12432.00 \text{ ha-m.}$$

$$\text{Volume for sugarcane} = 16,000 \times 1.106 = 17696.00 \text{ ha-m}$$

$$\text{Total volume of water} = 41648.00 \text{ ha-m}$$

Considering canal loss of 5%

$$\text{Water required at the head of canal} = 41648 \times \frac{105}{100} = 43730.40 \text{ ha-m}$$

Again considering, reservoir loss of 10%

$$\text{Capacity of reservoir} = 43730.40 \times \frac{110}{100} = 48103.44 \text{ ha-m}$$

Problem 6 The command area of a channel is 4000 hectares. The intensity of irrigation of a crop is 70%. The crop requires 60 cm of water in 15 days, when the effective rainfall is recorded as 15 cm during that period.

Find, (a) The duty at the head of field.

(b) The duty at the head of channel.

(c) The head discharge at the head of channel.

Assume total losses as 15%.

Solution

$$\text{Depth of water required} = 60 \text{ mm}$$

$$\text{Effective rainfall} = 15 \text{ cm}$$

$$\text{Depth of irrigation water} = 60 - 15 = 45 \text{ cm}$$

$$\therefore \text{Delta} = 45 \text{ cm} = 0.45 \text{ m, } B = 15 \text{ days}$$

$$\text{From relation, } \Delta = \frac{8.64 \times B}{D}$$

$$\text{Duty } D = \frac{8.64 \times 15}{0.45} = 288 \text{ hectares/cumec}$$

(a) So, duty at the head of field = 288 ha/cumec. Due to the losses of water the duty at the head of the channel will be reduced.

Here, losses are 15%.

$$(b) \text{ So, the duty at the head of channel} = 288 \times \frac{85}{100} = 244.80 \text{ hect/cumec}$$

(Duty will be reduced due to loss)

$$\text{Total area under crop} = 4000 \times \frac{70}{100} = 2800 \text{ hectares}$$

$$(c) \text{ The discharge at the head of channel} = \frac{2800}{244.8} = 11.438 \text{ cumec}$$

2.9 TYPES OF SOILS

The soils are divided into following four groups.

(a) Alluvial Soils

These soils are formed by the deposition of silt which is carried by the river water during floods. Again, the silt is formed due to the weathering action on the rocks by the heavy current of the river water in the hilly region. The alluvial soils are found in Indo-Gangetic plains, Bramhaputra plains and plains of other big rivers in India. The moisture absorbing capacity of these soils is very good and these are most suitable for agriculture as they possess good manure value.

(b) Black Soils

These soils originated from the weathering action on the rocks like granite, basalt, trap etc. These soils are mainly found in Andhra Pradesh, Madhya Pradesh, Gujarat, Tamil Nadu, etc. The characteristics of black soils are that these are sticky when wet and becomes very hard when dry. The black soil is suitable for the cultivation of cotton.

(c) Red Soils

These are formed by the weathering action on the rocks of igneous and metamorphic groups. These are also known as loam. The water absorbing capacity of red soil is very low. The red soils are found in Karnataka, Tamil Nadu, Maharashtra, Orissa, West Bengal, etc.

(d) Laterite Soils

These are formed by the weathering action on the laterite rocks. These are yellowish-red in colour and possess good drainage property. Laterite soils are found in Malabar, Kerala, Karnataka, Orissa, Assam, etc.

2.10 TYPES OF SOIL WATER

When water is spread over the soil either by irrigation or by rainfall, the water is absorbed by the pores of the soil. This water is termed as soil water or soil moisture. The following are the various forms of soil water.

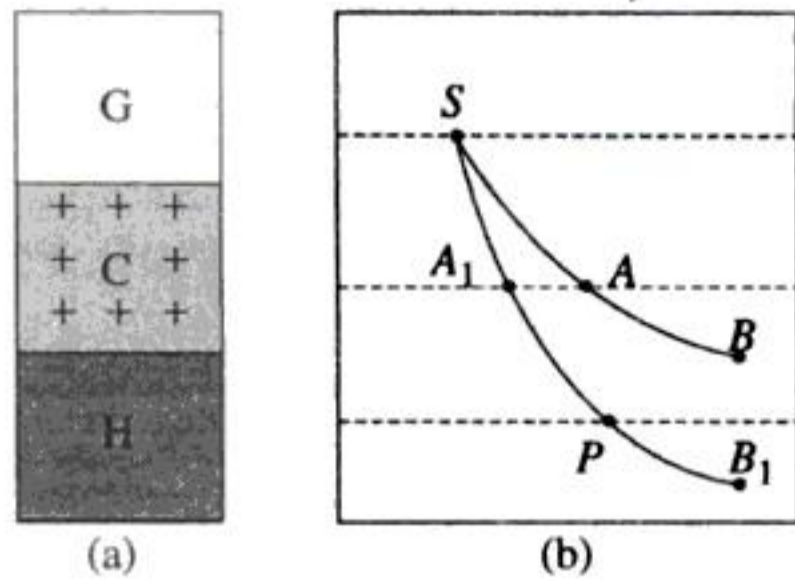
(a) Gravitational Water

When it rains or the irrigation water is supplied to the soil, the water content of the soil goes on increasing until a saturation point is reached (Fig 2.2). At this stage the soil pores are completely saturated and no more water is absorbed by

the soil. The surface water then starts flowing downwards due to the influence of gravity. The portion of water which flows down is known as gravitational water. The gravitational water is not useful for the plants as it flows out rapidly and it cannot be absorbed by the rootzone.

(b) Capillary Water

The portion of the water retained by the soil, after completely eliminating the gravitational water, is known as capillary water. This water gets absorbed by the root of the plants and is held in the capillary pores of the soil particles. The water content goes on reducing gradually due to evaporation and transpiration.



- Gravitational water = □ G
- Capillary water = ▒ C
- Hygroscopic water = ■ H
- S = Saturation point
- AA₁ = Field capacity
- P = Permanent wilting point

Fig. 2.2 Soil water

When there are no plants on the soil water content is reduced only by evaporation which is shown by the curve *SAB* (Fig. 2.2).

When there are plants on the soil, the water content gets reduced both by evaporation and transpiration which is shown by curve *SA₁PB₁*. Here, the point *P* is known as the permanent wilting point, and the water content corresponding to *A* or *A₁* is known as field capacity.

(c) Hygroscopic Water

The water content below the permanent wilting point is known as hygroscopic water. This water is retained by the soil in the form of thin film on the surface of soil particles. This water cannot be extracted or absorbed by the root of the plants. So, at this stage, the growth of the plants is stopped and ultimately the plants are dead.

(d) Field Capacity

The field capacity is defined as the amount of maximum moisture that can be held by the soil against gravity. It is expressed as percentage.

(e) Permanent Wilting Point

The permanent wilting point is defined as the amount of moisture held by soil which cannot be extracted by the plant roots for transpiration. At this point the wilting of the plant occurs. It is also expressed in percentage.

2.11 CONSUMPTIVE USE OF WATER

The consumptive use of water is defined as the total quantity of water used for the growth of the plants by transpiration and the amount lost by evaporation (which is known as evapo-transpiration).

It is expressed in hectare-metre per hectare or as depth of water (in m) for a specified period. The consumptive use of water is ascertained to know the water requirement for each crop. The value of consumptive use of water varies from crop to crop, time to time and even from place to place.

2.12 METHODS OF DETERMINING CONSUMPTIVE USE

The consumptive use of water is determined by the following methods.

(a) Lysimeter Method

In this method, a water tight tank of cylindrical shape having diameter about 2 m and depth about 3 m is placed vertically on the ground. The tank is filled with sample of soil. The bottom of the tank consists of a sand layer and a pan for collecting the surplus water. The consumptive use of water is ascertained by measuring the amount of water required for the satisfactory growth of the plants within the tank. The consumptive use of water is given by

$$C_u = W_a - W_d$$

where C_u = Consumptive use of water,

W_a = Water applied,

W_d = Water drained off.

(b) Field Experimental Method

In this method, some fields are selected for experiment. The quantity of water is applied in such a way that it is sufficient for the satisfactory growth of the crops. There should be no run off or deep percolation. If there is any runoff it should be measured and deducted from the total quantity of water applied. Since, the phenomenon of deep percolation cannot be ascertained in the field to get consumptive use of water some correction for deep percolation may be applied by finding the same (i.e. correction) from field observations.

(c) Soil Moisture Study

In this method, several plots of land are selected where irrigation water is to be supplied. The soil samples are taken from different depths at the root zone of the plants just before and after the irrigation. Then the water contents of the soil samples are ascertained by laboratory tests. The depth of water removed from the soil is determined by relation,

$$D_r = \frac{pwd}{100}$$

where, D_r = Depth of water removed in m; p = Percentage of water content; w = Sp. gr. of soil; d = depth of soil in m.

The total quantity of water removed in 30 days period is calculated. Then a curve of water consumption versus time is prepared. From this curve the water consumption for any period can be ascertained.

2.13 FREQUENCY OF IRRIGATION

The irrigation water is applied to the field to raise the moisture content of the soil up to its field capacity. The application of water is then stopped. The water content also reduces gradually due to transpiration and evaporation. If the moisture content is dropped below the requisite amount, the growth of the plants gets disturbed. So the moisture content requires to be immediately replenished by irrigation and it should be raised to the field capacity. The frequency of irrigation should be worked out in advance so that it can be applied in proper intervals.

The frequency of irrigation may be ascertained by the following expressions,

$$(a) \quad D_w = \frac{W_s \times d}{W_w} \times [F_c - M_o]$$

where, D_w = Depth of water to be applied in each watering; d = Depth of root zone; W_s = Unit wt. of soil; W_w = Unit wt. of water; F_c = Field capacity; M_o = Optimum moisture content.

$$(b) \quad f_w = \frac{D_w}{C_u}$$

where, f_w = Frequency of watering; D_w = Depth of water to be applied in each watering; C_u = Daily consumptive use of water.

Example Determine the frequency of irrigation from the following data.

- (i) Field capacity of soil = 35%
- (ii) Permanent wilting point = 18%
- (iii) Density of soil = 1.5 g/cm³
- (iv) Depth of root zone = 70 cm
- (v) Daily consumptive use of water = 17 mm

Solution

Available moisture = Field capacity – Permanent wilting point = 35 – 18 = 17%.

Let, readily available moisture is 75% of the available moisture,

$$\text{Readily available moisture} = 17 \times 0.75 = 12.75\%$$

$$\text{Optimum moisture content} = 35 - 12.75 = 22.25\%$$

Now, by applying irrigation water the moisture content is to be raised from 22.25% to 35%

From,
$$D_w = \frac{W_s \times d}{W_w} \times [F_c - M_o]$$

Here, $W_s = 1.5 \text{ g/cm}^3$, $W_w = 1 \text{ g/cm}^3$, $d = 70 \text{ cm} = 0.70 \text{ m}$, $F_c = 35\% = 0.35$, $M_o = 22.25\% = 0.2225$.

$$\begin{aligned} D_w &= \frac{1.5 \times 0.70}{1} \times [0.35 - 0.2225] \\ &= 1.05 \times 0.1275 \\ &= 0.133875 \text{ m} \\ &= 13.39 \text{ cm} \end{aligned}$$

Daily consumptive use of water (C_u) = 17 mm = 1.7 cm

From, $f_w = \frac{D_w}{C_u}$

Frequency of irrigation, $f_w = \frac{13.39}{1.7} = 7.87 = 8 \text{ days (say)}$

Hence, water should be applied in the field at an interval of 8 days.

2.14 STANDARD OF IRRIGATION WATER

Absolutely pure water cannot be expected for irrigation. However, there should be some acceptable limits to the impurities so that the yield of crop is not hampered. The following are the impurities that may exist in water.

(a) Sediment Concentration

The sediment of fine silt improve the fertility of land. Whereas other types of sedimentation decreases the fertility. Again, excessive sedimentation creates trouble in canals and reservoirs. So, water should not contain excessive suspended sediment.

(b) Concentration of Soluble Salt

The presence of salts of Calcium, Magnesium, Sodium and Potassium may be injurious to crops if it exceeds the permissible limit. The salt concentration may be measured electrically or it may be computed by laboratory test. The concentration is generally expressed in the following ways,

- (i) When expressed in P.P.M. the amount in excess of 700 P.P.M. is harmful to plants.
- (ii) Electrical conductivity of saline water is expressed in micro mhos/cm the value up to 250 micro mhos/cm is helpful for all crops. But the value from 250 – 750 micro mhos/cm is very injurious for crops.

(c) Proportion of Sodium Ions

Generally, all soils contain Calcium, Magnesium and Sodium ions. The percentage of Sodium ions should be less than 5. If the percentage increases to more than 10, it is injurious to crops. The proportion of sodium ions is designated by a factor which is known as Sodium Absorption Ratio (S.A.R.). The water having

the value of S.A.R. between '0' and '10' is helpful for all crops. The value more than 10 is unsuitable for irrigation.

(d) Concentration of Potentially Toxic Elements

Some elements are toxic to the crops. Initially, Boron is useful for the growth of crops, but its concentration above 0.3 P.P.M may be toxic to the plants. The concentration of selenium is also toxic to the plants.

(e) Bi-Carbonate Concentration

The concentration of Calcium and Magnesium bicarbonates increases the proportion of sodium ions which is hazardous for the plant's life.

(f) Bacterial Contamination

The bacterial contamination of irrigation water is not directly harmful to the plants, but the food grains or fruits which are grown by using bacterial contaminated water may be harmful to human beings.

2.15 IRRIGATION EFFICIENCY

The amount of irrigation water supplied to the land is not fully utilised for the growth of the crops. This is due to various losses. Now, the ratio of the amount of water available (output) to the amount of water supplied (input) is known as Irrigation Efficiency. It is expressed in percentage. The following are the various types of irrigation efficiencies.

(a) Water Conveyance Efficiency (η_c)

It is the ratio of the amount of water applied to the land to the amount of water supplied from the reservoir. It is obtained by the expression,

$$\eta_c = \frac{W_l}{W_r} \times 100$$

where, η_c = Water conveyance efficiency; W_l = Amount of water applied to land, W_r = Amount of water supplied from reservoir.

(b) Water Application Efficiency (η_a)

It is the ratio of the water stored in root zone of plants to the water applied to the land.

It is obtained by the expression,
$$\eta_a = \frac{W_z}{W_l} \times 100$$

where, η_a = Water application efficiency, W_z = Amount of water stored in root zone, W_l = Amount of water applied to land.

(c) Water Use Efficiency (η_u)

It is the ratio of the amount of water used to the amount of water applied.

It is obtained from the relation,

$$\eta_u = \frac{W_u}{W_l} \times 100$$

where, η_u = Water use efficiency; W_u = Water used; W_l = Water applied.

(d) Consumptive use Efficiency (η_{cu})

It is the ratio of the consumptive use of water to the amount of water depleted from the root zone. It is obtained from the expression,

$$\eta_{cu} = \frac{C_u}{W_p} \times 100$$

where, η_{cu} = Consumptive use efficiency; C_u = Consumptive use of water; W_p = Amount of water depleted from root zone.

REVIEW QUESTIONS

1. Fill up the blanks with appropriate word/words:
 - (i) If the _____ is nearer to the ground surface, the water requirement of the crop will be less.
 - (ii) In hot climate the _____ loss is more and hence the _____ will be more.
 - (iii) If the slope of the ground is _____, the water requirement will be more.
 - (iv) In deep ploughing, the soil can _____ moisture for longer period.
 - (v) The total area enclosed between the boundary line of an irrigation project is known as _____.
 - (vi) The area where the agriculture can be done is known as _____.
 - (vii) The season ranges from June to October is known as _____.
 - (viii) The season ranges from October to March is known as _____.
 - (ix) Cotton is known as _____ crop.
 - (x) Sugarcane is known as _____ crop.
 - (xi) The period from sowing a crop to the time of harvesting is known as _____.
 - (xii) The initial watering which is done on the land just before sowing any crop is known as _____.
 - (xiii) The first watering which is done when the crop has grown to few centimetres is known as _____.
 - (xiv) One cumec day is equal to _____ hectare-metre.
 - (xv) The duty of water is expressed in _____.
2. What are the points to be remembered while ascertaining the water requirement of crops?
3. What is the difference between the gross command area and culturable Command area?

4. What is duty? What points do you consider while determining the duty of water?
5. Define base, delta and duty and establish a relation between them.
6. Distinguish between *paleva* and *kor* watering.
7. Distinguish between gravitational water, capillary water and hygroscopic water.
8. What is meant by the frequency of irrigation? Why is the frequency of irrigation ascertained for?
9. What should be the standard of the irrigation water?
10. What are the different types of irrigation efficiency?

ANSWERS

1. (i) Water table (ii) evaporation, water requirement
(iii) steep (iv) retain
(v) gross command area (vi) culturable command area
(vii) *kharif* season (viii) *rabi* season
(ix) eight month's (x) perennial
(xi) crop period (xii) *paleva*
(xiii) *kor* watering (xiv) 8.64
(xv) hectares/cumec



HYDROLOGY

3.1 DEFINITION

The science of studying the different forms of water available above the earth surface or below the earth surface is known as hydrology. It includes the following points.

1. The measurement of precipitation, (i.e. rainfall).
2. The study of water losses due to transpiration, evaporation, absorption and infiltration.
3. Estimation of run-off and peak flow.
4. The procedure of river gauging.
5. Preparation of hydrograph to predict maximum food discharge.
6. The procedure of river training works.
7. The procedure of flood forecasting and flood control works.
8. Availability of underground water.

3.2 IMPORTANCE OF HYDROLOGY

The knowledge of hydrology is very essential for the applications:

- (a) Determination of the capacity of a reservoir from the rainfall records and the yearly discharge observation of a river.
- (b) Determination of peak flow of a river.
- (c) Determination of suitable site for hydro-electric power generation.
- (d) Sources of watersupply in a town or city.
- (e) Methods to be adopted for the flood control.

3.3 SOME TERMS RELATED TO HYDROLOGY

Catchment Area The catchment area of a river means the area from where the surface run off flows to that river through the tributaries, streams, springs etc. The area is bounded by watershed line.

Run-off When it rains, some portion of rain water infiltrates into the soil, some is intercepted by vegetation, some evaporates and the remaining portion flows

over the ground surface to join the rivers, streams, lakes etc. This portion of water which flows over the ground surface is known as surface run off or run-off.

The surface run off is also designated by rainfall excess or effective rainfall.

3.4 HYDROLOGIC CYCLE

The water of the universe always changes from one state to other under the effect of the sun. The water from the surface sources like lakes, rivers, ocean, etc. converts to vapour by evaporation due to solar heat. The vapour goes on accumulating continuously in the atmosphere. This vapour is again condensed due to the sudden fall of temperature and pressure. Thus clouds are formed. These clouds again causes the precipitation (i.e. rainfall). Some of the vapour is converted to ice at the peak of the mountains. The ice again melts in summer and flows as rivers to meet the sea or ocean. These processes of evaporation, precipitation and melting of ice go on continuously like an endless chain and thus a balance is maintained in the atmosphere. This phenomenon is known as hydrologic cycle (Fig. 3.1).

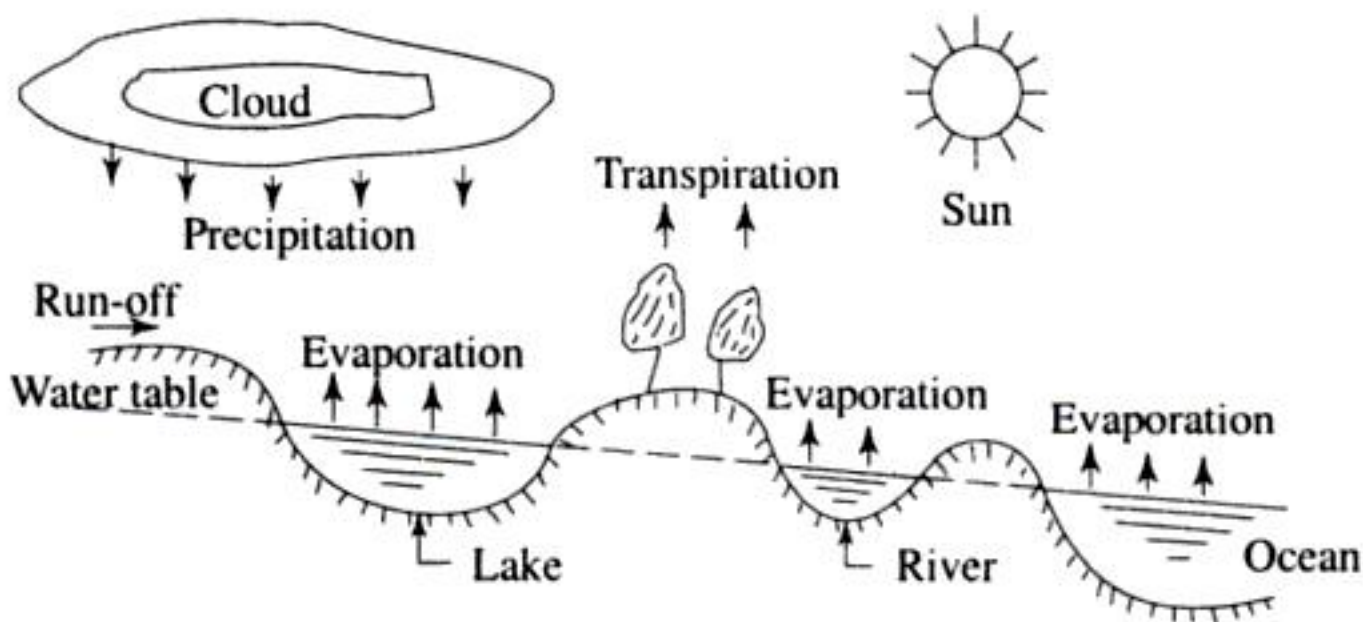


Fig. 3.1 Hydrologic cycle

3.5 HYDROGRAPH

The hydrograph is a graphical representation of the discharge of a river (in cumec) against the time (in hr or days). The discharge is plotted as ordinate (y-axis) and the time is plotted as abscissa (x-axis) (Fig. 3.2).

During the dry season, there is only base flow (i.e. ground water flow) but no surface run off. This may be shown by a line which is approximately straight (not shown in the figure).

In rainy season, at the beginning of the rainfall there is only base flow

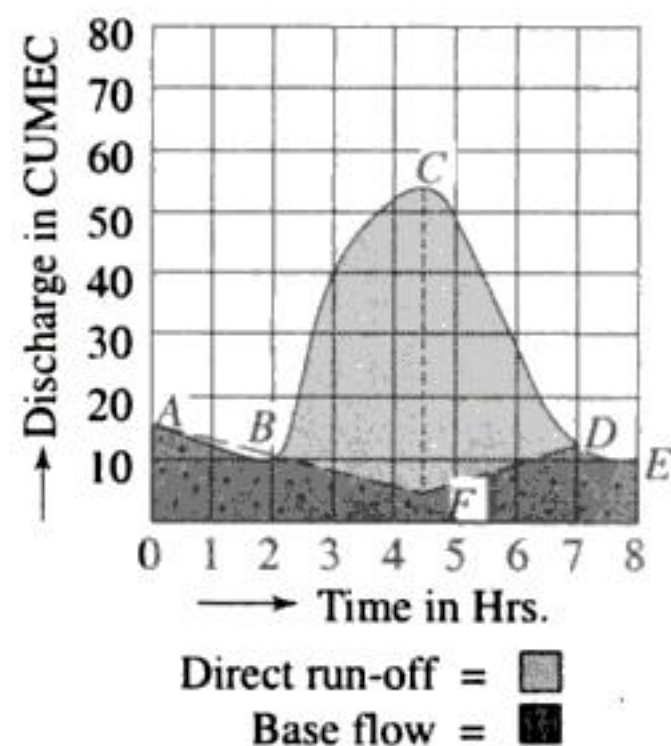


Fig. 3.2 Hydrograph

(shown by the line *AB*). After some period, when the initial losses (like interception, evaporation and infiltration) are fulfilled, the surface runoff starts and hence the discharge of the river goes on increasing. Hence the limb of the curve rises which is called rising limb (shown by the line *BC*). This line reaches to the peak value at 'C'. Again when the rain stops, the flow in the river decreases and the limb of the curve declines. This limb is known as recession limb) (as shown by the line *CD*). The discharge at the point *C* indicates the maximum discharge (i.e. peak discharge or flood discharge). The total area under the curve *ABCDE* indicates the total run off. But this run off includes the base flow and the direct runoff. So, to get the actual run off the base flow is to be deducted by separating it from total area.

The method of separation of base flow is discussed in Sec. 3.8.

3.6 HYETOGRAPH

The graphical representation of rainfall and run-off is known as hyetograph (Fig. 3.3). The graph is prepared with intensity of rainfall (in cm/hr) as ordinate and time (in hrs) as abscissa. The infiltration capacity curve is drawn on this graph to show the amount of infiltration loss (shown by dotted portion). The upper portion indicates the effective rainfall (shown by hatched lines). The centroid of the effective rainfall is ascertained on the graph for the determination of total run-off at any specified period.

3.7 UNIT HYDROGRAPH

A unit hydrograph may be defined as a hydrograph which is obtained from one cm of effective rainfall (i.e. run-off) for unit duration. Here, effective rainfall means the rainfall excess (i.e. run-off) which directly flows to the river or stream. The unit duration is the period during which the effective rainfall is assumed to be uniformly distributed. The unit duration may be considered as 1 hr, 2 hr, 3 hr, 4 hr ..., etc. As for example, if a hydrograph is prepared for an effective rainfall of one cm lasting for 2 hrs, then it is known as 2 hr. unit hydrograph, for the duration of 3 hrs it is known as 3 hr unit hydrograph and so on (Fig. 3.4).

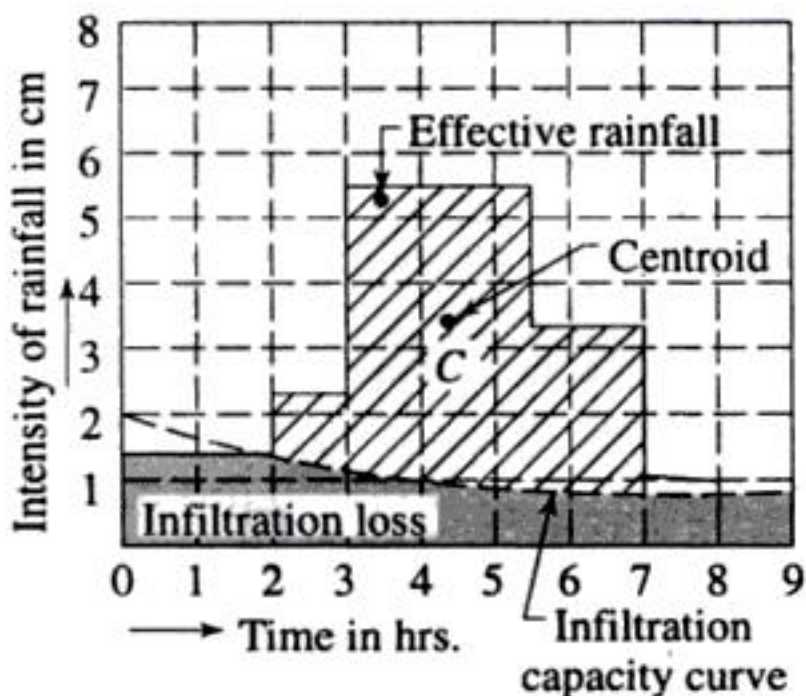


Fig. 3.3 Hyetograph

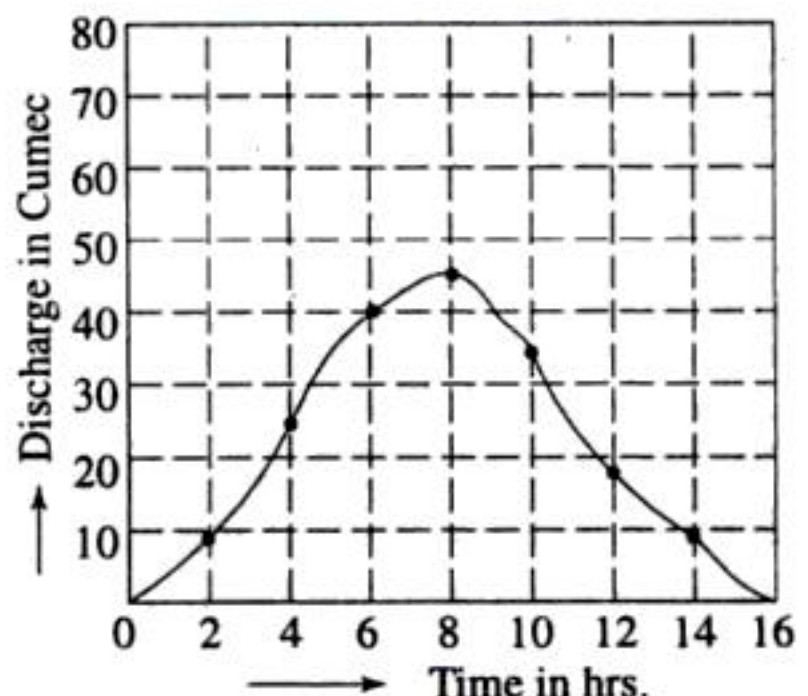


Fig. 3.4 Unit hydrograph

Concept of Unit Hydrograph

The unit hydrograph theory is based on the conception that if two identical storms occur on a drainage basin with identical conditions, then the unit hydrographs of runoff from the two storms may be expected as same. This conception of unit hydrograph was first given by L.K. Sherman in 1932.

Assumptions in Unit Hydrograph Theory The unit hydrograph theory is based on the following assumptions.

- (i) The effective rainfall is evenly distributed during the specified period of time.
- (ii) The effective rainfall is evenly distributed over the whole drainage basin.
- (iii) For a drainage basin, the base period of direct runoff corresponding to effective rainfalls of different intensities is constant, provided unit duration is same.
- (iv) The ordinates of all the hydrographs of a common base period are directly proportional to the total amount of direct run-off. This is also known as principle of linearity.
- (v) The hydrograph of direct run off prepared from a given pattern of effective rainfall remains invariable irrespective of time of occurrence. This is known as principle of time invariance.

Limitations of Unit Hydrograph Theory The following are the limitations of unit hydrograph.

- (i) This theory is not applicable to large areas because uniformly distributed effective rainfall cannot be expected in large area.
- (ii) This theory is not applicable in places where precipitation is composed of snowfall.
- (iii) The principle of time invariance is valid only for specified time and condition of drainage basin.
- (iv) Practically no two storms have the same nature in space and time period. So, it is not possible to construct unit hydrograph for each pattern.
- (v) The principle of linearity is not practically valid for smaller and larger storms.

Advantages of Unit Hydrograph Theory In spite of some limitation of the unit hydrograph theory, the following are the advantages it has

- (i) Flood hydrograph can be prepared quickly for a given basin.
- (ii) It can be utilised for the calculation of ordinates of hydrographs.
- (iii) From the unit hydrograph the expected volume of run-off from a basin can be computed.

Construction of Unit Hydrograph The rainfall records for a specified period are collected from the rain gauge stations of the catchment area. The discharge from the catchment area is also observed for the same period. A hydrograph is prepared from the rainfall records. A discharge hydrograph is also prepared from the recorded discharge. These two data are the basic requirement

for the construction of unit hydrograph. The volume of direct run-off (in cumec) obtained from the hydrograph is converted to cm/sec according to the following method.

The discharge (in cumec) is divided by the catchment area (in m²) to get run-off in cm/sec.

$$\text{i.e. run-off} = \frac{\text{m}^3/\text{sec}}{\text{m}^2} = \text{m}/\text{sec} = \text{m} \times 100 \text{ cm}/\text{sec}$$

Thus the ordinates of the storm hydrograph are obtained and it is prepared accordingly. From the storm hydrograph, the unit hydrograph is constructed.

Construction of Unit Hydrograph from Isolated Storm At first a discharge hydrograph is prepared from the discharge records of the catchment area. Here, the discharge (i.e. run-off) is expressed in cumec. This run-off is converted to cm/sec (as explained earlier) to get the ordinates of storm hydrograph and then storm hydrograph is prepared. From the storm hydrograph the average depth of run off is calculated, suppose it is *D*. Now, to get the ordinates of unit hydrograph the respective ordinates of storm hydrograph is multiplied by a factor $1/D$. The reduced ordinates are plotted at respective points to get the shape of the unit hydrograph.

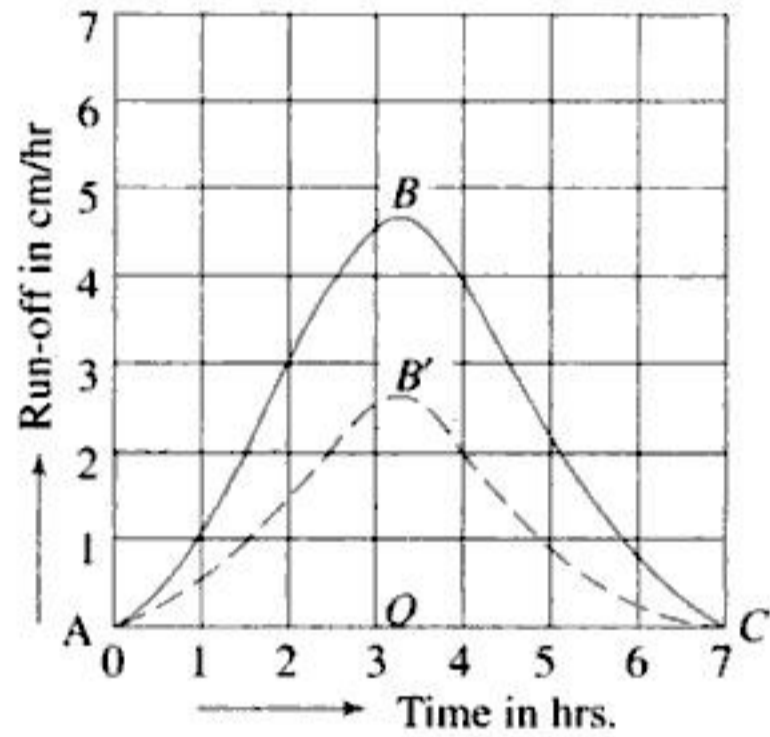


Fig. 3.5 Storm hydrograph

Example In a typical 4 hr storm producing 5 cm of run-off from a basin, the flows in the stream area as follows:

Time in hr	Flow in cumec
0	0.0
2	1.25
4	4.25
6	6.75
8	5.60
12	3.50
16	1.35
20	1.0

Plot the unit hydrograph for this storm.

Solution The storm produces 5 cm run-off. The hydrograph is drawn with the given data (Fig. 3.6). Here, the multiplying factor is $1/5$.

The ordinates of the given hydrograph is to be multiplied by $1/5$ to obtain the respective ordinates of unit hydrograph.

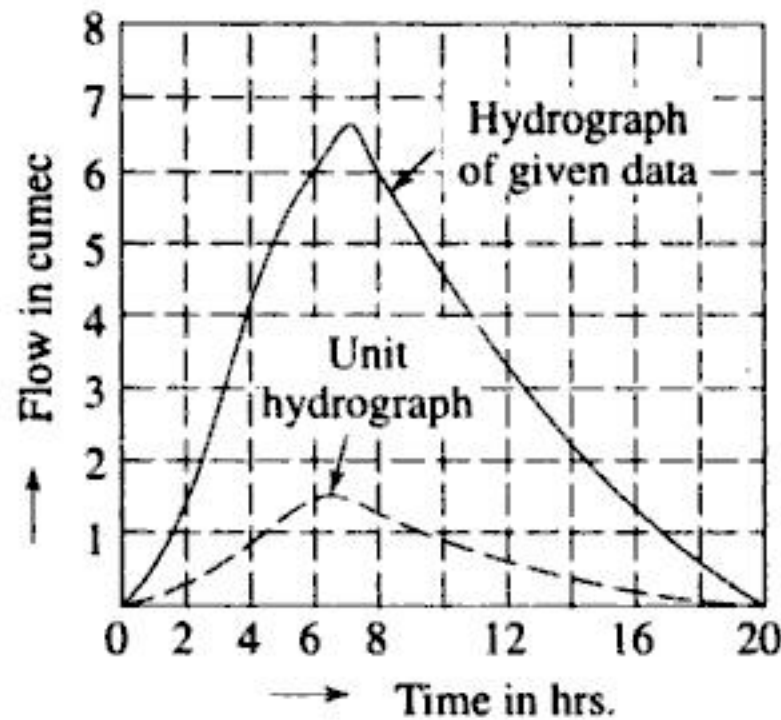


Fig. 3.6 Unit hydrograph

Now, ordinate at 0 = $1/5 \times 0.00 = 0.00$
 ordinate at 2 = $1/5 \times 1.25 = 0.25$
 ordinate at 4 = $1/5 \times 4.25 = 0.85$
 ordinate at 6 = $1/5 \times 6.75 = 1.35$
 ordinate at 8 = $1/5 \times 5.60 = 1.12$
 ordinate at 12 = $1/5 \times 3.50 = 0.70$
 ordinate at 16 = $1/5 \times 1.35 = 0.27$
 ordinate at 20 = $1/5 \times 0.00 = 0.00$

The calculated ordinates are plotted at respective points. The points are joined to get the shape of unit hydrograph (as shown by dotted line in Fig. 3.6).

Construction of Unit Hydrograph for Other Durations The unit hydrograph for different duration may be constructed by the principle of superposition. Suppose, it is required to construct a 9 hr unit hydrograph from 3 hr unit hydrograph. Then 3 hr unit hydrograph is plotted thrice with a time lag of 3 hr. The ordinates of those three overlapping unit hydrograph are summed up to obtain a summation hydrograph of 9 hr. The ordinates of 9 hr summation hydrograph are divided by 3 to obtain the ordinates of 9 hr unit hydrograph.

Example The ordinates of 3 hr unit hydrograph is given in the table. Construct a 9 hr unit hydrograph from it.

Time (hr)	0	3	6	9	12	15	18	21	24	27	30
Discharge (cumec)	0	9	20	25	18	10	8	4	2	1	0

Solution The 3 hr unit hydrograph is arranged thrice with time lag of 3 hr then the ordinates are summed up to get the ordinates of 9 hr summation hydrograph. The ordinates of 9 hr summation hydrograph are divided by 3 to obtain the ordinates of 9-hr unit hydrograph (Table 3.1).

Now, with the ordinates shown in the Column 5 a graph is drawn which represents the summation hydrograph of 9 hr [shown in Fig. 3.7(a)].

With the ordinates shown in the Column 6 a graph is drawn which represents 9 hr unit hydrograph [shown in Fig. 3.7(b)].

Table 3.1

Time (hrs)	3 hr unit hydrograph ordinate	3 hr unit hydrograph with 3 hr offset	3 hr unit hydrograph with 6 hr offset	Summation hydrograph	9 hr unit hydrograph ordinates
1	2	3	4	5 = (2 + 3 + 4)	6
0	0	-	-	0	0
3	9	0	-	9	3
6	20	9	0	29	9.67
9	25	20	9	54	18
12	18	25	20	63	21
15	10	18	25	53	17.67
18	8	10	18	36	12
21	4	8	10	22	7.67
24	2	4	8	14	7.33
27	1	2	4	7	2.33
30	0	1	2	3	1
33	-	0	1	1	0.33
36	-	-	0	0	0
	97.0	97.0	97.0	291.0	97.0

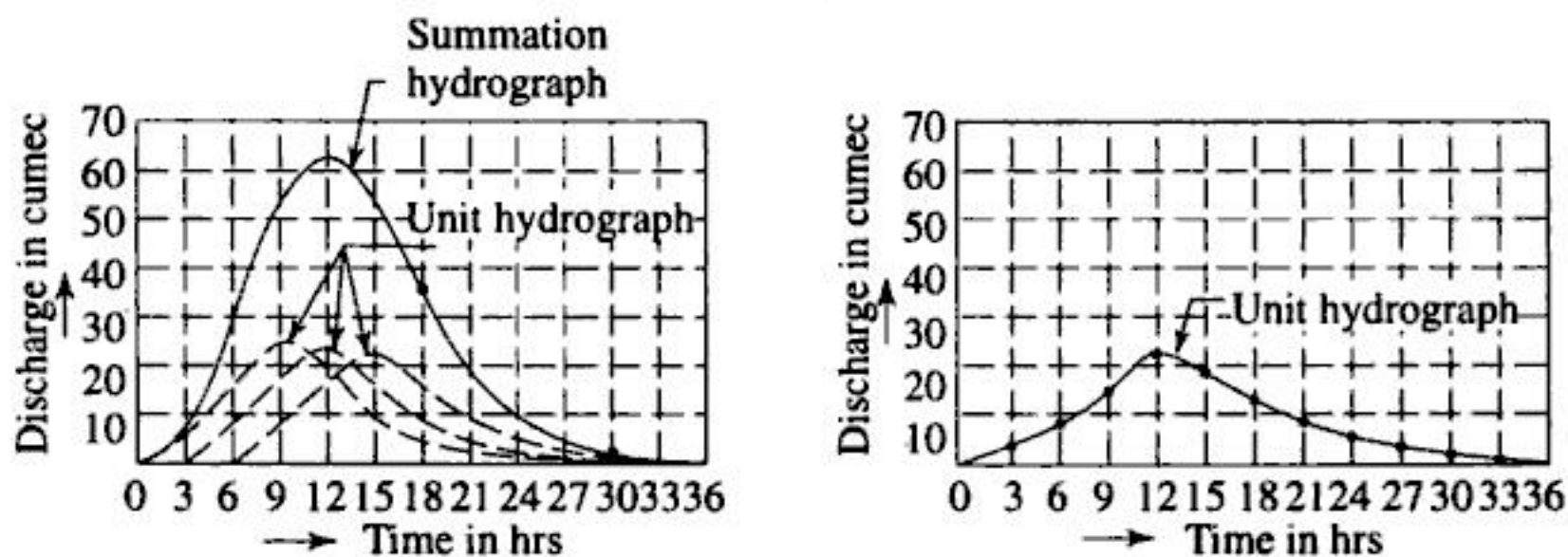
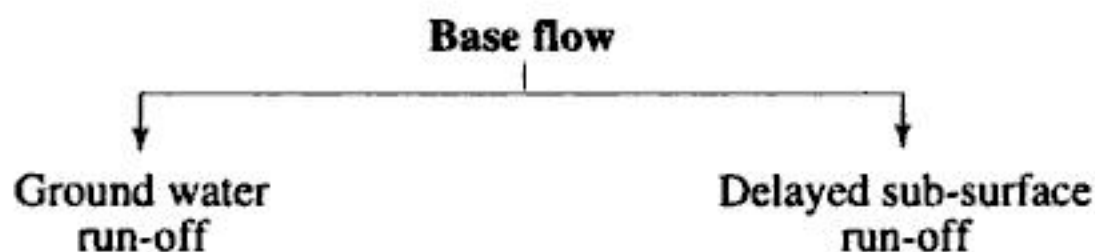


Fig. 3.7 (a) Summation hydrograph (b) hour unit hydrograph

3.8 BASE FLOW



The ground water contribution to the stream is known as base flow. It consists of two portions, (i) the ground water directly flows to the stream (ii) the rain water first infiltrates into the ground and then flows laterally to the stream even after the precipitation has stopped (Fig. 3.8).

Negative Base Flow When the water level of the stream is lower than the water table before the commencement of heavy rainfall, the ground water flows



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.

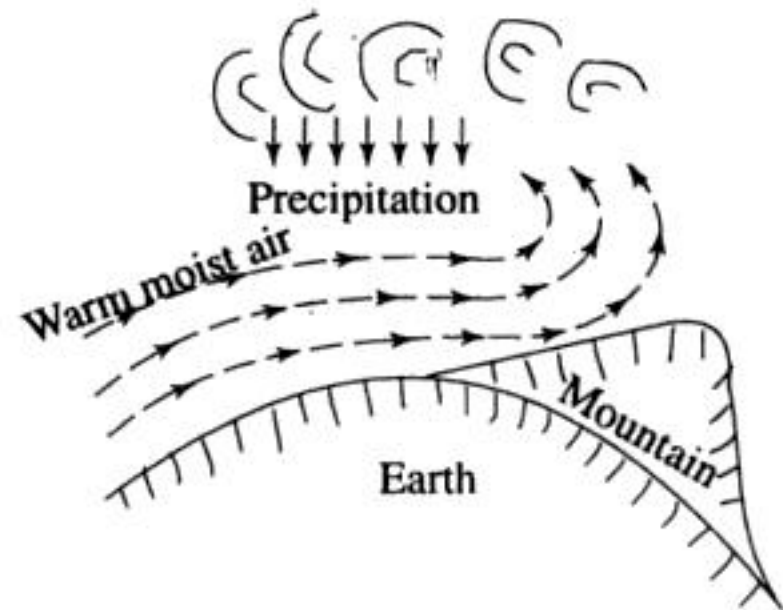
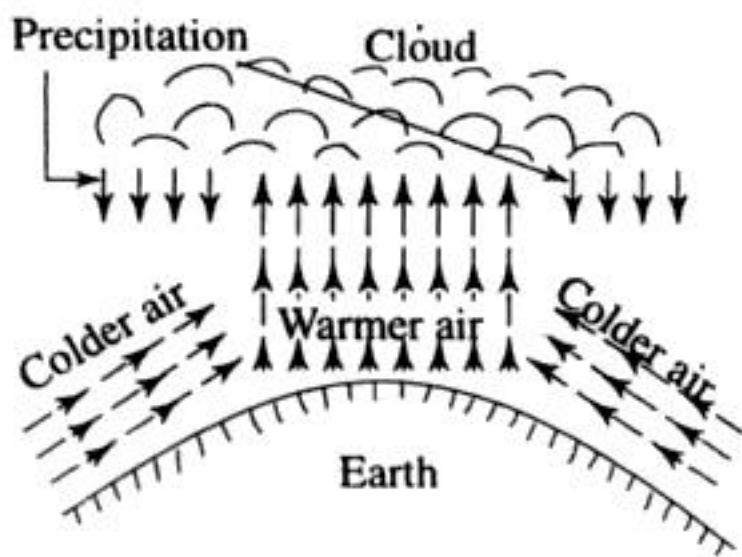


Fig. 3.13 Convective precipitation Fig. 3.14 Orographic precipitation

Measurement of Rainfall (i.e. Precipitation)

The instrument which is used to measure the amount of rainfall is known as rain gauge. The principle of rain gauge is that the amount of rainfall in a small area will represent the amount of rainfall in a large area provided the meteorological characteristics of both small and large area are similar. The rain gauges are of the following types.

1. Non-Recording Type Rain gauge Simon's rain gauge is a non-recording type of rain gauge which is most commonly used. It consists of metal casing of diameter 127 mm which is set on a concrete foundation. A glass bottle of capacity about 100 mm of rainfall is placed within the casing. A funnel with brass rim is placed on the top of the bottle. The arrangement is shown in Fig. 3.15.

The rainfall is recorded at every 24 hours. Generally, the measurement is taken at 8.30 a.m. everyday. In case of heavy rainfall the measurement should be taken 2 or 3 times daily so that the bottle does not overflow. To measure the amount of rainfall the glass bottle is taken off and the collected water is measured in a measuring glass, and recorded in the rain gauge record book. When the glass bottle is taken off it is immediately replaced with a new bottle of same capacity.

2. Recording Type Rain gauge In this type of rain gauge, the amount of rainfall is automatically recorded on a graph paper by some mechanical device (Fig. 3.16). Here, no person is required for measuring the amount of rainfall from the

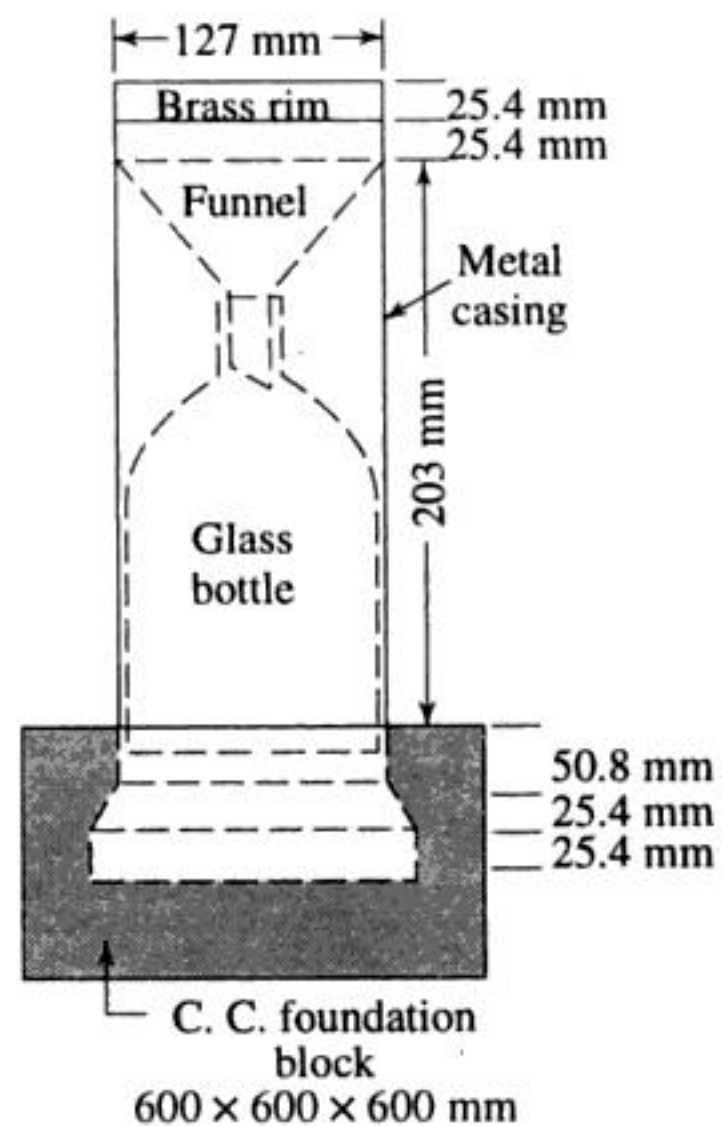


Fig. 3.15 Simon's rain gauge



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.

$$\text{Average depth precipitation} = \frac{6904.5}{748.0} = 9.23 \text{ cm.}$$

3. Iso-hyetal Method A Iso-hyet line represents a line joining the points of equal depth of precipitation. So, it is just like a contour line. In this method, all the rain gauge stations are located within the map of the required basin. Then depth of precipitation of all the stations are noted at the respective station point. Now, the Iso-hyet lines are drawn at 1 cm interval by the method of interpolation (as done during the plotting of contour lines), (Fig. 3.21). The area enclosed between the two successive Iso-hyet lines is found out by graph paper or by planimeter. The result is tabulated as shown to get the average depth of precipitation.

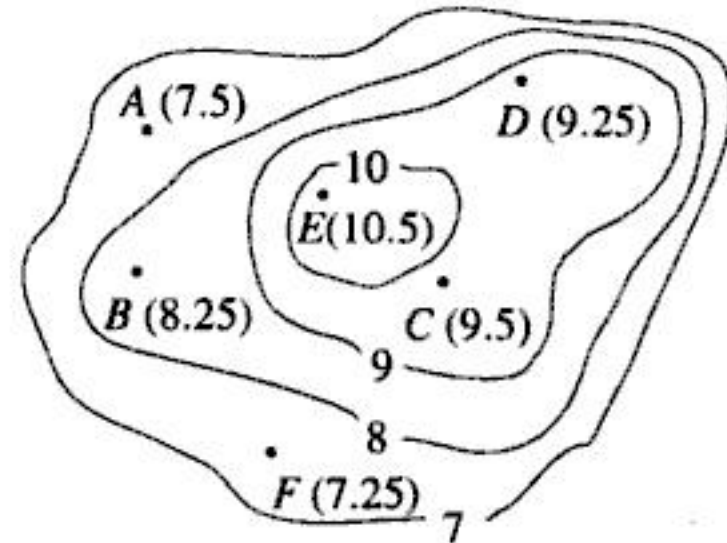


Fig. 3.21 Iso-hyet lines

<i>Iso-hyetal interval</i>	<i>Average depth</i>	<i>Area between two successive iso-hyet lines</i>	<i>Average depth × area</i>
(1)	(2)	(3)	(4) = (2) × (3)
10-9	9.5	a	9.5 × a
9-8	8.5	b	8.5 × b
8-7	7.5	c	7.5 × c
7-6	6.5	d	6.5 × d
		Σ A (say)	Σ B (say)

$$\text{Average depth of precipitation} = \frac{\Sigma B}{\Sigma A} = x \text{ cm (say)}$$

3.11 WATER LOSSES

Matter or energy cannot be lost, it only changes from one state to other. Similarly, water also cannot be lost, but it changes from one state to other, as we have seen in hydrological cycle. Here, the point 'Water losses' indicate the portion of water which cannot be observed or obtained as surface run-off directly during the period of precipitation that means,

$$\text{Water losses} = \text{Precipitation} - \text{Surface run-off}$$

Now, we are to study the causes of these losses. Under different observation it is found that the following are the main causes of water losses.

1. Interception Due to solar heat leaves, branches, trunks of trees and vegetative covers may get dried up and gain capacity of absorbing water. So, when precipitation starts some portion of water is directly absorbed by these absorbing agents. This phenomenon is known as interception. The interception continues



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.

Examples on Infiltration Indices

Example 1 The following are the rates of rainfall for successive 30 minutes period for a storm duration of 210 minutes.

5.5., 6.0, 12.5, 8.0, 3.25, 3.25, 6.5 cm/hr

Take ϕ -index as 4.50 cm/hr calculate

- The run-off in cm.
- Total rainfall.
- The value of W-index.

Solution The given intensity of rainfall is plotted in a graph. Then the value of ϕ -index is superimposed. The area shown by hatched lines represents the value of run-off (Fig. S-1)

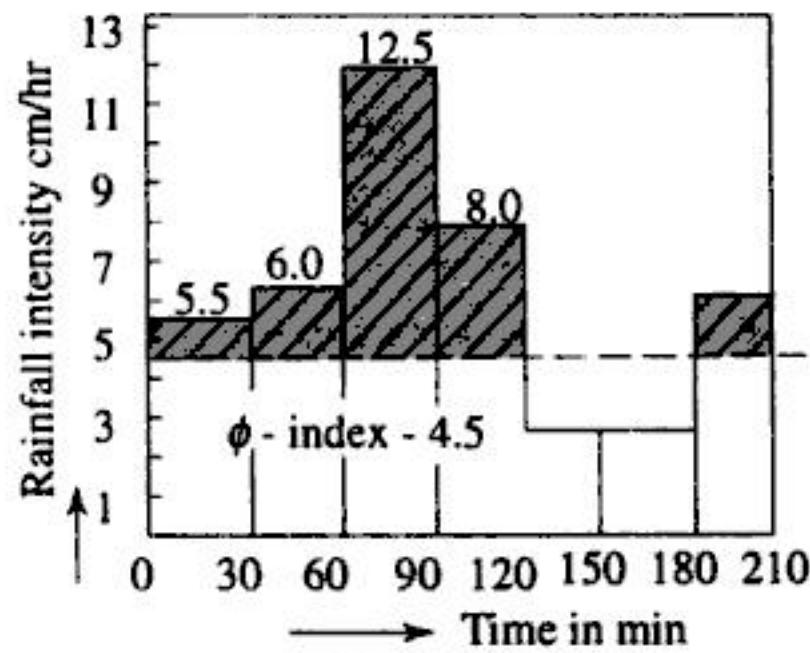


Fig. S-1

$$\begin{aligned}
 \text{(a) Run-off} &= (5.5 - 4.5) \times \frac{30}{60} + (6 - 4.5) \times \frac{30}{60} + (12.5 - 4.5) \\
 &\quad \times \frac{30}{60} + (8.0 - 4.5) \times \frac{30}{60} + (6.5 - 4.5) \times \frac{30}{60} \\
 &= 0.5 + 0.75 + 4.0 + 1.75 + 1.0 \\
 &= 8 \text{ cm}
 \end{aligned}$$

(b) Total rainfall =

$$\begin{aligned}
 &= 5.5 \times \frac{30}{60} + 6 \times \frac{30}{60} + 12.5 \times \frac{30}{60} + 8 \times \frac{30}{60} + 3.25 \\
 &\quad \times \frac{30}{60} + 6.5 \times \frac{30}{60} \\
 &= 2.75 + 3.0 + 6.25 + 4.0 + 1.625 + 3.25 \\
 &= 20.875 \text{ cm}
 \end{aligned}$$

$$\text{(c) W-index} = \frac{P - Q}{Tr} = \frac{20.875 - 8}{\frac{210}{60}} = \frac{12.875 \times 60}{210} = 3.679 \text{ cm/hr}$$

Example 2 The rainfall intensities for the successive one hour period for 8 hrs storm are given as,

20, 24, 30, 15, 35, 20, 10, 12 mm/hr



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.

D. Unit Hydrograph Method

The unit hydrograph is practically a kind of unit measurement of run-off occurring in some specific unit duration (i.e. 2 hr, 3 hr ..., etc.). Again a unit hydrograph is a graph of 1 cm of direct run-off during some unit time. So, the unit hydrograph of different duration are prepared and kept ready for the instant calculation of direct run-off by noting the amount of run-off for that unit period. As for example, if a run-off of 2 cm is noted for a unit duration of two hours, then the ordinates of the 2 hrs unit hydrograph will be doubled to get the run-off hydrograph for that specific period. Thus, with the help of unit hydrograph, the total run-off from any catchment area can be ascertained (Fig. 3.26).

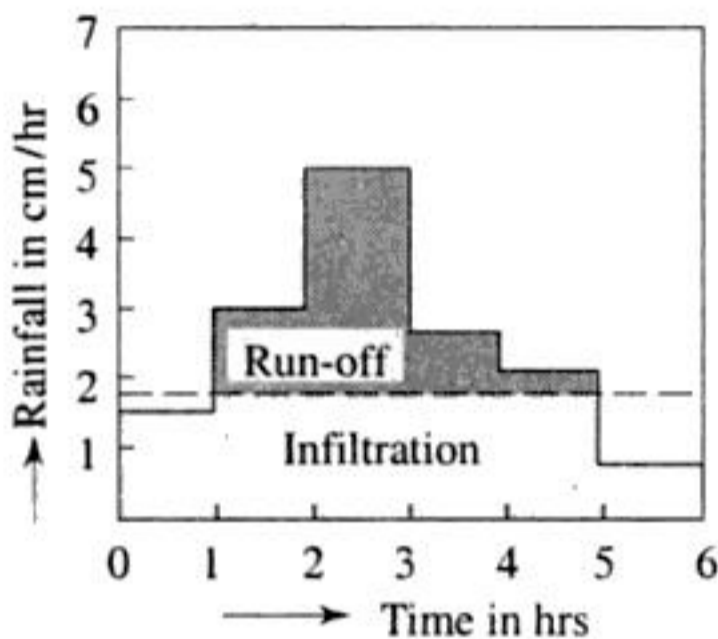


Fig. 3.25 Run-off and ϕ -index

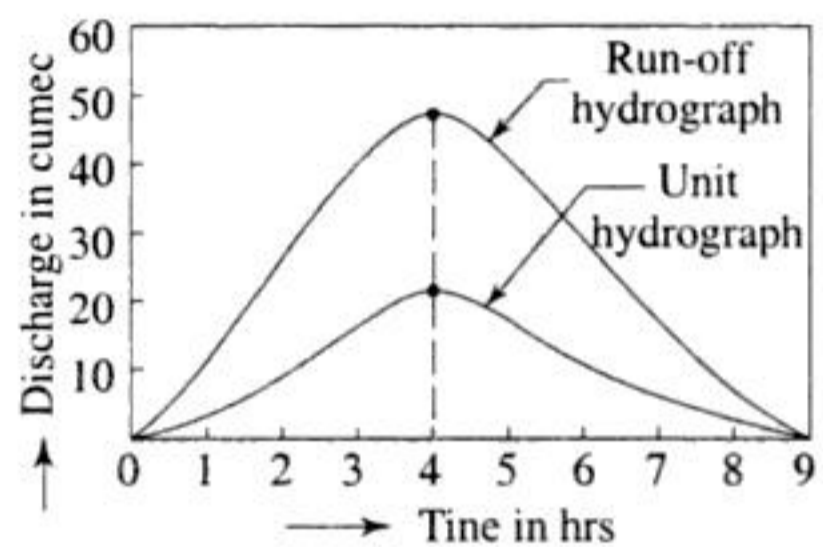


Fig. 3.26 Unit hydrograph method

3.15 S-HYDROGRAPH

S-hydrograph may be defined as a hydrograph which is constructed by summing up the ordinates of a series of unit hydrographs of same unit duration. So, it is also known as 'summation hydrograph'. This hydrograph represents the direct surface discharge resulting from successive storms of 1 cm in unit duration (i.e. 2 hr, 3 hr, 4 hr ..., etc.), for longer period. This hydrograph has continuously rising limb in the form of letter S until a constant value of discharge is reached. Let the base time (i.e. duration) of unit hydrograph be T and unit duration be t_r , the discharge will be constant at a time equal to $(T - t_r)$ hours (Fig. 3.27). Again the constant discharge is given by,

$$Q = \frac{2.778 A}{t_r} \quad (1)$$

where,

- Q = Constant discharge in cumec,
- A = Area of catchment in sq. km,
- t_r = Unit duration in hrs.

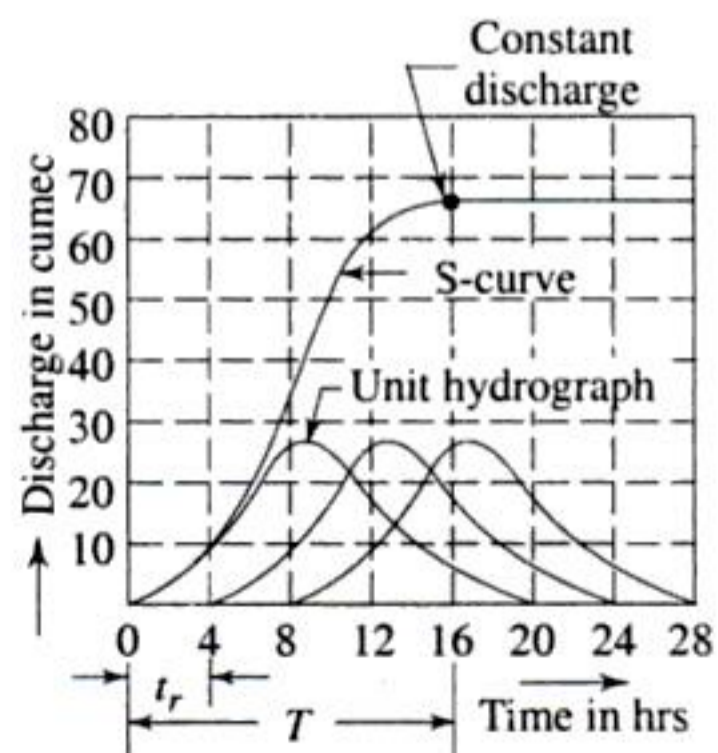


Fig. 3.27 S-hydrograph



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.

3.17 FLOOD ROUTING

Flood routing may be defined as a technique of determining the flood discharge and arresting the same in a reservoir for some period so that the sudden flood discharge may not create devastation in the down stream areas. It is hence a process of flood control works. By flood routing the maximum water level (i.e. full reservoir level) in the reservoir that may attain can be determined by only studying the rainfall records and previous flood hydrographs. Again, by flood routing the peak flow at the up stream side of the reservoir is controlled in such a way that the flow at the downstream side is reduced to safe discharge. (Fig. 3.28).

It is seen from the hydrograph that the upstream flood hydrograph has higher peak flow with shorter base (AB) but at the downstream hydrograph has lower peak flow with broader base (AC). It is achieved by detaining the flood water for some longer period by closing the spillways and then the excess flood water is released gradually by opening the spillways.

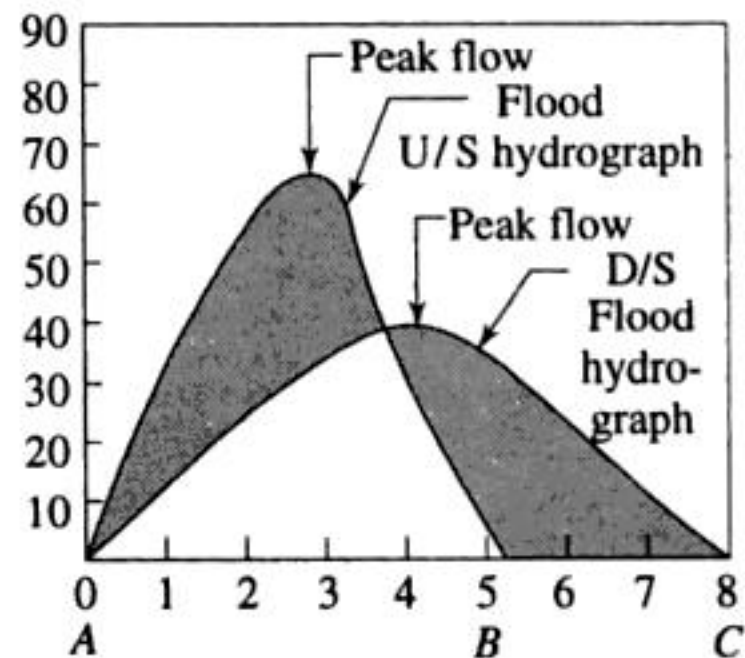


Fig. 3.28 Flood routing

Procedure of Flood Routing

There are various methods of flood routing:

(a) Flood Routing through Reservoir In normal cases, the rain water from the catchment area enters the reservoir and the water level reaches up to normal pool level, the excess water flows through the spillways. But due to the excessive rainfall during any period the discharge is highly increased and the water level exceeds the normal pool level and reaches up to maximum reservoir level. This volume of water is absorbed temporarily for some period and then allowed to flow to the down stream through the spillways (Fig. 3.29). So, the flood routing involves,

(1) The fixation of maximum reservoir level up to which the structure is completely safe.

(2) Implementation of outflow pattern from the reservoir so that it may not create any danger in the down stream side.

Thus, mathematically, $\text{Inflow} = \text{outflow} + \text{change in storage volume}$, i.e. $I = O + \Delta s$.

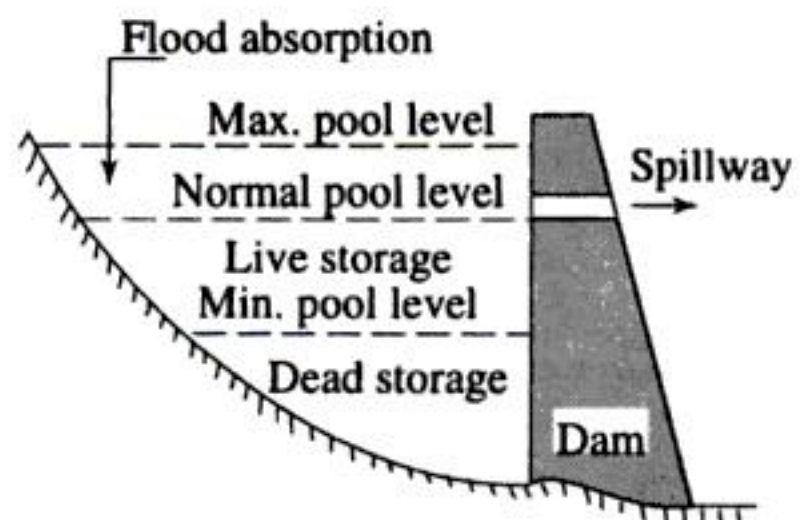


Fig. 3.29 Flood routing through reservoir



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.

Methods of Lifting Water Various methods can be applied for lifting the water by using man or animal power. The description of the common methods for lifting water follows:

(a) Doon It consists of a trough made of wooden or galvanised tin sheet. The trough is open at one end and closed at other. It is anchored over a fulcrum. The closed end is tied to a level with a rope. The other end of the lever carries a counter weight. The lever is pivoted at the middle point. Standing on a platform, the operator pushes the trough downwards until it is immersed in water. When the trough is filled with water, the pressure is released and the trough rises upwards. At some position the water of the trough starts getting discharged into the field channel. The operator now presses the trough again to immerse it in water. This process is repeated until the requirement is fulfilled (Fig. 4.1).

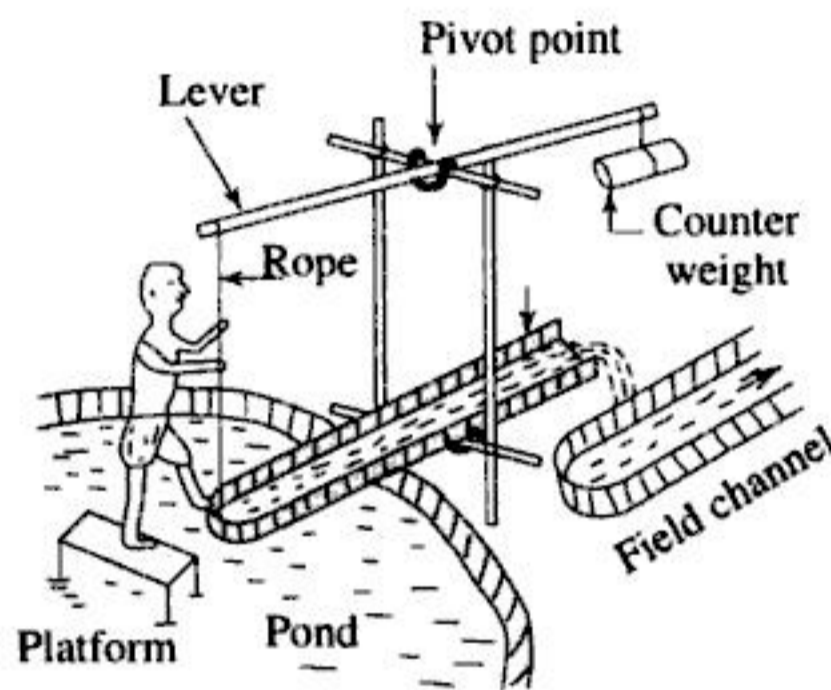


Fig. 4.1 Doon

(b) Archimedean Screw It consists of a wooden or metal cylinder with a helical coil fitted within. The cylinder is placed in an inclined position and fitted with two supports with bearings so that it can be rotated by a handle. The lower end of the cylinder is kept immersed in water. When the cylinder is rotated by a man with the handle, the water gets sucked through the helical coil and follows the path. The water is then discharged into the field channel through the upper end. (Fig. 4.2).

(c) Swinging Basket In this method, the water is lifted by swinging a bucket with the help of a pair of ropes by two persons standing on opposite sides. This method is suitable for lifting water to a small height. In the downward motion, the bucket is immersed in water by loosening the ropes. In the upward motion, the two persons exert maximum pressure on the ropes to raise the bucket above the water surface and then the bucket is tilted to discharge the water into the field channel. The process is continued until the requirement is fulfilled (Fig. 4.3).

(d) Denkli This process is adopted for lifting water from the dug well. It consists of a lever pivoted on a vertical post. One end of the lever carries a counter weight and the other end carries a bucket suspended by a string. On the



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.

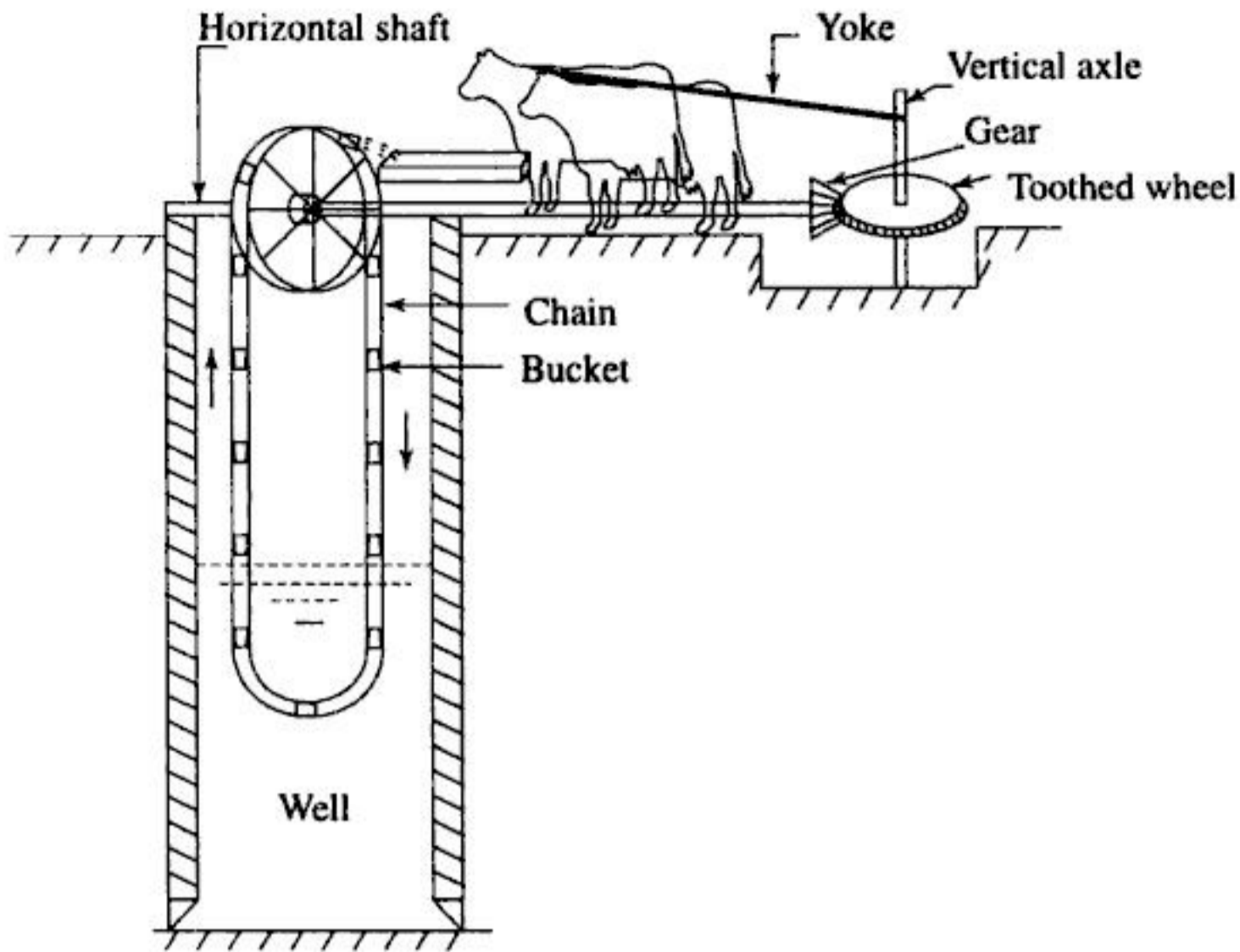


Fig. 4.8 Persian wheel

4.4 EXPLANATION OF DIFFERENT TERMS

1. Porosity

It is defined as the ratio of the volume of voids present in a soil mass to the total volume of that soil. It is expressed as percentage.

Thus,
$$n = \frac{V}{V_t} \times 100$$

where, n = porosity; v = Volume of voids; v_t = Total volume of soil mass.

Porosity depends on the fineness and sharpness of the soil. Porosity will be high when particles are of uniform size. It will be low when the particles are well-graded. So, porosity indicates the capacity of a soil to contain water.

2. Coefficient of Permeability

It is defined as the rate of flow of water through the aquifer per unit cross-sectional area per unit hydraulic gradient. So, it indicates the velocity of water through the soil and expressed in cm/sec. It is denoted by K .

3. Water Table

It is the surface or a line on the soil below which the soil mass is saturated with water. This surface varies with the change of seasons. In rainy season the water surface is near the ground surface. But in dry season this surface goes down appreciably towards the impervious layer.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.

the depressed head h and the water around the well enters into the well under the influence of the head $(H - h)$. This head is known as depression head or percolation head or drawdown (Fig. 4.12).

20. Shallow Well and Deep Well

Shallow Well The well which draws the water from the unconfined aquifer is known as shallow well. The yield of the well is dependant on the water table. In dry season when the water table goes below the bed of the well, the discharge of the well is stopped and the well is dried up (Fig. 4.13).

Deep Well The well which draws water from the confined aquifer is known as deep well. The yield of the well is not dependant on the water table. The discharge is reliable throughout the year (Fig. 4.13). In other words deep well goes below the mota layer.

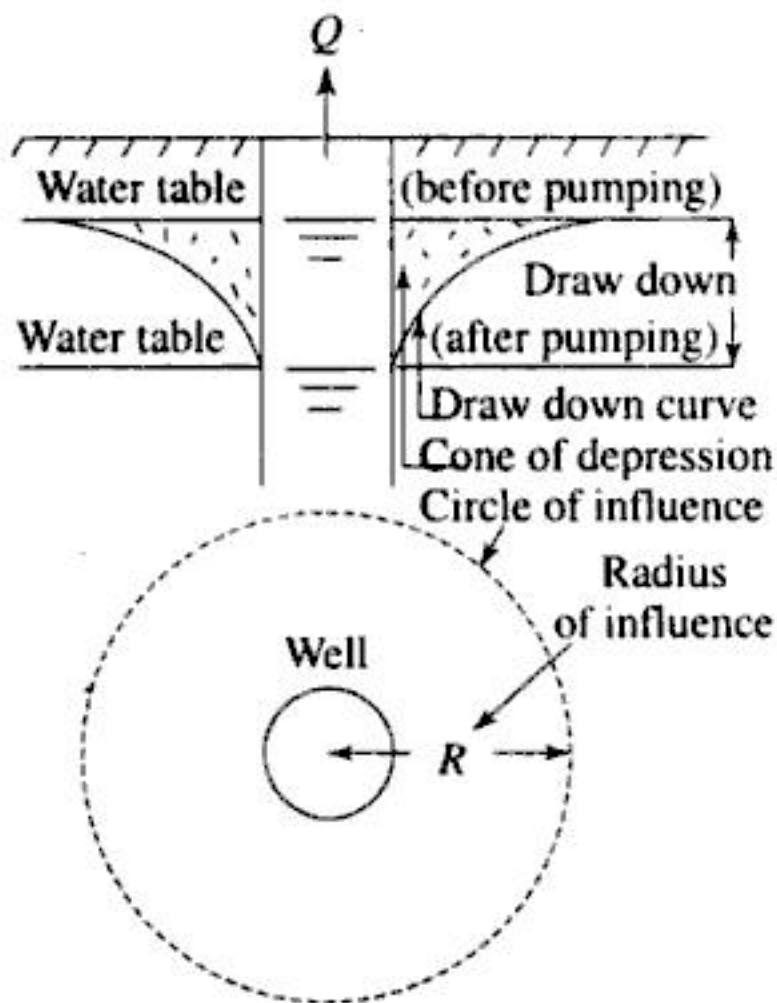


Fig. 4.12 Cone of depression

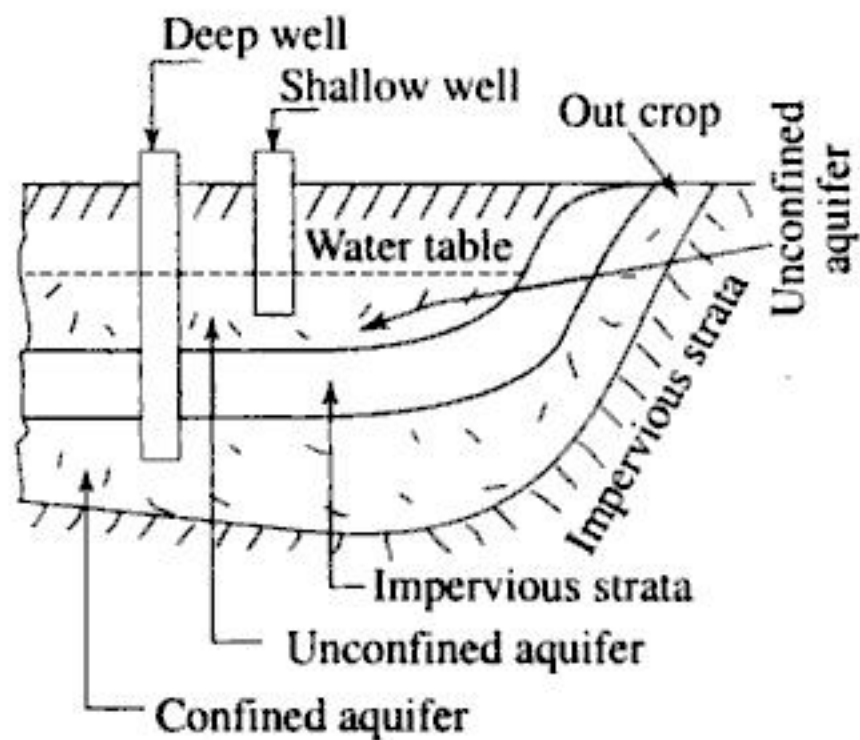


Fig. 4.13 Shallow and deep well

21. Coefficient of Transmissibility

It is defined as the rate of flow of water through the aquifer per unit width per unit hydraulic gradient covering the full saturated height of the aquifer. It is denoted by T .

Thus, $T = bK$. Where, b = Thickness of aquifer; K = Coefficient of permeability.

22. Interference Among Wells

When two wells are located close to each other, then their draw down curve will intersect and the discharge of one well will interfere with the discharge of the other. This is known as interference among the wells. Due to interference, the discharge of each well will be decreased, but the total discharge will be increased. The discharge of each individual well is given by,



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.

5.5 SELECTION OF SITE FOR INUNDATION CANAL

The inundation canal is simply an open cut in the bank of the inundation river. Sometimes, such a canal is taken off from the perennial river. However, the main idea of an inundation canal is that the irrigation facilities may be available without constructing any hydraulic structure or regulation work. While selecting the site for take-off point of the inundation canal, following points should be considered

1. The inundation canal should be taken off from the concave side of the curve in the river. This is to prevent the deposition of silt at the head of the canal (Fig. 5.7).
2. The take-off point should be on well defined banks of the river.
3. The take-off point should be close to the area to be irrigated. This is to avoid unnecessary excavation.
4. If a river consists of shoals in its course, then the canal should be taken off from the tail region of the shoal. Because, the shoal will create a pocket in front of the canal head making possible to control the entry of heavy silt in the canal (Fig. 5.8).

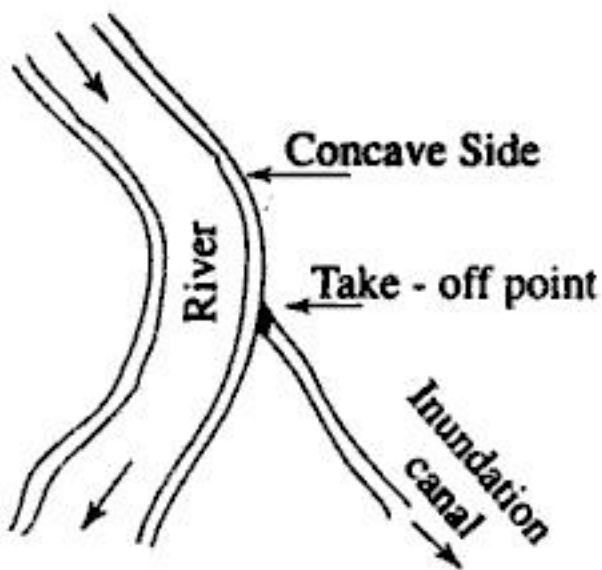


Fig. 5.7 Take-off point

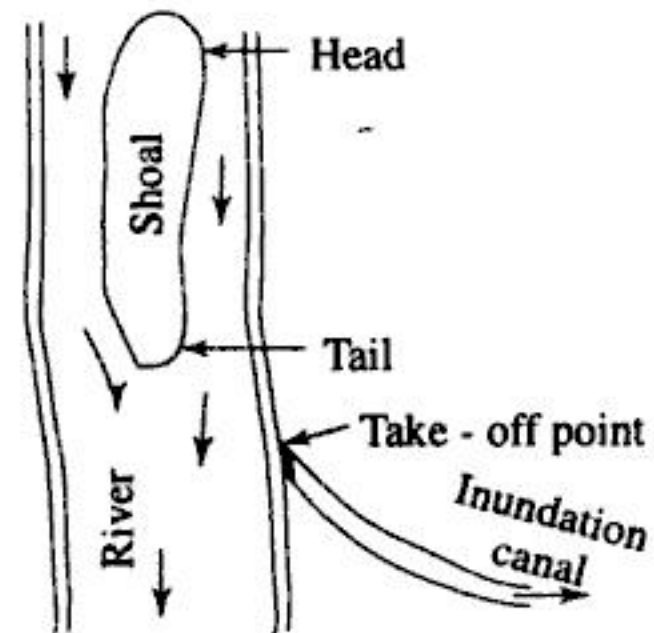


Fig. 5.8 Shoal

5.6 MAINTENANCE OF INUNDATION CANAL

In inundation canal system no silt excluder is constructed at the head of the canal to prevent the deposition of silt. So, every year the head reach and also the whole canal system goes on getting silted. Thus the capacity of the canals go on reducing year by year and ultimately the irrigation system may fail. Hence, provisions and maintenance systems should be provided to keep the canal system workable for a longer duration. The following are measures to be taken.

(1) Subsidiary Canals The subsidiary canals are taken off from the same river to connect the main canal. But the head of these subsidiary canals are kept closed. When the head reach of the main canal gets silted and the discharge capacity gets reduced, the heads of the subsidiary canals are opened to increase the discharge of the main canal. The length of these canals should be kept minimum



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.

irrigate the areas under different zones. While selecting the site for bandhara, the following points should be kept in mind.

- (a) The banks of the stream should be high and well defined.
- (b) The source of water should be reliable for constant supply.
- (c) Stable foundation should be available for the construction of bandhara.

5.10 ADVANTAGES AND DISADVANTAGES OF BANDHARA IRRIGATION SYSTEM

Advantages The following are the advantages of this system.

- (a) The water of small streams can be utilised for irrigation purpose by constructing a simple structure.
- (b) The culturable area is generally close to the source. Hence there is less possibility of transmission loss.
- (c) As there is no loss due to transmission, evaporation and percolation, the duty of water is high.

Disadvantages The following are the disadvantages of this system (a) Normally, the discharge capacity of small streams is low. Moreover, if bandhara irrigation system is implemented in such streams, the people residing on the down stream side will not get water for their use.

(b) The supply of water mainly depends on rainfall. So, in the period of drought this system is practically useless.

REVIEW QUESTIONS

1. Fill up the blanks with appropriate word/words.
 - (i) The river in which the water flows to its full capacity in rainy season only is known as _____ river.
 - (ii) The river in which the water flows more or less to its full capacity throughout the year is known as _____ river.
 - (iii) The canal which is constructed to feed another canal or river is known as _____ canal.
 - (iv) The canal which is constructed to generate hydroelectric power is known as _____ canal.
 - (v) The canal in which water flows in rainy season only is known as _____ canal.
 - (vi) The canal in which water flows throughout the year is known as _____ canal.
 - (vii) The canal which is aligned along the watershed line is known as _____ canal.
 - (viii) The canal which is aligned at right angles to the contour lines is known as _____ canal.
 - (ix) The area included under bandhara irrigation system is known as _____



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.

5. Width of external borrowpit if any.
6. A margin of 0.5 m from the outer edge of borrowpit on both sides, if external borrowpit becomes necessary.

6.13 BALANCING DEPTH

In constructing a canal section, if the quantity of excavated earth can be fully utilised for making the banks on both sides, then that canal section is known as economical section. The depth of cutting for that ideal condition is known as balancing depth. In this case, no borrowpit on spoil bank needs to be constructed. This condition may not occur in all the cases. It happens only when the canal section is partly in cutting and partly in banking. The cost of earth work will also be balanced.

The method of finding the balancing depth is described here.

Example Find the balancing depth for a canal section having the following data.

1. Base width of canal = 10 m.
2. Side slope in cutting = 1 : 1.
3. Side slope in banking = 2 : 1.
4. Top width of bank = 3 m.
5. Height of bank above G.L. = 3 m.

Solution Refer Fig. 6.14.

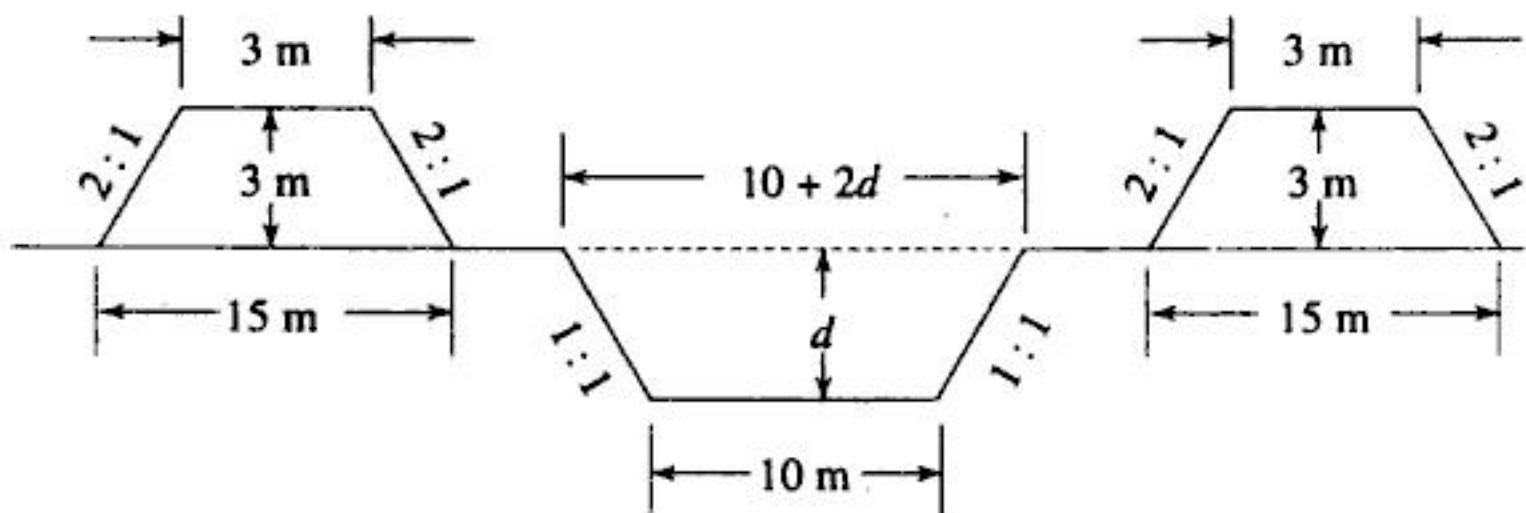


Fig. 6.14

$$\text{Area of banking} = 2 \times \frac{15 + 3}{2} \times 3 = 54 \text{ sq. m.} \quad (1)$$

Let d be the balancing depth of cutting.

$$\text{Area of cutting} = \frac{10 + 10 + 2d}{2} \times d = (10 + d) d \quad (2)$$

Equating the area of banking and cutting,

$$(10 + d) d = 54$$

$$d^2 + 10d - 54 = 0$$



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.



You have either reached a page that is unavailable for viewing or reached your viewing limit for this book.

IRRIGATION ENGINEERING

Completely covers the diploma syllabus of various State Boards of Technical Education and of AMIE Section B for Civil Engineering.

Salient Features

- Follows a simple and lucid style.
- Over 275 illustrations to support theory.
- Solved numerical problems interspersed within chapters.
- Exercises provided at the end of each chapter includes fill-in-the-blanks (151) and short-answer questions (117).
- An appendix containing 100 multiple-choice questions with answers and 143 review questions with hints.

Other Titles of Interest

N N Basak	: Surveying and Levelling
B K Sarkar	: Thermal Engineering
PDU	: Entrepreneurship Development
Kamala	: Environmental Engineering
TTTI (Madras)	: Quality Control

The McGraw-Hill Companies



Tata McGraw-Hill
Publishing Company Limited
7 West Patel Nagar, New Delhi 110 008

Visit our website at : www.tatamcgrawhill.com

ISBN 0-07-463538-7



9 780074 635384