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IRRIGATION AND WATER POWER ENGINEERING

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IRRIGATION AND WATER POWER ENGINEERING

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For Chapters 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 17, 18, 19, 21, 22, 23. Appendices and unsolved problems of all chapters
© 1992 **PANDE B.B. LAL**
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Preface

India has unequal distribution of rainfall over the country—varying from less than 25 cm in the North West deserts of Rajasthan to about 1150 cm in the Assam hills. Substantial variations in the quantity, incidence and duration of rainfall in individual tracts from year to year, make irrigation of supreme necessity in the country. The science of Irrigation Engineering in India has developed by leaps and bounds during the last six decades. The Irrigation Engineering occupy prominent place in the World.

The purpose of this book is to present the science of the practice of irrigation engineering in a concise form comprising practically all the modern developments. The book, written entirely in Metric Units covers the syllabi of Indian Universities and A.M.I.E. Examination in 'Irrigation and Water Power.' The various original formulae in F.P.S. units have also been given side by side. Most of the diagrams and the charts have been given in metric units.

The practices described are mainly those prevailing or coming into use in India, although many references are made to the work of engineers in other countries. The approach to the subject has been practical throughout. Indications are given to the most efficient way in which the work could be undertaken, without neglecting the basic principles involved.

The book has been primarily written for the students to use it as a text book at the first degree level. Some advanced topics included in this book will be useful at the M.E. level. The book will also be useful to the practising engineers, as a reference. A number of solved examples and detailed designs of major irrigation works have been included.

The authors gratefully acknowledge the help received from many standard text books and publications on irrigation engineering. The authors are thankful to Sri Kanhaiya Lal who has very nicely traced the diagrams. The authors are also thankful for the co-operation received and efficiency with which the printing was carried out.

Every effort was made to eliminate errors in the book, but should the reader discover some, we would appreciate having these brought to our attention. Suggestions from the readers for the improvement in the book will be most gratefully acknowledged.

Gandhi Jayanti **B.C. PUNMIA**
2-10-1969 **PANDE B.B. LAL**

Preface to the Second Edition

The revised and enlarged edition of the book incorporates the latest Indian Standards on the design of lined canals and on the criteria for design of hydraulic jump type stilling basins with horizontal and sloping aprons.

The authors are thankful to Shri R.S. Varshney, S.C. Gupta and R.L. Gupta for permitting us to use the Garrets's and Lacey's diagrams in metric units from their book "Theory and Design of Irrigation Structures."

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Account has been taken throughout of suggestions offered by the many users of the book and grateful acknowledgement is made to them. Further suggestions will be greatly appreciated.

Gandhi Jayanti
2-10-1972

B.C. PUNMIA
PANDE B.B. LAL

Preface to the Third Edition

In the Third Edition of the book the following three chapters have been completely rewritten : Chapter 7. Dams-1 : General ; Chapter 8. Dams-2 : Gravity Dams, and Chapter 11. Dams-5 : Spillways. In addition to these, Unsolved Problems, with Answers, have been added at the end of each chapter to enable the student to test his reading at different stages of his reading. Suggestions from the readers for the improvements in the book will be most gratefully acknowledged.

1-7-1975

B.C. PUNMIA

Preface to the Fifth Edition

In this edition, Chapter 3 has been rewritten and many new articles have been added. An Appendix on 'Khosla's Theory' has been added at the end. The subject matter of the entire book has been updated. The authors are thankful to many readers of the book for their useful suggestions. Further suggestions will be greatly appreciated.

26th Jan., 1979

B.C. PUNMIA

Preface to the Sixth Edition

In the Sixth Edition, the subject matter has been thoroughly revised and updated. Latest Indian Standard Recommendations and Codes have been incorporated in the text.

1-1-1981

B.C. PUNMIA

Preface to the Seventh Edition

In the Seventh Edition, few articles have been added in the chapter on Hydrology. Some solved illustrative examples have also been added on the computations for S-curve and unit hydrographs of different durations.

2-10-1982

B.C. PUNMIA

Preface to the Eleventh Edition

In the Eleventh Edition of the book, the Subject matter has been revised and updated. Many new articles have been added in various chapters.

Jodhpur
DEEPAWALI
29-10-1989

B.C. PUNMIA

Preface to the Twelfth Edition

In the Twelfth Edition, the book has been thoroughly **revised** and **enlarged.** The book has now been divided into **Four Sections.** *Section 1*, containing three chapters is on *Irrigation Practice. Section 2* devoted to *Water Resources Engineering* has nine chapters. *Section 3* is on *Distribution System*, and has seven chapters. Lastly, *Section 4* has five chapters on *Miscellaneous Topics*. Chapter 24, on *Important Dams of India*, contains eight photographic plates on important dams. **Thus, in the Twelfth Edition of the book, which has 24 chapters, three new chapters have been added.**

The entire matter of the book has been composed with DTP process and laser print out. It is hoped that with these changes, the New Edition will be more useful of both the students as well as Field Engineers.

Jodhpur
15-5-92

B.C. PUNMIA
PANDE B.B. LAL

Preface to the Sixteenth Edition

In the Sixteenth Edition, the entire book has been completely rewritten by way of revising, updating, rearranging and enlarging the earlier contents. In each chapter, many new articles and illustrative examples have been added. Questions from prominent competitive examinations, such as Indian Civil Services Examination, Engineering Services Examinations, Gate etc. have been added at the end of majority of the chapters. Latest IS Code recommendations have been included in each chapter. All the diagrams have been drawn using computer graphics and the entire book has been laser typeset using bigger size format. The authors are thankful to Shri M.S. Gehlot for fine laser type setting. The Authors are also thankful to Shri R.K. Gupta, Managing Director, Laxmi Publications, for taking keen interest in the publication of the book.

Jodhpur
Akshay Tritya,
27th April, 2009

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SECTION-I

IRRIGATION PRACTICE

Chapters :

1. **INTRODUCTION**
2. **METHODS OF IRRIGATION**
3. **WATER REQUIREMENTS OF CROPS**

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1

Introduction

1.1. DEFINITION

Irrigation may be defined as the process of artificially supplying water to soil for raising crops. It is a science of planning and designing an efficient, low-cost, economic irrigation system tailored to fit natural conditions. It is the engineering of controlling and harnessing the various natural sources of water, by the construction of dams and reservoirs, canals and headworks and finally distributing the water to the agricultural fields. Irrigation engineering includes the study and design of works in connection with river control, drainage of water-logged areas, and generation of hydroelectric power.

1.2. NECESSITY

India is basically an agricultural country, and all its resources depend on the agricultural output. Water is evidently the most vital element in the plant life. Water is normally supplied to the plants by nature through rains. However, the total rainfall in a particular area may be either insufficient, or ill-timed. In order to get the maximum yield, it is essential to supply the optimum quantity of water, and to maintain correct timing of water. This is possible only through a systematic irrigation system—by collecting water during the periods of excess rainfall and releasing it to the crop as and when it is needed. Thus, the necessity of irrigation can be summarised in the following points:

1. Less Rainfall

When the total rainfall is less than needed for the crop, artificial supply is necessary. In such a case, irrigation works may be constructed at a place where more water is available, and then to convey the water to the area where there is deficiency of water. Rajasthan canal is one such example. It conveys water to the arid zones of Rajasthan, where the annual rainfall hardly exceeds 100 to 200 mm.

2. Non-uniform Rainfall

The rainfall in a particular area may not be uniform over the crop period. During the early periods of the crop, rains may be there, but no rain water may be available at the end, with the result that either the yield may be less, or the crop may die altogether. By the collection of water during the excess-rainfall period, water may be supplied to the crop during the period when there may be no rainfall. Most of the irrigation projects in India are based on this premise. The rainfall during the winter

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is very scanty, and hence rabi crops need artificial supply of water through the irrigation works.

3. *Growing a number of crops during a year*

The rainfall in an area may be sufficient to raise only one type of crops during the rainy season (i.e. kharif crops), for which no irrigation may be required. However, with the provision of irrigation facilities in that area, crops can be raised in other season also (i.e. rabi crops).

4. *Growing perennial crops*

Perennial crops, such as sugar cane etc, which need water throughout the year, can be raised only through the provision of irrigation facilities in the area.

5. *Commercial Crops with Additional Water*

The rainfall in a particular area may be sufficient to raise the usual crops, but more water may be necessary for raising commercial and cash crops.

6. *Controlled Water Supply*

By the construction of proper distribution system, the yield of the crop may be increased because of controlled supply of water.

The importance of irrigation is well stated by Shri N.D. Gulati : "Irrigation in many countries is an old art – as old as civilisation – but for the whole World it is modern science – *the science of survival*".

Advantage of application of water by modern methods.

Application of water to the soil by modern methods of irrigation serves the following purposes :

1. It adds water to the soil to supply the moisture essential for the plant growth.
2. It saves the crops from drying during short duration droughts.
3. It cools the soil and the atmosphere, and thus makes more favourable environment for healthy plant growth.
4. It washes out or dilutes salts in the soil.
5. It reduces the hazard of soil piping.
6. It softens the tillage pans.

1.3. SCOPE OF IRRIGATION SCIENCE

The scope of irrigation is not limited to the application of water to the soil. It deals with all aspects and problems extending from the watershed to the agricultural farms. It deals with the design and construction of all works, such as dams, weirs, head regulators etc. in connection with the storage or diversion of water, as well as the problems of subsoil drainage, soil reclamation and water-soil-crop relationships. An irrigation engineer is also required to have the knowledge of cultivation of various crops, their maturing and protection from pests. Briefly speaking, the scope of irrigation can be divided into two heads :

(*a*) Engineering aspect.

(*b*) Agricultural aspect.

(*a*) Engineering Aspect

1. *Storage, Diversion, or Lifting of Water*

This is the first phase of irrigation engineering. By the construction of a dam across the river, a suitable reservoir can be created and water can be stored. Alternatively, if river is perennial and carries sufficient discharge, suitable diversion works, such as a weir, barrage and bandhara can be constructed across the river and water can be diverted to the canal. Places where ground water table is high, suitable wells can be dug and water can be lifted and fed to small channels or pipes.

2. *Conveyance of Water to the Agricultural Fields*

The stored or diverted water is conveyed to the agricultural fields through some suitable distribution system. If the project is big, the distribution system will consist of two or more main canals and a number of distributaries, and minors. From the canal, the water is led to the field through 'water course' or 'field channel'. These field channels take off from the distributaries or minors through modular or non-modular outlets, so that water supply can be regulated. Thus, this second phase includes the design and construction of suitable canal system, along with various regulatory works such as head regulators, cross regulators, falls etc. for the efficient working of the canal. In addition to these, suitable cross drainage works, such as aqueducts, super passages, level crossings, bridges, etc. will have to be designed and constructed at the places where the canal crosses a natural drain or a road.

3. *Application of Water to Agricultural Fields*

The water is applied to the crop by flooding, furrows, corrugations, subsoil irrigation or by sprinkling. A detailed account of these methods has been given in the next Chapter.

4. *Drainage and Relieving Water-Logging*

Proper disposition of excess water by suitable drainage methods is very important. Due to the conveyance losses, and excess application of water to the crop, the sub-soil water level is raised, and sometimes the soil is water-logged and becomes useless from production point of view. Hence the design of surface and sub-surface drainage system is of vital importance in maintaining the high productivity of irrigated lands.

5. *Development of Water Power*

Most of the irrigation projects are associated with the generation of the *hydroelectric power* either at the dam site or at canal falls.

(*b*) Agricultural Aspect

The agricultural aspect deals with the thorough study of the following points :

1. Proper depths of water necessary in single application of water for various crops.
2. Distribution of water uniformly and periodically.
3. Capacities of different soils for irrigation water, and the flow of water in soils.
4. Reclamation of waste and alkaline lands, where this can be carried out through the agency of water.

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1.4. MULTIPURPOSE RIVER VALLEY PROJECT

A multipurpose river valley project includes the following ***aspects*** :

1. Irrigation
2. Water supply for public health and sanitation
3. Generation of hydro-electric power
4. Flood control and river training
5. Erosion and sediment control : Soil conservation
6. Inland navigation
7. Fish culture.
8. Recreation
9. Drainage

A multipurpose river valley scheme embodies the study of the following ***sciences:***

1. Agronomy and animal husbandry
2. Soil science and mechanics
3. Engineering : Civil, mechanical, electrical and agricultural
4. Hydrography and hydrology
5. Hydraulics
6. Geology
7. Sociology
8. Economics
9. Infrastructure
10. Administration.

1.5. BENEFITS OF IRRIGATION

All the irrigation schemes are so designed that they increase the food production of the country. Apart from the increase in food, there are many indirect benefits or advantages of irrigation, as summarised below :

1. ***Increase in Food Production***. Due to the controlled and timely supply of water to the crop, the yield is increased. With the assured supply of water, superior crops take the place of inferior crops, and thus the value of crops is increased. For a given crop, the optimum quantity of water required may be determined experimentally, and then applied scientifically to the crop.

2. ***Protection from Famine***. The construction of irrigation works helps during the famine and drought period in two ways. During the construction of the irrigation works, employment is carried to the people and thus they get relief against famine. After the construction of such works, continuous water supply is maintained during drought.

3. ***Cultivation of Cash Crops***. Irrigation makes it possible to grow cash crops such as sugar-cane, indigo, tobacco, cotton, etc.

4. ***Elimination of mixed cropping***. If irrigation facilities are not available in an area, the farmers have a tendency to adopt *mixed cropping* whereby they grow two or more crops together in the same field. The advantage of mixed cropping is that if the weather conditions are not suitable for one of the crops, it may be suitable

for the others and thus the farmer may get atleast some yield from the same field. But, mixed cropping has several drawbacks, specially due to the fact that each crop has different requirements for field preparation, manuring, watering etc. However the availability of irrigation facilities in the area gives the farmers the protection against the vagaries of the weather, resulting in the elimination of the mixed cropping system.

5. ***Addition to the Wealth of the Country***. Almost all the irrigation projects are so designed that they bring some revenue to the state. In addition to the water tax obtained from the farmers, the bumper crops produced due to irrigation facilities makes country self-sufficient in food requirements, and thus saves the foreign exchange.

6. ***Increase in Prosperity of People***. Due to irrigation facility, the value of land is increased. Also due to increase in the yield of the crop, and due to the growing of cash crops, the farmers become prosperous, and thereby their living standard is improved.

7. ***Generation of Hydro-Electric Power.*** Major river valley projects are usually planned to provide hydro-electric power together with irrigation. Also, falls on the irrigation channels can be utilised to generate electricity which may help in industrialising the rural area, and also in solving the problem of fuel shortage.

8. ***Domestic and Industrial Water Supply***. The canals may also be utilised for domestic and industrial water supply. Some of the irrigation reservoirs also supply water to nearby rural and urban areas. The canals also provide facilities for bathing, cattle watering, boating and others recreations.

9. ***Inland Navigation***. Large canals can also be used for inland navigation, and thus transportation of agricultural products to the mandis.

10. ***Improvements of Communication***. Almost all the irrigation channels are provided with inspection roads. These roads can be metalled, and be used as means of communication.

11. ***Canal Plantations***. The stripped area along the canal is always damp, and therefore, trees etc. are planted along the canal banks, water courses and field boundaries. This increases the timber wealth of the country and also checks the soil erosion.

12. ***Improvement in the Ground Water Storage***. Due to the constant percolation and seepage of water, the ground water table is raised in the area where irrigation facilities are prevalent. So long as this water table remains well below the root zone of the crop, this improvement in the ground water storage is beneficial.

13. ***Aid in Civilisation***. Due to the introduction of river valley projects, the violent tribes adopt irrigation as their profession, and settle peacefully. Also due to increased yield and value of the crop, the standard of living of a common cultivator is improved, and he becomes more civilised.

14. ***General Development of the Country***. The most important benefit derived from the irrigation is the general development of an agricultural country such as ours in which majority of people live in villages and have agriculture as their profession. Due to the increased yield and value of the crop, means of communication, such as road-ways, railways and post and telegraph facilities are introduced. Due to the increase

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in agricultural revenue of the state, and due to rise in the living standards of the people, schools, hospitals and other facilities are provided. All these in turn have direct influence in making the people better citizens. There are instances in which the most dry and backward areas have become prosperous and civilised, mainly due to the introduction of irrigation facilities.

1.6. ILL-EFFECTS OF IRRIGATION

Excess irrigation and unscientific use of irrigation water may give rise to the following ill-effects :

1. ***Breeding Places for Mosquitoes :*** Due to excess application of water, and due to leakage of water, ponds and depressions get filled up with water and create breeding places for mosquitoes. Also, if the canal is leaky, mosquitoes breed all along the canal and spread malarial conditions.

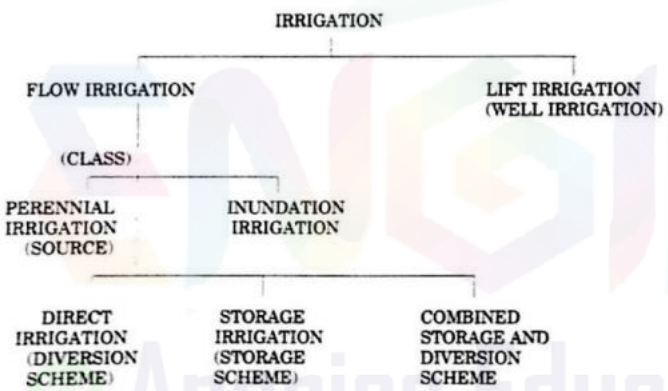
2. ***Water-Logging*** : If the water table is near the ground surface, over-irrigation may raise the water table. This saturates the crop root-zone completely, causes efflorescence and the whole area becomes waterlogged.

3. ***Damp Climate*** : The areas which are already damp and cold, become damper and colder due to irrigation.

1.7. TYPES OF IRRIGATION

Irrigation has the following main types or classes :

(*a*) Flow Irrigation, and (*b*) Lift Irrigation.



Flow Irrigation

Flow irrigation is that type of irrigation in which the supply of irrigation water available is at such a level that it is conveyed on to the land by the gravity flow.

Flow irrigation may further be divided into two classes :

(*i*) Perennial irrigation system (*ii*) Inundation or flood irrigation system.

Perennial Irrigation : In perennial irrigation system, the water required for irrigation is supplied in accordance with the crop requirements throughout the crop period. For such a system, therefore, some storage head works, such as dams and storage weirs or barrages are required to store the excess water during floods and release it to the crops as and when it is required.

Inundation Irrigation : Inundation irrigation is carried out by deep flooding and thorough saturation of the land to be cultivated which is then drained off prior to the planting of the crop.

Depending upon the source from which the water is drawn, flow irrigation can be further subdivided into three types :

(*i*) Direct irrigation (River canal irrigation) : Diversion scheme

(*ii*) Storage irrigation (Reservoir or tank irrigation) : Storage scheme

(*iii*) Combined storage and diversion scheme.

1. *Direct Irrigation or River Canal Irrigation*

In this direct irrigation system, water is directly diverted to the canal without attempting to store the water. For such a system, a low diversion weir or diversion barrage is constructed across the river. This raises the water level in the river and

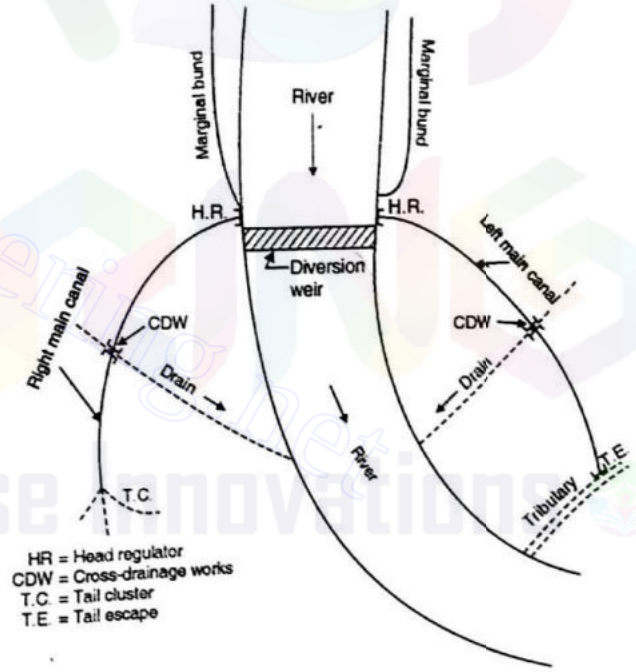


FIG. 1.1. DIRECT IRRIGATION SCHEME.

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thus diverts the water to the canal taking off upstream of the weir, as shown schematically in Fig. 1.1.

Generally, a direct irrigation scheme is of a smaller magnitude, since there are no rigid controls over the supplies. One or two main canals may take off directly from the river. Cross-draninage works are constructed wherever natrual drains or distributary streams cross the canals. In a bigger scheme, there may be branch canal taking off from the main canal.

2. *Storage Irrigation or Tank Irrigation*

In storage irrigation system, a solid barrier, such as a dam or a storage weir is constructed across the river and water is stored in the reservoir or lake so formed.

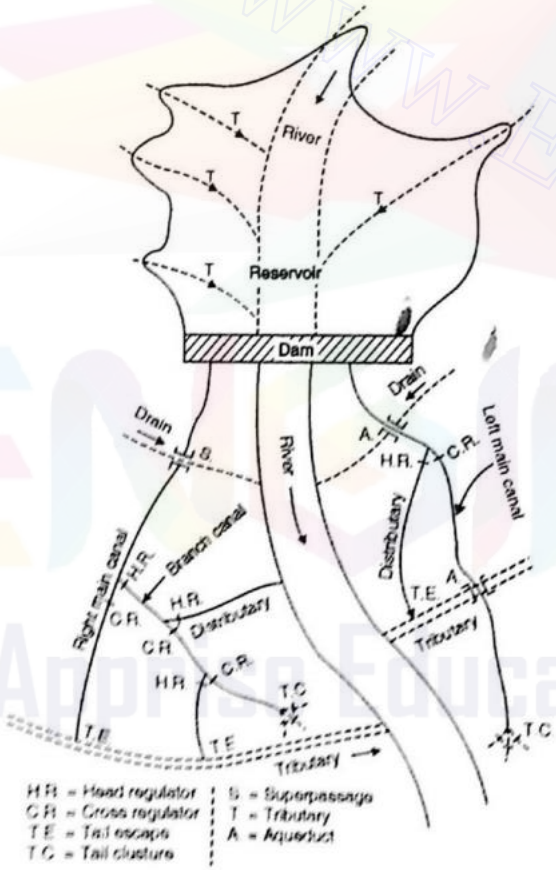

FIG. 1.2. STORAGE IRRIGATION SCHEME.

Depending upon the water requirements of crops, or the hydroelectric power generation, and upon the flow of water in the river, the volume of storage required is decided. From the contour plan of the basin at the site of construction, the elevation storage curve for the reservoir is known. The height of the dam is then decided from this curve, corresponding to the storage-volume required. In India, most of the irrigation schemes fall under this category. Fig. 1.2 shows the schematic plan for such a scheme.

Storage irrigation scheme is comparatively of a bigger magnitude, and involves much more expenditure than a direct irrigation scheme. One or two main canals take off from the reservoir. Due to the formation of reservoir, some land property may be submerged to the upstream of the dam. A network of canal system convey water to the agricultural fields, through various regulatory works. Cross-drainage works such as aqueducts, syphon aqueducts, super passages and canal syphons are constructed wherever natural drains cross the canals.

3. *Combined System (Storage cum Diversion Scheme)*

We have seen that in the storage irrigation system, water is stored in the reservoir, since the river is not perennial, while in the direct irrigation system, the river is

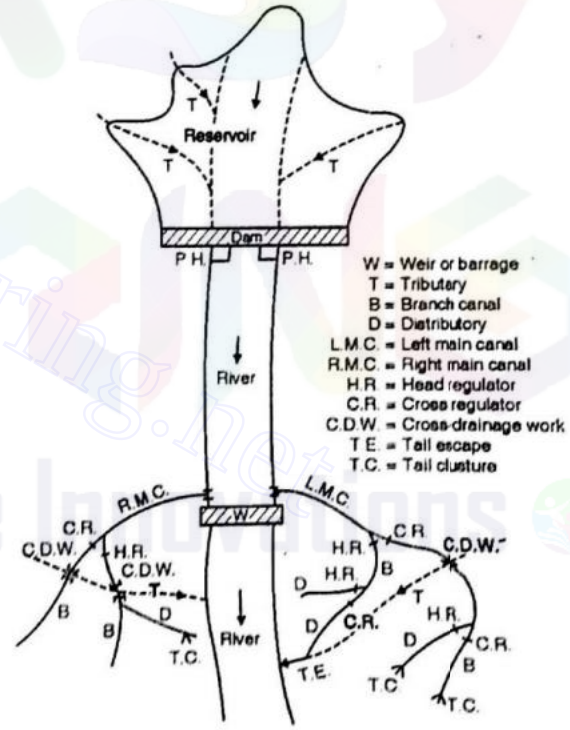

FIG. 1.3. STORAGE-CUM-DIVERSION SCHEME.

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perennial and hence the water is *diverted* from the river to the canal. Sometimes, a combined scheme is adopted in which the water is first stored in the reservoir formed at the upstream side of the dam, and this water is used for water power generation. The discharge from the power house is fed back into the river, to the downstream side of the dam. Thus, sufficient quantity of flow is again available in the river. At a suitable location in the downstream, a *pick-up weir* is constructed. This weir diverts the water from the river to the canal. Fig. 1.3 shows such a storage-cum-diversion scheme. One typical example of such a scheme is the Kota dam and Kota barrage on Chambal river in Rajasthan.

Choice Between the Systems

Direct irrigation scheme is adopted in the circumstances where the river is perennial and has a normal flow throughout the irrigation season, never less at any time than the requirements of the field. On the contrary, storage irrigation system is adopted when the river flow is either not perennial, or where flow is insufficient during certain parts of the crop season for irrigation requirements. In a multistage river-valley development, a combined storage-cum-diversion scheme is more useful.

Lift Irrigation

Lift irrigation is practised when the water-supply is at too low a level to run by gravitation on to the land. In such a circumstances water is lifted up by mechanical means. Irriagation from wells is an example of lift irrigation, in which sub-soil water is lifted up to the surface and is then conveyed to the agricultural fields.

1.8. HISTORY OF IRRIGATION DEVELOPMENTS IN INDIA

Irrigation practice[1] in India can be traced to prehistoric times. Perhaps the earliest reference to irrigation is given by the great sage, Narada, who came to see the Emperor, Yudhishthhira, around 3150 B.C and asked "Are the farmers sturdy and prosperous? Are the dams full of water and big enough and distributed in different parts of the kingdom ?"[2] Ancient Hindu rulers took very keen interest in construction of irrigation works. The account left by Megasthenese – the Greek Ambassador of Sleukos Nikator to the court of Chandra Gupta Maurya – also gives some idea about irrigation in India around 300 B.C.when "the whole country was under irrigation". Rock inscriptions found in the State of Kathiawar also credit Chandra Gupta with the construction of *Sudarsan lake* (300 B.C.- 457 A.D.). An excellent description of the *pleasant looking dam* is found from the inscriptions recording two major disasters that befell it, in one of which "by a breadth, four hundred and twenty cubits long, just as many broad (and) seventy-five cubits deep, all the water flowed out so that (the lake), almost like a sandy desert, (became) extremely ugly (to look at)."[2] Chola rulers of South India also constructed necessary irrigation works.

The Muslim rulers also took keen interest in constructing canals for irrigation. In the 14th century, Sultan Firoz Tughlaq constructed a number of canals from Sutlej

1. "*Irrigation in India : Past and Present*" by A. K. Biswas, Journal of the Irrigation and Drainage Division, ASCE March, 1965.

2. "*Selection from Sanskrit Inscriptions*", Vol. I, part II, by D.B. Diskalkar.

and Yamuna rivers. Akbar remodelled Firozshah canal in 16th century and put it in use again. Shah Jahan also constructed a number of new canals and remodelled old ones.

State-controlled irrigation works have begun to play a major role only in the last about 150–200 years. In the nineteenth century, the *British Raj* was more concerned with the improvement of existing irrigation works than with building new ones. Three important irrigation works — Western Yamuna Canal, Eastern Yamuna Canal and Cauvery Delta System — were remodelled and opened.

Sir Proby Cautley and Sir Arthur Cotton were perhaps amongst the leaders who laid the foundation of modern irrigation engineering in India. Cautley's finest work is the aqueduct over Solani river. He was also responsible for the Great Ganga Canal and the Eastern Yamuna Canal. Cotton worked on the Southern side of subcontinental peninsula, and built the upper anicut across Coleroon, a tributary of Cauvery river. He also developed Godavari and Krishna deltas. Table 1.1 shows the major irrigation works completed from 1820-1930.

TABLE 1.1
MAJOR IRRIGATION WORKS COMPLETED FROM 1820-1930

Project	*Year of completion*	*Area irrigated in thousand hectares*
Western Yamuna Canal	1820	431
Ganga Canal	1856	655
Lower Ganga Canal	1880	506
Sirhind Canal	1884	935
Cauvery Delta System	1889	434
Godavari Delta System	1890	497
Krishna delta System	1898	405
Sarda Canal	1930	525

Perhaps the first hydro-electric work in India was undertaken in 1897 near Darjeeling. The State of Mysore constructed in 1902, the Sivasamudram hydroelectric works with an installed capacity of 4500 kW which was later increased to 42,000 kW. Tatas constructed Khapoli hydroelectric works (1914) with an installed capacity of 50,000 kW, Bhivpuri-hydroelectric works (in 1920) with a capacity of 72,000 kW, and Bhira Scheme (1927) with an installed capacity of 110,000 kW. During the period between the two World Wars some hydroelectric schemes were taken up by various states. They include Jogindernagar hydroelectric scheme (48,000 kW), Ganga Canal power stations (17,400 kW), Pykara hydroelectric scheme (38,750 kW), Mettur hydroelectric scheme (30,000 kW) and Pillivasal scheme (13,500 kW). After Second World War and before independence, only two hydroelectric installations, *i.e.,* Papansam (21,000 kW) and Jog (48,000 kW) were made.

After independence (1947), the Government of India was concerned with the need for food for a vastly growing population and irrigation was given a much needed impetus. Nearly 27.2% of the total outlay in the First Five Year plan (1951-56) was set side for irrigation and power. In the Second Five Year Plan (1956-61), 19% of the total outlay was used for irrigation and power. In the Third Five Year Plan (1961-66), about 22 % of the total outlay was spent on irrigation and power development. Table 1.2 shows the major irrigation schemes undertaken after 1947.

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TABLE 1.2
MAJOR IRRIGATION SCHEMES AFTER 1947

Project	*Area to be irrigated (million hectares)*	*Total cost in crore rupees (of irrigation part only)*
Bhakra Nangal	1.46	101.9
Gandak	1.35	49.5
Hirakud	0.87	93.3
Nagarjuna Sagar	0.83	91.1
Chambal	0.57	54.9
Kosi	0.56	24.8
Damodar Valley	0.51	34.7
Mahi	0.30	41.0
Rajasthan canal	1.41	206.0

Table 1.3. gives the plan wise irrigation potential created, irrigation potential utilised and approximate expenditure incurred in India.

TABLE 1.3. PLANWISE IRRIGATION POTENTIAL CREATED, POTENTIAL UTILISED (CUMULATIVE) AND EXPENDITURE INCURRED

S.N.	*Plan with Period*	*Potential created (cumulative in Mha)*	*Potential utilised (cumulative in Mha)*	*Expenditure in curred (Rs. Crore)*
1.	Pre – Plan (upto 1951) and Ist plan (1951-56)	26.25	25.05	+ 443
2.	Second Plan (1956-61)	29.06	27.78	542
3.	Third Plan (1961-66)	33.57	32.18	1019
4.	Annual Plans (1966-69)	37.12	35.77	991
5.	Fourth Plan (1969-74)	44.20	42.09	2415
6.	Fifth Plan (1974-78)	52.02	48.26	3926
7.	Annual Plans (1978-80)	56.61	52.65	3061
8.	Sixth Plan (1980-85)	65.22	58.82	10786
9.	Seventh Plan (1985-90)	76.53	68.59	17387
10.	Annual Plan (1990-92)	81.09	72.86	27000
11.	Eighth Plan (1992-97)	95.43	80.37	
12.	Ninth Plan (1997-2002)	105.33	83.91	47000

India has unequal distribution of rainfall over the country varying from less than 25 cm in the north-west deserts of Rajasthan to about 1150 cm at Cherrapunji in the Assam hills. Substantial variations in the quantity, incidence and duration of rainfall in individual tracts from year to year, make irrigation of supreme necessity in the country.

PROBLEMS

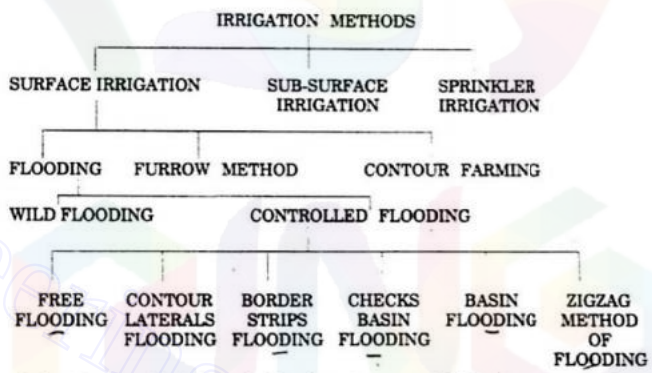
1. Define irrigation. What is the necessity of irrigation ?
2. Write a note on scope of irrigation. What is meant by a multipurpose river valley project ?
3. Discuss in brief the benefits and ill-effects of irrigation.
4. Write an essay on 'History of irrigatioin developments in India'.
5. Describe in brief some of the important irrigation projects and multipurpose river valley projects undertaken or completed after Independence of our country.

2

Methods of Irrigation

2.1. MODES OR METHODS OF APPLYING WATER TO CROPS

Irrigation water may be applied to the crops by three basic methods : (1) Surface irrigation method, (2) Sprinkler irrigation method, and (3) Sub-surface irrigation method. The surface irrigation method can futher be sub-divided into various methods as indicated below:



Every irrigation method has both advantages and disadvantages. Before selecting a particular method, the irrigation engineer (or agricultural engineer) must evaluate all the factors, and choose that method which is best suited to the local conditions.

The basic requirements for adaptation of any irrigation method or mode of application of water are as follows :

1. The method should be such that uniform water distribution with as small as 6 cm water depth applications can be made for light irrigation.
2. At the same time, it should afford heavy uniform application of 15 to 20 cm water depth.
3. It should allow the use of large concentrated water flows for reduction of conveyance losses, and labour cost.
4. It should be suitable for use with economic conveyance structure.

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5. It should be such that mechanised farming is facilitated.

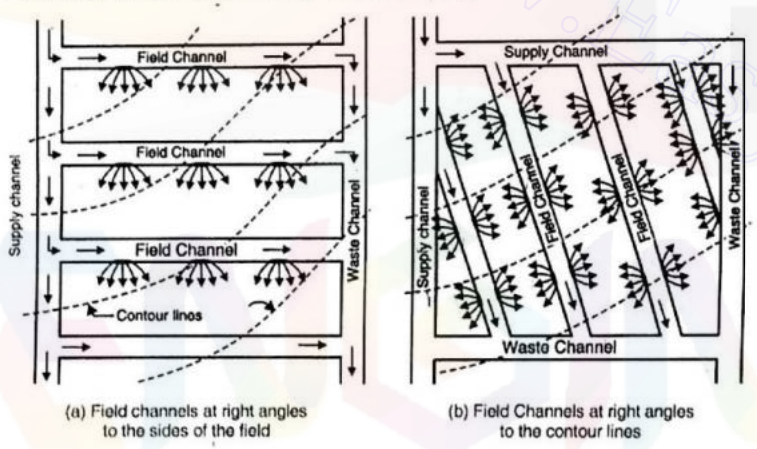
Good irrigation method results in increased yield and conservation of resources with soil productivity maintained and water utilised economically. Over irrigation results in soil erosion, leached fertilizers, drainage troubles and salt accumulation.

2.2. UNCONTROLLED OR WILD FLOODING

In this method, water is spread or flooded on a rather smooth flat land, without much control or prior preparation. This method is generally used in the inundation irrigation system in which water is forced to spread over vast tracts during the season of high stream flow. It is wasteful use of water, and is practised largely where irrigation water is abundant and inexpensive.

2.3. FREE FLOODING OR FLOODING FROM FIELD CHANNELS

In the *controlled flooding*, water is spread over the land, with proper methods to control the depth of application. Controlled flooding can be achieved by free flooding, contour laterals, border strips or by check flooding.



(a) Field channels at right angles to the sides of the field

(b) Field Channels at right angles to the contour lines

FIG. 2.1. FREE FLOODING METHOD.

Free flooding method consists of dividing the entire land to be irrigated into small strips by a number of field channels, known as *laterals*. These laterals may be either at right angles to the sides of the field, or at right angles to the contour lines, as shown in Fig. 2.1 (*a*) and (*b*) respectively. When the laterals are aligned at right angles to the sides of the field, irrigation is possible only to one side of the lateral. However, when the laterals are aligned at right angles to the contours, irrigation done to both the sides of the lateral (Fig. 2.1 *b*). The field channels receive water from the supply channel and discharge excess water in the *waste channel*. Water is applied to the strip of a land through feeding points provided at some interval along the laterals. This method of water application can be used both for flat lands as well as for relatively steep lands. The alignment and spacing of the laterals depends upon

the type of soil (i.e. its permeability characteristics) and topography of the land. If the slopes are steeper, closer spacing of laterals is required. Similarly, closer spacing is required for relatively more permeable soils. For flat land and for relatively less pervious soils, the spacing of the laterals may be increased. Normally the spacing of the laterals may vary from 10 to 50 metres. However, the method is more suited for irrigation fields containing medium type soil and having slopes ranging from 1 in 100 to 1 in 300.

2.4. FLOODING BY CONTOUR LATERALS

This is a special case of *free flooding* (or flooding from field channels) in which the field channels or laterals are aligned approximately along the contour lines.

This method is applicable for steeper terrain. The field is cut by relatively dense network of small contour laterals, the spacing of which depends upon the prominent grade of the field between two adjacent ditches or laterals, the uniformity of slope and the soil type.

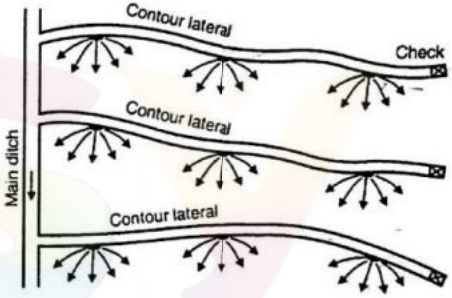


FIG 2.2. CONTOUR LATERALS.

2.5. BORDER STRIP FLOODING METHOD

In the border strip flooding method, the farm is divided into a series of strips 10 to 20 metres wide and 100 to 300 metres long. These strips are separated by low levees or borders (low flat dikes) and run down the predominant or any other desired slope. To irrigate, water (discharge varying from 0.014 to 0.028 cumec) is turned from the supply ditch onto the head of the border. Water advances — confined and guided by two borders — in a thin sheet towards the lower end of the strip. The surface is essentially level between two borders so that the advancing sheet of water covers the entire width of the strip. The lengthwise slope varies from 0.2 to 0.8%. The border strip should be level cross-wise.

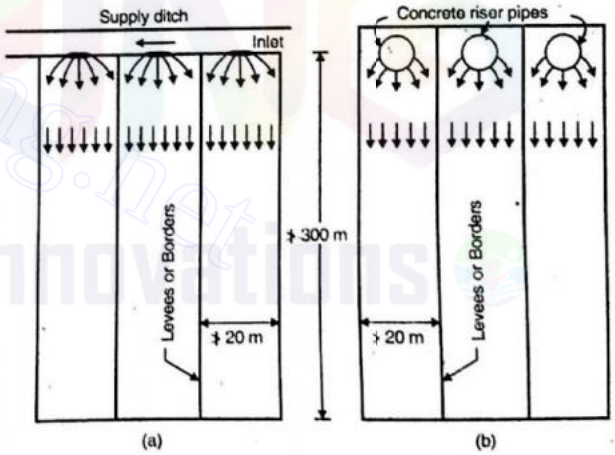


FIG. 2.3. BORDER STRIP METHOD.

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Cross-slopes within border strips cause water to concentrate along the lower side of the strip causing uneven irrigation. This method is especially suited to forage crops, its advantage being that for a relatively low investment a system can be developed which can afford the highest irrigation efficiency and lowest labour requirements. With highly mechanised farming, large area can be irrigated within a short time by border strip method. The length of border strip depends upon how quickly it can be wetted over its entire length. This, however, depends upon :

(*i*) Infiltration rate of the soil,

(*ii*) Longitudinal slope of the land, and

(*iii*) Size of irrigation stream available.

The following lengths are suggestesd for moderate conditions :

Types of soil	*Length of border strip*
(*i*) Sandy soil or sandy loam	60 to 90 m
(*ii*) Medium silt loam	90 to 150 m
(*iii*) Clay loam or clay soil	150 to 300 m

The first 6 to 12 m length of the strip should be made level to ensure uniform spreading of water.

Water is diverted to the border strips from the following :

(a) Earth or concrete ditches (canals) : These run at a flat longitudinal grade. The water is discharged into the strips via border gates, aluminium syphons or plastic piping [Fig. 2.3 (*a*)].

(b) Under-ground concrete pipes through risers : In this method, water is let into the strips by concrete risers, as shown in Fig. 2.3(*b*).

Distribution and control of water

In irrigation by the border strip method, water is carried along the *head ditch* (supply ditch) at the upper end of the borders and is diverted along the border strips where it is guided by border ridges to the lower end of the strip. Border ridges need be high enough not to be over topped by water. Water may be checked in the head ditch with portable canvas or metal dams, or a permanent system of check and turnout system may be used. It may be turned into border strips through siphon tubes or pipe turn-outs or open turn-outs consisting of a wooden or metal check gate.

The maximum *non-erosive* flow of water should be applied to each strip at the beginnings of irrigation. After the entire strip has been wetted, the flow may be reduced by adjus the gates so that water is applied only as fast as it can soak in. In this way, uiform depth of penetration is achieved and very little water is wasted by runoff the lower end of the strip.

Field trials with border strips in India have proved that uniform water application can be obtained with a minimum of labour in a properly designed irrigation system. This is true even in the sandy soils of Rajasthan.

Advance and Recession curves : Time of Ponding

The size of irrigation stream and *duration* of irrigation can be determined for any given field conditions by having *trial runs* and plotting the *advance* and *recession*

curves and thereby determining *time of ponding*. For this purpose, flags or stakes are placed at regular intervals (usually 5 m) on the ridge along the length the strip. The time the *water front* reaches at each such station is noted and the *advance curve*, is plotted. After the stream reaches the lower end of the strip, the water supply is cutoff. The water front then recedes from the head end towards the lower end. The time the water front disappears at each station is noted and the *recession curve* is plotted. At any station, the difference between the time of advance and time of recession gives the *time of ponding* (also known as *infiltration opportunity time*).

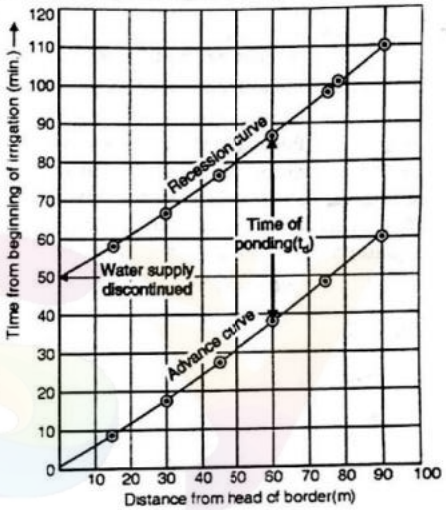

FIG. 2.4. ANALYSIS OF TIME IN BORDER STRIP METHOD.

Fig 2.4 shows typical advance and recession curves for a border strip having the following data :

(*i*) Irrigation stream : 2.40 litres per sec per metre of border width

(*ii*) Border width : 15 m

(*iii*) Border slope : 0.5%

(*iv*) Water depth required : 75 mm

(*v*) Total water depth applied : 78 mm

(*vi*) Water stored : 70 mm

(*vii*) Deep percolation and runoff : 8 mm

(*viii*) Soil type : Loamy sand.

The *time of ponding* at a given station, so determined, gives the duration the water has been standing at the station. *Uniform application is achieved by having the time of ponding practically same throughout the border strip* and this is achieved by having both the advance and recession curves practically parallel. The time of ponding can be altered by adjusting the size of stream or by prolonging the irrigation after it reaches the end. The *time of ponding selected should be as nearly as possible the same time which is required to infiltrate the required quantity of water into the soil.*

Analysis of time to cover a strip area

Size of irrigation stream applied to unit area of land is varied according to the rate of infiltration of water into the soil. When a large stream is applied to unit area of the soil of low infiltration rate, excessive surface runoff occurs. However, when a small stream is applied to a unit area of soil of high infiltration rate, excessive depths of water are lost by deep percolation. The relation between size of stream and time rate of water application over a given area of land can be most easily stated by means of a rational equation derived below (Fig. 2.5) :

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Let A = Area of land covered at any time t,

I = Rate of infiltration in m/hour

Q = Discharge for the strip in cumecs or ha-m/hour

t = Time required to cover area A.

y = Average depth of sheet of flowing water, in metres.

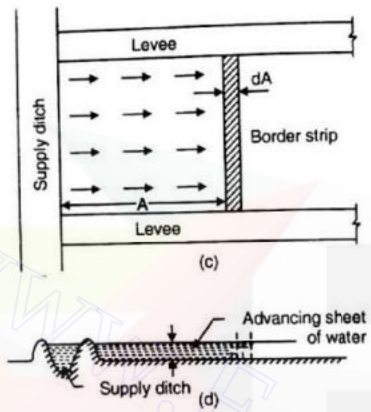

FIG. 2.5

Total quantity of water flowing in small time interval dt is equal to the quantity of water infiltrated in this time dt over the area A plus the quantity of surface flow over the area dA.

$$Q\,dt = y\,dA + IA\,dt$$

From which $$dt = \frac{y\,dA}{Q - IA} \quad ...(1)$$

Considering I and y as constants and integrating, we get

$$t = \frac{y}{I}\log_e \frac{Q}{Q - IA}$$

$$= 2.303\,\frac{y}{I}\,\log_{10}\frac{Q}{Q - IA} \quad ...(2)...(2.1)$$

The constant of integration being zero since $A = 0$ when $t = 0$. In the above equation, I has been considered constant, but actually I decreases as the soil gets saturated. Eq. (2) can be rewritten in the form below:

$$\log_{10}\frac{Q}{Q - IA} = \frac{I\,.\,t}{2.303\,y} = x\ (say)$$

or $$10^x = \frac{Q}{Q - IA}$$

From which $$A = \frac{(10^x - 1)\,Q}{10^x\,I} \simeq \frac{Q}{I} \quad ...(2.2)$$

Equation (3) is very important since it gives the maximum area that can be irrigated with a stream of discharge Q.

If B is the width of strip and L is the length of strip or length of run, we have $A = B.L$. Similarly, q = discharge per unit width $= Q/B$. Hence from Eq. 2.1, we have

$$t = \frac{y}{I}\log_e \frac{Q}{Q - IBL} = \frac{y}{I}\log_e \frac{q}{q - IL} \quad ...(2.1\ a)$$

Hence $$L = \frac{q}{I}\left[1 - e^{-It/y}\right] \quad ...(4)\ ...(2.3)$$

If t is the time required for infiltration of water to the desired depth d of irrigation to the root zone, we have

$$d = I.t \quad ...(5)$$

Substituting the value of $I.t$ in Eq. (4), we get

$$L = \frac{q}{I}\left[1 - e^{-d/y}\right] \quad ...(2.4)$$

Eq. 2.4 can be used for determining the length of border (L) for given values of I, q, d and y. Similarly, for given values of L, I, d and y, the unit flow rate q can be determined.

Average depth y of surface flow

The average depth of surface flow, y, is related to the *normal* or *uniform depth* y_0 by the relation

$$y = 0.665\,y_0 \quad ...(2.5)$$

Also, the normal or uniform depth y_0 is given by Manning's equation

$$y_0 = \left(\frac{nq}{\sqrt{s}}\right)^{0.6} \quad ...(2.6)$$

where s is the slope of the border strip and n is the *roughness coefficient* given by the following equation :

$$n = 0.55425 - 0.0001386\,q' \quad ...(2.7)$$

where q' = inflow per unit width of border strip, in $cm^3/min/cm$

Time of application of water to the strip

If the infiltration rate (I) and desired depth (d) of infiltration are known, the time of application is given by

$$t = d/I \quad ...(5a)\ ...(2.8)$$

Example 2.1. *Find the time required to cover an area of 0.1 hectares when a tube well is discharging at the rate of 0.03 cumec for irrigating rabi crops. Average depth of flow is expected to be 7.5 cm. Average infiltration rate for the soil may be taken as 5 cm/hour.*

Solution

Q = 0.03 cumec = 0.03 × 3600 m^3/hour = 0.0108 hectare-metre/hour

y = 7.5 cm = 0.075 m : I = 5 cm/hour = 0.05 m/hour

A = 0.1 hectare

Substituting in Eq. 2.1, we have

$$t = 2.303\,\frac{y}{I}\,\log_{10}\frac{Q}{Q - IA} = \frac{2.303 \times 0.075}{0.05}\log_{10}\left(\frac{0.0108}{0.0108 - 0.1 \times 0.05}\right)\text{hours} = \mathbf{56\ minutes.}$$

Example 2.2. *For the above example, find the maximum area that can be irrigated by the available discharge of 0.03 cumec.*

Solution : From Eq. 2.2, it is obvious that the maximum area that can be irrigated is Q/I. After this area, the surface flow will stop and total percolation will result.

$$\therefore \quad A = \frac{Q}{I}\ \text{hectares} = \frac{0.0108}{0.05} = \mathbf{0.216\ hectare.}$$

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Example 2.3. *For a given field soil, the average infiltration rate is 45 mm per hour, and desired depth of water application corresponding to the depth of root zone is 50 mm. Determine (a) optimum length of each border strip if the discharge of the water source entering into the border strip is 18 litres per second and width of each border strip is 9 m, and (b) the inflow rate if the length of each border strip is 150 m and its width is 9 m. What will be the time of water application in each case ? Take the slope of the border strip as 0.35%.*

Solution $d = 50 \text{ mm} = 0.05 \text{ m}$

Also, $I = 45 \text{ mm/hour} = \dfrac{45}{1000 \times 3600} = 1.25 \times 10^{-5} \text{ m/s}$

Time of water application, $t = \dfrac{d}{I} = \dfrac{50}{45} = \mathbf{1.111 \text{ hours} \triangleq 1 \text{ hour } 7 \text{ min.}}$

(*a*) ***Optimum length of border strip*** :

$$q = 18 \text{ lps per 9 m width} = \frac{18}{9 \times 1000} = 2 \times 10^{-3} \text{ m}^3/\text{s/m width}$$

$$q' = (\text{in cm}^3/\text{min/cm width}) = \frac{2 \times 10^{-3} (100)^3 (60)}{100} = 1200 \text{ cm}^3/\text{min/cm width}$$

From Eq. 2.7, $n = 0.55425 - 0.0001386\, q' = 0.55425 - 0.0001386 \times 1200 = 0.3879$

From Eq. 2.6, $y_0 = \left(\dfrac{nq}{\sqrt{s}}\right)^{0.6} = \left(\dfrac{0.3879 \times 2 \times 10^{-3}}{\sqrt{0.0035}}\right)^{0.6} = 0.0742 \text{ m}$

Hence from Eq. 2.5, $y = 0.665\, y_0 = 0.665 \times 0.0742 = 0.049 \text{ m}$

From Eq. 2.4, $L = \dfrac{q}{I}\left[1 - e^{-d/y}\right] = \dfrac{2 \times 10^{-3}}{1.25 \times 10^{-5}}\left[1 - e^{(-0.05/0.049)}\right] = \mathbf{102.3 \text{ m}}$

(*b*) ***Inflow rate for L = 150 m.***

For a given value of L, q is determined from Eq. 2.4. However, Eq. 2.4 also contains depth y which is dependent on y_0 and depth y_0 is again dependent on q as evident from Eq. 2.6. Hence the determination of discharge, for a given value of L, is essentially a process of trial and error.

First trial : In part (*a*), given inflow rate is 18/9 = 2 lps per m width for $L \triangleq 102.3$ m. Hence the inflow rate for $L = 150$ m will be approximately equal to (150/102.3) 2 = 2.93 lps. In the first trial, let $q = 3$ lps/m width.

Thus $q = 3 \text{ lps/m} = 3 \times 10^{-3} \text{ m}^3/\text{s/m width}$

$$\therefore \quad q' = \frac{3 \times 10^{-3} (100)^3 (60)}{100} = 1800 \text{ cm}^3/\text{min./cm width}$$

$$\therefore \quad n = 0.55425 - 0.0001386 \times 1800 = 0.3048$$

$$\therefore \quad y_0 = \left(\frac{0.3048 \times 3 \times 10^{-3}}{\sqrt{0.0035}}\right)^{0.6} = 0.0819 \text{ m}$$

$$\therefore \quad y = 0.665 \times 0.0819 = 0.0545 \text{ m}$$

$$\therefore \quad L = \frac{3 \times 10^{-3}}{1.25 \times 10^{-5}}\left[1 - e^{(-0.05/0.0545)}\right] = 144.11 \text{ m}$$

But given value of $L = 150$ m

Second trial : In the second trial, let $q = \dfrac{150}{144.11} \times 3 \triangleq 3.12$ lps/m

Assume $q = 3.15 \text{ lps/m} = 3.15 \times 10^{-3} \text{ m}^3/\text{s/m width}$

$$\therefore \quad q' = \frac{3.15 \times 10^{-3} (100)^3 (60)}{100} = 1890 \text{ cm}^3/\text{min./cm}$$

$$\therefore \quad n = 0.55425 - 0.0001386 \times 1890 = 0.2923$$

$$y_0 = \left(\frac{0.2923 \times 3.15 \times 10^{-3}}{\sqrt{0.0035}}\right)^{0.6} = 0.0823 \text{ m}$$

$$\therefore \quad y = 0.665 \times 0.0823 \triangleq 0.055 \text{ m}$$

$$\therefore \quad L = \frac{3.15 \times 10^{-3}}{1.25 \times 10^{-5}}\left[1 - e^{(-0.05/0.055)}\right] = 150.9 \text{ m}$$

This is approximately equal to the given length $L = 150$ m. Hence no further trial is necessary. Thus, required discharge $q = \dfrac{150}{150.9} \times 3.15 = 3.13$ lps/m width, and the discharge for each border strip $= 3.13 \times 9 \triangleq$ **28.2 lps.**

2.6. CHECK FLOODING

Check flooding is similar to free flooding except that the water is controlled by surrounding the *check area* with low, flat levees surrounding each *check* while in free flooding no such levees are provided and the strips are divided by field channels.

It is the most common method of irrigation used in India as well as in many other countries. The method is also known as *irrigation by plots* since the entire area is divided into several plots obtained by subdividing the entire area by levees. Each plot is practically level. The size of the levee depends upon the depth of water to be applied as well as the stability of the soil when it is wet. Water is conveyed to the land by a system of *supply channels* (known as *main ditch*) as well as *laterals* (known as *field channels*). Usually, there is one field channel for every two rows of plots as shown in Fig. 2.6. Water is admitted to these plots at the higher end and the supply is cutoff as soon as the lower part of the plot has received

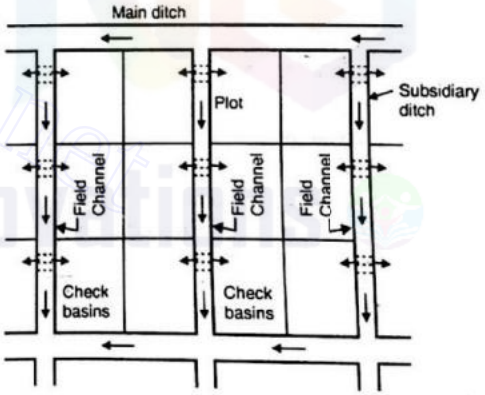

FIG. 2.6. CHECK FLOODING OR IRRIATION BY PLOTS

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the sufficient depth of water. Oblong plots are preferred to the square plots. The size of the plots depends on the porosity of the soil.

In a levelled ground, the plots are generally rectangular, but if the ground has same initial slope, the checks or levees may follow contours, as shown in Fig. 2.7. *Contour checks* are prepared by constructing ridges along contours at vertical intervals of 6 to 12 cm and connecting them with *cross-ridges* at intervals. Very little crop land is perfectly level, and the water does not stand at a uniform depth over the entire check. This results in uneven distribution of water within the plot. Low area will receive too much water and high gets too little.

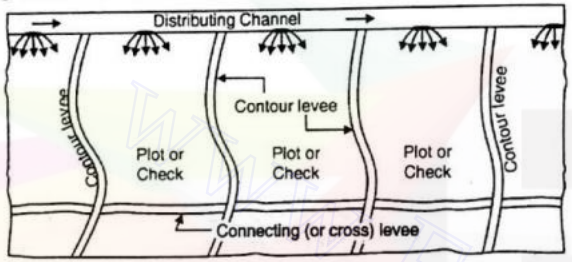

FIG. 2.7. CHECK FLOODING WITH CONTOUR LEVEES.

The size of *check basins* (also known as *checks* or plots) is dependent on the infiltration rate (also known as intake rate or the depth of water entering the soil per unit time). It may vary from 1 m^2 for growing vegetables and other intensive irrigation to 1 - 2 hectares for growing rice under wet land conditions. However, the more common size varies from 0.03 to 0.06 hectares for medium soils. The size of the stream should be sufficient to cover the entire basin in a relatively small portion of time required to apply the desired depth of irrigation water.

Since water is supplied through large stream, the method is more suitable for permeable soils which must be quickly covered with water in order to prevent excessive percolation losses near the supply ditches. The method is also suitable for impermeable soils in which the percolation rate is so slow that infiltration would be inadequate in the time required for the sheet of water flowing over it.

Design Features

Let t_L = time of advance (i.e. the time required to cover the entire length L of the basin)

t_d = time of ponding (Refer Fig. 2.4)

Since some time (t_L) is required for water to spread over the entire basin, the time of ponding (t_d) and hence the depth of water absorbed by the soil will not be the same for the entire basin. Thus, in order to obtain a higher water *application efficiency*, the time of advance should be as small as possible. *The general practice is to keep the time to spread water in the entire base equal to one fourth the time required to infiltrate the net depth (d) of irrigation water.*

The rate of infiltration (I) is a function of time t and can be expressed by the expression :

$$I = k \cdot t^n \qquad ...(1) \quad ...(2.9a)$$

where k and n are the constants depending upon the type of the soil.

Hence the *accumulated depth of infiltration* during the time of ponding (t_d) is given by

$$I_c = \int_0^{t_d} k t^n \, dt = \frac{k \cdot t_d^{(n+1)}}{n+1} = k' \, t_d^{n'} \qquad ...(2) \quad ....(2.9)$$

where $k' = k/(n+1)$ and $n' = n+1$

Neglecting the volume of water absorbed during the time of advance, the total volume of water (V_d) absorbed over a length L, per unit with of the check basin is given by

$$V_d = \int_0^L I_c \cdot dL = \frac{k}{n+1} \int_0^L t_d^{n+1} \, dL = \frac{k \, L \, t_d^{n+1}}{n+1} = k' \, L \, t_d^{n'} \qquad ...(3) \quad ....(2.10)$$

Let T = Total time of irrigating the check basin $= t_L + t_d$

The time of advance (t_L) is a function of stream size and soil characteristics, and can be expressed by the following *advance function*

$$L = a \, (t_L)^b \qquad ...(4) \quad ...(2.11)$$

where a and b are constants.

The *total volume* (V_T) absorbed over a length L, per unit width of check basin, during the total time $T \, (= t_L + t_d)$ is obtained from Eq. (3) in the form

$$V_T = \frac{k \, L \, T^{n+1}}{n+1} = k' \, L \, T^{n'} \qquad ...(5)$$

Hence *deep percolation loss*, expressed as a fraction of total volume of water is given by

$$p = \frac{V_T - V_d}{V_T} = \frac{T^{n+1} - t_d^{n+1}}{T^{n+1}} = \left[1 - \left(\frac{t_d}{T} \right)^{n+1} \right] \qquad ...(6) \quad ...(2.12)$$

Hence *water application efficiency* (η_a) is given by

$$\eta_a = \frac{V_d}{V_T} \times 100 = \left(\frac{t_d}{T} \right)^{n+1} 100 = \left(\frac{t_d}{t_L + t_d} \right)^{n+1} \times 100 = (1 - p) \, 100 \qquad ...(7) \quad ...(2.13)$$

Volume of water to be applied $= \dfrac{d \, L \, B}{\eta_a}$ ....(8) ...(2.14)

where B is the width of the basin

Time of irrigation $= \dfrac{d \, L \, B}{\eta_a \, Q}$ ...(a) ....(2.15)

where Q is the discharge of the irrigating ditch or stream.

Example 2.4. *For a check basin of size 12 m × 36 m, the following functions are available :*

1. Cumulative infiltration $I_c = 9 \, t^{0.42}$, *where* I_c *is in mm and t is in minutes*

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2. *Advance function :*

(a) $L = 5\, t_L^{0.6}$ *for a stream of size 1.5 lps/m width*

(b) $L = 8\, t_L^{0.6}$ *for a stream of size 3 lps/m width*

If the depth of irrigation is 70 mm, determine (a) deep percolation loss, (b) water application efficiency, and (a) time of irrigation for each of the above sizes of stream.

Solution : Given : $B = 12$ m ; $L = 36$ m and $d = 70$ mm; $k' = 9$; $n' = 0.42$

(a) *For stream of 1.5 lps/m width* : Given : $a = 5$ and $b = 0.6$

$$q = 1.5 \text{ lps and hence } Q = qB = (1.5 \times 12) \text{ lps} = 1.5 \times 12 \times 10^{-3} \text{ m}^3/\text{s}$$

From Eq. 2.11, $t_L = \left(\frac{L}{a}\right)^{1/b} = \left(\frac{36}{5}\right)^{1/0.6} = 26.85$ minutes

From Eq. 2.9, $t_d = \left(\frac{I_c}{k'}\right)^{1/n'} = \left(\frac{70}{9}\right)^{1/0.42} = 132.16$ minutes

$\therefore$ Total time $T = t_L + t_d = 26.85 + 132.16 = 159.01$ min.

Now $p = \left[1 - \left(\frac{t_d}{T}\right)^{n+1}\right] = \left[1 - \left(\frac{t_d}{T}\right)^{n'}\right] = \left[1 - \left(\frac{132.16}{159.01}\right)^{0.42}\right] = 0.0747 = \mathbf{7.47\%}$

Also, $\eta_a = (1 - p)\, 100 = (1 - 0.0747)\, 100 = 92.53\%$

Time of irrigation $= \frac{d\,L\,B}{\eta_a\, Q} = \frac{(70 \times 10^{-3})\,(36)\,(12)}{0.9253 \times 1.5 \times 12 \times 10^{-3}} \times \frac{1}{60} = \mathbf{30.3\ min.}$

(b) *For stream of 3 lps/m width* : Given $a = 8$ and $b = 0.6$

$$q = 3 \text{ lps and hence } Q = qB = (3 \times 12) \text{ lps} = 3 \times 12 \times 10^{-3} \text{ m}^3/\text{s}$$

$t_L = \left(\frac{L}{a}\right)^{1/b} = \left(\frac{36}{8}\right)^{1/0.6} = 12.27$ minutes

$t_d = \left(\frac{I_c}{k'}\right)^{1/n'} = \left(\frac{70}{9}\right)^{1/0.42} = 132.16$ minutes (as before)

$T = t_L + t_d = 12.27 + 132.16 = 144.43$ minutes

$p = \left[1 - \left(\frac{t_d}{T}\right)^{n'}\right] = \left[1 - \left(\frac{132.16}{144.43}\right)^{0.42}\right] = 0.0366 = \mathbf{3.66\%}$

$\eta_a = (1 - p)\, 100 = (1 - 0.0366)\, 100 = 96.34\%$

Time of irrigation $\frac{d\,L\,B}{\eta_a\, Q} = \frac{(70 \times 10^{-3})\,(36)\,(12)}{0.9634 \times 3 \times 12 \times 10^{-3}} \times \frac{1}{60} = \mathbf{14.6\ min.}$

2.7. RING BASIN FLOODING

The ring basin flooding (Fig. 2.8) is a special form of check basin flooding adapted to orchards. Ring basins are formed for each tree ; in some cases one ring basin may be formed for two or more trees. Water is supplied to these basins through a supply ditch. In some cases, a number of ring basins are inter-connected. Portable pipes or large hoses may also be used in place of ditches.

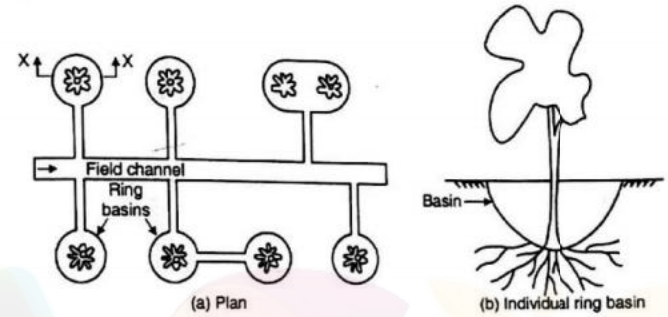

FIG. 2.8. RING BASIN FLOADING

2.8. THE ZIGZAG METHOD

It is special method of flooding where water takes circuitous route before reaching the dead end of each plot (Fig. 2.9). The whole area is divided into a number of square or rectangular plots ; each plot is then subdivided with the help of low bunds or levees. This method is suitable for relatively level plots. It is, however, highly unsuitable for farming operations with modern farm machinery.

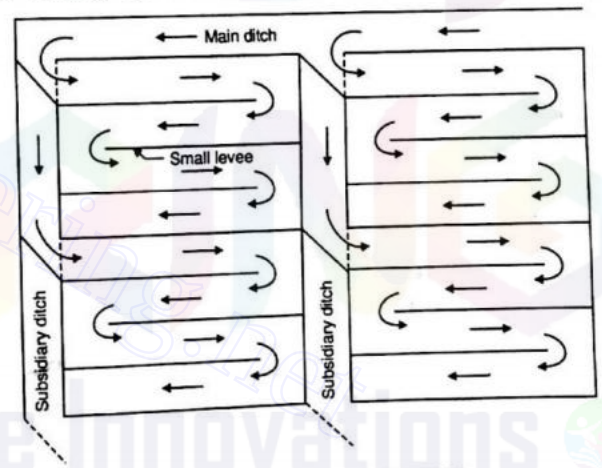

FIG. 2.9. THE ZIGZAG METHOD.

2.9. FURROW METHOD

The furrow method of irrigation is very much used for row crops like maize, jowar, sugarcane, cotton, tobacco, groundnut, potatoes etc. In the other irrigation methods described so far, almost the entire land suface is wetted, but in this method only one half to one-fifth of the surface is wetted, and thus evaporation losses are very much reduced. A furrow consists of a narrow ditch between rows of plants. The length

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of furrows varies from 3.0 m or less for gardens to as much as 500 m for field crops, the common length being 100 to 200 m. If the furrows are of excessive length, deep percolation losses and soil erosion near the upper end of the field may result. The general slopes provided for furrows may vary from 0.2 to 6%.

A minimum furrow grade of 0.05% is neede to assure surface drainage.

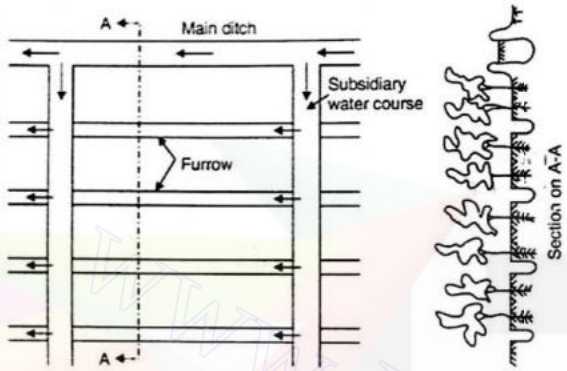

FIG. 2.10. FURROW METHOD.

Furrow spacing for corn, potatoes, sugarcane and other row crops is determined by the proper spacing of the plant rows, one irrigation furrow being provided for each row. The spacing of furrows is kept from 1 to 2 m in orchard irrigation. If the spacing is kept more, it is essential to check the distribution of moisture after each watering by auger boring. For soil of low permeability, the depth of furrows may vary from 20 to 30 cm. It is essential in irrigating the root crops (such as sugarcane etc.) to have furrows deep enough, and the stream in each small enough so that water cannot come in contact with the plant. The common size of furrow for row crops such as cotton, tobacco and potatoes is about 25 cm wide and 8 to 10 cm deep.

Type of Furrows

Depending upon the alignment, furrows may be of two types :

(*i*) Straight furrows, and (*ii*) Contour furrows.

(i) Straight furrows : Straight furrows are used where the land slope is nominal. These are aligned more or less along straight lines, parallel to each other, and along the slope of the land. These are normally adopted where the slopes do not exceed 0.6%.

(*ii*) ***Contour furrows*** : Contour furrows are practically laid along the contours. Therefore, these are not straight but are curvilinear in plan. With *contour furrows irrigation*, the direction of flow is across a sloping field rather than down the slope to reduce water velocity. The furrows are laid out with enough grade to carry the irrigation streams. *Head ditches* are run across the slope or down hill using drop structures as needed, to feed the individual furrow. Contour furrows method can be successfully used in nearly all irrigable soils. Light soils can be irrigated successfully across slopes upto 5 percent. Where the soils are stable and will not be cultivated (as in orchards), slopes upto 20 percent can be irrigated by contour furrowing.

Construction of furrows

Furrows are made before planting, at the time of planting or after the plants have grown large enough not be covered up. The time of furrowing depends upon the

crop grown and the method of planting used. Often young plants are irrigated by small furrows until a good root system is developed. Thereafter, the furrow is made larger. The furrows at any stage must be large enough to carry the water needed for irrigation.

In most soils, crops are grown on the top of the ridge while in deep sand, it is better to have the seedling near the bottom of the small furrow. Alternate method specially adapted to sandy soils is to transplant vegetables in the furrow, irrigate it once or twice and then establish furrows between the rows after plants have grown larger.

Furrows are made with various cultivating tools depending on the type of crop to be grown. Large furrows are normally made with a double mould board plough or lister. A wooden plough with furrower attachment can also be used in place of listers. Disc-drum corrugator furrower is very useful to make small size furrows in sandy soils.

Advantages of Furrow Irrigation

Furrow irrigation method has the following advantages :

(*i*) In the furrow irrigation, water contacts only 1/5 to 1/2 of the land surface, therby reducing pudding and crusting of the soil. Evaporation losses are also reduced.

(*ii*) Earlier cultivation is possible in heavy soil and may be adapted to use without erosion on a wide range of natural slope by carrying furrows across a sloping field rather than down the slope.

(*iii*) It is specially suitable for those crops (like maize etc.) that are injured by contact with water.

(*iv*) Labour requirements in land preparation and irrigation are very much reduced.

(*v*) There is no wastage of land in field ditches.

Corrugation Method

Furrows and corrugations are essentially similar — in both the cases water is conveyed to the plant through long, small-capacity channelets dug at regular intervals. While furrows are channelets of a comparatively large cross-section and are used on flat slopes, corrugations are channelets of smaller cross-sections and run down the predominant slope. Thus, corrugations are small furrows and are used for grain and other forage crops such as alfalfa. The corrugations are advantageous when the available irrigation streams are small and also for land of uneven topography.

Design Features for furrows irrigation

The discharge in the furrows (also called *furrow stream*) should be such that it does not cause soil erosion in the upper reaches and at the same time uniform irrigation is obtained. The maximum *non-erosive* flow rate (q_m) in a furrow naturally depends upon the slope (s) of the furrows and is estimated by the following empirical expression:

$$q_m = \frac{0.6}{s} \qquad \text{...(1) ...(2.16)}$$

where s = slope of furrow, expressed as percent

and q_m = max. non-erosive discharge in lps.

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Water is fed to the furrows at the above rate, to start with, till the water reaches the lower end of the furrows. After that, the stream size (i.e. the discharge) is reduced, the reduction being known as *cut back* and the reduced stream is known as *cut-back stream*. The cut-back stream is allowed to flow in the furrow till the required amount of water is applied. It q is the discharge in the cut-back stream, the *average depth of water application* (d) applied during an irrigation of duration t is given by

$$d = \frac{3600\, q \,.\, t}{WL} \qquad ...(2.17)$$

where d = average depth of water applied (mm) during irrigation.

t = duration of irrigation, in hours.

q = discharge in the furrow, in litres/second.

L = length of furrow in metres.

W = spacing of furrows in metres.

Determination of Infiltration Characteristics

The determination of infiltration characteristics, such as infiltration rate and time required to infiltrate the given depth of water for irrigation is done by two methods: (1) inflow-outflow method, and (2) ponding method. Out of these, the inflow-outflow method gives better results and is commonly followed.

For the inflow-outflow method, a 30 m long reach is picked up and uniform stream of water is applied to three consecutive furrows consisting of the central furrow and two outer furrows, known as *guard furrows*. The inflow and outflow rates are measured in the central furrow, for the reach of 30 m. If q_1 and q_2 are the inflow and outflow rates, in litres per minute at any instant of time t minutes after the start of the test, the quantity of water absorbed per unit time (i.e. infiltration rate) is given by

$$I = (q_1 - q_2) \text{ lpm, per 30 m length of furrows} \qquad ....(1)$$

If the values of I are obtained for different values of time t, and plotted on a log-log scale (i.e. I versus t), a straight line is obtained which can be expressed by the equation :

$$I = k\, t^n \qquad ....(2) \quad ....(2.18)$$

in which k and n are constants.

The *accumulated infiltration (V)* in a given time T is given by

$$V = \int_0^T I\, dt = \int_0^T k\, t^n\, dt = \frac{k\, T^{n+1}}{(n+1)} \text{ litres} \qquad ...(3) \quad ...(2.19)$$

However, if d is the total depth of infiltration in mm, we have

$$V = \frac{d}{1000} \times W \times 30 \text{ m}^3 = \frac{d}{1000} \times 30\, W \times 1000 \text{ litres} = 30\, d \,.\, W \qquad ...(4)$$

Equating (3) and (4), we get

$$30\, dW = \frac{k\, T^{n+1}}{n+1}$$

From which $$d = \frac{k\, T^{n+1}}{30\, W\, (n+1)} \qquad ...(5) \quad ....(2.20)$$

Also, the total time T to infiltrate the desired depth d is given by

$$T = \left[\frac{30\, dW\, (n+1)}{k}\right]^{1/(n+1)} \qquad ...(6) \quad ...(2.21)$$

Computation of instantaneous rate of infiltration

Let i = instantaneous rate of infiltration, in mm/hour

Then $$I = \left(\frac{i}{1000} \times 30\, W\right) \text{m}^3/\text{hour}$$

But from observation, $$I = (q_1 - q_2) \text{ lpm} = \frac{q_1 - q_2}{1000} \times 60 \text{ m}^3/\text{hour}$$

Hence $$\frac{i}{1000} \times 30\, W = \frac{q_1 - q_2}{1000} \times 60$$

or $$i = \frac{2\,(q_1 - q_2)}{W} \text{ mm/hour} \qquad ...(7) \quad ...(2.22)$$

Example 2.5. *During an inflow-outflow test for an irrigation furrow 100 m long, following observations were taken for time of advance :*

Distance (m)	Time of advance t_d (min.)	Distance (m)	Time of advance t_d (min.)
0	0	90	88
30	23	120	127
60	52		

The stream size used during the test was 24.5 lpm. The infiltration characteristics for the furrow can be expressed by the following equation :

$$I = 38\, t^{-0.49} \text{ lpm per 30 m length}$$

Irrigation was continued with original stream size for 16 minutes after the water reached the end of the furrow and there after the stream size was cut back. Compute (a) size of cut back stream, (b) the time of irrigation and average depth of water applied if the crop needs 37.5 mm of water. Assume furrow spacing of 1 m.

Solution : 1. *Determination of size of cut-back stream*

At any observation station along the furrow, the time of ponding (t_d) is evidently equal to the total time of irrigation T (= 127 + 16 = 143 min.) minus the time of advance t_L. Hence the time of ponding (t_d) at every station can be computed and entered in column (3) of the Table given below. Similarly, the furrow infiltration rate (I) is given by Eq. 2.18, expressed as below as per data given :

$$I = 38\, t^{-0.49} \text{ per 30 m length (where } t = t_d)$$

Hence the value of furrow infiltration can be computed for every observation station, corresponding to t_d value (column 3) of that station and tabulated in column (4) of the Table. Column (5) of the Table gives the average infiltration for the stretch

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between consecutive stations while column (6) gives the cumulative infiltration for the stretch between the stations.

Distance (m)	*Time of advance t_L (min.)*	*Time of ponding $t_d = T - T_L$*	*Furrow infiltration I (lpm/30 m)*	*Average infiltration I_{av} (lpm/30 m)*	*Cumulative infiltration I_c (lpm)*
(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*
0	0	143	3.34		
				3.49	3.49
30	23	120	3.64		
				3.90	7.39
60	52	91	4.17		
				4.75	12.14
90	88	55	5.33		
				7.55	19.69
120	127	16	9.77		

From the above Table, we find that cumulative infiltration rate for the entire furrow is 19.69 lpm. Hence the size of the cut-back stream should be equal to 19.69 lpm or slightly less than this.

2. Time required for putting 37.5 mm depth of water

From Eq. 2.21, putting $d = 37.5$ mm, $W = 1$ m; $n = -0.49$ and $k = 38$, we get

$$T = \left(\frac{30\,dW\,(n+1)}{k}\right)^{1/(n+1)} = \left[\frac{30 \times 37.5 \times 1\,(-0.49+1)}{38}\right]^{1/(-0.49+1)} = \mathbf{205\ min.}$$

3. Average depth of water applied

The average depth of water may be calculated by taking the size of stream as 24.5 lpm for the first 143 min. and taking the size of cutback stream as 19.69 lpm for the remaining period of $205 - 143 = 62$ minutes.

$$\therefore \quad d_{av} = \left(\frac{24.5 \times 143 + 19.69 \times 62}{1000}\right)\frac{1}{120 \times 1} \times 1000 = \mathbf{39.4\ mm}$$

However, let q be the size of cut back stream to have 37.5 mm average depth of water application. In that case

$$d_{av} = 37.5 = \left(\frac{24.5 \times 143 + q \times 62}{1000}\right)\frac{1}{120 \times 1} \times 1000$$

From which, we get $q = 16.07$ lpm

Hence maximum size of cut back stream is 19.69 lpm and the minimum size of cut back stream is 16.07 lpm.

Example 2.6. *Furrows, 100 m long and 1 m apart, having longitudinal slope of 0.3 percent are initially irrigated by a non-erosive stream for 80 minutes. The stream size is then reduced to 40% and continued for another 35 minutes. Determine the average depth of irrigation.*

Solution : Given $L = 100$ m; $W = 1$ m ; $s = 0.3\%$

From Eq. 2.6, $q_m = \dfrac{0.6}{s} = \dfrac{0.6}{0.3} = 2$ lps

Cut back discharge $q = 0.4\,q_m = 0.4 \times 2 = 0.8$ lps

Hence average depth of water applied

$$= \frac{2 \times 80 \times 60 + 0.8 \times 35 \times 60}{1000} \times \frac{1}{100 \times 1} \times 1000 = \mathbf{112.8\ mm}$$

2.10. CONTOUR FARMING

Contour farming is practised in hilly areas having steep slopes with quickly falling contour. Contour farming is the practice of conducting field operations, such as ploughing, planting and cultivating land, across the slope rather than up and downhill. The area is divided into longitudinal curved plots, the bunds of the plots following the contours. The irrigation water, stored in some depression higher up, flows between the bunds. Before starting contour farming on land which is not terraced or bunded, contour guide lines are established first. On average hill sides, the first contour should ordinarily be laid about 1.2 to 1.5 m vertically below the top of the hill. Additional contour lines are located with the same spacing as the first.

The design of contour *bunds* involves the selection of the vertical and horizontal interval and determining dimensions of the bund cross-section. Table 2.1 gives Gadkary's recommendations for the spacing of contour bunds on different land slopes. Table 2.2 gives Ghumare's recommendations for the dimensions of contour bunds of various types of soils.

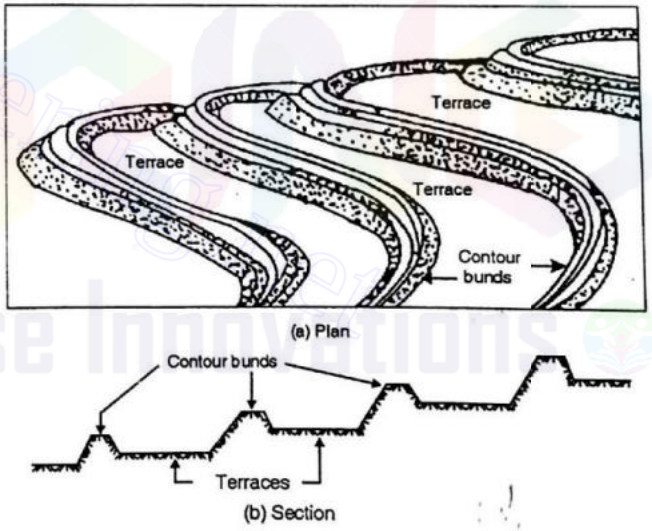

FIG. 2.11. CONTOUR FARMING

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TABLE 2.1. SPACING OF CONTOUR BUNDS

Slope of land (%)	*Vertical interval (m)*	*Horizontal distance (m)*
0 to 1	1.05	105
1 to $1\frac{1}{2}$	1.20	98
$1\frac{1}{2}$ to 2	1.35	70
2 to 3	1.50	60
3 to 4	1.65	52

TABLE 2.2. SPECIFICATION FOR BUND CROSS-SECTION

	Depth of soil	*Base width (m)*	*Top width (m)*	*Height (m)*	*Side Slopes*
1.	Shallow soils (7.5 to 22.5 cm)	2.67	0.38	0.75	$1\frac{1}{2}$: 1
2..	Medium soil (22.5 to 45 cm)	3.12	0.60	0.85	$1\frac{1}{2}$: 1
3.	Medium deep soil (45 to 90 cm)	4.25	0.90	0.90	2 : 1

2.11. SUB-SURFACE IRRIGATION

The sub-surface irrigation method consists of supplying water directly to the root zone of the crop. The favourable conditions for the sub-surface irrigation practice are:

1. Impervious sub-soil at reasonable depth (2 to 3 m) or existence of high water table.
2. Permeable soil such as loam or sandy loam in the root zone of the soil.
3. Uniform topographic conditions.
4. Moderate slopes.
5. Good quality irrigation water.

If all these favorurable conditions are fulfilled and if proper precautions are taken to prevent alkali accumulation or excess water-logging, the method results in economical use of water, high crop yield and low labour cost in preparing the irrigation plots.

Subsurface irrigation may be of two classes :

(*i*) Natural sub-irrigation and (*ii*) Artificial sub-irrigation

Natural sub-irrigation

In this system, water is supplied to the root zone of the plants by controlling the level of local water table. Such a high level of water table in the area may be available due to water seeping from earthen canals, drains, rivers etc. In order to ensure the requisite supply of water to the root zone, it is essential to maintain the desired water level by artificial means. For this purpose, water is supplied to a series of ditches half to one metre deep and 25 to 50 cm wide having vertical sides. These ditches are spaced from 15 to 100 m apart depending upon the permeability of subsoil and topography of land. The depth of the ditches may vary from 0.3 to 1 m and the width may vary from 0.3 to 0.5 m. These channels have relatively flat slopes.

Water flows at a slow rate and seeps into the ground to maintain the water table at a height such that water from the capillary fringe is available to the crops. Proper drainage of excess water is permitted, either naturally or with the other drainage works to prevent water logging of the fields. Sometimes the upward capillary water flow from shallow water table may produce saline and alkali conditions and may make the land less productive. Under such circumstances, the sub-surface irrigation method has to be discontinued and irrigation has to be resorted by sprinkling method.

Artificial sub-irrigation

This method consists of supplying water directly to the root zone of crops through a net work of buried perforated pipes. Water is made to pass under pressure, through these underground perforated pipes. This method is suitable only for those soils formations which have high horizontal permeability to permit free lateral movement though the root zone of the crops and low vertical permeability so that deep percolation losses are minmised. The pipe are buried 0.3 to 0.4 m deep, so that cultivation operations are not hindered, and are spaced 0.4 to 0.5 m horizontally, for uniform distribution of water.

2.12. SPRINKLER IRRIGATION

The sprinkler method consists of applying the water in the form of a spray, somewhat as in ordinary rain, as is done in the garden lawn sprinkling. The greatest advantage of sprinkler irrigation is its adaptabilities to use under conditions where surface irrigation methods are not efficient. This method is more useful where :

(*i*) The land cannot be prepared for surface methods
(*ii*) Slopes are excessive
(*iii*) Topography is irregular
(*iv*) Soil is erosive
(*v*) Soil is excessively permeable or impermeable
(*vi*) Depth of soil is shallow over gravel or sand.

In this system, the cost of land preparation and permanent water delivery system of channels or conduits is less. However, there is large initial investment in the purchase of the pumping and sprinking equipment.

Sprinkler system can be classified under three heads :

(*i*) Permanent system,
(*ii*) Semi-permanent system, and
(*iii*) Portable system.

Earlier, stationary over-head perforated pipe installations were used. However, with the introduction of light weight steel pipes and quick couplers, portable sprinkler system were devloped. In the permanent system, pipes are permanently buried in such a way that they do not interfere with tillage operations. In the semi-permanent system, the main lines are buried while the laterals are portable. Portable system have both portable mains lines and laterals. These systems are designed to be moved from around the farm from field to field. A pump usually lifts the water from the source, pushes it through the distribution system and through the sprinkler nozzel on the sprinkler heads mounted on rising pipes attached to the laterals. Turbine and horizontal centrifugal

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pumps are used. Sprinkler system usully is composed of perforated pipes or revolving head sprinklers and may be 'high pressure' (2.1 kg/cm^2) or "low pressure" (1.4 kg/cm^2) system. Generally, a perforated pipe system operates on the low pressure where as the revolving head sprinklers operate in both ranges depending on the type of rotary head used.

Type of sprinklers

Sprinklers may be of three types : (*i*) fixed nozzle pipe system (*ii*) perforated pipe system and (*iii*) rotating sprinklers system. In the *fixed nozzle pipe system* lateral pipes, supported on row of posts, are installed parallel to each other at a distance of 15 m apart. These pipes have a line of small holes drilled at top at regular interval along their length, and small nozzles are fitted in these holes. The spray of water is developed through these nozzles. By turning the pipes through 135°, the entire width of 15 metres between the pipe lines can be irrigated. In the *perforated pipe system*, the laterals, having perforations drilled along the sides and top, are laid on the ground parallel to each other at distances of 6 to 15 m. Sprays of water are developed from both the sides and top of the pipe. However, the more commonly used *rotating sprinker system* consists of single-nozzle or twin-nozzle rotating sprinkler mounted on a body which is rotated slowly about its vertical axis by the action of deflecting vane connected to it. The spray of water developed through the nozzles sprinkles over a circular area of land around each sprinkler. The rotating sprinklers are mounted on the riser pipes and are located just above the crop to be irrigated, the height of riser pipes being dependent on the maximum height of crops. Such riser pipes fitted with sprinklers, are fixed at regular intervals along the length of the laterals. The spacing of the sprinklers is so selected that area of spread from each sprinkler overlap with the spread from the adjacent sprinkler, so that uniform application of water is achieved. The percentage overlap depends on wind velocity. Normally, the spacing between the sprinklers varies from 65% to 30% of the diameter of water spread area, *for no wind condition* to *high wind condition* (> 13 km/hour) respectively.

The discharge, required through each rotating sprinkler is given by the following expression :

$$q = \frac{S_l \times S_m \times I}{3600}$$

where q = discharge required from each sprinkler (litres/sec.)

S_l = spacing of sprinklers along the laterals (m)

S_m = spacing of laterals along mains (m)

I = optimum water application rate (mm/hour)

Advantages of Sprinkler Irrigation

(*i*) Erosion can be controlled

(*ii*) Uniform application for water is possible.

(*iii*) Irrigation is better controlled; light irrigation is possible for seedling and plants which are young.

(*iv*) Land preparation is not required. Labour cost is reduced. More land is available for cropping, as borders and ditches are not required. Surface run off is eliminated.

(*v*) Small streams of irrgation water can be used efficiently.

(*vi*) Time and amount of fertilizers can be controlled for application.

(*vii*) Crop damage from frost can be reduced.

(*viii*) It is a stand-by drainage pumping plant.

Limitations

(*i*) Wind may distort sprinkling pattern.

(*ii*) A constant water supply is needed for commerical use of equipment.

(*iii*) Water must be clean and free from sand etc.

(*iv*) The power requirement is high.

(*v*) Heavy soil with poor intake cannot be irrigated efficiently.

Efficiency : If η_a is the water application efficiency of the plant, W_s is the irrigation water stored in root zone and W_f =water pumped into the system, then

$$\eta_a = \frac{W_s}{W_f} \times 100.$$

About 80 % irrigation efficiency is possible with sprinkler irrigation particularly in semi-arid and humid areas. The efficiency decreases by 5 % for each 7.5 km per hour of wind.

2.13. DRIP IRRIGATION

In drip irrigation, also known as *trickle irrigation*, water is applied in the form of drops directly near the base of the plant. Water is conveyed through a system of flexible pipe lines, operating at low pressure, and is applied to the plants through drip nozzles. This technique is also known as *'feeding bottle'* technique where by the soil is maintained in the most congential form by keeping the soil-water-air proportions in the optimum range. Drip irrgation limits the water supplied for consumptive use of the plant by maintaining a minimum soil moisture, equal to the field capacity, thereby maximising the saving. The system permits the fine control on the application of moisture and nutrients at stated frequencies.

The method of drip irrigation was first introduced in Israel, but is now practiced in many countries of the World. Along with irrigation water, nutrients (fertilizer solution) are also fed to the system. Water is first filtered so that the impurities may not clog the fine holes of the drippers. The whole aarrangement consists of the following components:

(*i*) a *pump* to lift water.

(*ii*) a *head tank* to store the water and to maintain a pressure head of 5 to 7 m.

(*iii*) *Central distribution system* which filters the water, adds nutrients (or fertilizer solution) and regulates the pressure and amount of water to be applied.

(*iv*) *Mains and secondray lines* made of polyethylene, polyvinyle chloride or a alkathyelene material. The diameter of the piping may vary from 20 mm to 40 mm. A water meter may be fixed at the beginning of the mains.

(*v*) *Trickle lines* consisting of 10 to 20 mm dia. PVC pipes with perforations at a distance equal to the spacing of the crops. The trickle lines are fitted to the secondary lines at a distance equal to the row to row spacing of the crops, which

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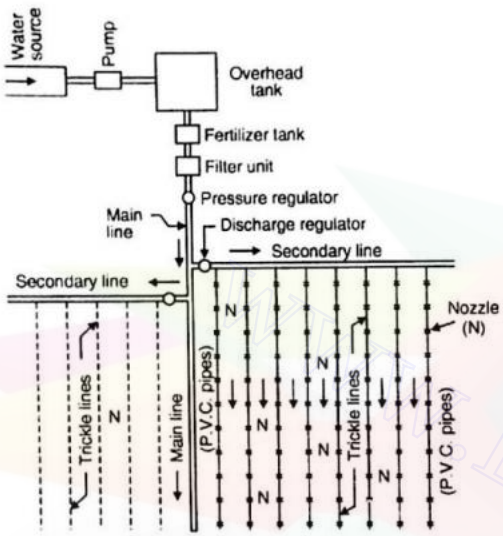

FIG. 2.12 ARRANGEMENT FOR DRIP IRRIGATION SYSTEM.

may vary between 60 cm to 90 cm, a more common value being 75 cm for the most of the crops. The spacing of the nozzles, to be fitted in the perforations of the trickle lines, depends upon the planting distance along a row, and this distance may vary between 30 cm to 50 cm.

(*vi*) *Plastic nozzles* having perforations attached to the trickle line. The perforations are so designed that water leaves the nozzle at a very slow rate, usually ranging between 2 to 10 litres per hour, depending upon the irrigation requirements of the crop.

The whole field is divided into suitable plots. A secondary line is provided for each such plot, and a number of trickle lines are connected to each secondary line. A discharge regulater is provided at the beginning of each secondary line, and its capacity is fixed in accordance with the size and number of nozzles used. The automatic valve at the head is so adjusted to deliver the desired quantity of water and the irrigation terminates automatically after this amount is discharged. The drip irrigation system is suitable to practically all types of crops, except paddy which requires standing water. It is also suitable to all climatic conditions and to all types of soils. However, it is most suited to coarse sandy formations.

Advantages Of Drip Irrigation System

1. ***Less requirement of irrigation water***. The evaporation and percolation losses, commonly associated with surface irrigation method are reduced.

2. ***Water supply at optimum level***. An optimum water level, equal to the field capacity can always be maintained, by the water flow controls available in this method. Soil is maintained in most congenial form.

3. ***Water logging avoided***. Because of check over deep percolation losses, the chances of water logging are all together removed.

4. ***High yield***. Because of proper control over the factors govering soil-water-crop relationships, higer yield is obtained.

5. ***Cultivation of cash crops***. The method is specially suited to cash crops such as vegetables, cotton, tabbacco and orchard products.

6 ***No over-irrigation***. In surface methods of water application, over-irrigation is sometimes done to provide sufficient moisture at deficient area. This is avoided in this method since water is suplied to the root zone directly for each crop.

7. ***Variation in application rate***. It is possible to vary the application rate, throughout the crop period. When the crop is infant, application rates can be easily increased.

8. ***Weed control***. The nuisance of weeds commonly associated with surface application methods is avoided. This will, in turn, result in increase in crop production, and saving in farm application.

9. ***Increase in net irrigable area***. In surface application, a lot of area is wasted in the construction of field channels etc. As water is carried through small diameter pipes, there is considerable saving in land.

10. ***Nutrients preservation***. Soil nutrients are preserved because of reduction in deep percolation losses. Morever, feeding of water enriched with fertilizers results in proper maintenance and preservation of nutrients at optimum level.

11. ***Effective pest control***. Insect and pest combating chemicals can be directly conducted into the root zone.

12. ***Reduced labour cost***. The labour cost, otherwise associated with the maintenance of field channels, furrows etc., is reduced.

13. ***No soil erosion***. The problems of surface soil erosion, associated with surface application methods, are practically absent in this method.

14. ***Suitability for saline soils***. The saline, alkaline or brakish soils otherwise unsuitable, can be utilized by cultivation by the drip irrigation method.

15. ***Maintenance of high surface temperature***. In surface appplication method, soil temperature is lowered because of water spread over the entire area. However, in this method, entire soil surface is not wetted. Hence high soil temperature is maintained which will be useful in hastening the ripening or maturity of the crop.

16. ***Suitable for any topography***. No land levelling is required, and is suitable even for sloping and undulating terrain.

Disadvantages of Drip Irrigation System

(*i*) ***High initial cost***. The initial cost of various components such as pumping unit, filter units, pipelines, nozzles etc. is very high.

(*ii*) ***Danger of blockade of nozzles***. The nozzle holes are very small in size (0.5 to 1 mm dia.). Hence they are very frequently clogged, if the water has high degree of total dissolved salts which cannot be removed by filtration.

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(iii) *Change in spacing of nozzles* due to change in the crops may result in frequent replacement of trickle lines.

(iv) *Shallow root depth* of the crops, specially for fruit trees etc., may result in instability of the crop or tree which may topple during high winds.

2.14. EXAMPLES FROM COMPETITIVE EXAMINATIONS

Example 2.7. *For border strip method of irrigation, determine the time required to irrigate strip of land of 0.04 hectare in area from tube well with a discharge of 0.02 cumec. The infiltration capacity of the soil may be taken as 5 cm/hour and the average depth of flow on the field as 10 cm. Also, determine the maximum area that can be irrigated from this tube well.* ***(Engg. services Exam. 2000)***

Solution

This example is similar to Example 2.1 of the book.

$Q = 0.02$ cumec $= 0.02 \times 3600$ m^3/hour $= 0.0072$ hectare-m/hour

$y = 10$ cm $= 0.1$ m.

$I = 5$ cm/hour $= 0.05$ m/hour

$A = 0.04$ hectare

$$\therefore \quad t = 2.303 \frac{y}{I} \log_{10} \frac{Q}{Q - IA} = \frac{2.303 \times 0.1}{0.05} \log_{10} \frac{0.0072}{0.0072 - 0.05 \times 0.04}$$

$= 0.651$ hours $=$ **39.06 min.**

Maximum area that can be irrigated $= \frac{Q}{I} = \frac{0.0072}{0.05} =$ **0.144 ha**

PROBLEMS

1. Discuss in brief various methods of surface irrigation.
2. What do you understand by contour farming ? Compare it with wild flooding method.
3. Write a note on sub-surface irrgation, stating clearly the conditions under which this method is suitable.
4. Describe border strip method of irrigation. Derive the expression for the time required to cover a given area by this method, for a given rate of discharge and the rate of infiltration of water in the soil.
5. Write a note on sprinkler method of irrigation.
6. Compare surface irrigation with sub-surface irrigation.

3

Water Requirements of Crops

3.1. FUNCTIONS OF IRRIGATION WATER

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

(1) It acts as a solvent for the nutrients. Water forms the solution of the nutrients, and this solution is absorbed by the roots. Thus, water acts as the nutrient carrier.

(2) The irrigation water supplies moisture which is essential for the life of bacteria beneficial to the plant growth.

(3) Irrigation water supplies moisture which is essential for the chemical action within the plant leading to its growth.

(4) Some salts present in soil react to produce nourishing food products only in the presence of water.

(5) Water cools the soil and the atmosphere, and thus makes more favourable environment for healthy plant growth.

(6) Irrigation water, with controlled supplies, washes out or dilutes salts in the soil.

(7) It reduces the hazard of soil piping.

(8) It softens the tillage pans.

3.2. QUALITY OF IRRIGATION WATER

A good irrigation water is the one which performs the above mentioned functions without any side effects which retard the plant growth. Irrigation water may be said to be unsatisfactory for its intended use if it contains (1) chemicals toxic to plants or the persons using plant as food, (2) chemicals which react with the soil to produce unsatisfactory moisture characteristics and (3) bacteria injurious to persons or animals eating plants irrigated with the water.

Impurities in irrigation water

The quality of irrigation water depends upon various types of impurities present in water, the following being the prominent ones :

1. Concentration of sediments in water
2. Total concentration of soluble salts (known as TDS)
3. Proportion of sodium ions to other cations

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4. Concentration of toxic elements such as boron concentration
5. Concentration of bicarbonate in relation to the concentration of calcium and magnesium.
6. Bacterial concentration.

The effect of concentration of sediments transported by irrigation water depends upon the type of soil of irrigation fields. If the field contains sandy soil, its fertility is improved by the deposition of sediments carried by irrigation water. However, if the sediment has been derived from eroded areas, if may reduce the fertility and decrease the permeability of soil. High concentration of salts in water may be harmful in the long run. Similarly, if water contains high concentration of sodium ions, the irrigation soils become plastic and sticky when wet and become prone to form clods and they crust on drying. Similarly high percentage of toxic elements may be harmful to certain plants such as nuts, citrus fruits and deciduous plants. High concentration of bicarbonate ions may result in precipitation of calcium and magnesium bicarbonates from the soil solution, increasing the relative proportion of sodium irons and causing sodium hazards. Bacterial contamination may not be directly harmful to the plants as such, but it may be injurious to persons or animals eating these plants.

Classification of irrigation water

Irrigation water may be classified on the following basis :

(*i*) Classification based on total concentration of soluble salts

(*ii*) Classification based on sodium concentration

(*iii*) Classification based on electrical conductivity (EC), total salt content (TDS), sodium concentration (ESP), boron concentration etc.

1. Classification based on total concentration of soluble salts

Irrigation water may contain various types of salts such as sodium, calcium, magnesium and potassium etc. A high concentration of these salts may prove to be injurious to the crops. The salt content of irrigation water is usually expressed by one of the following ways :

(*i*) Parts per million (ppm) or milligram per litre (mg/l), both units being equal.

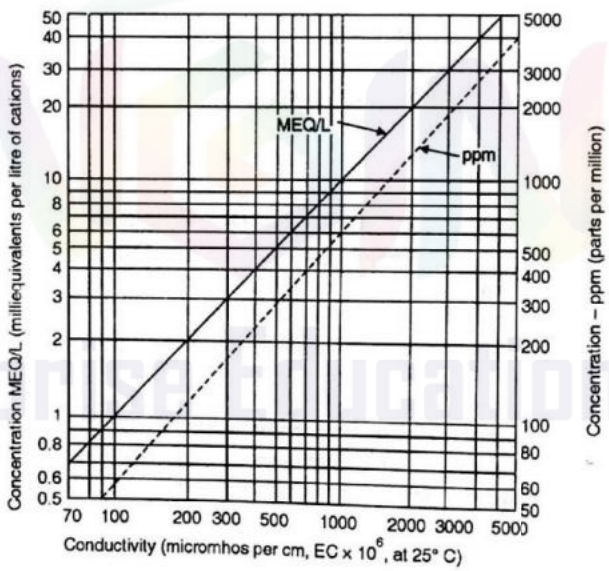

FIG. 3.1. RELATION BETWEEN CONCENTRATION AND ELECTRICAL CONDUCTIVITY.

(*ii*) Milli equivalents per litre (MEQ / L).

(*iii*) Electrical conductivity, expressed in micromhos per centimetre (EC × 10^6).

Fig. 3.1 shows the relationship between the three.

Salts of sodium, calcium, magnesium and potasium may prove to be injurious in irrigation water. In excessive quantity, these salts reduce the osmotic activity of the plants, thus preventing the absorption of nutrients from the soil. In addition, they may have indirect chemical effects on the metabolism of the plant and may reduce soil permeability. The *salinity concentration of soil solution* (C_s) can be determined from the following formula :

$$C_s = \frac{C.Q}{Q - (C_u - P_{eff})} \quad ...(3.1\,a)$$

where C = concentration of salt in irrigation water

Q = total quantity of water applied to the soil

C_u = consumptive use of water

P_{eff} = useful rainfall.

Based on the salt concentration or electrical conductivity, U.S.D.A. classifies irrigation water in four types : Low conductivity, water (C1), Medium conductivity water (C2), High conductivity water (C3) and very high conductivity water (C4) as indicated in Table 3.1.

TABLE 3.1 CLASSIFICATION OF IRRIGATION WATER BASED ON SALT CONCENTRATION

S.N.	Types of water	Suitability for irrigation
1.	**Low salinity water (C1)** Conductivity between 100 to 250 micro-mhos/cm at 25°C.	Suitable for all types of crops and all kinds of soils. Permissible under normal irrigation practices except in soil of extremely low permeability.
2.	**Medium salinity water (C2)** Conductivity between 250 to 270 micro-mhos/cm at 25°C.	Can be used, if a moderate amount of leaching occurs. Normal salt tolerant plants can be grown without much salinity control.
3.	**High salinity water (C3)** Conductivity between 750 to 2250 micro-mhos/cm at 25°C	Unsuitable for soil with restricted drainage. Only high-salt tolerant plants can be grown.
4.	**Very high salinity (C4)** Conductivity more than 2250 micro-mhos/cm at 25°C	Unsuitable for irrigation.

2. Classification Based on Sodium Concentration : Irrigation water having a higher sodium percentage will, after some time, give rise to a soil having a large percentage of replaceable sodium in the colloid. Such a soil is often known as *black alkali*. The *percentage of sodium*, also known as *exchangeable sodium percentage* (ESP), is determined from the following equation:

$$\text{Percentage sodium} = \text{ESP} = \frac{100\ Na^+}{Ca^{++} + Mg^{++} + Na^+ + K^+} \quad ...(3.1\,b)$$

If the percentage of sodium is more, the aggregation of soil grains break down, and the soil becomes less permeable and of proper tilth. Even on sandy soils with good drainage, water of 85% sodium or higher (given by equation 3.1 *b*) are likely

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to make soils impermeable after prolonged use. With constant irrigation with high sodium water, the soil becomes plastic and sticky when wet and forms clods and crust on drying.

Irrigation water is classified on sodium concentration, on the basis of a factor called *Sodium-Absorption Ratio* (SAR), given by the following equation :

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}} \quad ...(3.1\,c)$$

Based on SAR value, water is classified into four types : (*i*) *Low sodium water* (S1), (*ii*) *Medium sodium water*, (S2), (*iii*) *High sodium water* (S3), (*iv*) *Very high sodium water* (S4). The characteristics of the four types of irrigation water are given in Table 3.2.

TABLE 3.2. CLASSIFICATION OF IRRIGATION WATER BASED ON SODIUM ABSORPTION RATIO (SAR)

S.No.	Type of water	Suitability
1.	**Low sodium water (S1)** SAR : 0 to 10	Suitable for all types of crops and all types of soils, except for those crops which are highly sensitive to sodium.
2.	**Medium sodium water (S2)** SAR : 10 to 18	Suitable for coarse textured of organic soil with good permeability. Relatively unsuitable in fine textured soils.
3.	**High sodium water (S3) SAR : 18 to 26**	Harmful for almost all types of soils. Requires good drainage, High leaching, gypsum addition.
4.	**Very high sodium water (S4)** SAR above 26	Unsuitable for irrigation.

3. Classification based on EC, TDS, Sodium concentration, boron concentration etc : Table 3.3 gives an alternative classification of irrigation water based on the following four factors : (*i*) electrical conductivity, (*ii*) total salt concentration, (*iii*) % sodium (given by Eq. 3.1 *a*) and (*iv*) Boron concentration (ppm).

TABLE 3.3. CLASSIFICATION BASED ON EC, TDS, ESP AND BORON CONCENTRATION : STANDARDS OF IRRIGATION WATER

Water class	Electrical conductivity ($EC \times 10^6$)	Total salt content TDS (ppm)	Exchangeable sodium percentage (ESP) (%)	Boron concentration (ppm)	Chloride concentration (ppm)	Sulphate concentration (ppm)
1.	0 - 1000	0 - 700	60	0.0 to 0.5	0 - 142	0 - 192
2.	1000 - 3000	700 - 2000	60 - 75	0.5 - 2.0	142 - 355	192 - 480
3.	over 3000	over 2000	over 75	over 2.0	over 355	over 480

Boron Concentration : The boron content of water is of great importance for many crops. Sugarcane may tolerate large concentration of boron in the irrigation water while other crops such as beans, ground-nuts etc. are very sensitive to an excess of boron. Boron concentration of more than 2 ppm is harmful to most of the crops.

Class 1 waters are considered to be excellent to good for most plants. Class 2 waters are considered as good to injurious, probably harmful to more sensitive crops. Class 3 waters are considered unsuitable under most conditions.

Example 3.1. *An irrigation water has the following characteristics :*

1. *Concentration of* Na^+ *: 24 milli-equivalents per litre*
2. *Concentration of* Ca^{++} *: 3.6 milli-equivalents per litre.*
3. *Concentration of* Mg^{++} *: 2 milli-equivalents per litre.*
4. *Electrical conductivity : 180 micro-mhos at 25° C*

(*a*) *Classify the above irrigation water.*

(*b*) *Explain the problems that may arise due to use of such water in fine textured soils*

(*c*) *Suggest the remedial measures to reduce these problems.*

Solution :

(*a*)
$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}} = \frac{24}{\sqrt{\frac{3.6+2}{2}}} = 14.34$$

From Table 3.2, we find that for SAR = 14.34, the water falls into the S2 class (medium sodium water)

Also, EC = 180 micro-mhos at 25° C. Hence from Table 3.1, the water falls into C1 class (low salinity water)

Hence the water falls into **C1-S2** class

(*b*) From Table 3.2, we observe that such water is not suitable for fine textured soils, as it may cause the following problems :

1. Soil becomes impermeable after prolonged use.
2. There is reduction in proper tilth of soil.
3. Soil becomes plastic and sticky when wet.
4. Soil forms clods and crusts on drying.
5. The pH of soil increases towards that of alkaline soil, tending to become *black alkali* after prolonged use.

(*c*) The sodium hazards of irrigation water can be reduced by addition of powdered gypsum ($CaSO_4$) either to water or to soil.

3.3. TYPES OF SOILS

Soil furnishes the following for the plant life :

(*i*) Anchor for its roots.

(*ii*) Water for its transpiration.

(*iii*) Minerals for its nutrition.

(*iv*) Oxygen for its metabolism.

Soils may be classified in the following five ways :

(I) Classification according to age of formation :

In this class, soils are of three types :

(*a*) *Youthful* : Youthful soil is fully pervious.

(*b*) *Mature* : Mature soil has low permeability.

(*c*) *Senile* : A senile soil has little or no productivity. The soil becomes hard and of very low permeablitiy.

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(II) Classification according to geological process of formation :

(*a*) *Residual soils* : They are formed by disintegration of rock in place under various actions.

(*b*) *Alluvial soils* : They are formed by deposition by water borne material.

(*c*) *Eolian soils* : They are formed by deposition by wind action.

(*d*) *Colluvial soils* : They are formed by deposition by rainwash below foot hills.

(*e*) *Glacial soils* : They are formed by transportation and deposition by glaciers.

(*f*) *Volcanic ash* : They are ash deposits due to volcanic eruptions.

(*g*) *Soils of aggradation* : These are accumulating soils.

(*h*) *Soils of degradation* : These are the soils which are continuously zooning out.

(*i*) *Pan, clay pan* : These are impervious hard layers formed due to compaction or cementation by $CaCO_3$, Fe_2O_3, silica, etc.

(III) Classification according to content of content of calcium, aluminium and iron salts :

(*a*) *Ped-o-cal* : Soil rich in calcium carbonate.

(*b*) *Ped-al-fer* : Soil rich in aluminium or iron salts.

(*c*) *Humus* : Soil rich in organic salts.

IV Classification based on EC, ESP and pH : Saline and alkaline soils

Based on electrical conductivity (EC), exchangeable sodium percentage (ESP) and pH value soils are classed as *saline alkaline* or *saline-alkaline* as indicated in Table 3.4.

TABLE 3.4. CLASSIFICATION OF SALINE AND ALKALINE SOILS

S.N.	Classification	Electrical conductivity (EC) in micro-mho/cm	ESP	pH value
1.	*Saline soil* (white alkali)	> 4000	< 15	≤ 8.5
2.	*Alkaline soil* (non saline alkali or sodic soil or black alkali)	< 4000	> 15	8.5 to 10.0
3.	*Saline - alkaline soil*	> 4000	> 15	< 8.5

Such soils are formed from normal non-saline soils through the accumulation of *salts* applied from irrigation water or by upward moving ground water or by a combination of both these effects. These salts usually appear in the form of a white efflorescent crust on the surface of the soil. These soils are not suitable for cultivation, unless these are reclaimed by adopting suitable methods.

(V) Soil classification on regional basis :

(*a*) Regions of autogeneous soil development.

(*b*) Regions of balanced decomposition.

(*c*) Regions of excessive denudation.

(*d*) Regions of eroded colian accumulation.

(VI) Soil classification on the basis of particle size : Textural classification

A composite soil can be classified on the basis of particle sizes, depending upon the percentage of and, silt and clay content. Soil texture refers to composition of the

soil reflected by the particle size, shape and gradation. According to the international soil classification, the range of particles for each type of soil is given in Table 3.5.

TABLE 3.5 INTERNATIONAL SOIL CLASSIFICATION

Type of soil	Range of particle diameter (mm)
1. Coarse sand	2 to 0.2
2. Fine sand	0.2 to 0.02
3. Silt	0.02 to 0.002
4. Clay	< 0.002

Fig. 3.2 gives the *textural classification* chart for following twelve *main textural classes* of soils given by United States Department of Agriculture (USDA):

1. Sand
2. Silt
3. Clay
4. Loam
5. Loamy sand
6. Sandy loam
7. Silty loam
8. Sandy clay loam
9. Sandy clay
10. Clay loam
11. Silty clay loam
12. Silty clay

For example : Let the percent of sand, silt and clay in a soil sample be 25%, 60% and 15% respectively, determined as per Table 3.5. In Fig. 3.2, lines are drawn according to these percentages, parallel to the arrows indicated in the figure. We find that point of intersection (*P*) of these three lines (shown dotted) falls in the sector of silty loam. Hence the soil is *silty loam* as per USDA classification system.

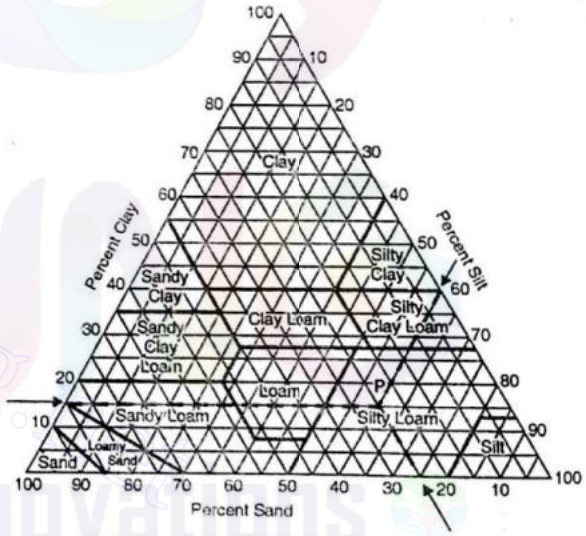

FIG. 3.2. SOIL TEXTURAL CLASSIFICATION CHART BY USDA

Indian soils : Following are some of the principal Indian soils:

(1) *Alluvial soil* : Alluvial soils are formed by deposition under water. They are found in the Indo-Gangetic plains. Alluvial soils area very fertile. They absorb fair percentage of rainfall and act as a good source of ground water reservoir.

(2) *Red soil* : Red soil is a residual soil which has been left in place as a result of decay of the underlying parent rock, concealing the parent rock below the

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ground surface. Red soils are light textured, porous and friable. They have a varying fertilty and have low content of soluble salts.

(3) ***Laterite soil*** : Laterite soils are also residual soils. They are usually porous and well drained, but lack common nutrients.

(4) ***Black soil*** : The texture of black soils varies from clay to loam. They develop cracks on account of drying by heat or sun. It has generally good drainage, but where heavy type of clay called chopan, forms the substrata, the soil is likely to be water logged. The soil is quite fertile if adequate rainfall is available.

(5) ***Clayey soil*** : They are potentially rich soils but lacks drainage.

(6) ***Sandy soil*** : These are found in deserts of some parts of Punjab and greater part of Rajasthan. The soil has high pH value, low organic content and free drainage.

(7) ***Humus***.

(8) ***Peats and marshes***.

Suitability of Soil for Irrigation

The soil should be carefully studied with regard to the following:

(*a*) Size of soil particles. (*b*) Compactness.

(*c*) Depth. (*d*) Organic matter content.

(*e*) Position of water table.

All the above aspects influence the depth of available water that the irrigation can store in the root zone of soil in a single application of water and hence influence the required frequency of watering. The soil conditions essential for good plant growth–originally worked out by Morgan and his associates in 1938 are given below:

(1) Suitablity for the agricultural *implements* required for most efficient production.

(2) Effective resistance to destructive soil erosion or soil depletion under croping system.

(3) Adequate moisture storage to meet the water requirements of crops under normal rainfall or irrigation.

(4) Aadequate aeration to a suitable depth to permit the developement of a favourable root system for the mature plant.

(5) Available plant nutrients sufficient for profitable yields.

(6) Freedom from adverse chemical conditions such as harmful concentration of soluble consituents and from other special soil conditions that favour the development of organsims parasitic to the crop.

3.4. PREPARATION OF LAND FOR IRRIGATION

The land hitherto uncultivated should be properly prepared before irrigation water is applied upon it. This can be done as follows :

(*i*) Removal of thick jungle, bushes etc., from the raw land. The roots of the trees should be extracted and burnt. The land should thereafter be properly deaned.

(*ii*) The land should be made level. High patches should be scraped and depression filled. Unless this is done, water will fill the depression and duty may be too low.

(*iii*) The land should be provided with regular slope in the direction of falling gradient.

(*iv*) The land should be divided into suitable plots by small levees according to the method of irrigation to be practiced.

(*v*) Permanent supply ditches and water courses should be excavated at regular spacings which facilitate proper distribution of the water to the entire field.

(*vi*) A drain ditch which carries the waste water should also be excavated.

(*vii*) Proper drainage measures should be adopted where the danger of water logging may become eminent after the introduction of canal irrigation.

3.5. CLASSES AND AVAILABILITY OF SOIL WATER

Water present in the soil may be classified under three heads (Fig. 3.3) :

1. Hygroscopic water,
2. Capillary water,
3. Gravitational water.

When an oven-dried sample is kept open in the atmosphere, it absorbs some amount of water from the atmosphere. This is known as *hygroscopic water*, and is not capable of movement by the gravity or capillary forces.

Capillary water is that part in excess of hygroscopic water which exists in the pore space of the soil by molecular attraction.

Gravitational water is that part in excess of hygroscopic and capillary water which will move out of the soil if favourable drainage is provided.

Water may also be classified as *unavailable, available* and *superfluous*. This classification is based on the availability of soil water to plants.

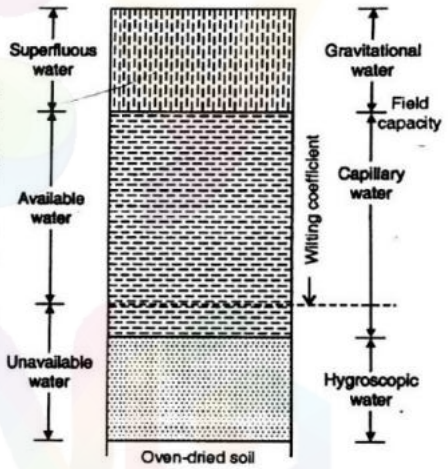

FIG. 3.3 CLASSES OF SOIL WATER.

Soil Moisture tension : The force per unit area that must be exerted in order to extract water from the soil is known as *soil moisture tension* and is expressed in terms of *atmosphere* (atm). It is also known as *Capillary potential, Capillary tension* or *force of suction*. Soil moisture tension is inversely proportional to moisture content of a soil of given texture and structure. It is measured in the laboratory with the help of various instruments such as *centrifuge, tensiometer* etc.

Soil moisture stress : Soil moisture stress is defined as the sum of the soil moisture tension and osmotic pressure of soil solution. Osmotic pressure is the increase in the force (or tension) caused by the salts present in the soil solution. The growth of plants is a function of both soil moisture tension as well as the osmotic pressure, and hence is a function of soil moisture stress. The osmotic pressure of the soil solution should be maintained as low as possible by *controlled leaching*, thus maintaining the

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soil moisture stress at the root zone in a range that will provide adequate moisture to the roots of the plants and is discussed below.

Soil moisture constants : Various soil moisture constants are described below.

1. *Saturation Capacity*

This can also be called as *maximum moisture holding capacity* or *total capacity* and is the amount of water required to fill all the pore spaces between soil particles by replacing all air held in pore spaces. It is the upper limit of possible moisture content. When the porosity of a soil is known, the saturation capacity can be expressesd as equivalent cm of water per metre of soil depth. So, if the porosity is 50 % by volume, the moisture in each meter of saturated soil is equivalent to depth of 50 cm the field surface.

2. *Field Capacity*

The field capacity is the moisture content of the soil after free drainage has removed most of the gravity water. The concept of field capacity is extremely useful in arriving at the amount of water available in the soil for plant use. Most of the gravitational water drains through the soil before it can be used consumptively by plants.

3. *Permanent Wilting Point*

Permanent wilting point or the *wilting coefficient* is that water content at which plants can no longer extract sufficient water from the soil for its growth. The permanent wilting point is at the lower end of the available moisture range. If the plant does not get sufficient water to meet its needs, it will wilt permanently. A plant is considered to be permanently wilted when it will not regain its turgidity even after being placed in a saturated atmosphere where little or no consumptive water use occurs. However, it will regain its turgidity if water is added to the soil.

The permanent wilting point depends upon the rate of water used by the plant, the depth of the root zone and the water holding capacity of the soil. Permanent wilting point is higher in a hot climate than in a cool climate. At the permanent wilting point, the soil moisture tension may range between 7 to 40 atm, depending upon rate of consumptive use, type of crop, soil texture, salt content of soil etc. However, recent studies indicate that the wilting point is closely indicated by the moisture retained against a tension of 15 atm. At the permanent wilting point, the films of water around the soil particles are held so tightly that the plant roots cannot extract enough moisture at sufficient rate to satisfy transpiration requirements of the plant, resulting in wilting of the plant. As an approximation, the permanent wilting percentage can be estimated by dividing the field capacity by a factor varying from 2.0 to 2.4, depending upon the amount of silt in the soil. For most of the soils, wilting coefficient is about 150 % of the hygroscopic water.

Temporary Wilting

Temporary wilting may sometimes take place during hot windy-day, but the plant will recover in the cooler portion of the day. No addition of water is required. Thus temporary wilting may take place during the hot summer day, even when soil moisture is higher than the wilting coefficient, because of increased transpiration rates.

Ultimate Wilting

Ultimate wilting is slightly different from permanent wilting. When ultimate wilting occurs, the plant will not regain its turgidity even after the addition of sufficient water to the soil and the plant will die. The soil moisture tension at ultimate wilting point is as high as 60 atm. The *ultmate wilting point* occurs at the hygroscopic water content. Hence the ultimate wilting point is also known as *hygroscopic coefficient*. The *ultmate wilting point* or the *hygroscopic coefficient* is about 2/3 of the permanent wilting point.

4. *Available Moisture*

The difference in water content of the soil between field capacity and permanent wilting point is known as available water or available moisture.

5. *Readily Available Moisture*

It is that portion of the available moisture that is most easily extracted by plants, and is approximately 75 % of the available moisture.

The above mentioned soil-moisture constants for different types of soils are shown below in a tabular form (Table 3.6) :

TABLE 3.6

Types of Soil	*Wilting Coefficient*	*Field Capacity*	*Available water*
Sand	4	9	5
Sandy loam	6	14	8
Loam	10	22	12
Clay loam	13	27	14
Silty clay	15	31	16
Clay	17	35	18

6. *Moisture Equivalent*

This is an artificial moisture property of the soil and is used as an index of the natural properties. It is the percentage of moisture retained in a small sample of wet soil 1 cm deep when subjected to a centrifugal force 1000 times as great as gravity, usually for a period of 30 minutes. Moisture equivalent is used as a single factor to which the properties of soil can be related within reasonable limits. The moisture equivalent roughly equals field capacity for a medium textured soil. The relation between these are as follows :

Moisture equivalent = Field capacity
= 1.8 to 2 Permanent wilting point
= 2.7 Hygroscopic coefficient.

7. *Soil-Moisture Deficiency*

Soil-moisture deficiency or field moisture deficiency is the water required to bring the soil moisture content of the soil to its field capacity.

Depth of water stored in root zone and available to plants :

In order to estimate the depth of water stored in the root zone of soil containing water upto field capacity, let d be the depth of root zone (in metres) and F_c be the field capacity (expressed as ratio).

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Let γ_d = dry unit weight of soil.

γ_w = unit weight of water.

Consider unit area (1 sq. metre) of soil area. Then

$$F_c = \frac{\text{Wt. of water retained in unit area}}{\text{Wt. of soil of unit area}} = \frac{\text{Wt. of water retained in unit area}}{(\gamma_d \times 1 \times d)}$$

$\therefore$ Wt. of water retained in unit area $= F_c \cdot \gamma_d \cdot d$

$$\therefore \text{ Depth of water stored (in depth } d) = \frac{F_c \cdot \gamma_d \cdot d}{\gamma_w} \text{ metres} \quad ...(3.2)$$

A part of this depth of water will be available for evapo-transpiration.

Available moisture depth (d_w) is given by

$$d_w = \frac{\gamma_d \cdot d}{\gamma_w} \left[\text{Field capacity} - \text{Wilting coefficient}\right] \quad ...(3.2\,a)$$

$$d_w = S_g\, d\, [F_c - w_c] \quad ...(3.2\,b)$$

where S_g = apparent specific gravity of soil $= \gamma_d/\gamma_w$

F_c = field capacity, expressed as rato

w_c = wilting coefficient, expressed as ratio

Example 3.2. *The root zone of an irrigation soil has dry weight of 15 kN/m³ and a field capacity of 30%. The root zone depth of a certain crop, having permanent wilting percentage of 8% is 0.8 m. Determine (a) depth of moisture in the root zone at field capacity (b) depth of moisture in the root zone at permanent wilting point, and (c) depth of water available.*

Solution

(*a*) Depth of water in root zone at field capacity, per metre depth of soil

$$= \frac{\gamma_d}{\gamma_w} \times F_c = \frac{15}{9.81} \times 0.3 = 0.459 \text{ m/m} = \mathbf{459\ mm/m}$$

(*b*) Depth of water in root zone at permanent wilting point, per m depth of soil:

$$= \frac{\gamma_d}{\gamma_w} \times \text{ permanent wilting point } = \frac{15}{9.81} \times 0.08 = 0.122 \text{ m/m} = \mathbf{122\ mm/m}$$

(*c*) Depth of water available in root zone

$$= \frac{\gamma_d \cdot d}{\gamma_w} [F_c - \text{permanent wilting point}]$$

$$= \frac{15}{9.81} \times 0.8\,[0.3 - 0.08] = 0.269 \text{ m} = \mathbf{269\ mm}$$

Example 3.3. *The field capacity of a certain soil is 15% and the moisture content of the soil before irrigation is 8%. Determine the depth upto which the soil profile will be wetted with an application of 60 mm of water. Take the dry unit weight soil as 15.3 kN/m³.*

Solution : $\gamma_d/\gamma_w = 15.3/9.81 = 1.56$

$$\text{Depth of water applied} = \frac{\gamma_d \cdot d}{\gamma_w} [\text{Field capacity} - \text{moisture content before irrigation}]$$

$\therefore$ $60 = 1.56\, d\, [0.15 - 0.08]$

From which $d \simeq$ **550 mm**

Example 3.4. *The field capacity of a certain soil is 20% and its apparent specific gravity is 1.6. Before applying irrigation water, a wet sample of soil was taken and its mass was found as 150 gm. The same sample weighed as 136 gm after oven drying. Determine the depth of water that must be applied to irrigate the soil to a depth of 0.9 m.*

Solution : $\gamma_d/\gamma_w = 1.6$

$$\text{Moisture content before irrigation} = \frac{150 - 136}{136} \times 100 = 10.29\%$$

$\therefore$ Depth of water required to bring the moisture up to field capacity.

$= S_g \cdot d\, [F_c -$ moisture content before irrigation$]$

$= 1.6 \times 0.9\, [0.2 - 0.1029] \simeq 0.14$ m = **140 mm**

Example 3.5. *Find the field capacity of a soil for the following data :*

Root zone depth	= *2 m*
Existing water content	= *5%*
Dry density of soil	= *15 kN/m³*
Water applied to the soil	= *500 m³*
Water loss due to evaporation and deep percolation	= *10%*
Area of plot	= *1000 sq.metres.*

Solution.

Total water applied = 500 m³

Loss of water = 10%

$\therefore$ Water used in the soil $= 500 \times \frac{90}{100} = 450$ m³

Weight of water used = 450 × 9.81 = 4414.5 kN

Total dry weight of the soil = 1000 × 2 × 15 = 30000 kN

$\therefore$ % of water added $= \frac{4414.5}{30000} \times 100 = 14.72\%$

$\therefore$ New water content = 5% + 14.72% = 19.72%

$\therefore$ Field capacity = **19.72%**

Example 3.6. *A loam soil has field capacity of 22% and wilting coefficient of 10%. The dry unit weight of soil is 15 kN/m³. If the root zone depth is 70 cm, determine the storage capacity of the soil. Irrigation water is applied when moisture content falls to 14%. If the water application efficiency is 75%, determine the water depth required to be applied in the field.*

Solution :

Given $\gamma_d = 15$ kN/m³. Also, $\gamma_w = 9.81$ kN/m³

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Maximum storage capacity = Available moisture

$$= \frac{\gamma_d \cdot d}{\gamma_w}\left[\text{Field capacity} - \text{Wilting coefficient}\right]$$

$$= \frac{15 \times 0.70}{9.31}\left[0.22 - 0.10\right] \text{m} = 0.128 \text{ m} = \mathbf{12.8 \text{ cm}}$$

Depth of irrigation water

$$= \frac{\gamma_d \cdot d}{\gamma_w}\left[\text{Field capacity} - w\right] \quad \text{where } w = 14\%$$

$$= \frac{1.5 \times 0.7}{9.81}\left[0.22 - 0.14\right] \text{m} = 0.086 \text{ m} = \mathbf{86 \text{ mm}}$$

Field irrigation requirement

$$= \frac{86}{0.75} = \mathbf{115 \text{ mm.}}$$

3.6. LIMITING SOIL MOISTURE CONDITIONS

It is essential to maintain *readily available water* in the soil if crops are to make satisfactory growth. The plant growth may be retarded if the soil-moisture is either deficient or excessive. If the soil moisture is only slightly more than the wilting coefficient, the plant must expend extra energy to obtain it and the plant will not grow healthy. Similarly, excessive flooding fills the soil pores with water, thus driving out air. Since air is essential to satisfactory plant growth, excessive water supply retards plant growth. The *optimum moisture percentage* is thus that moisture corresponding to which optimum growth of plant takes place, as shown in Fig. 3.4.

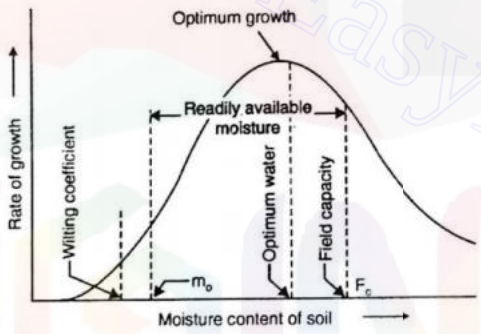

FIG. 3.4. LIMITING SOIL MOISTURE CONDITIONS.

3.7. DEPTH AND FREQUENCY OF IRRIGATION

As explained earlier, *available moisture* is the moisture between wilting point and the field capacity. The *readily available moisture* is that moisture which is easily extracted by the plants, and is approximately 75 % of the available moisture. At any time, therefore, the moisture content in the soil should be between the *field capacity* and the *lower limit* (m_0), of the readily available moisture, as shown in Fig. 3.5.

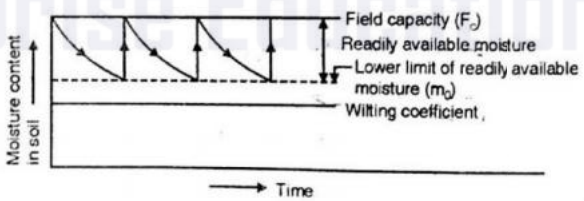

FIG. 3.5. FREQUENCY OF IRRIGATION

Thus, m_0 is the maximum level upto which the soil moisture may be allowed to be depleted in the root zone without fall in the yield.

When watering is done, the amount of water supplied should be such that the water content is equal to the field capacity. Water will be gradually utilized consumptively by plants after the water application, and the soil moisture will start falling. When the water content in the soil reaches the value m_0, fresh doses of irrigation may be done so that water content is again raised to the field capacity of the soil.

The frequency of irrigation is controlled by the amount of available water contained in the root zone of the soil and the consumptive use rate. If d is the root zone depth (metres), F_c is the field capacity and m_o is the lower limit of readily available moisture content, the depth of water d_w to be given during each watering is found from the following expression,

$$d_w = \frac{\gamma_d}{\gamma_w} \cdot d\left[F_c - m_0\right] \text{ metres} \qquad ...(3.3)$$

(where γ_d is the dry unit weight of soil and γ_w is the unit weight of water). Both F_c and m_0 are the moisture contents to be expressed as ratio.

If C_u is the daily consumptive use rate, frequency of watering f_w is given by

$$f_w = \frac{d_w}{C_u} \text{ days} \qquad ...(3.4)$$

Time required to irrigate a certain area

Let t be the time required to apply the desired water depth d_w to bring the water level in the soil from m_0 to the field capacity F_c, over an irrigation field of area A. If q is the discharge in the field channel, in cumecs, we have

$$t = \frac{A \cdot d_w}{q} \text{ seconds} \qquad ...(3.5)$$

where A is the area in square metres and d_w is the depth of water to be applied in metres. If, however, area A is expressed in hectares, we have

$$t = \frac{d_w}{q} \cdot A \times 10^4 \text{ seconds} = \frac{2.778 A d_w}{q} \text{ hours} \qquad ...(3.5\ a)$$

Example 3.7. *After how many days will you supply water to soil (clay loam) in order to ensure efficient irrigation of the given crop, if*

(i) *Field capacity of soil = 27%*
(ii) *Permanent wilting point = 14%*
(iii) *Dry density of soil = 15 kN/m³*
(iv) *Effective depth of root zone = 75 cm*
(v) *Daily consumptive use of water for the given crop = 11 mm.*

Solution. Available moisture = Field capacity − permanent wilting point
= 27 − 14 = 13%

Let the *readily available moisture* be 80% of the available moisture.

∴ Readily available moisture = 13 × 0.8 = 10.4%

∴ m_0 = 27 − 10.4 = 16.6%

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Hence when irrigation water is applied, moisture is raised from 16.6% to 27%.

∴ Depth of water stored in root zone, during each watering

$$= \frac{\gamma_d \cdot d}{\gamma_w} d \text{ [Field capacity} - m_0] = \frac{\gamma_d}{\gamma_w} d \left[0.27 - 0.166\right] \text{ metres}$$

$$= \frac{1.5 \times 0.75}{9.81} \times 0.104 = 0.119 \text{ m} = 11.9 \text{ cm}$$

Thus, depth of water available for evapo-transpiration = 11.9 cm

Daily consumptive use of water = 1.1 cm

$$\therefore \text{ Watering frequency } = \frac{11.9}{1.1} = 10.82 \text{ days} \simeq \mathbf{10\ days}$$

Hence, water should be applied after every 10 days.

Example 3.8. *An irrigation field 40 m wide 250 m long has soil which has apparent specific gravity equal to 1.56 and field capacity equal to 22%. The depth of root zone is 0.6 m. If the irrigation is started when 70% of the available moisture has been used, compute (a) net depth of irrigation water required, and (b) time required to irrigate the field if the discharge in the field channel is 20 litres per second.*

Solution : (*a*) Given : $F_c = 22\% = 0.22$; $S_g = 1.56$; $d = 0.6$ m

Moisture content before start of irrigation, $m = 0.3 \times 0.22 = 0.066$

$$\therefore \quad d_w = S_g\, d\, [F_c - m] = 1.56 \times 0.6\, [0.22 - 0.066] = 0.144 \text{ m} = \mathbf{144\ mm}$$

(*b*) Discharge $q = 20$ lps $= 20 \times 10^{-3} \times 3600$ m^3 / hour $= 72$ m^3 / hour

Hence from Eq. 3.5, $t = \frac{A d_w}{q} = \frac{40 \times 250 \times 0.144}{72} = \mathbf{20\ hours}$

3.8. PRINCIPAL CROPS AND CROP SEASONS

Crops can be classified in the following ways :

1. Agricultural classification
2. Classification based on crop seasons
3. Classification based on irrigation requirement

1. Agricultural classification

This consists of the following types of crops.

(*i*) ***Field crops*** : Such as wheat, rice, maize, barley, oats, great millet, spiked millet, gram, pulses etc.

(*ii*) ***Commercial crops*** : Such as sugar cane, cotton, tobacco, hemp, sugar beat etc.

(*iii*) ***Oil seed crops*** : Such as mustard, ground nut, sesame, linseed, caster etc.

(*iv*) ***Horticulture crops*** : Consisting of various fruit crops, various vegetable crops and flower crops

(*v*) ***Plantation crops*** : Such as tea, coffee, cocao, coconut, rubber etc.

(*vi*) ***Forage crops*** : Such as fodder, grass etc.

(*vii*) ***Miscellaneous crops*** : Such as medicinal crops, aromatic crops, sericulture crops, condiments and spices.

2. Classification based on crop seasons

Based on crop season, crops are classified as follows.

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

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

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

(*iv*) ***Eight months crops*** : These crops, such as cotton, require irrigation water for 8 months.

3. Classification based on irrigation requirements : Based on irrigation requirements, crops can be classified as (*i*) dry crops, (*ii*) wet crops and (*iii*) garden crops. *Dry crops* are the one which do not require water for irrigation; only rain water is sufficient for their growth. *Wet crops* are those which cannot grow without irrigation. *Garden crops* require irrigation throughout the year.

Principal crops of India

Table 3.7 gives the principal crops of India, along with crop season and average depth of water required (i.e. delta).

TABLE 3.7. PRINCIPAL CROPS OF INDIA

Crop	*Sowing time*	*Harvesting time*	*Average Delta (cm)*
(A) Kharif Crops			
Rice	June–July	Oct.–Nov.	120
Makai (Maize)	June–July	Sept.–Oct.	45
Bajra (Spiked Millet)	June–Aug.	Sept.–Oct.	30
Jowar (Great Millet)	June–July	Oct.–Nov.	30
Pulses (Mung, Moth, Urd)	June–July	Nov.–Dec.	30
Ground Nut	May		45
(B) Rabi Crops			
Gram	Sept.–Oct.	March–April	30
Wheat	Oct.–Nov.	March–April	40
Barley	Oct.–Nov.	March–April	45
Peas	Oct.–Nov.	March–April	50
Mustard	Oct.	Feb.–March	45
Tobacco	Feb.–March	June	60
Potato	Oct.	Feb.	75
(C) Eight Months Crops			
Cotton	May–June	Dec.–April	45
(D) Perennial Crops			
Sugar-cane	Feb.–March	Dec. to March	90

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Crop Ratio. It is the ratio of the area irrigated in Rabi season to the area irrigated in Kharif season. Since the water requirements of Kharif crops are two to three times more than that required for rabi, the ratio is so kept that almost uniform discharge is required for this purpose.

Overlap Allowance : It may happen sometimes that the crop of some season may overlap some period of the next crop season. When such overlapping takes place, the crops of both the seasons require water simultaneously. Thus the overlap allowance is the extra discharge for this purpose.

3.9. DUTY AND DELTA

Duty represents the irrigating capacity of a unit of water. It is the relation between the area of a crop irrigated and the quantity of irrigation water required during the entire period of the growth of that crop. For example, if 3 cumecs of water supply is required for a crop sown in an area of 5100 hectares, the duty of irrigation water will be 5100/3 = 1700 hectares/cumec, and the discharge of 3 cumecs will be required throughout the base period.

Delta is the total depth of water required by a crop during the entire period the crop is in the field and is denoted by the symbol Δ. For example, if a crop requires about 12 waterings at an interval of 10 days, and a water depth of 10 cm in every watering, then the delta for that crop will be $12 \times 10 = 120$ cm = 1.20 metres. If the area under that crop is A hectares, the total quantity will be $1.20 \times A = 1.2\ A$ hectare-metres in a period of 120 days.

Crop period : Crop period is the time, in days, that a crop takes from the instant of its sowing to that of its harvesting.

Base period : Base period for a crop refers to the whole period of cultivation from the time when irrigation water is first issued for preparation of the ground for planting the crop, to its last watering before harvesting.

Ways of Reckoning Duty

The duty of water is reckoned in the following *four ways* :

(i) By the number of hectares that one cumec of water can irrigate during the base period, *i.e.* 1700 hectares/cumec.

(ii) By total depth of water (or Delta), *i.e.* 1.20 metres.

(iii) By number of hectares that can be irrigated by a million cubic metre of stored water. This system is used for tank irrigation.

(iv) By the number of hectare metres expended per hectare irrigated. This is also used in tank irrigation.

For a precise statement of duty by the first method, which is quite common in canal irrigation system, it is necessary to state the following along with the duty figures :

(*a*) the base period, and

(*b*) the place of measurement of duty.

Thus duty of water for a certain crop is 1700 hectares/cumec *at the field,* for a base period of 120 days.

Variation of Duty with the Place of its Measurement

The duty varies with the place of its measurement, because of continuous conveyance losses as the water flows. The *duty of water goes on increasing as the water flows.* For example, let C (Fig. 3.6) be the head of the field, B be the head of the water course or the field channel, and A be the head of the distributary. Let the area of the field be 1700 hectares, and let 1 cumec water be required to be delivered at point C, for the growth of the crop. Thus, the duty at the *head of the field* will be 1700 hectares/cumec. Assuming the conveyance losses between B and C to be 0.1 cumecs (say), the discharge required at B will be 1.1 cumecs, and hence duty of water measured at B will be 1700/1.1 = 1545 hectares/cumec only. Again, if the losses between A to B are taken to be equal to 0.2 cumec, the discharge required at the head of the distributary will be $1.1 + 0.2 = 1.3$ cumecs, *i.e.* if 1.3 cumecs are discharged at A, then 1 cumec will reach at the head of the field. Hence the duty of water at A will be 1700/1.3 = 1308 hectares/cumec only. Thus, duty at the head of the water course (at B) is lesser than the duty at the head of the field, and is greater than the duty at the head of the distributary. The duty at the head of the water-course is called the *outlet duty.* Thus measurements of duty are taken at four points noted below:

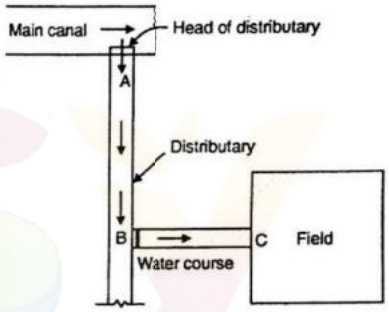

FIG. 3.6

(*i*) At the head of main canal — known as *Gross Quantity.*

(*ii*) At the head of a branch canal — known as *Lateral Quantity.*

(*iii*) At the outlet of a canal — known as *Outlet Factor.*

(*iv*) At the head of land to be irrigated — known as *Net Quantity.*

Relation Between Duty and Delta

Let D = duty in hectares/cumec

Δ = total depth of water supplied (in metres)

B = base period in days.

(*i*) If we take a field of area D hectares, water supplied to the field corresponding to the water depth Δ metres will be $= \Delta \times D$ hectare-metres

$$= D \times \Delta \times 10^4 \text{ cubic-metres.} \quad ...(1)$$

(*ii*) Again for the same field of D hectares, one cumec of water is required to flow during the entire base period. Hence, water supplied to this field

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

Equating Equations (1) and (2), we get

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$$D \times \Delta \times 10^4 = B \times 24 \times 60 \times 60$$

or

$$\Delta = \frac{B \times 24 \times 60 \times 60}{D \times 10^4} = 8.64 \frac{B}{D} \text{ metres} \quad ...(3.6)$$

Note : 1 hectare = 10^4 sq. metres
1 cumec-day = 8.64 hectare-metres.

High and Low Duty

Duty is being referred to as being high or low according to the number of hectares/cumec irrigated is large or small.

Gross Commanded Area (G.C.A.)

An area is usually divided into a number of watersheds and drainage valleys. The canal usually runs on the watershed and water can flow from it on both sides, due to gravitational action only up to drainage boundaries. Thus in a particular area lying under the canal system, the irrigation can be done only upto the drainage boundaries. The *gross commanded* area is thus the total area lying between drainage boundaries which can be commanded or irrigated by a canal system.

Culturable Commanded Area (C.C.A.)

The gross commanded area also contains unfertile barren land, alkaline soil, local ponds, villages and other areas as habitation. These areas are known as unculturable areas. The remaining area on which crops can be grown satisfactorily is known as culturable commanded area (C.C.A.).

Thus G.C.A. = C.C.A.+ Unculturable area.

The culturable commanded area can further be classified as culturable cultivated area and culturable uncultivated area.

Culturable Cultivated Area

It is the area in which crop is grown at a particular time or crop season.

Culturable Uncultivated Area

It is that area in which crop is not sown in a particular season. Such area is kept under no cultivation due to the following reasons:

1. To increase the fertility of the soil which has been reduced due to intense cultivation.
2. To provide pasture land for animals.
3. The crop to be sown in that land has a different crop season.
4. To protect the land from the possible danger of water-logging.

Intensity of Irrigation

Intensity of irrigation is defined as the percentage of culturable commanded area proposed to be irrigated during either a crop season or during a year. For example, if C.C.A. of an irrigation field is 120 hectares, out of which 90 hectares of the land is cultivated during *kharif season* and 60 hectares of the land is cultivated during *rabi season*, the *intensity* of irrigation during Kharif season will be = (90/120) 100 = 75% and the *intensity* of irrigation *during rabi crop* will be (60/120) × 100 = 50%. *However, the*

yearly intensity of *irrigation* will be equal to the sum of the two, i.e. equal to 75 + 50 = 120%. Thus yearly intensity of irrigation can be more than 100%.

3.10. FACTORS AFFECTING DUTY

The duty of water of canal system depends upon a variety of the factors. The principal factors are :

1. Methods and system of irrigation ;
2. Mode of applying water to the crops ;
3. Method of cultivation ;
4. Time and frequency of tilling ;
5. Type of the crop ;
6. Base period of the crop ;
7. Climatic conditions of the area;
8. Quality of water ;
9. Method of assessment of irrigation method ;
10. Canal conditions ;
11. Character of soil and sub-soil of the canal ;
12. Character of soil and sub-soil of the irrigation fields.

1. ***Methods and Systems of Irrigation***

In the perennial irrigation system, soil is continuously kept moist, and hence water required for initial saturation is less. Also, due to the shallow depth of the water table, deep percolation losses are less. In the inundation irrigation, there is wasteful use of water. Hence, the perennial irrigation system has more duty than the inundation irrigation. The flow irrigation system has lower duty due to the conveyance losses in the network of the canals, while the lift irrigation system has higher duty because the commanded area of each well is very near to it. Tank irrigation gives high duty due to rigid control.

2. ***Mode of Applying Water***

The flood irrigation system has lesser duty than the furrow system. Sub-irrigation system gives still higher duty. The ring basin irrigation and uncontrolled flooding give less duty.

3. ***Method of Cultivation***

If the land is properly ploughed and made quite loose before irrigating, the soil will have high water retention capacity in its unsaturated zone. Thus, the number of waterings can be reduced, increasing the duty. The old and conventional methods of cultivation gives less duty in comparison to the modern methods.

4. ***Time and frequency of Tilling***

Frequency of cultivation reduces the loss of moisture through weeds. Soil structure affects the plant growth to a very great extent. A good structure (*i.e.* the good arrangement of soil particles in relation to one another) is called good *tilth* of soils. When the soil is in good tilth, evaporation losses from the surface of soil is less, soil becomes properly aerated, and hence the yield of crop is also better.

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5. ***Type of the crop***

The duty varies from crop to crop.

6. ***Base Period of the Crop***

If the base period of the crop is more, the amount of water required will be high, hence duty will be low and *vice-versa.*

7. ***Climatic Conditions of the Area***

The climatic conditions which affect the duty are : (*i*) temperature, (*ii*) wind, (*iii*) humidity, and (*iv*) rainfall. Due to high temperature and wind, evaporation losses will be more, and duty will be less. A humid atmosphere reduces the losses. Rainfall during the crop-period will reduce the irrigation-water requirement, and the duty will thus be higher. In this context there are two popular terms : (*i*) *Duty inclusive of rainfall, i.e.* duty be considered by taking rainfall into account ; (*ii*) *Duty exclusive of rainfall,* that is the duty has been considered by not considering the rainfall in the area.

8. ***Quality of water***

If the harmful salt-content and alkali content of the water is more, water will have to be applied liberally so that the salts are leached off. This will, in turn, reduce the duty. More fertilizing matter in water will cause less consumption of water, and increase duty.

9. ***Method of Assessment of water***

Volumetric method of assessment always leads to a higher duty. This is because the farmer will use water economically. If, however, the method of assessment is based on the area under cultivation, the farmer will have a tendency to use more water, and the duty will be low.

10. ***Canal Conditions***

In an earthen canal, the seepage and percolation losses will be high, resulting in the low duty. If, however, the canal is lined, the losses will be less, and duty will be high. If the high canal is so aligned that the irrigated areas are concentrated along it, the duty will be higher. The dispersion of the irrigated areas with respect to the canal tends to reduce the duty.

11. ***Character of Soil and Sub-soil of the Canal***

If the canal is unlined, and if it flows through coarse grained, permeable soils, the seepage and percolation losses will be high. If the canal flows through fine grained soil, such losses will be less, and hence the duty will be higher.

12. ***Character of Soil and Sub-soil of the Irrigation Field***

If the soil and sub-soil of the field is coarse-grained, percolation losses will be high. However, if there is hard pan at depth 1 to 2 metre below surface, the percolation loss reduces. The duty is also affected by the topography of the land. If the field is not level, the lower portions get more water, while higher portions may remain drier. In order to supply water to the higher places, more water will be used, and the duty will be reduced.

3.11. METHODS OF IMPROVING DUTY

When once the various factors affecting duty are properly understood, the duty can be improved by making those factors less effective which tend to reduce the duty.

1. Suitable method of applying water to the crops should be used.

2. The land should be properly ploughed and levelled before sowing the crop. It should be given good tilth.

3. The land should be cultivated frequently, since frequent cultivation reduces loss of moisture specially when the ground water is within capillary reach of ground surface.

4. The canals should be lined. This reduces seepage and percolation losses. Also, water can be conveyed quickly, thus reducing evaporation losses.

5. Parallel canals should be constructed. If there are two canals running side by side, the F.S.L. will be lowered, and the losses will thus be reduced.

6. The idle length of the canal should be reduced.

7. The alignment of the canal either in sandy soil or in fissured rock should be avoided.

8. The canal should be so aligned that the areas to be cultivated are concentrated along it.

9. The source of supply should be such that it gives good quality of water.

10. The rotation of crops must be practiced.

11. Volumetric method of assesment should be used.

12. The farmers must be trained in the proper use of water, so that they apply correct quantity of water at correct timing.

13. The land should be redistributed to the farmers so that they get only as much land as they are capable of managing it.

14. Research stations should be established in various localities to study the soil, the seed and conservation of moisture. The problems concerning the economical use of water should be studied at research stations.

15. The canal administrative staff should be efficient, responsible and honest. The operation of canal system should be such that the farmers both at the head of the canal as well as at the tail end get water as and when they need it.

3.12. SOME DEFINITIONS

1. ***Kor period and Kor depth***

We have already dicussed the base period. The distribution of water during the period is however, not uniform. Crops require maximum water during first watering after the crops have grown few centimetres. During the subsequent watering the quantity of water needed by crops gradually decreases and is least when crop gains maturity. The first watering is known as *kor watering*, and the depth applied is known as *kor depth*. The portion of the base period in which kor watering is needed is known as *kor period*. While designing the capacity of a channel, kor water must be taken into account since discharge in the canal has to be maximum during this time.

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2. ***Outlet Factor*** : It is defined as the duty at the outlet.

3. ***Time Factor***

The time factor of a canal is the ratio of the number of days the canal has actually run to the number of days of irrigation period. For example, if the number of days of irrigation period = 12, and the canal has actually run for 5 days, the time factor will be = 5/12. A day has a period of 24 hours (*i.e.* it includes the night).

4. ***Capacity Factor***

This is the ratio of the mean supply (discharge) to the full supply of a canal.

5. ***Cumec Day***

The quantity of water flowing for one day at the rate of 1 cumec is known as a cumec-day. It is equal to 8.64 hectare-metres.

6. ***Paleo***

It is the first watering before sowing the crop. This is done in order to add sufficient moisture to the unsaturated zone of the soil and is required for the initial growth of the crop.

7. ***Full Supply Coefficient***

It is defined as the area estimated to be irrigated during the base period divided by the design full supply discharge of the channel at its head during maximum demand. This is also known as *duty on capacity.*

8. ***Nominal Duty***

In some states, cultivators have to submit an application for water required for their land under irrigation, to the department in advance of every season. After a permit is granted, they have to pay full amount for the water irrespective of the area they actually irrigate. Nominal duty is, therefore, the ratio of the area of which the permit has been granted for the period divided by the mean supply for the base period.

9. ***Open Discharge***

It is the ratio of the number of cumec-days to the number of days the canal has actually been used for irrigation.

10. ***Root Zone Depth***

Root zone depth is the maximum depth of soil strata in which the crop spreads its root system and derives water from the soil.

Example 3.9. *Find the delta for a crop if the duty for a base period of 110 days is 1400 hectares/cumec.*

Solution : Given : $B = 110$ days and $D = 1400$ hectares/cumec

$$\therefore \quad \Delta = 8.64\frac{B}{D} = \frac{8.64 \times 110}{1400} \text{ m} = 0.68 \text{ m} = \mathbf{68 \text{ cm}}$$

Example 3.10. *A crop requires a total depth of 92 cm of water for a base period of 120 days. Find the duty of water.*

Solution : Given : $B = 120$ days and $\Delta = 92$ cm $= 0.92$ m

$$D = \frac{8.64\,B}{\Delta} \text{ hectares/cumec} = \frac{8.64 \times 120}{0.92} = \mathbf{1127 \text{ hectares/cumec.}}$$

Example 3.11. *An irrigation canal has gross commanded area of 80,000 hectares out of which 85% is culturable irrigable. The intensity of irrigation for Kharif season is 30% and for Rabi season 60%. Find the discharge required at the head of the canal if the duty at its head is 800 hectares/cumecs for Kharif season and 1700 hectares cumec for rabi season.*

Solution

Culturable irrigable area = 80000 × 0.85 = 68000 hectares

Area under Kharif season = 68000 × 0.30 = 20400 hectares.

Area under Rabi season = 68000 × 0.60 = 40800 hectares

The ratio of area irrigated in Rabi season to that irrigation in kharif season is known as *crop ratio.* In this example crop ratio is 2. The crop-ratio is so selected that the discharge in the canal during both the seasons may be uniform.

Water required at the head of the canal to irrigate the land under Kharif season

$$= \frac{20400}{800} \text{ cumecs} = 25.5 \text{ cumecs.}$$

Water required at the head of canal to irrigate the land under Rabi season

$$= \frac{40800}{1700} \text{ cumecs.} = 24 \text{ cumecs}$$

Thus the water requirement during Kharif is more than that in Rabi. Hence, the canal must be designed to carry a discharge of 25.5 cumecs. Actually, the canal must be designed to carry the *peak discharge* and not the average discharge calculated based on the average duty figure. The peak requirements may be taken to be equal to 20% to 25% higher than the average requirement, or calculated from the kor period and kor depth of water, if available.

Example 3.12. *A water course has culturable commanded area of 2600 hectares, out of which the intensities of irrigation for perennial sugar-cane and rice crops are 20% and 40% respectively. The duty for these crops at the head of water course are 750 hectares/cumec and 1800 hectares/cumec respectively. Find the discharge required at the head of water course if the peak demand is 120% of the average requirement.*

Solution

Area under sugar-cane $= 2600 \times 0.2 = 520$ hectares.

Area under rice $= 2600 \times 0.4 = 1040$ hectares.

Water required for sugar-cane $= \frac{520}{750} = 0.694$ cumec

Water required for rice $= \frac{1040}{1800} = 0.578$ cumec.

Since sugar-cane is perennial crop, it will require water through-out the year. Hence, the water course must carry a total discharge of (0.694 + 0.578) = 1.272 cumecs. The design discharge, to meet the peak demand, will be 1.272 × 1.2 = **1.53 cumecs.**

Example 3.13. *The left branch canal carrying a discharge of 20 cumecs has culturable commanded area of 20,000 hectares. The intensity of Rabi crop is 80 percent,*

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and the base period is 120 days. The right branch canal carrying discharge of 8 cumecs has culturable commanded area of 12,000 hectares, intensity of irrigation of Rabi crop is 50 percent, and the base period is 120 days. Compare the efficiencies of the two canal systems.

Solution

(a) *For the left canal*

Area under Rabi crop = 20000 × 0.8 = 16000 hectares

Discharge = 20 cumecs

$$\therefore \quad \text{Duty} = \frac{16000}{20} = 800 \text{ hectares/cumec}$$

(b) *For the right canal*

Area under Rabi crop = 12000 × 0.50 = 6000 hectares

Discharge = 8 cumecs

$$\therefore \quad \text{Duty} = \frac{6000}{8} = 750 \text{ hectares/cumec.}$$

Since the left canal system has higher duty, it is more efficient.

Example 3.14. *A water course has a culturable commanded area of 1200 hectares. The intensity of irrigation for crop A is 40% and for B is 35%, both the crops being Rabi crops. Crop A has a kor period of 20 days and crop B has kor period of 15 days. Calculate the discharge of the water course if the kor depth for crop A is 10 cm and for B it is 16 cm.*

Solution : **(a) *For crop A***

Area under irrigation = 1200 × 0.40 = 480 hectares

Kor period = b = 20 days

Kor depth = δ = 10 cm = 0.1 m

$$\therefore \quad \text{Duty} = \frac{8.64(b)}{\delta} = \frac{8.64 \times 20}{0.1} = 1728 \text{ hectares/cumec}$$

$$\text{Hence discharge required} = \frac{\text{Area under irrigation}}{\text{Outlet factor}}$$

$$= \frac{480}{1728} = 0.278 \text{ cumec}$$

(b) *For crop B*

Area under irrigation = 1200 × 0.35 = 420 hectares

Kor period = b = 15 days

Kor depth = δ = 16 cm = 0.16 m

$$\therefore \quad \text{Duty or outlet factor} = \frac{8.64(b)}{\delta} \text{ hectares/cumec}$$

$$= \frac{8.64 \times 15}{0.16} = 810 \text{ hectares/cumec}$$

$$\text{Hence discharge required} = \frac{420}{810} = 0.519 \text{ cumec}$$

Thus, the design discharge of water course

$$= 0.278 + 0.519 = 0.797 \simeq \mathbf{0.8 \text{ cumec.}}$$

Example 3.15. *A water course commands an irrigated area of 600 hectares. The intensity of irrigation of rice in this area is 60%. The transplantation of rice crop takes 12 days, and total depth of water required by the crop is 50 cm on the field during the transplantation period. During the transplantation period, the useful rain falling on the field is 10 cm. Find the duty of irrigation water for the crop on the field during transplantation, at the head of the field and also at the head of the distributory, assuming losses of water to be 20% in the water course. Also, calculate the discharge required in the water course.*

Solution

The rice seed is generally germinated in separate seed beds and the young plants from seed beds are transplanted, being thrust by hand into previously prepared land. The preparation of land for rice cultivation usually consists of flooding the land till water stands several centimetres in depth over it and ploughing it when in this state, so as to thoroughly puddle the surface soil, reducing it to a soft slush. The operation of preparing a plot and transplanting it takes about 10 to 15 days and a very large quantity of water, varying in different soils and localities from about 30 to 60 cm on the field is required for the whole operation.

Now $\quad \Delta = \dfrac{8.64\,B}{D}$

Here $\quad B$ = transplantation period = 12 days

Δ = depth of irrigation water actually applied in the field

= 50 − 10 = 40 cm = 0.4 m

D = duty of irrigation water, on the field in hectares/cumec.

$$\therefore \quad D = \frac{8.64\,B}{\Delta} = \frac{8.64 \times 12}{0.40} = \mathbf{259.2 \text{ hectares/cumec.}} \text{ (on the field)}$$

Since the losses in the canal are 20%, 1 cumec of water discharge at the head of the water course will be reduced to 0.80 cumec at the head of the field, and hence will irrigate 259.2 × 0.8 = 207.36 hectares only. Hence, the duty of water at the head of the water course will be **207.36 hectares/cumec.**

Now total area under rice plantation = 600 × 0.6 = 360 hectares

$$\therefore \text{ Discharge at the head of water course} = \frac{360}{207.36} \simeq \mathbf{1.74 \text{ cumecs.}}$$

Example 3.16. *Table below gives the necessary data about the crop, their duty and the area under each crop, commanded by a canal taking off from a storage tank. Taking a time factor for the canal to be 13/20, calculate the discharge required at the head to the canal. If the capacity factor is 0.8, determine the design discharge.*

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Crop	Base period (days)	Area (hectares)	Duty at the head of the canal (hectares/cumec)
Sugar-cane	320	850	580
Overlap for sugar-cane in hot weather	90	120	580
Wheat (Rabi)	120	600	1600
Bajri (Monsoon)	120	500	2000
Vegetable (Hot weather)	120	360	600

Solution

Discharge required for crops

$$\text{Discharge for sugar-cane} = \frac{850}{580} = 1.466 \text{ cumecs}$$

$$\text{Discharge for overlap sugar-cane} = \frac{120}{580} = 0.207 \text{ cumec}$$

$$\text{Discharge for wheat} = \frac{600}{1600} = 0.375 \text{ cumec}$$

$$\text{Discharge for Bajri} = \frac{500}{2000} = 0.25 \text{ cumec}$$

$$\text{Discharge for vegetables} = \frac{360}{600} = 0.60 \text{ cumec.}$$

Since sugar-cane has a base period of 320 days, it will require water in Rabi, Monsoon and Hot weather.

$\therefore$ Discharge required in Rabi $= 1.466 + 0.375 = 1.841$ cumecs

Discharge required in Monsoon $= 1.466 + 0.25 = 1.716$ cumecs

Discharge required in Hot Weather $= 1.466 + 0.207 + 0.6 = 2.273$ cumecs.

Thus, the maximum demand of 2.273 cumecs is in the hot weather. The *time factor* is the ratio of the number of days the canal has actually run to the number of days the canal was supposed to run. Here, time factor is 13/20.

$\therefore$ Full supply discharge at the head to canal will be

$$= 2.273 \times \frac{20}{13} = \mathbf{3.497 \text{ cumecs}}$$

Design discharge = Full supply discharge/capacity factor 3.497/0.8 = **4.372 cumecs**

Example 3.17. *The base period, intensity of irrigation and duty of various crops under a canal system are given in the Table below. Find the reservoir capacity if the canal losses are 20% and reservoir losses are 12%.*

Crop	Base period (days)	Duty at the field (hectares/cumec)	Area under the crop (hectares)
Wheat	120	1800	4800
Sugar-cane	360	800	5600
Cotton	200	1400	2400
Rice	120	900	3200
Vegetables	120	700	1400

Solution

(i) Wheat

$$\text{Discharge required} = \frac{4800}{1800} \text{ cumecs}$$

$$\therefore \text{ Volume of water required} = \frac{4800}{1800} \times 120 = 320 \text{ cumec-days.}$$

(ii) Sugar-cane

$$\text{Discharge required} = \frac{5600}{800} = 7 \text{ cumecs}$$

$$\therefore \text{ Volume of water required} = 7 \times 360 = 2520 \text{ cumec-days.}$$

(iii) Cotton

$$\text{Discharge required} = \frac{2400}{1400} \text{ cumecs}$$

$$\therefore \text{ Volume of water required} = \frac{2400}{1400} \times 200 = 343 \text{ cumec-days.}$$

(iv) Rice

$$\text{Discharge required} = \frac{3200}{900} \text{ cumecs}$$

$$\therefore \text{ Volume of water required} = \frac{3200}{900} \times 120 = 427 \text{ cumec-days.}$$

(v) Vegetables

$$\text{Discharge required} = \frac{1400}{700} = 2 \text{ cumecs}$$

$\therefore$ Volume of water required $= 2 \times 120 = 240$ cumec-days.

Hence, total volume of water required on the field for all crops

$= 320 + 2520 + 343 + 427 + 240$

$= 3850$ cumec-days.

Now 1 cumec-day = 1 cumec flowing for the whole day $= (1 \times 24 \times 60 \times 60)\ m^3$

1 hectare-metre $= 1 \times 10^4\ m^3$

$$\text{Hence 1 cumec-day} = \frac{(1 \times 24 \times 60 \times 60)}{1 \times 10^4} = 8.64 \text{ hectare-metres}$$

$\therefore$ Total volume of water required on the field

$= 3850 \times 8.64$ hectare-metres.$= 33264$ hec-m.

Since losses in the canal system are 20% the volume of water required at the head of the canal

$$= 33264 \times \frac{100}{80} = 41580 \text{ hec-m.}$$

Allowing 12% reservoir losses, the storage capacity of the reservoir

$$= 41580 \times \frac{100}{88} = \mathbf{47250 \text{ hectare-metres.}}$$

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Alternative solution

The above example can also be solved by first finding the Delta for each crop and then multiplying the area by Delta to get the total volume of water needed.

$$\Sigma V = \Sigma (\Delta \times A)$$

The calculations are done in tabular form :

Crop (1)	*Base period (days) (B)* (2)	*Duty at the field hectare / cumec (D)* (3)	*Δ in m* $= \frac{8.64\,B}{D}$ (4)	*Area A in hectares* (5)	*Volume (Δ × A) hectare-m* (6)=(4) × (5)
Wheat	120	1800	0.576	4800	2764.8
Sugar-cane	360	800	3.888	5600	21772.8
Cotton	200	1400	1.234	2400	2962.3
Rice	120	900	1.152	3200	3686.4
Vegetable	120	700	1.481	1400	2073.6
				Cumulative Volume	33259.9 hec-m

Say, 33260 hec-m as calculated previously.

$\therefore$ Capacity of reservoir $= \frac{33260}{0.8 \times 0.88}$ = **47245 hectare-metres.**

3.13. CONSUMPTIVE USE OF WATER (EVAPO-TRANSPIRATION)

Evapo-transpiration or consumptive use of water by a crop is the depth of water consumed by evaporation and transpiration during crop growth, including water consumed by accompanying weed growth. Water deposited by dew or rainfall, and subsequently evaporating without entering the plant system is part of consumptive use. When the consumptive use of the crop is known, the water use of large units can be calculated.

Evaporation

Evaporation is the transfer of water from the liquid to the vapour state. The rate of evaporation from water surface is proportional to the difference between the vapour pressure at the surface and the vapor pressure in the overlaying air (Dalton's law). When irrigation water is applied by flooding methods, large amounts of water are lost by direct evaporation from soil surface without having passed through the roots, stems and leaves of the plants.

Transpiration and Transpiration Ratio

Transpiration is the process by which plants dissipate water from the surface of their leaves, stalks and trunks in the process of growth. As much as 99% of total water received by a plant through its roots is lost to the atmosphere by this process. *Transpiration* is associated with *photosynthesis* of plants; it is therefore, a process of day light hours. Water from soil is taken up by plant roots through a membrane by a process called *osmosis*. Green cells, called *chloroplasts* in plant leaf prepare food in presence of sun light and CO_2 and leave water through tiny openings called *stomata* the density of which may vary from 8000 to 12000 per sq. cm. *The transpiration ratio* is the ratio of the weight of water transpired by the plant during its growth to the

weight of dry matter produced by the plant exclusive of roots. The average values of transpiration ratio for wheat and rice are 560 and 680 respectively.

Factors Affecting Consumptive Use of Water

1. Evaporation, which depends upon humidity.
2. Mean monthly temperature.
3. Growing season of crop and cropping pattern.
4. Monthly precipitation in the area.
5. Irrigation depth or the depth of water applied for irrigation.
6. Wind velocity in the locality.
7. Soil and topography.
8. Irrigation practices and methods of irrigation.

Potential Evapo-transpiration (PET) and Actual Evapo-transpiration(AET)

We know that evapo-transpiration is the total loss of water from farm land as evaporation and from plants grown on it as transpiration. If *sufficient* moisture is *always available* to completely meet the needs of the plants, the resulting evapo-transpiration is called *potential evapo-transpiration* (PET). The real evapo-transpiration occurring in a specific situation is called actual evapo-transpiration (AET). At the moisture content in the soil corresponding to field capacity (F_c), the water supply to the plant is adequate and hence AET will be equal to PET, or in other words, the ratio AET/PET will be equal to 1. With the reduction in the *available moisture* in the soil, the ratio AET/PET decreases and finally AET will be zero at wilting point. A relation between AET/PET and *available moisture* can be developed for different types of soils on the basis of experimental results. Fig. 3.7 shows two such curves for sandy soil and clayey soil. For the same AET/PET ratio, sandy soil has more available moisture than clayey soil. In other words, for the same percent of available moisture, the ratio, AET/PET will be less for sandy soil than for clayey soil.

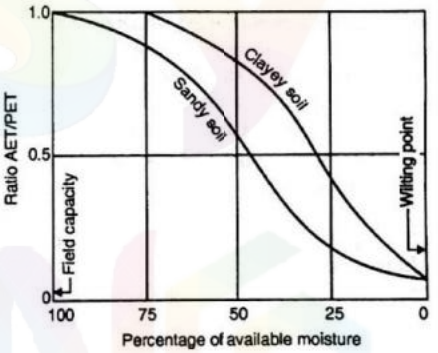

FIG. 3.7. VARIATION OF AET/PET WITH AVAILABLE MOISTURE

(A) DIRECT MEASUREMENT OF CONSUMPTIVE USE

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

1. Tank and Lysimeter methods.
2. Field experimental plots.
3. Soil moisture studies.

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4. Integration method.
5. Inflow and outflow studies for large area.

1. Tank and Lysimeter Method

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

2. Field Experimental Plots

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

3. Soil Moisture Studies

This method is specially suited to those areas where soil is fairly uniform and ground water is deep enough so that it does not affect the fluctuations in soil moisture within the root zone of the soil. Soil moisture measurements are done before and after each irrigation. The quantity of water extracted per day from soil is computed for each period. A curve is drawn by plotting the rate of use against time and from this curve, *seasonal use* can be determined.

4. Integration Method

In this method, it is necessary to know the division of total area under irrigation crops, natural vegetation, water surface area and bare land area. The integration method is summation of the products of (*i*) unit consumptive use for each crop times its area, (*ii*) unit consumptive use of native vegetation times its area, (*iii*) water surface evaporation times the water surface area, and (*iv*) evaporation from bare land times its area. Thus, in this method, annual consumptive use for the whole of the area is found, in hectare–metre units.

5. Inflow-Outflow Studies for Large Areas

In this method also, annual consumptive use is found for large areas. If U is the *valley consumptive* use, its value is given by

$$U = (I + P) + (G_s - G_e) - R \qquad ...(3.7)$$

where, U = Valley consumptive use (in hectare-metre)

I = Total inflow during 12-months year

P = Yearly precipitation on valley floor

G_s = Ground storage at the beginning of the year

G_e = Ground storage at the end of the year

R = Yearly outflow.

All the above volumes are measured in hectare-metres.

(B) CONSUMPTIVE USE DETERMINATION BY USE OF EQUATIONS

The following are some of the commonly used methods for computation of consumptive use:

1. Blaney-Criddle method.
2. Penman method.
3. Hargreaves class *A* pan evaporation method.

1. Blaney-Criddle method

Blaney and Criddle (1962) proposed an empirical relation which is largely used by irrigation engineers. Blaney Criddle equation expresses potential evapo-transpiration (consumptive use) in terms of temperature and day time hours. If c_u is *monthly* consumptive use, its value is given by

$$c_u = k \cdot f \qquad ...(3.8\ a)$$

where c_u = monthly consumptive use in cm.

k = monthly *crop coefficient* to be determined from experimental data

f = monthly consumptive use factor given by

$$f = (0.0457\, t_m + 0.8128)\, p \triangleq \frac{p}{40}\,[1.8\, t + 32] \qquad ...(3.9)$$

t_m = mean monthly temperature in °C

p = monthly percentage of hours of bright sunshine in the year (Table 3.9)

If C_u is the *seasonal consumptive use*, its value is given by

$$C_u = k\, \Sigma f \qquad ...(3.8\ b)$$

However, if the crop coefficient (or crop factor) also varies from month to month, the *total consumptive use* or seasonal consumptive use is given by

$$C_u = \Sigma\, k f \qquad ...(3.8)$$

The value of k can be found from charts for different crops available at various agriculture research stations. However, in absence of these charts, the value of k can be taken from Table 3.8.

TABLE 3.8. MONTHLY CROP COEFFICIENT FACTOR k (FOR USE IN BLANEY-CRIDDLE METHOD)

Crop	*Rice*	*Wheat*	*Maize*	*Sugarcane*	*Cotton*	*Potato*	*Corn*	*Vegetables*	
								Light	*Dense*
Value of k	1.1	0.65	0.65	0.9	0.65	0.7	0.75	0.80	1.20
Range of k	0.85 – 1.3	0.5 – 0.75	0.5 – 0.75	0.8 – 1.0	0.5 – 0.9	0.65 – 0.75	0.65 – 0.85	0.7 – 1.0	1.1 – 1.4

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TABLE 3.9
MONTHLY DAYTIME (SUNSHINE) PERCENTAGE HOURS (p)

Latitude Degress	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
North												
0	8.50	7.66	8.49	8.21	8.50	8.22	8.50	8.49	8.21	8.50	8.22	8.50
5	8.32	7.57	8.47	8.29	8.65	8.41	8.67	8.60	8.23	8.42	8.07	8.30
10	8.13	7.47	8.45	8.37	8.81	8.60	8.86	8.71	8.25	8.34	7.91	8.10
15	7.94	7.36	8.43	8.44	8.98	8.80	9.05	8.83	8.28	8.26	7.75	7.88
20	7.74	7.25	8.41	8.52	9.15	9.00	9.25	8.96	8.30	8.18	7.58	7.66
25	7.53	7.14	8.39	8.61	9.33	9.23	9.45	9.09	8.32	8.09	7.40	7.42
30	7.30	7.03	8.38	8.72	9.53	9.49	9.67	9.22	8.33	7.99	7.19	7.15
32	7.20	6.97	8.37	8.76	9.62	9.59	9.77	9.27	8.34	7.95	7.11	7.05
34	7.10	6.91	8.36	8.80	9.72	9.70	9.88	9.33	8.36	7.90	7.02	6.92
36	6.99	6.85	8.35	8.85	9.82	9.82	9.99	9.40	8.37	7.85	6.92	6.79
38	6.87	6.79	8.34	8.90	9.92	9.95	10.10	9.47	8.38	7.80	6.82	6.66
40	6.76	6.72	8.33	8.95	10.02	10.08	10.22	9.54	8.39	7.75	6.72	6.52
42	6.63	6.65	8.31	9.00	10.14	10.22	10.35	9.62	8.40	7.69	6.62	6.37
44	6.49	6.58	8.30	9.06	10.26	10.38	10.49	9.70	8.41	7.63	6.49	6.21
46	6.34	6.50	8.29	9.12	10.39	10.54	10.64	9.79	8.42	7.57	6.36	6.04
48	6.17	6.41	8.27	9.18	10.53	10.71	10.80	9.89	8.44	7.51	6.23	5.86
50	5.98	6.30	8.24	9.24	10.68	10.91	10.99	10.00	8.49	7.45	6.10	5.65
South												
0	8.50	7.66	8.49	8.21	8.50	8.22	8.50	8.49	8.21	8.50	8.22	8.50
5	8.68	7.76	8.51	8.15	8.34	8.05	8.33	8.38	8.19	8.56	8.37	8.68
10	8.86	7.87	8.53	8.09	8.18	7.86	8.14	8.27	8.17	8.62	8.53	8.88
15	9.05	7.98	8.55	8.02	8.02	7.65	7.95	8.15	8.15	8.68	8.70	9.10
20	9.24	8.09	8.57	7.94	7.85	7.43	7.76	8.03	8.13	8.76	8.87	9.33
25	9.49	8.21	8.60	7.84	7.66	7.20	7.54	7.90	8.11	8.36	9.04	9.58
30	9.70	8.33	8.62	7.73	7.45	6.96	7.31	7.76	8.07	8.97	9.24	9.85

2. Penman Method

Penman developed a theoretical formula based on principles of both energy budget and mass-transfer approaches to compute potential evapo-transpiration in the following form

$$E_t = \frac{A \cdot H + \alpha E_a}{A + \alpha} \qquad ...(3.10)$$

where E_t = Evapo-transpiration, mm/day

α = psychromatic constant = 0.49 mm Hg/°C

A = Slope of the curve between saturated vapor pressure (e_s) and temperature at mean air temperature (Table 3.10)

E_a = drying power of air which includes wind velocity and saturation deficit and is given by the relation.

$$E_a = 0.002187\,(160 + u_2)\,(e_s - e_a) \qquad ...(3.11)$$

u_2 = mean wind speed in km/day measured 2 m above the ground

e_s = Saturation vapour pressure at mean air temperature, in mm Hg (Table 3.10)

e_a = actual vapour pressure in the air, in mm of Hg = $e_s \cdot R_H$ where R_H is the relative humidity (%)

H = daily net radiation in mm of H_2O, given by the relation

$$H = R_A\,(1 - r)\,(0.29 \cos\varphi + 0.55\, n/N) - \sigma\, T_a^4\,(0.56 - 0.092\sqrt{e_a})\,(0.10 + 0.9\, n/N) \qquad ...(3.12)$$

R_A = mean monthly extra-terrestrial radiation in mm H_2O/day (Table 3.11)

φ = latitude of the place where E_t is being computed.

r = reflection coefficient of the surface

= 0.15 to 0.25 for close crops

= 0.05 to 0.45 for barren land

= 0.05 for water surface

n = actual duration of bright sunshine which is a function of latitude of the place, and is an observed data at the place. Alternatively, the value of n can be taken equal to p given by Table 3.9.

N = maximum possible hours of bright sunshine available at different locations (Table 3.12)

σ = Stefan-Boltzman constant = 2.01×10^{-9} mm/day.

T = mean air temperature in $K = 273 + °C$

The wind speed measured at any other height z can be reduced to 2 m height by the relation (known as 1/7 *th power law*).

$$u_2 = u\left(\frac{2}{z}\right)^{1/7} = u\left(\frac{2}{z}\right)^{0.143} \qquad ...(3.13)$$

Thus, measuring n, e_a and u_2 at the place, and knowing all other relevant data from Tables 3.10, 3.11 and 3.12, the value of E_t can be computed from Eq. 3.10 given by Penman.

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TABLE 3.10. SATURATION VAPOUR PRESSURE OF WATER

Temp. °C	Saturation Vapour pressure e_s (mm Hg)	Slope of plot between (1) and (2)	Temp. °C	Saturation vapour pressure e_s (mm Hg)	Slope of plot between (1) and (2)
(1)	(2)	(3)	(1)	(2)	(3)
0	4.58	0.30	25	23.76	1.4
5.0	6.54	0.45	27.5	27.59	1.61
7.5	7.78	0.54	30	31.81	1.85
10.0	9.21	0.60	32.5	36.68	2.07
12.5	10.87	0.71	35	42.81	2.35
15.0	12.79	0.80	37.5	48.36	2.62
17.5	15.00	0.95	40	55.32	2.95
20.0	17.54	1.05	42.5	62.18	3.25
22.5	20.44	1.24	45	71.2	3.66

TABLE 3.11. MEAN MONTHLY SOLAR RADIATION (R_A) INCIDENT ON EARTH'S OUTER SPACE (EXTRA-TERRESTRIAL RADIATION) IN mm OF EVAPORABLE WATER PER DAY (AFTER CRIDDLE)

Month	Northern Hemisphere									Southern Hemisphere									
	90°	80°	70°	60°	50°	40°	30°	20°	10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°
Jan.	...	...	...	1.3	3.6	6.0	8.5	10.8	12.8	14.5	15.8	16.8	17.3	17.3	17.1	16.6	16.5	17.3	17.6
Feb.	...	...	1.1	3.5	5.9	8.3	10.5	12.3	13.9	15.0	15.7	16.0	15.8	15.2	14.1	12.7	11.2	10.5	10.7
Mar.	...	1.8	4.3	6.8	9.1	11.0	12.7	13.9	14.8	15.2	15.1	14.6	13.6	12.2	10.5	8.4	6.1	3.6	1.9
Apr.	7.9	7.8	9.1	11.1	12.7	13.9	14.8	15.2	15.2	14.7	13.8	12.5	10.8	8.8	6.6	4.3	1.9	...	...
May	14.2	14.6	13.6	14.6	15.4	15.9	16.0	15.7	15.0	13.9	12.4	10.7	8.7	6.4	4.1	1.9	0.1	...	...
June	18.1	17.8	17.0	16.5	16.7	16.7	16.5	15.8	14.8	13.4	11.6	9.6	7.4	5.1	2.8	0.8	...	...	...
July	16.8	16.5	15.8	15.7	16.1	16.3	16.2	15.7	14.8	13.5	11.9	10.0	7.8	5.6	3.3	1.2	...	...	...
Aug.	11.2	10.6	11.4	12.7	13.9	14.8	15.3	15.3	15.0	14.2	13.0	11.5	9.6	7.5	5.2	2.9	0.8	...	...
Sept.	2.6	4.0	6.8	8.5	10.5	12.2	13.5	14.4	14.9	14.9	14.4	13.5	12.1	10.5	8.5	5.2	3.8	33	...
Oct.	...	0.2	2.4	4.7	7.1	9.3	11.3	12.9	14.1	15.0	15.3	15.3	14.8	13.8	12.5	10.7	8.8	7.1	7.0
Nov.	...	...	0.1	1.9	4.3	6.7	9.1	11.2	13.1	14.6	15.7	16.4	16.7	16.5	16.0	15.2	14.5	15.0	15.3
Dec.	...	...	....	0.9	3.0	5.5	7.9	10.3	12.4	14.3	15.8	16.9	17.6	17.8	17.8	17.5	18.1	18.9	19.3

TABLE 3.12. MAXIMUM POSSIBLE HOURS OF BRIGHT SUNSHINE IN HOURS (N)

Month	North Latitude in Degrees					
	0°	10°	20°	30°	40°	50°
Jan	12.1	11.6	11.1	10.4	9.6	86
Feb	12.1	11.8	11.5	11.1	10.7	10.1
March	12.1	12.1	12.0	12.0	11.9	11.8
April	12.1	12.4	12.6	12.9	13.2	13.8
May	12.1	12.6	13.1	13.7	14.4	15.4
June	12.1	12.7	13.3	14.1	15.0	16.4
July	12.1	12.6	13.2	13.9	14.7	16.0
Aug	12.1	12.4	12.8	13.2	13.8	14.5
Sept	12.1	11.9	12.3	12.4	12.5	12.7
Oct	12.1	11.9	11.7	11.5	11.2	10.8
Nov	12.1	11.7	11.2	10.6	10.0	94
Dec	12.1	11.5	10.9	10.2	9.1	81

3. Hargreaves Class A Pan Evaporation Method

This method is very much used in India, apart from its use in Israel , Philippines and U.S.A. According to this method, the consumptive use (C_u) or Evapo-transpiration (E_t) is given by

$$E_t \text{ or } C_u = K E_p \qquad ...(3.14)$$

where K = Consumptive use coefficient, which is different for different crops, and for each crop, it depends upon many environmental factors. It is determined experimently. Table 3.14 gives the value of K for some Indian crops.

E_p = Class A pan evaporation, which can be determined by the following Christiansen formula :

$$E = 0.459\ R_A . C_t . C_w . C_h . C_s . C_e . \ \text{(cm)} \qquad ...(3.15)$$

where R_A = Extra-terrestrial radiation (cm), to be determined from Table 3.10.

C_t = Coefficient for temperature, to be determined from the expression :

$$C_t = 0.393 + 0.02796\ T_c + 0.0001189\ T_c^2$$

(T_c being mean temp. in °C) ...(3.16)

C_w = Coefficient for wind velocity, given by

$$C_w = 0.708 + 0.0034\ W - 0.0000038\ W^2 \qquad ...(3.17)$$

(W being the mean wind velocity in km/day at 0.5 m above ground surface)

C_h = Coefficient for relative humidity given by

$$C_h = 1.250 - 0.0087\ H + 0.75 \times 10^4\ H^2 - 0.83 \times 10^{-8}\ H^4 \qquad ...(3.18)$$

(H being the mean % relative humidity at noon or average relative humidity for 11 and 18 hours.

C_s = Coefficient for percent of possible sunshine and is given by :

$$C_s = 0.542 + 0.008\ S - 0.78 \times 10^{-4}\ S^2 + 0.62 \times 10^{-6}\ S^3 \qquad ...(3.19)$$

(S = mean perecentage of bright sun-shine hours taken as 100 n/N)

C_e = Coefficient of elevation given by $C_e = 0.97 + 0.00984\ E$ ...(3.20)

(E being the elevation in 100 metres).

Values of Hargreaves monthly consumptive use coefficient K : The value of K depends upon (*i*) type of crop (*ii*) place or location of irrigation field, and (*iii*) stage of the growth of the crop or % of crop growing season. At a given place, the value of K is different for different crops. Similarly, for the same crops, the value of K is different for different places. Lastly, for the same crop, at a given place, the value of K depends upon its stage of growth at a given time. In absence of local figures for specific crops, the data given in Table 3.13, recommended by Hargreaves, can be used. In the table, various crops have been divided into the following groups:

Group A : Potato, Cotton, Maize, Bean, Peas, Jowar, Beat
Group B : Tomato, Olive, Plumes, and some delicius fruits
Group C : Onions, Grapes, Melons, Carrots, Hops
Group D : Wheat, Barley, Celery and other grass type plants
Group E : Pesters, Plantain, Orchard crops etc.
Group F : Oranges, Fruits, Citrus crops

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Group G : Sugarcane, Alfalfa etc.
Paddy (Rice)
Table 3.14 gives the value of K for same Indian crops.

TABLE 3.13. HARGREAVES AVERAGE VALUE OF K

% of crop growing season	Value of consumptive use coefficient K							
	Group A	Group B	Group C	Group D	Group E	Group F	Group G	Rice
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
0	0.20	0.15	0.12	0.08	0.90	0.60	0.50	0.80
5	0.20	0.15	0.12	0.08	0.90	0.60	0.55	0.90
10	0.36	0.27	0.22	0.15	0.90	0.60	0.60	0.95
15	0.50	0.38	0.30	0.19	0.90	0.60	0.65	1.00
20	0.64	0.48	0.38	0.27	0.90	0.60	0.70	1.05
25	0.75	0.56	0.45	0.33	0.90	0.60	0.75	1.10
30	0.84	0.63	0.50	0.40	0.90	0.60	0.80	1.14
35	0.92	0.69	0.55	0.46	0.90	0.60	0.85	1.17
40	0.97	0.73	0.58	0.52	0.90	0.60	0.90	1.21
45	0.99	0.74	0.60	0.58	0.90	0.60	0.95	1.25
50	1.00	0.75	0.60	0.65	0.90	0.60	1.00	1.30
55	1.00	0.75	0.60	0.71	0.90	0.60	1.00	1.30
60	0.99	0.74	0.60	0.77	0.90	0.60	1.00	1.30
65	0.96	0.72	0.58	0.82	0.90	0.60	0.95	1.25
70	0.91	0.68	0.55	0.88	0.90	0.60	0.90	1.20
75	0.85	0.64	0.51	0.90	0.90	0.60	0.85	1.15
80	0.75	0.56	0.45	0.90	0.90	0.60	0.80	1.10
85	0.60	0.45	0.36	0.80	0.90	0.60	0.75	1.00
90	0.46	0.35	0.28	0.70	0.90	0.60	0.70	0.90
95	0.28	0.21	0.17	0.60	0.90	0.60	0.55	0.80
100	0.20	0.20	0.17	0.60	0.90	0.60	0.50	0.20

TABLE 3.14. VALUE OF K FOR SOME INDIAN CROPS (TO BE USED IN THE EQUATION $E_t = K E_p$)

% of crop growing season	Wheat (Ludhiana)	Wheat (Poona)	Cotton (Poona)	Maize (Ludhiana)
0	0.14	0.30	0.22	0.40
5	0.17	0.40	0.22	0.42
10	0.23	0.51	0.23	0.47
15	0.33	0.62	0.24	0.54
20	0.45	0.73	0.26	0.63
25	0.60	0.84	0.35	0.75
30	0.72	0.92	0.58	0.85
35	0.81	0.96	0.80	0.96
40	0.88	1.10	0.95	1.04
45	0.90	1.10	1.03	1.07
50	0.91	1.00	1.08	1.09
55	0.90	0.91	1.08	1.10
60	0.89	0.80	1.07	1.11
65	0.86	0.65	1.05	1.10
70	0.83	0.51	1.00	1.07
75	0.80	0.40	0.93	1.04
80	0.76	0.30	0.85	1.00
85	0.71	0.20	0.73	0.97
90	0.65	0.12	0.62	0.89
95	0.58	0.10	0.50	0.81
100	0.51	0.10	0.40	0.70
Seasonal Value of K	0.61	0.61	0.68	0.86

3.14. IRRIGATION EFFICIENCIES

Efficient use of irrigation water is an obligation of each user as well as of the planners. Even under the best method of irrigation, not all the water applied during an irrigation is stored in the root zone. In general, efficiency is the ratio of water output to the water input and is expressed as percentage. The objective of efficiency concepts is to show when improvements can be made which will result in more efficient irrigation. The following are the various types of irrigation efficiencies : (*i*) water conveyance efficiency, (*ii*) water application efficiency, (*iii*) water use efficiency, (*iv*) water storage efficiency, (*v*) water distribution efficiency and (*vi*) consumptive use efficiency.

1. *Water Conveyance Efficiency* (η_c)

This takes into account the conveyance or transit losses and is determined from the following expression :

$$\eta_c = \frac{W_f}{W_r} \times 100 \qquad ...(3.21)$$

where η_c = water conveyance efficiency
W_f = water delivered to the farm or irrigation plot
W_r = water supplied or diverted from the river or reservoir.

2. *Water Application Efficiency* (η_a)

The water application efficiency is the ratio of the quantity of water stored into the root zone of the crops to the quantity of water delivered to the field. This focuses the attention of the suitability of the method of application of water to the crops. It is determined from the following expression :

$$\eta_a = \frac{W_s}{W_f} \times 100 \qquad ...(3.22)$$

where η_a = water application efficiency
W_s = Water *stored* in the root zone during the irrigation
W_f = water delivered to the farm.

The common sources of loss of irrigation water during water application are (*i*) surface run off R_f from the farm and (*ii*) deep percolation D_f below the farm root-zone soil. Hence

$$W_f = W_s + R_f + D_f \qquad ...(3.23)$$

and

$$\eta_a = \frac{W_f - (R_f + D_f)}{W_f} \times 100 \qquad ...[3.23(a)]$$

In a well designed surface irrigation system, the water application efficiency should be atleast 60% ; in the sprinkler irrigation system this efficiency is about 75%. The common factors which are responsible for low water application efficiency are : (*i*) irregular land surfaces, (*ii*) shallow soils underlain by gravels of light permeability, (*iii*) either very small or excessively large irrigation streams, (*iv*) non–attendance of water during irrigation, (*v*) long irrigation runs, (*vi*) wrong irrigation methods, (*vii*) improper preparation of land, (*viii*) compact impervious soil, (*ix*) steep slopes of land surfaces and (*x*) excessive single application.

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3. ***Water Use Efficiency*** (η_u)

It is the ratio of water beneficially used, including leaching water, to the quantity of water delivered, and is determined from the following expression :

$$\eta_u = \frac{W_u}{W_d} \times 100 \quad ...(3.24)$$

where η_u = water use efficiency

W_u = water used beneficially or consumptively

W_d = water delivered.

4. ***Water Storage Efficiency*** (η_s)

The concept of water storge efficiency gives an insight to how completely the required water has been stored in the root zone during irrigation. It is determined from the following expression:

$$\eta_s = \frac{W_s}{W_n} \times 100 \quad ...(3.25)$$

where η_s = water storage efficiency

W_s = water *stored* in the root zone during irrigation

W_n = water *needed* in the root zone prior to irrigation

= (Field capacity – Available moisture).

5. ***Water Distribution Efficiency*** (η_d)

Water distribution efficiency evaluates the degree to which water is uniformly distributed throughout the root zone. Uneven distribution has many undesirable results. The more uniformly the water is distributed, the better will be the crop response. It is determined from the following expression :

$$\eta_d = 100\left[1 - \frac{y}{d}\right] \quad ...(3.26)$$

where η_d = water distribution efficiency

y = average numerical deviation in depth of water stored from average depth stored during irrigation.

d = average depth of water stored during irrigation.

The efficiency provides a measure for comparing various systems or methods of water application, *i.e.* sprinkler compared to surface, one sprinkler system compared to the other system or one surface method compared to other surface method.

6. ***Consumptive Use Efficiency*** (η_{cu})

It is given by $$\eta_{cu} = \frac{W_{cu}}{W_d} \times 100 \quad ...(3.27)$$

where W_{cu} or C_u = normal consumptive use of water

W_d = net amount of water *depleted* from root zone of soil.

The efficiency, therefore, evaluates the loss of water by deep percolation and by excessive surface evaporation following an irriagtion.

(C) DETERMINATION OF IRRIGATION REQUIREMENTS OF CROPS

In order to determine the irrigation requirements of certain crop, during its base period, the following terms are required :

(i) Effective Rainfall (R_e)

Effective rainfall is that part of the precipitation falling during the growing period of a crop that is available to meet the evapo-transpiration needs of the crop.

(ii) Consumptive Irrigation Requirement **(CIR)**

Consumptive irrigation requirement is defined as the amount of irrigation water that is required to meet the evapo-transpiration needs of the crop during its full growth. Therefore,

$$\text{CIR} = C_u - R_e \quad ...(3.28)$$

where C_u is the consumptive use of water.

(iii) Net Irrigation Requirement **(NIR)**

Net irrigation requirement is defined as the amount of irrigation water required at the plot to meet the evapo-transpiration needs of water as well as other needs such as leaching etc. Thus

$$\text{NIR} = C_u - R_e + \text{water lost in deep percolation for the purpose of leaching etc.} \quad ...(3.29)$$

(iv) Field Irrigation Requirement **(FIR)**

Field irrigation requirement is the amount of water required. to meet 'net irrigation requirements' plus the water lost in percolation in the field water courses, field channels and in field applications of water. If η_a is water application efficiency, we have

$$\text{FIR} = \frac{\text{NIR}}{\eta_a} \quad ...(3.30)$$

(v) Gross Irrigation Requirement **(GIR)**

Gross irrigation requirement is the sum of water required to satisfy the field irrigation requirement and the water lost as conveyance losses in distributaries upto the field. If η_c is the *water conveyance efficiency*, we have

$$\text{GIR} = \frac{\text{FIR}}{\eta_c} \quad ...(3.31)$$

Determination of FIR and GIR using Hargreaves method :

In order to determine the field irrigation requirement (FIR) or gross irrigation requirement (GIR) of a certain crop, it is essential to have the knowledge of monthly or periodical pan evaporation data as well as the knowledge of pan evaporation cofficient K. Table 3.15 shows sample calculations for wheat at a certain location. Following is the procedure for calculations :

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