STUDY MATERIAL

on

DAE 232

ON-FARM IRRIGATION AND DRAINAGE PRACTICES

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DAE 232 ON-FARM IRRIGATION AND DRAINAGE PRACTICES 3 (1+2)

Objective

To impart the knowledge and skills on various concepts like duty, delta, soil-plant-water relationships, irrigation scheduling and to enable the students to design and execute proper surface and sub-surface drainage systems in salt affected and water logged areas in agricultural lands and to improve land productivity by controlling the twin problems of water logging and salinity and thereby to enhance the crop production and productivity

Lecture Outlines

Theory

Sl. No.	Detailed Lecture Outlines	Reference books
UNIT-I		
1.	Irrigation – Introduction and necessity, Irrigation development and Irrigation Terminology, Classification of Irrigation works in India,	**1, 5**
2.	Objectives of irrigation development and management, Surface water sources of India, Ground water sources of India and ground water regions of India	**1, 5**
UNIT-II		
3.	Duty, delta and Base period- Definitions, Duty and Delta relationship and problems	**5**
4.	Measurement of Irrigation water- units of measurement, methods of measurement (list), direct measurement of velocity by using the current meter	**5, 6**
UNIT-III		
5.	Evaporation, transpiration and concept of Evapotranspiration and estimation of ET- Blaney Cridlle, Thrornth Waite, Penman and Modified Penman- Monteith equations	**1,5**
6.	Water and irrigation water requirement of crops- importance of water in plant growth, procedures for working out the net irrigation	**1, 5**

	(depth of irrigation), gross irrigation requirement	
UNIT-IV		
7.	Irrigation efficiency – conveyance, application, storage, distribution and water use efficiency and related problems	**1, 2, 5**
8.	Surface methods of water applications- Classification, Border Irrigation Method- Basic details, Components of border irrigation- width, length and slope of different soils and their adaptability, Hydraulics and design of Border Irrigation (Israelson's equation only)	**1, 2, 5**
UNIT-V		
9.	Check basin irrigation method- Types, , Advantages and Disadvantages, Adaptability and Design Considerations	**1, 2, 5**
10.	Furrow irrigation method- Types, Adaptability, Characteristics, Hydraulics and Design Considerations	**1, 2, 5**
UNIT-VI		
11.	Waterlogging- Introduction, forms of excess water, Effects, causes & impacts, Approach to drainage problems, Interrelationship of irrigation and drainage	**2, 3**
12.	Surface drainage system -Definition, types and applications of surface drainage methods- Design of open ditches (Mannings's Equation)	**2, 3**
UNIT-VII		
13.	Drainage coefficient and its importance in drainage design, Various methods to determine drainage coefficient – Cypress Creek Formula only and problems	**2, 3**
14.	Hydraulic Conductivity-Single auger hole method (Hooghoudt's equation only) Inverse auger hole method (equation only) & problems	**2, 3**

UNIT-VIII		
15.	Sub surface drainage system – Purpose and benefits of sub-surface drainage, Investigation for subsurface drainage (list only), Layouts of tile drainage systems, Capacity of tile drains, grades, sizes and materials of tile drains including envelope materials	**3**
16.	Tile Drainage- Depth and Spacing of tile drains, Hooghoudt's equation for spacing of tile drain under steady state flow conditions only & problems	**2, 3**

Practical

1. Problems on duty-delta relations
2. Study of measurement of velocity by using the current meter
3. Study of determination of Evapotranspiration by Blaney-criddle formula
4. Study of determination of Evapotranspiration by Thornthwaite formula
5. Study of determination of Evapotranspiration by Penman formula
6. Study of determination of Evapotranspiration by Modified Penman- Monteith formula
7. Study of determination of Evapotranspiration by pan evaporation formula
8. Study of irrigation water requirements for different crops
9. Study of different irrigation efficiencies
10. Study of border irrigation system
11. Study of check basin irrigation system
12. Study of furrow irrigation system
13. Study of surface drainage system for flat areas
14. Study of surface drainage system for slopping areas
15. Determination of Hydraulic Conductivity by using Single auger hole method
16. Determination of Hydraulic Conductivity by using Inverse auger hole method
17. Determination of Drainage Coefficient by using Cypress Creek formula
18. Design of open ditches using Manning's formula
19. Study of layouts of subsurface drainage
20. Design of Spacing for tile drains using Hooghoudt's equation under Steady state condition
21. Cost estimation of surface drainage system
22. Cost estimation of sub-surface drainage system

23. Design of tile drainage system
24. Problem on Capacity of tile drains using manning's formula
25. Study of different envelope materials
26. Study of drainage execution machinery
27. Visit to surface irrigation systems
28. Visit to subsurface irrigation systems
29. Visit to irrigation project management
30. Visit to surface drainage system
31. Visit to subsurface drainage system
32. Practical examination

References

1. A. M. Michael., 2015. Irrigation - Theory and Practice, Vikas publishing Private limited, New Delhi.

2. A.M. Michael and T.P. Ojha., 2013. Principles of Agricultural Engineering, Jain Brothers Publishers, New Delhi

3. V.V.N. Murthy and Madan. K. Jha. 2013. Land and Water Management Engineering., Kalyani Publishers, Ludhiana

4. D. Lenka., 2005. Irrigation and Drainage. Kalyani Publishers, Ludhiana,

5. Garg, S.K. 2012. Irrigation Engineering and Hydraulic Structures, Khanna Publishers, New Delhi

6. Subramanya, K., 2013. Engineering Hydrology. Tata McGraw Hill Publishing Co. Ltd., New Delhi

LECTURE 1

Irrigation – Introduction and necessity, Irrigation development and Irrigation Terminology, Classification of Irrigation works in India

1.1 INTRODUCTION AND DEFINITION OF IRRIGATION

Plants are living beings and do require water and air for their survival, as do human beings require. Their requirement of water varies with their type. Different types of plants require different quantities of water, and at different times, till they grow up completely.

Water is normally supplied to these plants by nature through direct rain or through the flood waters of rivers which inundate large land areas during floods. The flood water may saturate the land before the flood subsides. The water absorbed by the land during floods, supplements the water requirement of the crop during dry season. These natural processes, whereby, the water is supplied to the crops for their growth are dependent upon 'Nature' or 'God', may call it. Sometimes, there may be very heavy rains creating serious floods and damaging the crops, and sometimes, there may not be any rains at all, creating scarcity of water for the crops. Thus, famine and scarcity conditions are to control the nature, man discovered various methods by which the water can be stored during the periods of excess rainfall, and to use that stored water during periods of 'less rainfall' or 'no rainfall'.

The art or the science by which it is accomplished, defined as the science of artificial application of water to the land, in accordance with the 'crop requirements' throughout the 'crop period' for full-fledged nourishment of the crops termed, as irrigation

1.2 NECESSITY OF IRRIGATION IN INDIA

India is a tropical country with a vast diversity of climate, topography and vegetation. Rainfall in India, varies considerably in its place of occurrence, as well as in its amount. Even at a particular place, the rainfall is highly erratic and irregular, as it occurs only during a few particular months of the year. Crops cannot, therefore, be raised successfully, over the entire land, without providing artificial irrigation of fields.

More than 70% of our population, directly depends on agriculture, and the remaining depends indirectly on agriculture. Out of a total geographical area of about 328 million hectares, about 184 million hectares is the cultivable area. In order to save this area from the complete wishes and vagaries of nature, and to ensure full growth of crops, it is necessary to provide adequate artificial irrigation facilities. In order to achieve this, the Indian Government is trying hard and spending enormously to provide irrigation facilities for the entire cultivable land. So far developed irrigation facilities in India have been shown under "Introduction" in the previous pages.

1.3 IRRIGATION DEVELOPMENT

Irrigated agriculture has developed most extensively in the arid and semi-arid regions and areas having prolonged dry spells. The practice is essentially to supplement the available rainfall in an area. A review of the development of irrigation in the world is fascinating It reveals the ingenuity and foresightedness of many of the ancient civilizations in harnessing the resources of nature for the benefit of man. It also shows the importance of careful planning of irrigation systems and efficient water management for maintaining the productivity of the land. The decline of irrigated agriculture in many countries has been due to unstable governments and lack of proper measures to ensure efficient water management.

The principal irrigation practice of the ancient times was diverting the flow of springs and streams with temporary irrigating the adjoining fields. Tanks of various sizes were in existence since the ancient times. Major river diversion projects to harness waters of large rivers were constructed by ancient rulers using indigenous technology. However, modern well designed large scale irrigation system mainly after the 18^{th} century. Irrigation technology made rapid strides in the 21^{st} century storing water in was were developed.

1.4 IRRIGATION TERMINOLOGY

Application Efficiency

The ratio of the water that is stored in the root zone for later use by the plants to the total water applied. [%, decimal]

Available Water Capacity (AWC)

Also known as available water (AW). The portion of water in a soil that can be readily absorbed by plant roots. It is the amount of water between field capacity and permanent wilting point. Usually measured in either %, in/ft, in/in, mm/mm, or m/m.

Basin Irrigation

A surface irrigation method where water is applied to a completely level area surrounded by dikes. On high clay content soils and managed correctly basin irrigation can be very efficient.

Border Irrigation

Water is applied at the upper end of a strip having parallel berms or earthen dikes anywhere from 10 to 100 feet apart that serve to confine the water to a strip or rectangular area.

Conveyance Efficiency

The ratio of the water that is delivered to a field to the total water diverted or pumped into the conveyance system at the upstream end. [%, decimal]

Corrugation Irrigation

Surface irrigation method where small channels or corrugations are used to guide water across a field. No attempt is made to confine the water entirely to the corrugations.

Deficit Irrigation

Not completely refilling the soil profile to field capacity. Not giving the plants all of the water that they can use. This may be deliberate, or inadvertent.

Distribution Uniformity

Test for determining the evenness or uniformity of irrigation water over an area. Numerical indices of uniformity include DU (distribution uniformity of the low quarter) and CU (Christiansen's coefficient of uniformity). [unit less]

Effective Precipitation

Portion of the total precipitation that is stored in the soil profile for later use by the plants. [in, mm]

Evaporation

Loss of water as vapor from the soil surface or wet leaves. Differs from transpiration in that the water does not pass through the plant leaves. [mm]

Evapotranspiration (ET)

Combined water lost from both transpiration from plant leaves and evaporation from soil and wet leaves. Also known as crop water use, or consumptive use. The crop ET (ETc) can be estimated by calculating the reference ET for a particular reference crop (ETo for clipped grass, and ETr for alfalfa) from weather data and multiplying this by a crop coefficient. [mm]

Field Capacity (FC)

Maximum amount of water that a soil can hold indefinitely against gravity. Put another way it is the amount of water left in the soil after all the free water has had a chance to drain out through the force of gravity. [%, in/ft, m/m].

Flood Irrigation

Also known as wild flood irrigation. Water is turned into a field without any flow control such as furrows, boarders or corrugations. This is the least efficient, least uniform and least effective method of irrigation.

Full Cover

The point in the plant's growth stage where the canopy covers all available ground space and using all available sunlight. Usually refers to row crops.

Furrow Irrigation

Also known as rill irrigation. Water is applied to row crops in small ditches or channels between the rows made by tillage implements.

Infiltration Rate

Rate at which water can enter the soil. Usually measured in units of depth per unit time [in/hr, mm/hr]

Intake Rate (Basic)

Rate at which water enters the soil after infiltration has decreased to a low and nearly constant value. This value should be used for sprinkler and drip irrigation system designs. [in/hr, mm/hr]

Irrigation Efficiency

Proportion of the water that is beneficially used to the irrigation water applied. [%, decimal]

Irrigation Scheduling

Process of determining when to irrigate and how much. This can be done by monitoring the soil, the crop, or calculating water use (evapotranspiration). The goal is

to schedule irrigation timing and amounts such that the soil water content remains between field capacity and the permanent wilting point

Leaching

Moving soluble materials down through the soil profile with the water.

Leaching Requirement

Amount of water that is required to flush excessive soil salts below the plant root zone. [mm]

Level Basin

Water is applied at relatively high flow rates to a completely level field. Precision laser leveling is required to achieve the level fields suitable for this method.

Management Allowable Depletion (MAD)

Also known as maximum allowable depletion, management allowable deficit, management allowable deficiency, allowable soil depletion or allowable soil water depletion. The portion of plant available water that is allowed for plant use prior to irrigation based in plant and management considerations. Usually a % of the available water capacity. [%, decimal]

Matric Potential

The force (measured in units of negative pressure) that the soil exerts (pulls) on water. [bars, kPa]

Osmotic Potential

The equivalent force that a salinity differential can cause across a semi-permeable membrane (plant root). [bars, kPa]

Permanent Wilting Point (PWP)

Soil moisture content at which plants can no longer get water from the soil and will wilt and die. [%, decimal, m/m]

Plant Available Water

The available water located in the root zone. Calculated as the root zone depth multiplied by the available water capacity. [%, decimal, m/m]

Pore Space

Empty space between soil particles that is normally filled with either air and/or water.

Pressure

The measurement of force within a system. This is the force that moves water through pipes, sprinklers and emitters. Static pressure is measured when no water is

flowing and dynamic pressure is measured when water is flowing. Pressure and flow are affected by each other. [bars, psi, kPa]

Pressure Regulator

A device that maintains a constant downstream pressure (cannot increase pressure).

Pump

Converts mechanical energy into hydraulic energy (pressure and/or flow). A centrifugal pump is the most common type used for irrigation.

Pump Efficiency

Ratio of the water power produced by the pump to the power delivered to the pump by the motor. [%, decimal]

PVC

Polyvinyl Chloride. Plastic material widely used in irrigation for pipe and fittings because it is light, inexpensive, easy to assemble, and can have a long useful life. It is typically buried.

Root Zone

Also referred to as the root depth or effective rooting depth. The depth or volume of soil from which plants effectively extract water from. Typically this is defined as the depth of soil containing 80 percent of the plant roots. [ft, m]

Salinity (Saline)

Concentration of salts in irrigation water. High concentrations can limit the crops ability to take up and use the water in the soil. [dS/m, mg/l, ppm]

Siphon Tube

Relatively short, light-weight, curved tube used to convey water over ditch banks to irrigate furrows or borders.

Soil Moisture Deficit

Also known as soil moisture depletion. The difference between field capacity and the actual soil water content in the root zone. [%, decimal, in/ft, m/m]

Subirrigation

Water is applied to open ditches or to tile lines to bring the water table up to where it is high enough to be used by the plants. Typically this is only practical in locations with high water tables, flat ground, and sandy soils.

Surface Irrigation

Irrigation method where the soil surface is used to transport the water via gravity flow from the source to the plants. Common surface irrigation methods are furrow irrigation, corrugation irrigation, border irrigation, basin irrigation, and flood irrigation.

Surge Irrigation

Water is sent down a furrow in pulses. After the initial surge, the furrow is allowed to dry. This wetting and drying cycle continues throughout the whole irrigation event. Surge increases uniformity for furrow irrigation and increases application efficiency.

System Capacity

The ability of an irrigation system to deliver water to an acreage. [m^3/ha]

Transpiration

Water taken up by the plant's roots and transpired out of the leaves. [in, mm]

Water Holding Capacity

The difference between field capacity and wilting point.

Water Horsepower

The energy or power added to water by the pump. [hp, kW]

Water Table

The upper surface of a saturated zone below the soil surface where the water is at atmospheric pressure. If you dig a hole deep enough water will start filling the hole at the water table.

Water Use Efficiency

Percentage of the applied water that is beneficially used (consumptive use and/or satisfying the leaching requirement). [%, decimal]

Weir

A flow measuring device for open-channel flow. Water flows over a particularly shaped restriction and the flow can be measured on a staff gauge. Commonly used by irrigation districts to measure water.

1.5 CLASSIFICATION OF IRRIGATION WORKS IN INDIA

Post-independence development of irrigation works in India were on the basis of classification of works into major, medium and minor projects. The classification has changed over the years from the basis of the extent of culturable command area of the project to that of expenditure involved in the project and back again to the basis of culturable command area. During the pre- plan period (prior to AD 1961 irrigation projects were classified on the basis of culturable command area of the project. During the period ranging from 1951 to 1978 the classification was based on the cost involved in the schemes. Since 1978, the basis of classification of irrigation projects has again been on the basis of the culturable command area of the project. Accordingly, irrigation projects in India are presently classified into the following three categories:

1.5.1 Major irrigation projects:

All irrigation schemes with a culturable command area of 10,000 ha or more are classified as major irrigation projects. They are involving large-scale storage diversion works.

1.5.2 Medium irrigation projects.

Projects having a culturable command area of 2000 ha to 10,000 ha are classified as medium Medium irrigation projects are also usually surface water projects, excepting a few large lift irrigation schemes, essentially irrigation projects.

1.5.3 Minor irrigation projects:

All irrigation schemes having a culturable command area upto 2000 ha individually are classified as minor irrigation projects. Minor irrigation schemes are further grouped schemes, (a) surface water minor irrigation and (b) groundwater minor irrigation schemes

LECTURE 2

Objectives of irrigation development and management, Surface water sources of India, Ground water sources of India and Ground water regions of India

2.1 OBJECTIVES OF IRRIGATION DEVELOPMENT AND MANAGEMENT

- To improve water-use-efficiency by progressive reduction in conveyance and water application losses
- To bridge the gap between irrigation potential created and its utilization, strengthening the Command Area Development Programme, institutional reforms and promoting farmers involvement in irrigation management
- To complete the ongoing projects, particularly those which were started during the Pre-Five year Plan periods
- To restore and modernize the old irrigation systems
- To introduce rational pricing of irrigation water, based initially on operation costs take maintenance
- To definite steps towards integrated development of surface water resources and explore the possibility of a transfer of water after ensuring environmental and ecological safety of the original river basin
- To promote adaptive research to ensure cost-effective and efficient development and management of higher level of inter-basin irrigation systems
- To promote participatory irrigation system management with the involvement of farmers
- To encourage conjunctive use of ground and surface waters towards optimal utilization of water resource
- To promote the development of groundwater on sound technical, environmental and economic considerations

2.2 SURFACE WATER SOURCES OF INDIA

Precipitation in the form of rainfall occurs only for a few days in a year. Hence, there is a need to conserve it in the soil profile, aquifers, ponds, lakes, reservoirs and during the dry periods. The management rivers for use of surface and groundwater resources requires a thorough understanding of the hydrology of the surface and

groundwater systems, agro-ecosystem, soil-water- plant-environment interactions, existing and expected demands of water, availability of energy and social dynamics.

For sustained agricultural production it is necessary to manage and utilize the water resources optimally supplies quality of land and water resources does not deteriorate so that (i) both surface and groundwater are maintained at the desired level, and (ii) the with time.

Water for irrigation is obtained from natural streams or rivers, from surface reservoirs and from underground reservoirs. Flood water from rivers is collected in surface reservoirs by constructing dams at suitable sites and by diverting water by constructing weirs or barrages at appropriate locations. Runoff water from small areas can also be collected by constructing ponds or tanks. Water from underground and installing pumps or other water lifts. Water from surface reservoirs or diversion points is conveyed through canals.

Based on whether the source of water is above or below the field surface, irrigation is classified into two types: (a) Flow Irrigation where the water reaches the f held from the source by gravity flow; and (b) Lift Irrigation requiring the water to be raised or lifted from source to the field surface. India is blessed with a large number of big and small rivers, the sweet waters of which can be put to many uses such as drinking, other domestic needs, agriculture and industrial uses, navigation, recreation, power generation and other uses. In the national strategy for water resource utilization, drinking water requirement is given priority over all other needs.

The river systems of India can be classified into four groups, namely (i) Himalayan rivers, (ii) Deccan rivers, iii) Coastal rivers, and (iv) Rivers of the inland drainage basins. The Himalayan rivers derive their flows from rainfall runoff and by melting of snows and glaciers. Therefore, they have nearly continuous flow throughout the year. During the monsoon months, Himalayas receive heavy rainfall and rivers swell, causing frequent floods. The Deccan rivers are rainfed. Hence, they have major fluctuations in the volume of flow. Many of them are non-perennial.

The coastal rivers, specially on the west coast, are short in length catchment areas. Most of them are non-perennial. They drain into salt lakes like Sambhar or disappear in sands with no outlet to the sea. The northern slopes of the Himalayas drain into Indus and Brahmaputra, while the southern slopes drain into the Ganga system. The large Indo-Gangetic plains lies between the Himalayas on the north and the plateau of

the peninsula in the south and extends from the Bay of Bengal in the east and India's boundary with Pakistan on the west. These plains are fertile and support a major part of the population of the country. The heavy rainfall area of India, lying in the eastern and north-eastern regions, are drained by the Brahmaputra and its tributaries.

2.3 GROUNDWATER RESOURCES OF INDIA

Groundwater has a significant role in India's economy. The resource has gained importance as a source of drinking water and food security. Because the groundwater abstraction structures (wells) under the direct control of the user, groundwater has become are usually the preferred various uses. Source Groundwater contributes to about 50% irrigation water, 80% water for domestic use in rural areas and 50% water for urban and industrial areas.

The groundwater resource has two components, namely, static and dynamic. The static groundwater resources i.e. aquifer zones below the zone of water level fluctuation, of India have been estimated as 10,812 billion m^3. Generally, the static water resource is not regularly replenished on an annual basis. The dynamic resource is replenished annually, which has been assessed as 432 billion m^3. As per the National Water Policy, the development of groundwater resources is to be limited to the utilization of the dynamic component of groundwater. There is, however, scope for development of the static resources in periods of drought. The annual availability of groundwater is predicted by the annual recharge of the aquifer. The water extracted from an aquifer in any year should be Source:

Based on Ministry of Water replenished through recharge from the succeeding precipitations (or other sources of recharge), a cycle of 2, 3 or 5 years, the ground water table does not go down. When there is over-exploitation of groundwater known so that over down as mining, the water table goes progressively. Such over-exploitations have occurred at several places in India, and has caused ingress of saline waters from the sea in some of the coastal areas

2.4 GROUNDWATER REGIONS OF INDIA

Based on the occurrence of groundwater in geological formations, nature and extent of aquifer bodies and flow characteristics, the Central Groundwater Board (1989) generalized the hydrological formations of India as follows:

2.4.1 Unconsolidated formations:

The quaternary rocks comprising recent alluvium, older alluvium and coastal alluvium. They unconsolidated formations found in the Indo- are the important Gangetic plains, coastal plains, Brahmaputrs basin, inter-montane Himachal Pradesh, and intra-crotonic basins like Narmada, Tapi and Purna basins, aeolian sands of Rajasthan and Gujarat, arid tracts, including valley fill and buried channel areas.

2.4.2 Semi-consolidated formations:

These are composed chiefly of shale, sandstone and limestone generally found in north-western region and the terrestrial deposits belonging to Gondwana group

2.4.3 Consolidated hard rock formations:

They occupy almost two-thirds of the area of India and can be classified in broad lithological units o sedimentary and meta-sedimentary, volcanic rocks and crystalline and metamorphic rocks.

LECTURE 3

Duty, delta and Base period- Definitions, Duty and Delta relationship and problems

3.1 Duty of Water (D): This is defined as the area that can be irrigated with a continuous non-stop supply of irrigation water at the rate of one cumec or cusec throughout the base period. It is expressed as acre/cusec or hectare/cumec.

3.2 Base Period (B): This is the period over which irrigation water is to be supplied for the production of any crop. Normally this is equal to the period between the first and last irrigation applied to a crop.

3.2 Delta (Δ): This the depth of water required by a crop during the crop season to meet its requirements. This does not have any relevance to the area of the cropped field. It is expressed in mm or cm.

Relationship between D, Δ and B

$$\Delta = 864 \frac{B}{D}$$

Where,
Δ in cm,
B in days and
D in ha/cumec.

3.4 Relation between duty and delta.

Let there be a crop of base period B days.

Let one cumec of water be applied to this crop on the field for B days

Now, the volume of water applied to this crop during B days

V= (1 x 60 x 60 x 24 x B) m^3 = 86 400 B (cubic metre)

By definition of duty (D), one cubic metre supplied for B days matures D hectares of land

This quantity of water (V) matures D hectares of land or 104 D sq.m of area.

Total depth of water applied on this land, = Volume/Area = $86400B/(10^4 D)$

By definition , this depth of water is called delta (Δ)

$$\Delta = 864 \frac{B}{D}$$

Where,
Δ in cm,
B in days and
D in ha/cumec.

Example 3.1.

If rice requires about 10 cm of depth of water at an average interval about 10 days, and the crop period for rice is 120 days, find out the delta for rice.

Solution:

Water is required at an interval of 10 days for a period of 120 days.

It evidently means that 12 no. of waterings depth of water is required. and each time, 10 cm are

Therefore, total depth of water required

Δ= 12 x 10 cm =120 cm.

Hence Δ for rice = 120 cm.

Example 3.2.

If wheat requires about 7.5 cm of water after every 28 days and the base period for wheat is 140 days, find out the value of delta for wheat.

Solution:

Assuming the base period to be representing the crop period, as per usual practice and it can easily infer that the water is required at an average interval, of 28 days up to a total period of 140 days.

This means that 140/28= 5 no. of waterings are required

The depth of water required each time= 7.5 cm

The total depth of water required in 140 days =5 x 7.5= 37.5 cm

Hence Δ for wheat = 37.5 cm

3. Find the delta for a crop when its duty is 864 hectares/cumec on the field, the base period of this crop is 120 days.

Sol:

By definition , this depth of water is called delta (Δ)

$$\Delta = 864 \frac{B}{D}$$

Given, B= 120 days and D= 864 ha/cumec

Δ= 864x120/864= 120 cm

LECTURE 4

Measurement of Irrigation water- Units of measurement, methods of measurement (list), direct measurement of velocity by using the current meter

4.1 UNITS OF WATER MEASUREMENT

Irrigation water is conveyed either through open channels or pipes and knowing the quantity of water available is essential for irrigation water management. Sometimes one will want to know only the volume of water used; while, at other times one will want to know the rate of flow. Conversion factors simplify changing from one unit of measurement to another.

Water may be measured in two condition viz. (i) at rest and (ii) in motion. At rest means volume of water is measured and different units used for volume measurement are litre, cubic metre, hectare-centimetre, hectare-metre etc. Water is measured in motion means rate of flow is measured and different units used for this are litre per second, cubic metre per second, etc.

- Litre: The volume equal to one cubic decimetre or 1/1000 cubic metre.
- Cubic metre: A volume equal to that of a cube 1 metre long, 1 metre wide and 1 metre deep.
- Hectare – centimetre: A volume necessary to cover an area of 1 hectare (10,000 sq.m) up to a depth of 1 centimetre (1 hectare – centimetre = 100 cu. m = 100,000 litres)
- Hectare –metre: A volume necessary to cover 1 hectare (10,000 sq.m) up to a depth of 1 metre (1 hectare –meter = 10,000 cu. m = 10 M litres)
- Litre per second: A continuous flow amounting to 1 litre passing through a point each second.
- Cubic metre per second: A flow of water equivalent to a stream 1 metre wide and 1 metre deep, flowing at a velocity of 1 metre per second.

4.2 METHODS OF WATER MEASUREMENTS

There are several methods used for the measurements of irrigation water on the farm. They can be grouped into four categories as,

1. Volumetric or volume methods of water measurement
2. Area – Velocity Method
3. Measuring Structures (Orifices, Weirs and Flumes)
4. Tracer methods.

4.3. DIRECT MEASUREMENT OF VELOCITY BY USING THE CURRENT METER

In the area velocity method, current meters are generally used to measure the velocity of flow at the different sections. The current meter consists of a small revolving wheel or vane that is turned by the movement of water (Fig. 4.1). It may be suspended by a cable for measurements in deep streams or attached to a rod in shallow streams. The propeller is rotated by the flowing water and speed of propeller is proportional to the average velocity of flow. Corresponding to the number of revolutions, the velocity can obtained from calibration graphs or tables.



Fig 4.1 Current meter.

Procedure for velocity measurement using the current meter: Stretch a tape across the channel cross-section. Divide the distance across the channel to at least 25 divisions. Use closer intervals for the deeper parts of the channel.

1. Stretch a tape across the channel cross-section. Divide the distance across the channel to at least 25 divisions. Use closer intervals for the deeper parts of the channel.
2. Start at the water's edge and call out the distance first, then the depth and then the velocity. Stand downstream from the current meter in a position such that the velocity is least affected by the meter. Hold the rod in a vertical position with the meter directly into the water.
3. To take a reading, the meter must be completely under water, facing the current, and free of interference. The meter may be adjusted slightly up or downstream to avoid boulders, snags and other obstructions. The note taker will call out the calculated interval, which the meter operator may decide to change (e.g., taking readings at closer intervals in deep, high-velocity parts of the channel). Record the actual distance called out by the meter operator as the center line for the subsection.

    - Take one or two velocity measurements at each subsection.
    - If depth (d) is less than 60 cm, measure velocity once for each subsection at 0.6 times the total depth (d) measured from the water surface.
    - If depth (d) is greater than 60 cm, measure velocity twice, at 0.2 and 0.8 times the total depth. The average of these two readings is the velocity for the subsection.

4. Allow a minimum of 40 seconds for each reading. The operator calls out the distance, then the depth, and then the velocity. The note taker repeats it back as it is recorded, as a check.
5. Calculate discharge in the field. If any section has more than 5% of the total flow, subdivide that section and make more measurements.

Current meters are designed in a manner such that the rotation speed of the blades varies linearly with the stream velocity. This can be expressed by the following equation:

$$v = a N_s + b$$

Where,

v = stream velocity at measuring site in m/s

N_s = revolutions per second of the meter

a, b = constants of the meter.

To determine the constants, which are different for each instrument, the current meter has to be calibrated before use. This is done by towing the instrument in a tank at a known velocity and recording the number of revolutions N_s. This procedure is repeated for a range of velocities.

It has to be kept in mind that for shallow streams the measurement can be taken at a depth= 0.6 of the total depth, whereas for deeper streams two measurements are needed at 0.2 and 0.8 of total depth and then averaged to get the actual velocity.

LECTURE 5

Evaporation, Transpiration and Concept of Evapotranspiration and Estimation of ET- Blaney Cridlle, Throrntth Waite, Penman and Modified Penman- Monteith equations

5.1 EVAPORATION AND TRANSPIRATION

Evapotranspiration is one of the major components of the hydrologic cycle and affects crop water demand. Therefore, its quantification is necessary for proper irrigation planning. The term evapotranspiration refers to combination of two processes, namely, evaporation and transpiration (Fig. 5.1). Evaporation is a process by which water is lost in the form of vapour from natural surfaces, such as freewater surface, bare soil, from live or dead vegetation. Transpiration is a process by which water is lost in the form of vapour through plant leaves. Therefore evapotranspiration is a combined loss of water from the soil (evaporation)and plant (transpiration) surfaces to the atmosphere through vaporization of liquid water, and is expressed in depth per unit time (for example mm/day).

Consumptive use (CU) – CU is used to designate the losses due to ET and water that is used for its metabolic activities of plants thus CU exceed ET by the amount of water used for digestion, photosynthesis, transport of minerals and photosynthates, structural support and growth. Since this difference is usually less than 1%, ET and CU are normally assumed to be equal. But both (CU &ET) terms are used simultaneously.

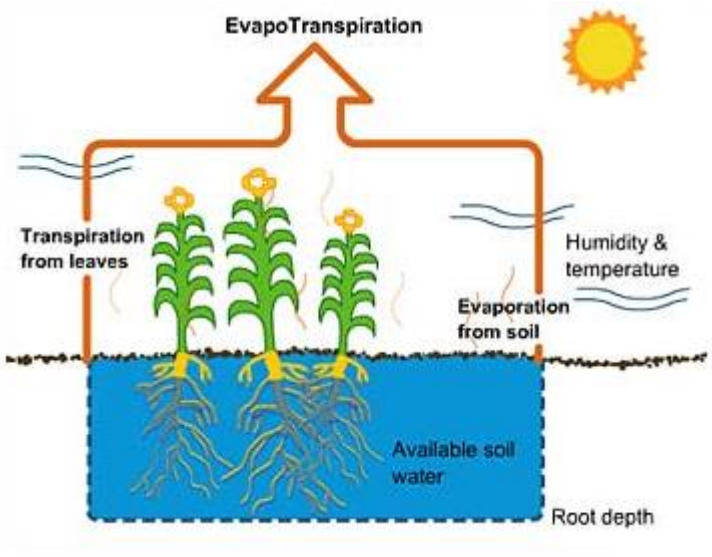


Fig. 5.1 Evapotranspiration process.

ET can be either directly measured for a given crop, soil and climatic conditions or computed using the reference crop ET, which is generally estimated by various methods depending upon availability of data for a particular case.

5.2 CONCEPT OF REFERENCE CROP EVAPOTRANSPIRATION

Reference Crop ET – is the potential ET for a specific crop (usually either grass or alfalfa) and set of surrounding (advective) conditions. According to Doorenbos and Pruitt (1977)"ET from an extensive surface of 8 10 15 cm tall, green grass covers of uniform height, actively growing, completely shading the ground and not short of water".

Allen *et al.* (1998) modified the above definition to represent hypothetical grass surface. Reference crop evapotranspiration from an extensive surface of green grass of uniform height(0.12m), actively growing, completely shading the ground with an albedo of 0.23 and having ample water supply is called reference crop evapotranspiration and is denoted by ET_o (Fig. 5.2).

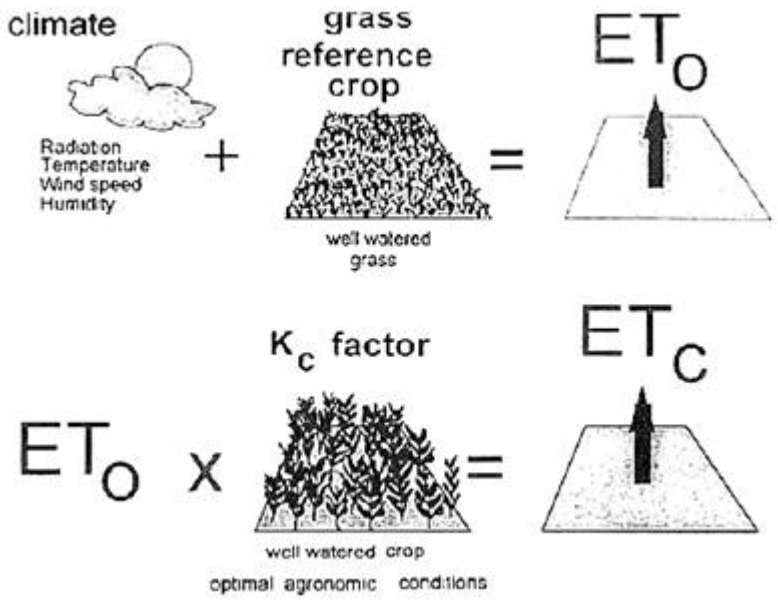


Fig. 5.2 Estimation of reference crop evapotranspiration.

Climatic parameters are the only factors affecting ET_o and it can be computed from weather data. ET for specific crop can be estimated using reference crop ET and crop coefficients.

Typical ranges for ET_o values for different agro-climatic regions are given in Table 5.1.

Table 5.1 Average ETo for different agro-climatic regions in mm/day

Regions	Mean daily temperature (°C)		
	Cool (~10°C)	Moderate (20°C)	Warm (> 30°C)
Tropics and subtropics			
Humid and Sub-humid	2 – 3	3 - 5	5 – 7
Arid and Semi-arid	2 – 4	4 - 6	6 – 8
Temperate region			
Humid and Sub-humid	1 – 2	2 - 4	4 – 7
Arid and Semi-arid	1 – 3	4 - 7	6 – 9

5.3 EVAPOTRANSPIRATION ESTIMATION METHODS

Due to wide application of evapotranspirtaion data, various indirect ET estimation methods have been developed over the years. These methods can be grouped

into four major categories. Although there is large number of methods developed in each category, a few examples are given below:

1. Temperature based (Thornwaite, SCS Blainey-Criddle, FAO24 Blaney-Criddle, Hargreaves)
2. Radiation based (Turc, Preistly Taylor, Jensen-Haise, and FAO 24 Radiation)
3. Pan evaporation based (Pan evaporation, FAO 24 Pan)
4. Combination (Penman, Penman Moneith, FAO 56 Penman Monteith)

Data requirement as well as performance of each of these methods varies. In order to help user with ETo estimation, A Decision Support System for ETo estimation is developed at IIT Kharagpur (Bandopadhyaya et al. 2012), which estimates ETo by 22 well established method and ranks them based on their ETo estimation performance.

5.3.1 Blaney-Criddle Method

This method requires the use of only two factors, temperature and information of day light hours which is a factor based purely on the latitude of the place. Using Blaney-Criddle approach, potential evapotranspiration can be expressed as follows, in metric unit:

$$PET = 0.46p(T + 17.8)$$

Where,

PET = potential evapotranspiration, mm of water per day (mean value over the month)

p= monthly percent of total day time hours of the year

T= mean monthly temp. In °C (Average of daily max and minvalues)

The seasonal consumptive use of a crop can be determined from the following relationship,

$$U = KF = \sum kf = \sum u$$

Where, U = seasonal consumptive use of water by the crop for a given period (mm/inches)

u = monthly consumptive use (mm)

K = empirical seasonal consumptive use consumptive us for the growing season

F = sum of the monthly consumptive use factors (f) for the growing season

k = empirical consumptive use crop coefficient for the month (u/f)

f = value of monthly PET in mm

5.3.2 Thornthwaite Method

The relationship is expressed as:

$$ETo = 1.6\ (10\ T/I)^{a}$$

Where,

ETo = Monthly potential evapotranspiration (cm) or reference crop ET (i.e., ETo)

T= Mean monthly temperature (°C)

I = A heat index for a given area which is the sum of 12 monthly index values i

i is derived from mean monthly temperatures using the following formula:

$$i = (T/5)^{1.514}$$

a = an empirically derived exponent which is a function of I

$$a = 6.75 \times 10^{-7} I^{3}\text{-}7.71 \times 10^{-5} I^{2} 6.75 \times 10^{-7} I^{3} + 1.79 \times 10^{-2}\ I + 0.49$$

25.4

5.3.3 Penman formula

The penman formula is a semi-empirical equation combining mass transfer (Ea) and energy budget (H) methods. The formula was developed by Penman in 1948 and is

still widely used for calculating the potential evaporation using synoptic meteorological data. According to Penman the potential evaporation Eo (in mm/day) can be calculated as:

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

Where, Δ/γ is an empirical parameter depending on temperature .

H is calculated as $H = (1\text{-}r)R_{in} - R_o$ where R_{in} (incoming radiation) is given by

$$(1\text{-}r)R_{in} = 0.95R_a(0.18 + 0.55n/N)$$

Where,

R_a is the solar radiation, R_o is the outgoing radiation, r is the albedo (0.05 for water), and n/N is the ration between actual sunshine hours and possible sunshine hours. The term n/N can also be estimated using the cloudiness, e.g., a cloudiness of 60 % gives an n/N of 40 % (= 100 - 60).

R_o is calculated by

$$R_o = \sigma T_a^4 (0.56 - 0.09\sqrt{e_d})(0.10 + 0.90n/N)$$

Where, e_d is the actual vapor pressure, and σTa^4 is the theoretical black body radiation

E_a is calculated by

$$E_a = 0.35(0.5 + u_2/100)(e_a - e_d)$$

Where, u_2 is the wind speed in miles/day (1 mile = 1609 m) and e_a is the saturation vapor pressure. Remember that the relative humidity $RH = e_d/e_a$

5.3.4 Modified Penman- Monteith equation

Allen *et al.* (1998) modified the Penman–Monteith equation for estimation of grass reference crop evapotranspiration (ETo).

The mathematical relationship is as follows:

$$ET_0 = \frac{0.408\,\Delta\,(Rn-G)+\gamma\,\frac{900}{T+273}U_2(e_s-e_a)}{\Delta+\gamma\,(1-0.34U_2)}$$

Where,

ETo = Reference crop evapotranspiration (mm/day)

Rn = Net radiation at the crop surface (MJ/m^2/day)

G = Soil heat flux density (MJ/m^2/day)

T = Air temperature at 2 m height (°C)

U_2 = Wind speed at 2 m height (m/s)

e_s = Saturation vapour pressure (kPa)

e_a = Actual vapour pressure (kPa)

(e_s – e_a) = Saturation vapour pressure deficit (kPa)

Δ = Slope vapour pressure curve (kPa/°C)

γ = Psychrometric constant (kPa/°C)

Details of parameter estimation for the above ETo methods can be found in Allen *et al.* (1998) and Michael (2008).

Application & Limitations

- Method requires all weather data, i.e., minimum and maximum temperature, minimum and maximum RH, wind speed, Solar radiation or sunshine hour
- Wide applicability i.e., in arid, semi-arid, humid, sub-humid conditions
- Gives a very satisfactory estimate of ETo
- Can provide basis for developing consistent crop coefficients

LECTURE 6

Irrigation water requirement of crops- importance of water in plant growth, procedures for working out the net irrigation (depth of irrigation), gross irrigation requirement

6.1 IRRIGATION WATER REQUIREMENT

It is defined as the total quantity of water required by a crop irrespective of its source in a given period of time for its normal growth and development under field conditions at a given place. In means that it is the total quantity of water required to mature an adequately irrigated crop to meet the losses due to evapotranspiration (ET), plus the losses during the application of irrigation water (unavoidable losses) and the additional quantity of water required for special operations such as land preparation, transplanting, leaching of salts below the crop root zone, frost control *etc*. It is expressed in depth per unit time.

Crop water demand can also be expressed in term of supply as:

$$\mathbf{WR = IRR + ER + \Delta S + GWC}$$

Where,

WR = Total depth of water required during the life of crop irrespective of source

ER = Effective rainfall received during crop life

ΔS = Profile water use i.e., difference in soil moisture in the crop root zone at the beginning and end of the crop

GWC= Groundwater contribution, if any

IRR = Irrigation

In the previous lecture crop ET estimation procedure based on reference crop ET and crop coefficient approach is described. A number of methods are available for estimation of reference crop ET (ETo) using the weather data. However, crop ET can also be measured using the field water balance or lysimeter. These methods are

laborious and time consuming and therefore, indirect methods of crop ET estimation are commonly used and will be covered in this lecture.

The term effective rainfall has a different meaning to different users. For example for hydrologist effective rainfall means runoff, whereas for irrigation engineers of agriculturist effective rainfall means useful or utilizable rainfall for the purpose of crop growth. Dastane (1974) has defined effective rainfall as “that portion of the total annual or seasonal rainfall which is useful directly and/or indirectly for meeting the crop water needs in crop production at the site where it falls but without pumping”. Thus, it is the portion of rainfall that does not include losses due to surface runoff, unnecessary deep percolation and residual moisture after harvest. This concept of effective rainfall is suggested for use in planning and operation of irrigation projects. A number of factors affects effective rainfall include, rainfall characteristics, land topography, soil and crop characteristics, management practices, carryover moisture content and groundwater contribution. A number of methods are in practice for determining effective rainfall. These include, field water balance approach, drum culture approach for rice, and empirical relationship (SCS method).The water requirement of different crops are given in Table.

Table 6.1 Water requirement of different crops

Crop	Water requirement (mm)	Crop	Water requirement (mm)
Rice	1200	Tomato	600 – 800
Wheat	450 – 650	Potato	500 – 700
Sorghum	450 – 650	Pea	350 – 500
Maize	500 – 800	Onion	350 – 550
Sugarcane	1500 – 2500	Chillies	400 – 600
Sugarbeet	550 – 750	Cabbage	380 – 500
Groundnut	500 – 700	Banana	1200 – 2200
Cotton	700 – 1300	Citrus	900 – 1200
Soybean	450 – 700	Grapes	700 – 1200
Tobacco	400 – 600	Mango	1000 – 1200
Beans	300 – 500	Turmeric	1200 – 1400

6.2 NET IRRIGATION REQUIREMENT

The net irrigation requirement is the total amount of irrigation water required to bring the soil moisture content in the root zone depth of the crops to field capacity i.e., difference between the field capacity and the soil moisture content in the root zone before application of irrigation water. This may be obtained by the relationship given below:

$$NIR = \sum_{i=1}^{n} \frac{M_{fc\,i} - M_{b\,i}}{100} . \rho_{b\,i} . D_i$$

Where,

NIR = net amount of water to be applied during an irrigation, cm

M_{fci} = gravimetric moisture content at field capacity in the ith layer of the soil, (%)

M_{bi} = gravimetric moisture content before irrigation in the ith layer of the soil, (%)

ρ_{bi} = bulk density of the soil in the ith layer, g/cm^3

D_i = depth of the ith soil layer, cm, within the root zone, cm

N = number of soil layers in the root zone D.

6.3 GROSS WATER REQUIREMENT

The total amount of water, inclusive of losses, applied through irrigation is termed as gross irrigation requirement which in other words in net irrigation requirement plus application and other losses.

$$GIR = \frac{NIR}{\text{Overall irrigation efficieny}}$$

Example 6.1: A tank has a water spread area of 40 ha. With an average water depth of 3m. Calculate the area of paddy crop (120 days duration) that can be irrigated, if the duty is expressed as:

I. 960 ha per m^3s^{-1}
II. 110 ha cm and
III. 90 ha / million cu m of water

Solution:

The total water available = 40 x 3 x 100 ha. Cm

$$\Delta = 846 \text{ x } \frac{B}{d} = 864 \text{ x } \frac{120}{960} = 108 \text{ cm}$$

1. Area that can be irrigated = $\frac{40 \times 3 \times 100}{108} =$ 111 ha. Ans.

2. Area that can be irrigated $= \frac{40 \times 3 \times 100}{110} =$ 108 ha. Ans.

3. Water available in million cu. m $= \frac{40 \times 3 \times 10{,}000}{10{,}00{,}000}$

Area that can be irrigated $= \frac{40 \times 3 \times 10{,}000}{10{,}00{,}000} \times 90$ = 108 ha. Ans.

Example 6.2: The following data were obtained in determining the soil moisture content at successive depths in the root zone prior to applying irrigation water.

Depth of sampling, cm	Wt. moist soil sample, gm	Oven dry wt. of soil sample, gm
0-25	135.60	127.82
25-50	137.28	128.95
50-75	123.95	116.32
75-100	111.92	103.64

The bulk density of the soil in the root zone was 1.65 gm/cc. the available moisture holding capacity of the soil was 18.0 cm/m depth. Determine

1. The moisture content at different depths in the root zone
2. Moisture content in the root zone at the time of irrigation
3. Net depth of water to be applied to bring the moisture content to field capacity
4. Gross irrigation requirement at an estimated field irrigation efficiency of 70 %

Solution:

a. Soil moisture content at different depths

0-25 cm: $\frac{(135.6-127.82)100}{127.82}$ = 6.08% = 6.08 x 1.65 = 10 cm/ m depth

= 10 x 25/100 = 2.5 cm

25-50 cm: $\frac{(137.28-128.95)100}{128.95}$ = 6.46% = 6.46 x 1.65 = 10.66 cm/ m depth

= 10.66 x 25/100 = 2.66 cm

50-75 cm: $\frac{(123.95-116.35)100}{116.35}$ = 6.53% = 6.53 x 1.65 = 10.77 cm/ m depth

= 10.77 x 25/100 = 2.69 cm

75-100 cm: $\frac{(111.92-103.64)100}{103.64}$ = 7.98% = 7.98 x 1.65 = 13.18 cm/ m depth

= 13.18 x 25/100 = 3.292 cm

b. Moisture content in the root zone at the time of irrigation = 2.5+2.66+2.69+3.292 =

11.14 cm

c. Net irrigation requirement = 18 – 11.14 = **6.85 cm**

d. Gross irrigation requirement = 6.85 / 70 x 100 = **9.79 cm.**

LECTURE 7

Irrigation efficiency – conveyance, application, storage, distribution and water use efficiency and related problems

7.1 IRRIGATION EFFICIENCY

The term irrigation efficiency expresses the performance of a complete irrigation system or components of the system. Irrigation efficiency is defined as the ratio between the amount of water used to meet the consumptive use requirement of crop plus that necessary to maintain a favorable salt balance in the crop root zone to the total volume of water diverted, stored or pumped for irrigation. Thus, water applied by the irrigation system and not being made available to be taken up by plant roots is wasted and reduces irrigation efficiency. Fig.7.1 shows components of water loss from source to point of application. In addition, losses can also occur during storage in case of pond, tank, or reservoirs. The major causes for reduced irrigation efficiency include storage losses, conveyance losses and field application losses. In India, overall irrigation efficiency of major irrigation projects ranges between 35-40%. This is one of the reasons for increasing gap between irrigation potential created (102.77 M ha till end of 10^{th} plan 2007) and utilized (87.23 M ha). This gap of about 16%, is same as the irrigation potential created between 1951 and 1970. At the end of eighth plan, Planning commission estimated that with a 10% increase in the present level of water use efficiency in irrigation systems, an additional 14 Mha area can be brought under irrigation from the existing irrigation capacities. In order to meet the growing demands of water for food, environment, urban and industry, it is necessary to improve irrigation efficiency at all levels.

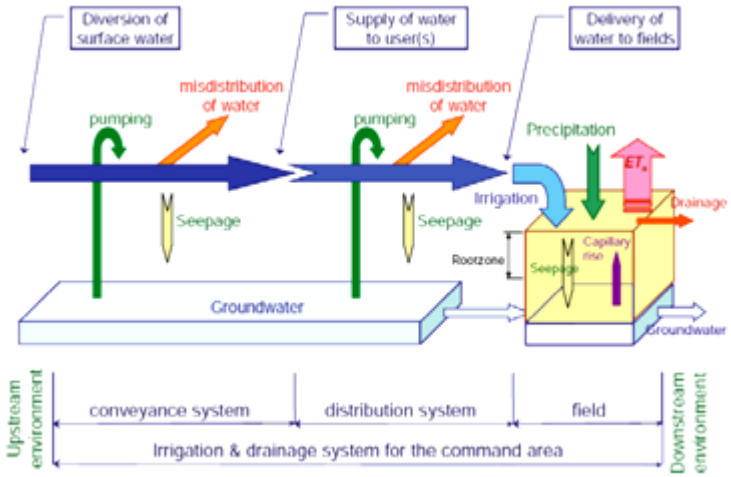


Fig.7.1 Schematic water flow in irrigation drainage system.

7.1.1 Water Conveyance Efficiency

The conveyance efficiency is used to measure the efficiency of water conveyance systems associated with the canal network, water courses and field channels. It is defined as the ratio between the water that reaches a field and that diverted from the irrigation water source. Mathematically it is represented as follows:

$$E_c=100\ (V_f/V_d)$$

Where,

E_c= the conveyance efficiency (%),

V_f = the volume of water that reaches the farm or field (m^3),

V_d= the volume of water diverted ($m^{3)}$ from the source.

7.1.2 Water Application Efficiency

Water Application efficiency relates to the actual storage of water in the root zone to meet the crop water needs in relation to the water applied to the field. It might be defined for individual irrigation or parts of irrigations or irrigation sets. Water Application efficiency includes any application losses to evaporation or seepage from surface water channels or furrows, any leaks from sprinkler or drip pipelines,

percolation beneath the root zone, drift from sprinklers, evaporation of droplets in the air, or runoff from the field. In case of surface irrigation evaporation losses are generally small but runoff and deep percolation are substantial. However, air losses (droplet evaporation and drift) can be very large if the sprinkler design or excessive pressure produces a high percentage of very fine droplets. Application efficiency is defined as:

$$E_a = 100(V_s/V_f)$$

Where,

E_a= the application efficiency (%),

V_s= the volume of water stored in root zone (m^3),

V_f = the water delivered to the field or farm (m^3).

Table 7.1 Typical values of application efficiency for different irrigation systems

System Type	Application Efficiency Range* (%)
Surface Irrigation	
Basin	60 - 95
Border	60 - 90
Furrow	50 - 90
Surge	60 - 90
Sprinkler Irrigation	
Handmove	65 - 80
Traveling Gun	60 - 70
Center Pivot & Linear	70 - 95
Solid Set	70 - 85
Microirrigation	
Point source emitters	75 - 95
Line source emitter	70 - 95

7.1.3 Water Storage Efficiency

The water storage efficiency evaluates the storage of water in the root zone after the irrigation in relation to the need of water prior to irrigation.

$$E_s = 100\ (V_s/V_{rz})$$

Where,

E_s= the storage efficiency (%)

V_{rz}= the root zone storage capacity (m^3).

The root zone depth and the water-holding capacity of the root zone determine V_{rz}. The storage efficiency has little utility for sprinkler or micro irrigation because these irrigation methods seldom completely refill the root zone.

7.1.4 Water Distribution Efficiency

It is the ratio between the mean of numerical deviations from the average depth of water stored during irrigation (Y) and the average depth stored during irrigation (d). It is mathematically expressed as:

$$E_d = (1 - \frac{\bar{Y}}{\bar{d}})\ \text{x}\ 100$$

Where,

Y= Average numerical deviation in depth of water stored from average depth

stored during irrigation

d = Average depth of water stored during irrigation.

It is a measure of water distribution within the field. A low distribution efficiency means non-uniformity in the distribution of irrigation water. This may be due to uneven land levelling. There may be existing low patches where water will penetrate more and high patches where water cannot reach. This leaves some spots unirrigated unless excess irrigation water is applied. Excess water application lowers irrigation

efficiency. It may be noted that water distribution efficiency is identical to Christiansen's Uniformity Coefficient which is discussed later.

7.1.5 Water Use Efficiency

The term water use efficiency denotes the production of crops per unit water applied. It is expressed as the weight of crop produce per unit depth of water over a unit area. i.e., kg/cm/ha.

7.1.5.1 Crop Water Use Efficiency

It is the ratio of crop yield per amount of water depleted by the crop in the process of evapotranspiration (ET).

Crop water use efficiency = Y/ET

7.1.5.2 Field Water Use Efficiency

It is the ratio of crop yield (Y) to the total amount of water used in the field (WR).

Field water use efficiency = Y/WR

Example 7.1 :

A stream of 140lps was diverted from a canal and 110 lps were delivered to the field. An area of 1.65 ha was irrigated in eight hours. The effective depth of root zone was 1.85 m. The runoff loss in the field was 435 m^3. The depth of water penetration varied linearly from 1.85 m at the head end of the field to 1.25 m at the tail end. Available moisture holding capacity of the soil is 25 cm/m depth of soil.

Determine the water conveyance efficiency, water application efficiency, water storage efficiency and water distribution efficiency, irrigation was started at a moisture extraction level of 50 percent of the available moisture.

Solution:

1. Water conveyance efficiency, $Ec=100(V_f/V_d) = 100(110/140) =78.5\%$

2. Water application efficiency, $E_a = 100(V_s/V_f)$

Water delivered to the field = (110 x 60 x 60 x 8) / 1000 = 3168 m^3

Water stored in the root zone = 3168 – 435 = 2733m^3

= (2733 x 100)/ 3168 = 86.26%

3. Water storage efficiency

We Know, E_s= 100 (V_s/V_{rz})

Now, Water holding capacity of the root zone = 20 x 1.85 = 37 cm

Moisture required in the root zone = $37 - \frac{37 \times 50}{100} = 18.5\ cm$

Or $= \frac{18.5}{100} \times 1.65 \times 10,000$

= 3052.5 m^3

Water storage efficiency = $\frac{3052.5}{3168} \times 100$

= 96.3%

4. Water distribution efficiency

We know, $Ed = (1 - \frac{\bar{Y}}{\bar{d}})$ x 100

$$\bar{d} = \frac{1.85 + 1.25}{2} = 1.55\ m$$

Numerical deviation from depth of penetration

At upper end = 1.85 – 1.55 = 0.3

At lower end = 1.55 – 1.25 = 0.3

Average numerical deviation = $\frac{0.3+0.3}{2}$ = 0.3

$Ed = (1 - \frac{0.3}{1.55})$ x 100 = 80.6%

LECTURE 8

Surface methods of water applications- Classification, Border Irrigation Method- Basic details, Components of border irrigation- width, length and slope of different soils and their adaptability, Hydraulics and design of Border Irrigation (Israelson’s equation only)

8.1 SURFACE IRRIGATION METHODS

Surface irrigation is the oldest and widely used method of water application to agricultural land. The term 'surface irrigation' refers to a broad class of irrigation methods in which water is distributed over the field by overland flow. A flow is introduced at upper edge of the field which covers the field gradually. The water front advance is dependent largely on the differences between the inflow onto the field and the accumulating infiltration into the soil. In addition, other factors such as field slope, surface roughness, and the geometry or shape of the flow cross-section also influence advance rate. In this chapter the components and hydraulics of irrigation will be discussed.

Surface irrigation methods refer to water application through gravity flow to the cultivated land. Water is applied either the entire field (uncontrolled flooding) or part of the field (furrows, basins, border strips). For efficient application of water it is important to select the method of irrigation which best suits the crop and soil characteristics of the field. In doing so it may be essential to use more than one method of irrigation in an area or a given farm (shown in Fig. 8.1 and 8.2).

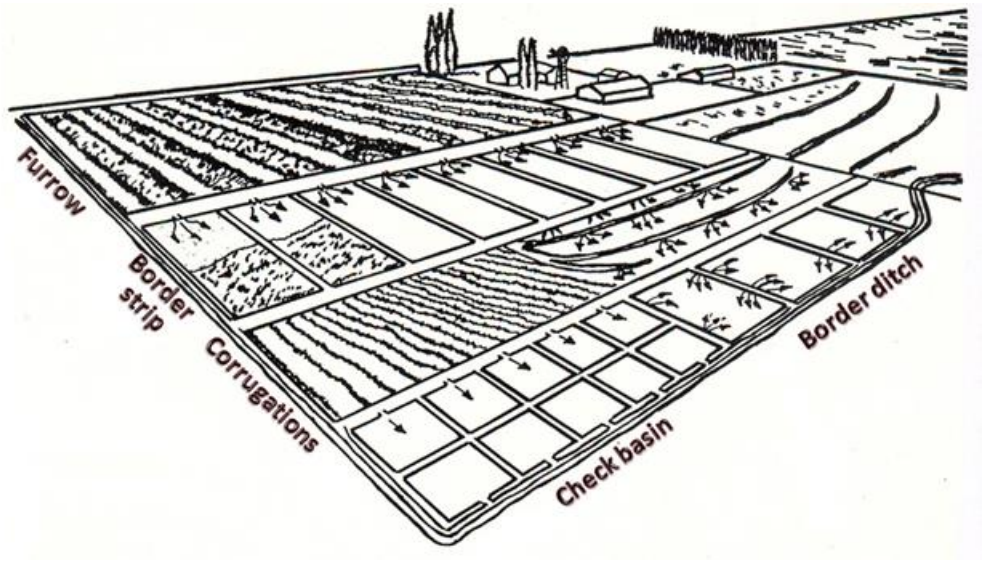


Fig.8.1 Different methods of irrigation on a farm.

The factors which determine the suitability of any method of irrigation are local conditions (soil type - its permeability & water storage capacity; land topography, climate, water availability & water quality), crop type, type of technology, previous experiences, required labour inputs etc. Good yield of crops can be obtained from irrigated land only if the water is applied judiciously to meet the needs of the plant. Fig. provides a brief classification of surface irrigation methods.

Irrigation Method can be broadly classified into three categories.

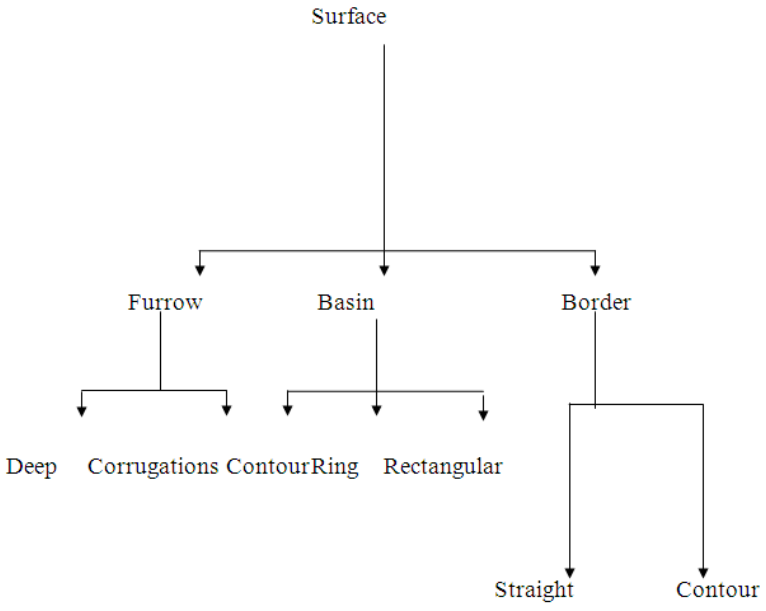


Fig. 8.2 Classification of surface irrigation methods.

8.2 BORDER IRRIGATION METHOD

In case of border irrigation, the field is divided into a number of long parallel strips, generally 5 to 15 m in width and 75 to 300 m in length separated by small border ridges or low dykes of about 15 cm.

Irrigation water is released into each strip connected directly to irrigation channel situated at the upstream end of the border strip. The sheet of water advances towards the downstream (Fig 8.3). After sufficient water is applied to one strip, the irrigation stream is turned into another strip. A specific requirement in border irrigation is that the longitudinal slope must be uniform, and the transverse slope must be zero or negligible (< 0.03%). This method is suitable for irrigating a wide variety of close growing crops such as wheat, barley, groundnut, bajra and berseem.

Border irrigation is suited to all crops that are not damaged by inundation for short periods. It can be used on nearly all irrigable soils but is best suited to soils whose intake rates are neither extremely low nor extremely high.

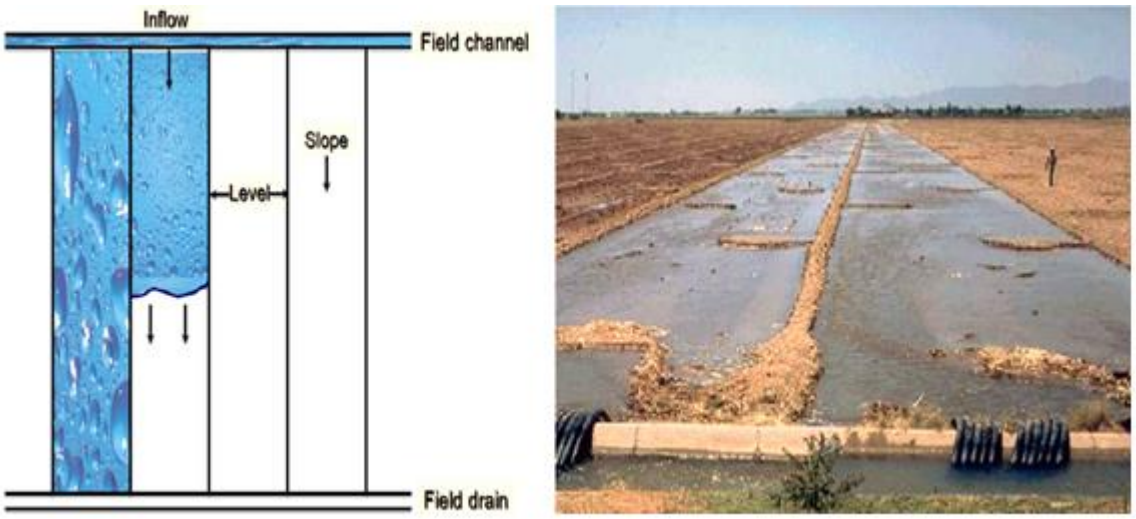


Fig.8.3 Border irrigation method.

\

Two types of borders are formed:

8.2.1. Straight Border

These borders are formed along the general slope of the field. These are preferred when fields can be levelled or be given a gentle slope economically.

8.2.2. Contour Border

These are formed across the general slope of the field and are preferred when land slope exceeds the safe limits. Based on the management strategy adopted, borders can be grouped into three major categories which are fixed flow, cutback and tail water reuse.

Advantages:

- ✓ Large water streams can be used safely
- ✓ Provides uniform wetting of soil profile
- ✓ Low labour requirement

Disadvantages:

- o Requires relatively large water streams for quick advance of water to minimize deep percolation losses at the upper end of the border strip.
- o Wastage of water by deep percolation in coarse textured soils.

8.3 DESIGN CONSIDERATIONS

8.3.1 Layout

The border strips are so located that a supply channel or pipeline delivers water to the upper end of the border. It is also suggested that the border strips are constructed parallel to the filed boundary to facilitate the intercultural operations. For long fields with soils having high infiltration capacity more than one border strip should be constructed along the entire length of the field. The main factors to be considered during the design of layout are given below:

8.3.2 Water Source Location

It is desirable to choose a water source in the central position of the filed to minimize the construction of channel and pipes also keeping in mind the fact that the water source should be in a position to facilitate the gravity flow to the field channels.

8.3.3 Border Strip Width

Border strip widths suitable for any particular field depend on (1) available stream size (2) amount of cross slope that must be removed, (3) kind of equipment used, and (4) accuracy of land levelling as related to the normal depth of flow expected.

The width of a border usually varies from 3 to 15 meters, depending on the size of irrigation stream available and the degree of land levelling practicable.

8.3.4 Border Strip Length

Longer border strip are desirable to reduce the labour and other operating costs, however the aspect of uniformity and application efficiency of the border strip should be kept in mind while determining the length of the border. Long border strips are easier to farm than short strips because fewer turns by farm equipment are required. Soil type is the most important aspect which determines the length of the border. Typical border lengths for different soils are given in Table 8.1.

Table 8.1 Recommended border length for different type of soil for moderate slopes and small to moderate size irrigation streams

Type of soils	Border length, (m)
Sand	60 to 90
Loamy sand	75 to 150
Sandy loam	90 to 250
Clay loam	90 to 300
Clay	180 to 350

8.4 Hydraulics and design of Border Irrigation (Israelson's equation only)

Israelsen (1955) proposed the following equation based on volume-balance approach (Fig.8.2)

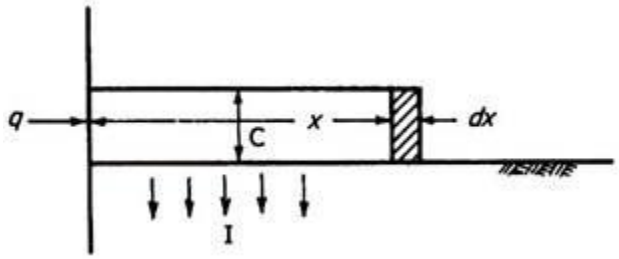
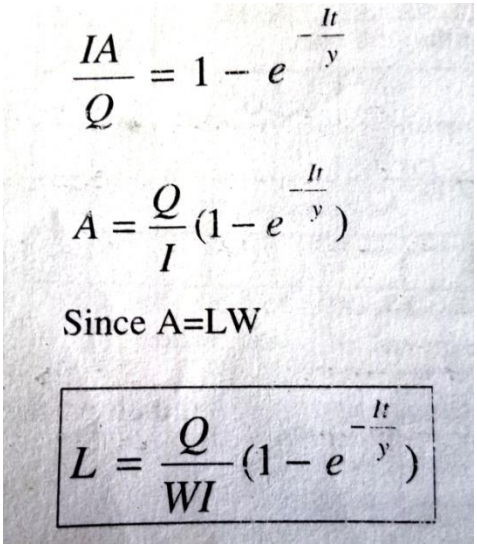


Fig.8.2 Definition Sketch for Volume Balance method

$$q \cdot dt = I \cdot x \cdot dt + c \cdot dx$$

where, q = inflow per unit width of border,
I = infiltration rate (assumed constant),
x = distance of water advance in time t, and
c = depth of surface flow (assumed constant).



$$\frac{IA}{Q} = 1 - e^{-\frac{It}{y}}$$

$$A = \frac{Q}{I}(1 - e^{-\frac{It}{y}})$$

Since A=LW

$$L = \frac{Q}{WI}(1 - e^{-\frac{It}{y}})$$

Where,

A=area of border

Q=constant discharge rate

y= constant depth of flow

I= constant infiltration rate

dt- time increment

L= Length of the border

W= Width of the border

LECTURE 9

Check basin irrigation method- Types, Advantages and Disadvantages, Adaptability and Design Considerations

9.1 BASIN IRRIGATION SYSTEM

Basin irrigation is a class of surface irrigation methods in which area is divided into number checks or basins.

Basin irrigation design is simpler than either furrow or border design since tail water is prevented from the existing field and the slopes are usually very small or zero. Thus, recession and depletion are accomplished at the same time and nearly uniform over the entire basin. Because longitudinal and transverse slopes are small or zero, the driving force in the flow is limited to the hydraulic slope of the water surface. Consequently, the uniformity of the field surface topography is critically important.

Check basin irrigation is suited for smooth gentle and uniform land slopes and for soils having moderate to low infiltration rates. Steep slopes require complex layouts and heavy land leveling. Both row crops and close-growing crops are adopted to be used with basins as long as the crop is not affected by temporary inundation or is planted in raised beds so that it will remain above the water level. The method is specially adopted for irrigation of grain and fodder crops in heavy soils where water is absorbed slowly and is required to stand for a relatively long time to ensure adequate irrigation.

Check basins are useful when leaching is required to remove salts from the soil profile. The method enables the conservation of rainfall and reduction in soil erosion by retaining a large part of the rain in the basin to be infiltrated gradually, without loss due to surface runoff. The method usually results in high water application and distribution efficiencies if the desired net depth of irrigation can be estimated adequately and if the size of the irrigation streams measured properly.

9.2 DESIGN CONSIDERATIONS

Check basins are necessarily rectangular or square areas with bunds constructed around the area to control the irrigation water. However for rolling topography the

bunds are constructed along the contours and are intersected at definite intervals by cross ridges. The size of the area may vary widely (1 sq. m to 2 ha), based upon the crop, available water supply, soil infiltration characteristics and other local factors. For soils with high infiltration capacity (loam and sandy loam) large sized basins may prove to be uneconomical and inefficient (in terms of irrigation efficiencies). However for clay soils with lower infiltration rates the size can of the check basin can be increased. The height of the bund depends on the amount of water to be retained while its width depends mainly on the bearing strength of the soil.

9.2.1 Layout

In order to maximize the spacing between supply channels it is desirable that the long axis of the basin be perpendicular to the supply channel or pipe line (Fig. 9.1). The main factors to be taken into consideration are:

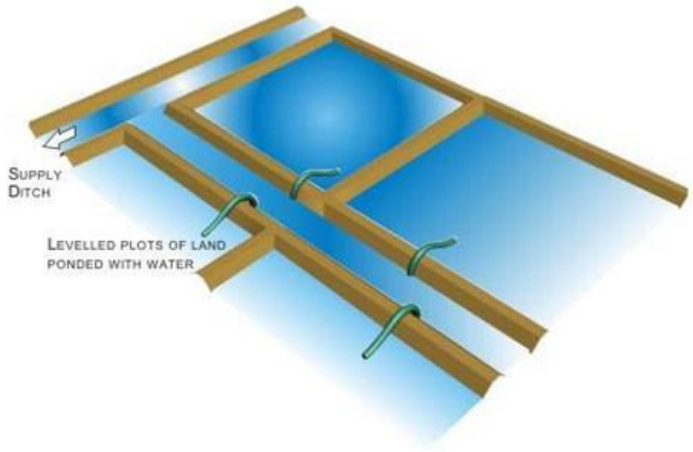


Fig. 9.1 Layout of check basin irrigation system.

9.2.2 Water Source Location

It is desirable to choose a water source in the central position of the filed to minimize the construction of channel and pipes also keeping in mind the fact that the water source should be in a position to facilitate the gravity flow to the field channels.

9.2.3 Terrain

Level land facilitates the construction of rectangular basin whereas in undulating topography the basin shapes are generally irregular. In case of high slopes terracing is done to obtain level basins.

9.2.4 Basin sizes

Basin dimensions are generally determined by the inflow stream size and the infiltration characteristics of the soil. Longer basins can be designed for fine textured soils whereas the basin size has to be kept small for sandy soils. The following table (Table) gives a rough estimate of the basin size for different soil types. However local factors and previous experience play a major role in the determinate of basin size.

Table.9.1Area of basins for different soil types

Slope %	Maximum width (m)	
	average	range
0.2	45	35-55
0.3	37	30-45
0.4	32	25-40
0.5	28	20-35
0.6	25	20-30
0.8	22	15-30
1.0	20	15-25
1.2	17	10-20
1.5	13	10-20
2.0	10	5-15
3.0	7	5-10
4.0	5	3-8

9.2.5 Basin Width

The main limiting factor for basin width is the slope of the land. For higher slopes the width should be small or else huge amount of earthwork would be necessary to level the land. The other factors which play an important role in the determination of basin width are depth of fertile soil, method of basin construction and agricultural practices.

If the topsoil is shallow, there is a danger of exposing the infertile subsoil when the terraces are excavated. This can be avoided by reducing the width of basins and thus limiting the depth of excavation. Basins are narrow if they are constructed by the hand

but they are wider when machines are used. The basins can be narrow if hand implements are used for intercultural operations however if machines are to be used for intercultural operations the width should be larger. Table gives a standard for the basin width in different slopes.

From the above discussions the following conclusions can be drawn:

Basins should be small if the

- Slope of the land is high
- Soil is highly permeable (sandy)
- Inflow stream is small in size
- Required depth of the irrigation is small
- Field preparation is done by hand or animal traction.

Basins can be large if the

- ✓ Slope of the land is gentle or flat
- ✓ Soil has low infiltration rate (clay)
- ✓ Inflow stream is large in size
- ✓ Required depth of the irrigation application is large
- ✓ Field preparation and intercultural operations are mechanized.

9.2 .6 Land Smoothening

The levelling of the land by the removal of high and low areas, which cause uneven infiltration, is essential to achieve higher irrigation efficiencies. The levelling of the land also facilitates the construction of supply channels and farm roads.

9.2.7 Stream Size

For level basins the maximum non erosive stream size should be used to achieve better uniformity and minimum deep percolation losses.

9.2.8 Irrigation Time

Irrigation time is the infiltration opportunity time. It is calculated from the empirical equations to calculate depth of infiltration noting that the cumulative

infiltration should be able to meet the irrigation requirements. The level of water in the field may be maintained by the use of check gates with the height of the shutter adjusted to the required depth of submergence.

9.2.9 Inflow Time

The time for which the water flows into the basin is called the inflow time. This is selected to allow the desired depth of infiltration taking place at the far end of the basin. In general this is the summation of the advance time and the time required to deliver the volume of water needed for adequate irrigation.

9.2.10 Ridge/Bunds Dimensions

Bunds form an important part of any basin. Bunds are small earthen borders which contain the irrigation water within the basin. The height of the bund is determined by the depth of irrigation to be maintained within the basin. The width of the bund should be such that the bund is stable.

Temporary bundsare usually 60-120 cm wide at the base and have a height of 15-30 cm above the original ground surface, including a freeboard of 10 cm (which means an irrigation depth of 5-20 cm). Temporary bunds are rebuilt each season and they surround fields on which annual crops are grown. Permanent bundsusually have a base width of 130-160 cm and a height of 60-90 cm when constructed. The settled height will be 40-50 cm. This settling (compaction of the soil) will take in several months. Permanent bunds are mostly used in rice cultivation, where the same crop is planted on the same fields year after year. The bunds are used as paths in the rice fields as well.

Water is conveyed to the field by a network of laterals which are fed by a main supply channel situated on the upper side of the field. Generally every two rows of check basins are fed by one lateral (Fig.9.2). The size of the inflow stream should be sufficient enough to cover the basin within a short period of time and provide adequate amount of water to supply the infiltration demands.

For irrigating widely spaced plants in the orchards ring basins may be used. In this method, generally for each tree, a separate basin is made which is usually circular in shape as shown in Fig. 9.2. The size of the basin may be increased as the plant

matures. The entire area is not flooded in the case of ring basin and hence the irrigation efficiency increases.

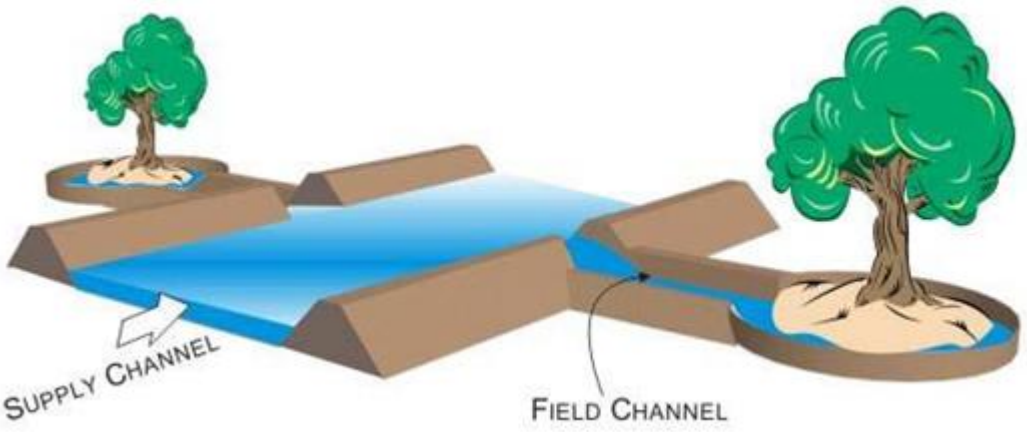


Fig.9.2 Layout of ring basin irrigation system.

9.3 HYDRAULICS OF CHECK BASIN

The irrigation event in the check basin can be considered to have the following four phases.

9.3.1 Initial spreading of the entrance stream to cover the full width

After the initiation of the stream into the field the stream spreads along the width of the border till the total width of the border is covered. The stream also advances along the slope during this period.

9.3.2 Water front advance

The water front advance takes place in almost similar manner to that of border irrigation. Land slope, surface roughness, soil type and stream size play the main role in determining the advance characteristics of the water front.

9.3.3 Water Storage

The ponding of water begins once the water reached the downstream end of the check basin. The volume of water stored during a time period is equal to the difference of the volume admitted to the basin and the amount of infiltration taking place.

9.3.4 Recession of Water

In case of check basin the recession of water takes place due to infiltration and the empirical infiltration equations can be used calculate the time required for complete subsidence of water.

Advantages

- Water can be applied uniformly.
- Even small streams can be used for irrigation of crops efficiently.
- Simple and cheap when equipment is used for constructing bunds.

Disadvantages

- Unless the land is levelled, distribution of water in plot is uneven.
- Considerable area is lost under field channels and bunds i.e. nearly 30% of area.
- Bunds interfere in working of inter-cultivation equipment
- More labour is required for field layout and irrigation

LECTURE 10

Furrow irrigation method- Types, Adaptability, Characteristics, Hydraulics and Design Considerations

10.1 FURROW IRRIGATION SYSTEM

Furrow irrigation is a class of surface irrigation methods in which water is field is divided into ridge and furrows. The crop is grown on the ridge whereas irrigation water is applied to the furrow.

10.2 ADAPTABILITY OF FURROW IRRIGATION

The adaptability of furrow irrigation to a specific site depends on climate, soils, topography, crops to be grown, and water supply.

10.2.1Climatic Factors

Precipitation and wind may affect suitability as well as the design criteria. Risk of surface runoff and excessive soil erosion due to excessive precipitation, concentrated runoff in the channels resulting in crop damage from flooding; these conditions must be considered in determining which furrow method is suitable for a given area.

10.2.2 Soil

Medium to moderately fine-textured soils of relatively high available water holding capacity are desirable. Intake characteristics should facilitate both lateral and vertical water penetration (Fig.10.1).Furrow irrigation generally is not recommended on soils containing high concentrations of salts.

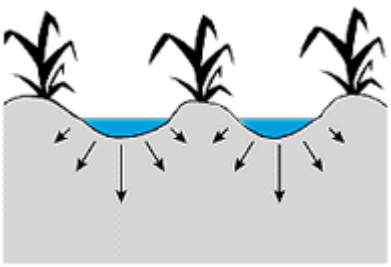


Fig.10.1 Lateral and vertical water movement during furrow irrigation.

10.2.3 Topography

The rows can be laid out on a continuous grade. The topography must be such that levelling does not expose unproductive soil or that the cost of levelling is not excessive. The topography must not be so steep that it exceeds the allowable corrugation grade or prohibits installation of graded contour furrows that meet the design grade and cross-slope criteria.

10.2.4 Crops

Adapted for nearly allirrigated crops except those grown in ponded water, such as rice. Suitable for irrigating crops subject toinjury if water covers the crown or stems of the plants.

10.2.5 Water Supply

The quantity and quality of the water supply determines its suitability for use in furrow irrigation.

10.3 HYDRAULICS AND DESIGN CONSIDERATIONS OF FURROW IRRIGATION

Efficient irrigation by furrow method is obtained by selecting proper combination of spacing, length, slope of furrows, suitable size of the irrigation stream and duration of water application.

10.3.1 Furrow Spacing

Furrows should be spaced close enough to ensure that water spreads to the sides into the ridge and the root zone of the crop, to replenish the soil moisture uniformly.

Table 10.1 Recommended furrow spacing for different soil types, and depths of irrigation for complete wetting

Soil type	Depths of irrigation (m)	Furrow spacing (cm)
Sandy soil	1 to 1.5	50 to 60
Clay soil	1 to 1.5	100 or more

10.3.2 Furrow Length

The optimum length of a furrow is usually the longest furrow that can be safely and efficiently irrigated. Proper furrow length depends largely on the hydraulic conductivity of soil. The length of furrow may be limited by the size and shape of the field.

Table 10.2 Recommended furrow length for different soil types, furrow slopes and depths of irrigation

Furrow slope (%)	Furrows length (m)						
	Slope type						
	Clay		loam		sands		
	Net depth of water application						
	7.5 cm	15cm	5 cm	10 cm	5 cm	7.5 cm	10 cm
0.05	300	400	120	270	60	90	150
0.10	350	440	180	330	90	120	190
0.20	370	470	220	370	120	190	250
0.30	390	500	280	400	150	225	280
0.50	380	500	280	370	120	190	250
1.0	270	400	250	300	90	150	220

10.3.3 Furrow Slope

Furrow slope controls the speed at which water flows down the furrow. A minimum slope of 0.05% is needed to ensure surface drainage. In general, the ranges in slope recommended for borders apply to furrows also.

10.3.4 Furrow Stream

The size of furrow stream usually varies from 0.5 to 2.5 litres per second.

The maximum size of irrigation stream that can be used at the start of the irrigation is limited by considerations of erosion in furrows, overtopping of furrows and prevention of runoff at the downstream end. The maximum non-erosive flow rate in furrows is estimated by the following empirical formula:

$$q_m = \frac{0.60}{s}$$

Where,

q_m = maximum non-erosive stream, $Lsec^{-1}$

s= slope of furrow expressed in percent

The average depth of water applied during irrigation can be calculated from the following relationship:

$$d = \frac{q \times 360 \times t}{w \times L}$$

Where,

d = average depth of water applied, cm

q= stream size, Ls^{-1}

t= duration of irrigation, h

w = furrow spacing, m

L= furrow length, m

Example 10.1:

A non-erosive stream is applied for a period of 15 minutes in a furrow of 80 m long spaced 65 cm apart and having a slope of 0.15 %. Determine the average depth of water applied?

Answer:

In case of furrow irrigation non-erosive stream,

$$q_m = \frac{0.60}{0.15} = 4\ L/s$$

Where,

q_m= maximum non-erosive stream, litres per second

s= slope of furrow expressed as a percent

So,

In a furrow 4lt/s water is applied.

Average depth of water applied,

Where, $d = \frac{q \times 360 \times t}{w \times L}$

d = average depth of water applied, cm

q= stream size, Ls^{-1}

t= duration of irrigation, h

w = furrow spacing, m

L= furrow length, m

Now, $d = \frac{q \times 360 \times t}{w \times L} = \frac{4 \times 360 \times 0.25}{0.65 \times 80} = 6.92\ cm$

LECTURE 11

Waterlogging- Introduction, forms of excess water, Effects, causes & impacts, Approach to drainage problems, Interrelationship of irrigation and drainage

11.1 DEFINITION, CLASSIFICATION AND IMPACT OF WATERLOGGING

11.1.1 Definition of Waterlogging

Generally, the term '**waterlogging**' refers to the condition of a land (soil) in which the water table comes within or very near the root zone due to which crop yields decrease below the normal yield or the land cannot be used for cultivation. The soil becomes waterlogged when the water fills up all the pore space present in the soil profile, and it remains waterlogged when drainage facility is inadequate or absent. This type of waterlogging is quite common in irrigated agricultural lands and is known as '**subsurface waterlogging**' or simply '**waterlogging**'. According to FAO (FAO, 1973), waterlogged areas are those where soils are temporarily saturated or where the water table is too shallow such that capillary rise of groundwater encroaches upon the root zone and may even reach the soil surface. Moreover, waterlogging also occurs when water is stagnant on the land surface for considerable time due to absence of a proper outlet and insignificant infiltration. This type of waterlogging is known as '**surface waterlogging**'.

11.1.2 Classification of Waterlogging

The working group on problem identification in Irrigated Areas, constituted by the Ministry of Water Resources, Government of India (MOWR, 1991) adopted the following norms for the identification of waterlogged areas:

(i) Waterlogged Area: Water table within 2 m from the land surface.

(ii) Potential Area for Waterlogging: Water table between 2-3 m from the land surface.

(iii) Safe Area: Water table below 3 m from the land surface.

The above categorization does not consider the time of the year or type cropping season in relation to the water table depths and runoff accumulation over the crop land. Crops vary greatly in their rooting depth and susceptibility to waterlogging. The dry season crops are more susceptibility to waterlogging than the wet season crops.

Therefore, it will be useful if the categorization of waterlogged areas is linked with the crop season or time of the year. The common approaches to express the water table depth from the soil surface are:

(a) pre-monsoon (April/May) depth to water table,

(b) post-monsoon (October/November) depth to water table,

(c) seasonal (monsoon/winter/summer) or annual average depth to water table, and

(d) sum of the number of days when water table is shallower than a specified depth.

Out of these four approaches, the first two are the simplest approaches to express the water table depth from the soil surface.

A deep water table at pre-monsoon reduces the chances of soil salinization and ensures successful crop production during monsoon (kharif) season. A deep water table in the post-monsoon period helps maintaining timeliness of field operations for the winter (rabi) season crops. Keeping these facts in view, the following norms are suggested for the classification of different categories of waterlogged areas in India and other South Asian countries (Bhattacharya and Michael, 2003):

(i) Waterlogged Area: Water table is within 2 m from soil surface during pre-monsoon (April/May) or water table is within 1 m from soil surface during post-monsoon (October/November).

(ii) Critical Area for Waterlogging: When the water table is between 2 and 3 m from the soil surface during pre-monsoon and/or between 1 and 2 m during post-monsoon, it is considered as critical. In a critical area, waterlogging condition may develop within a short period of time if suitable measures are not adopted. Such measures are location specific and may comprise providing a drainage system, land development and scientific management of irrigation water.

(iii) Potential Area for Waterlogging: In monsoon Asia, irrigated areas with water table between 3 and 5 m during pre-monsoon may be considered as potential areas for waterlogging.

11.1.3 Impacts of Waterlogging

The physical effects of waterlogging are: (i) lack of aeration in the root zone, (ii) difficulty in soil workability, and (iii) deterioration of soil structure. If the waterlogging prolongs for considerable time, it produces its chemical effect which is known as soil salinization. Both waterlogging and soil salinity adversely affect the growth and yield of crops (Figs. 11.1, 11.2 and 11.3). The extent of crop damage depends upon the magnitude, duration and frequency of the waterlogged condition and the degree of soil salinity.

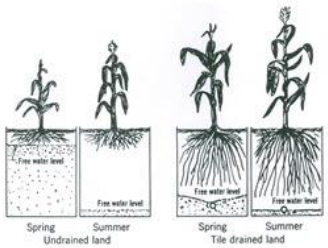


Fig. 11.1 Root development of crops on drained and undrained land

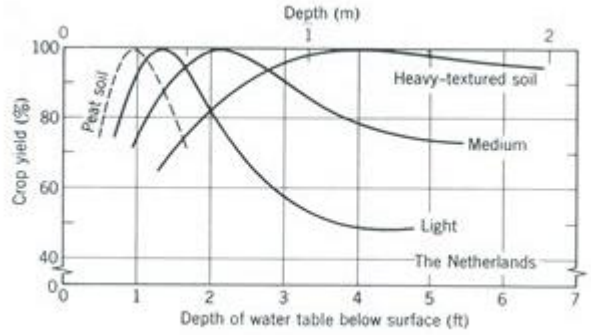


Fig. 11.2. General relationship between crop yield and constant water table depth during growing season in the Netherlands.

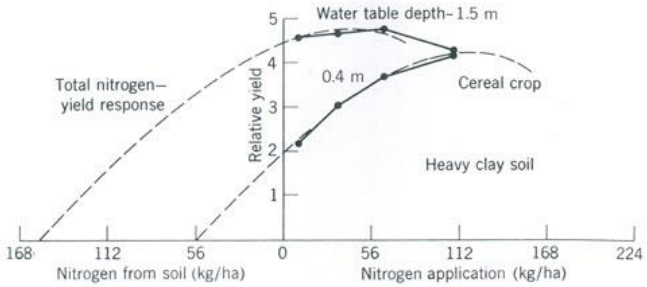


Fig. 11.3 Influence of water table depth on nitrogen supplied by the soil

11.1.3.1 Salt Build-up in Soils

Soluble salts in the parent rocks which have weathered to form soil, seawater intrusion and high evaporation are the major natural causes for the salinisation of agricultural lands. Under a monsoon climate much of the accumulated salts are washed or leached out during the rainy season. However, high evaporation during the remaining dry and hot months in the year draws up the saline groundwater at shallow depths towards the land surface. The salts are left behind after the water evaporates (Fig. 1.4). Furthermore, important anthropogenic causes for salinity development are the use of poor quality water for irrigation and the excess application of irrigation water.

Salt problem is a major cause of decreasing agricultural production in many of the irrigated areas. Irrigation with water of low salinity but with dominant anion, and migration of sodic salts in arid climate promote salinity. The main causes of soil salinity and sodicity (alkalinity) are: (i) irrigation mismanagement; (ii) poor land leveling; (iii) leaving land fallow during dry periods especially in regions of shallow water table; (iv) improper use of heavy machinery resulting in soil compaction; (v) leaching without adequate drainage, and (vi) adoption of improper cropping patterns and crop rotations. In irrigated agriculture, scientific management of water and land is the key to avoid waterlogging and salt problems.

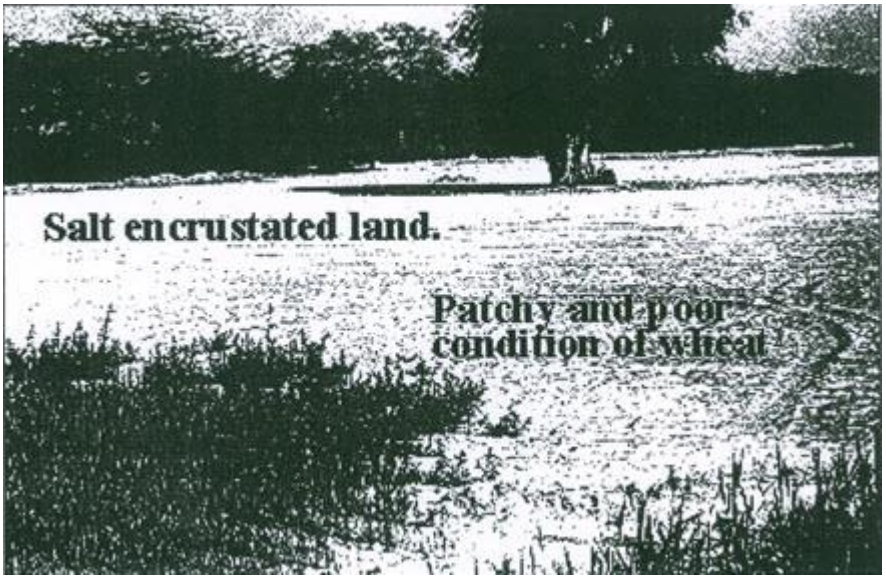


Fig. 11. 4. Surface salt due to evaporation from shallow and saline groundwater

Salinity is a major problem in many non-irrigated areas also where cropping is based on limited rainfall. In rainfed agriculture, surface drainage is required to prevent waterlogging and flooding of low lands which lead to soil salinity hazards. Salinity in dryland areas has been a threat to land and water resources in many parts of the world. In rainfed agricultural lands of coastal areas, seawater intrusion is the main cause of salinization during dry periods. In semi-arid areas of the world, the scarcity and the variability of rainfall and high potential evapotranspiration affect the water and salt balance in the soil. Low humidity, high temperature, and high wind velocity induce upward movement of soil solution resulting in a high concentration of salts at the land surface and within the root zone. In arid regions, various types of Sodium, Magnesium and Calcium salts are concentrated mainly in Chloride and Sulphate forms. In less arid regions, Sodium salts in the Carbonate and Bicarbonate forms enhance the formation of sodic soils due to the adsorption of Sodium in the soil exchange complex.

11.1.3.2 Drainage Problems in Rainfed Areas

The progress of the net sown area and its break-up into un-irrigated and irrigated areas in India is shown in Fig. 11.5. Although the un-irrigated area has decreased with increasing irrigation development, about 80 Mha of the cropped land is still un-irrigated (rainfed). As the pace of irrigation development has slowed down in recent years, much of the cultivated area may remain un-irrigated in the future. Thus, it is irrigation rather than drainage which should be of concern for rainfed areas. However, due to the diversity of climate and soil, even rainfed areas experience excess water during

monsoon season and excess salts during dry season (non-monsoon season). For example, land inundation during the monsoon season and high soil salinity during the dry season prevent cultivation in the coastal areas of Medinipur District, West Bengal. Vast flat lands in south-western Haryana and south-western Punjab, despite a low annual rainfall, get waterlogged due to sudden rains and lack of drainage to clear out the runoff fast. Lands in the plains of Bihar and Uttar Pradesh (U.P.) are uncultivable during monsoon due to excess water. Thus, drainage is relevant even in the un-irrigated areas to ensure crop production.

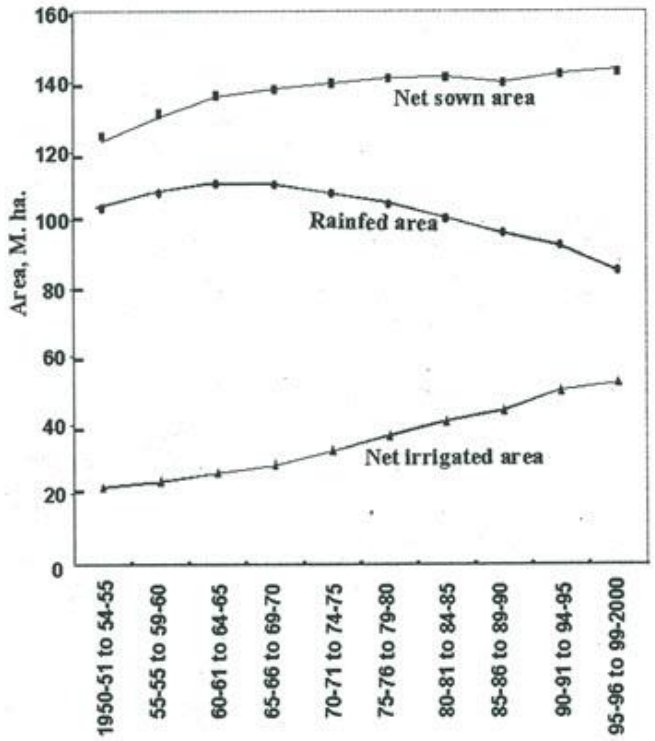


Fig. 11.5. Progressive development of net sown, irrigated and rainfed areas in India during 1950-2000

11.1.3.3 Technical Limitations and Current Status of Land Drainage

Making major changes in the physical, morphological, and chemical properties of the land and water resources are infeasible. Equally infeasible is to change the climate of a region. However, the occurrence of waterlogging and salinity problems can be substantially reduced when proper attention is given to the factors listed above. The man-made causes, which are mainly concerned with the development and use of land and water resources, are theoretically easier to prevent and even to rectify. The rectification is, however, expensive, and the prevention has proved to be elusive up to

now. Therefore, we are seriously concerned about the adverse impacts of waterlogging and salinity on agricultural production. Also, agriculture sector needs a serious attention because of the fact that while land and the water resources are limited in quantity and degradable, human population is gradually increasing in most Asian and African countries. This necessitates more agricultural productivity per unit of land and water, which will be possible only if further deterioration of land and water resources is avoided or minimized, degraded lands are reclaimed and these two vital resources are utilized judiciously.

Among the various activities in the agricultural production system, drainage is perhaps the most neglected in India as well as in many other developing countries. The misuse of irrigation water is slowly but inevitably leads to drainage problems. Of great relevance in the context is the history of land and groundwater degradation due to their unscientific use in different parts of the world. In 1876, the Reh Commission had cautioned against undermining the importance of agricultural drainage in the irrigated areas of India. According to (Bower and Hufschmidt, 1984), irrigation and drainage, as practiced in the developing countries, is functionally inefficient, technology primitive, economically unremunerative and environmentally degrading. Also, in the past, there have been an unspecified number of recommendations of a large number of seminars and symposia, highlighting the necessity of land drainage in enhancing and sustaining agricultural production. Most recently, there are the crisp observations of the Standing Committee of Agriculture (Lok Sabha Secretariat, 1996) of the 11th Lok Sabha of India, on the undesirable neglect of the agricultural drainage in the irrigated areas of India. Thus, modernization of irrigation and drainage is urgently needed in India as well as in many other developing countries across the world.

11.2 APPROACH TO DRAINAGE PROBLEMS

The progress of the net sown area and its break-up into unirrigated and irrigated areas in India is shown in Fig. (FAI, 1998). Although the unirrigated area has decreased with increasing irrigation development, about 80 Mha of the cropped land is still unirrigated (rainfed). As the pace of irrigation development has slowed down in recent years, much of the cultivated area may remain unirrigated in the future. Thus, it is irrigation rather than drainage which should be of concern for rainfed areas. However, due to the diversity of climate and soil, even rainfed areas experience excess water during monsoon season and excess salts during dry season (non-monsoon season). For

example, land inundation during the monsoon season and high soil salinity during the dry season prevent cultivation in the coastal areas of Medinipur District, West Bengal. Vast flat lands in south-western Haryana and south-western Punjab, despite a low annual rainfall, get waterlogged due to sudden rains and lack of drainage to clear out the runoff fast. Lands in the plains of Bihar and Uttar Pradesh (U.P.) are uncultivable during monsoon due to excess water. Thus, drainage is relevant even in the unirrigated areas to ensure crop production.

11.2.1 Drainage Problems in India

Waterlogging and salt accumulation are major constraints to sustainable agricultural production in most countries of the world, especially in developing countries (including India). In India, drainage problem is acute in the states of Punjab and Haryana, while it also prevails in the command areas of other states. Broadly speaking, waterlogging is a situation of an agricultural land when the root zone gets saturated. Such a condition restricts normal air circulation, reduces the oxygen level and increases carbon dioxide level in the root zone. On the other hand, salt affected soils are those in which the concentration of salts in the root zone adversely affects the normal root activity. Both the waterlogging and salt affected soils produce detrimental effects on crop growth and yield as well as cause environmental degradation. Waterlogging and salinity of agricultural lands are caused due to natural causes or artificial causes (i.e., human interventions). Important natural causes are high rainfall during the rainy season, unfavourable topography, backwater entry from rivers, seawater intrusion, high evaporation during long dry periods, and the salts present in the soil. On the contrary, important human factors are unscientific management of land and irrigation water, use of poor-quality water for irrigation, adoption of unscientific and non-sustainable cropping pattern, and obstruction of natural outlets because of urbanization and construction of highways and railways.

11.3 INTERRELATIONSHIP OF IRRIGATION AND DRAINAGE

Irrigation and drainage constitutes a subset of water resources system and are crucial for human survival Land drainage, or the combination of irrigation and land drainage, is one of the most important input factors to maintain or improve agricultural productivity. To enlarge the present cultivated area, more land must be reclaimed than the land that is lost due to urban/industrial development, roads and land degradation.

However, in some areas, land is a limiting resource, whereas in other areas, agriculture cannot expand at the cost of nature.

Drainage is a reverse process of irrigation. It is broadly defined as the removal (disposal) of excess water from a land (usually agricultural land). The terms '**drainage**', '**land drainage**', '**agricultural drainage**' and '**field drainage**' are used as synonyms in practice. Since drainage (land drainage) is necessary not only for the removal of excess surface water or groundwater but also for removing salts from the soil, a precise definition of drainage has been given by the constitution of the International Commission on Irrigation and Drainage (ICID, 1979). According to ICID (1979), land drainage is defined as follows:

"Land drainage is the removal of excess surface and subsurface water from the land to enhance crop growth, including the removal of soluble salts from the soil".

LECTURE 12

Surface drainage system -Definition, Types and Applications of surface drainage methods- Design of open ditches (Mannings's Equation)

12.1 INTRODUCTION

Drainage can be either natural or artificial. Natural drainage is often inadequate, and hence artificial (man-made) drainage is required. There are two types of artificial drainage: surface drainage and subsurface drainage (FAO, 1985). Broadly speaking, surface drainage is the removal of excess water from the surface of the land. It is the oldest drainage practice and is defined as (ICID, 1982):

"The diversion or orderly removal of excess water from the surface of land by means of improved natural or constructed channels, supplemented when necessary by shaping and grading of the land surface to such channels".

Surface drainage is applied primarily on flat lands where slow infiltration, low permeability, or restricting layers in the profile prevent the ready absorption of high-intensity rainfall. Therefore, this drainage system is intended to eliminate ponding and prevent prolonged saturation by accelerating flow to an outlet without causing soil erosion or siltation. Two primary methods of surface drainage are land grading and field ditches. The selection of surface drainage facilities for individual field areas depends largely on the topography, soil characteristics, crops, and availability of suitable outlets. Note that surface drainage may be required even though subsurface drains are installed.

12.2 TYPES OF DRAINAGE SYSTEMS

Three most commonly used techniques for removing (draining) excess water are: (a) surface drainage, (b) subsurface drainage, and (c) vertical drainage (also known as 'tube well drainage'). Besides these conventional drainage techniques, there is an emerging non-conventional drainage technique known as bio-drainage. An introduction to the conventional drainage techniques is presented below, and their details are provided in later lessons.

12.3.1 Surface Drainage

Surface drainage can be defined as “Surface drainage is the removal of excess water from the soil surface in time to prevent damage to crops and to keep water from ponding on the soil surface, or, in surface drains that are crossed by farm equipment, without causing soil erosion”. Surface drainage is a suitable technique where excess water from rainfall or surface irrigation cannot infiltrate into the soil and move through the soil to a drain, or cannot move freely over the soil surface to a natural/artificial drainage channel. Surface drainage problems occur in flat or nearly flat areas, in the areas having uneven land surfaces with depressions or ridges preventing natural runoff, and in the areas where there is no outlet.

12.3.1 Types of surface drainage system

12.3.1.1 Random Field Drain System

Random field drains are best suited to the drainage of scattered depressions or potholes where the depth of cut is not more than 1 m. In cross section, they are a flat ‘V’ or parabolic in shape (Schwab et al., 2005). The layout of a typical random field drain system is shown in Fig. 12.1. The design of field drains is similar to the design of grass waterways. Where farming operations cross the channel, the side slope should be flat, i.e., 8:1 or greater for depths of 0.3 m or less and 10:1 or greater for depths over 0.6 m. Minimum side slope of 4:1 is desired if the field is farmed parallel to the ditch.

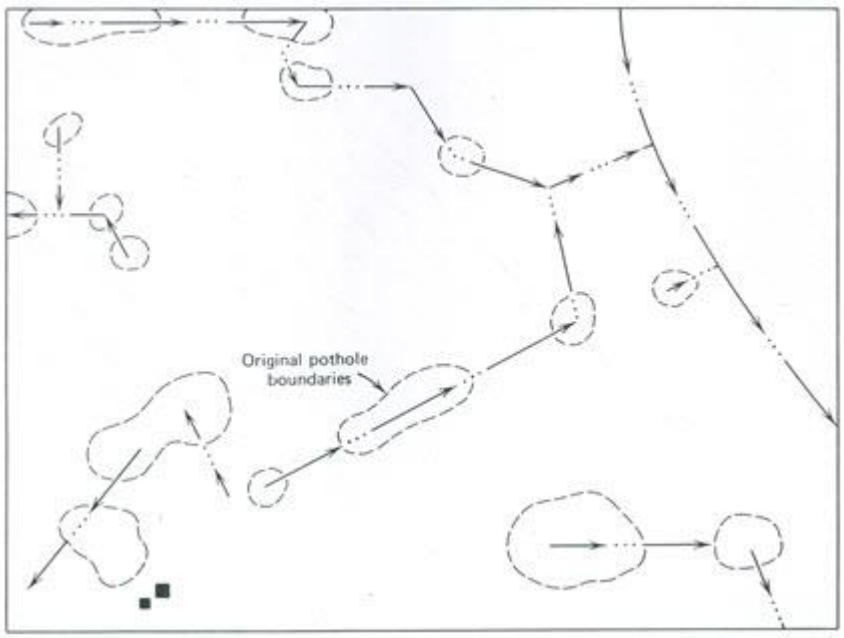


Fig. 12.1. A random field drain system. (Source: Schwab et al., 2005)

The depth is determined primarily by the topography of the area, outlet conditions, and capacity of the channel. The grade in the channel should be such that the velocity does not cause erosion or sedimentation. Minimum velocities vary with the depth of flow; however, these range from about 0.3 to 0.6 m/s for depths of flow less than 1 m. The maximum grade for sandy soil is about 0.2% and for clay soils, 0.5%. The minimum grade is 0.05%. The roughness coefficient in the Manning's equation may be taken as 0.04, if more reliable coefficients are not available. The capacity of the drain is usually not considered for areas less than 2 ha provided the minimum design specifications are met. However, where the area is larger than 2 ha, the capacity should be based on a 10-year return period storm, making allowances for minimum infiltration and interception losses. Since most field crops are able to withstand inundation for only a short period without damage, it is desirable to remove surface water within 12 to 24 hours.

Generally, the channel should follow a route that provides minimum cut and least interface with farming operations. The outlet for such a system may be a natural stream, constructed drainage ditch, or protected slope if no suitable ditch is available. Where the outlet is a broad, flat slope, the water is permitted to spread out on the land below. This type of outlet is practical only if the drainage area is small.

12.3.1.2 Bedding Field Drain System

Bedding is a method of surface drainage consisting of narrow-width plow lands in which the dead furrows run parallel to the prevailing land slope (Fig. 12.2). The area between two adjacent dead furrows is known as a bed. Bedding is most practicable on flat slopes less than 1.5%, where the soils are slowly permeable and pipe drainage is not economical. Studies have shown that the leveled land provides slightly better yield than the bedded land (Schwab et al., 2005).

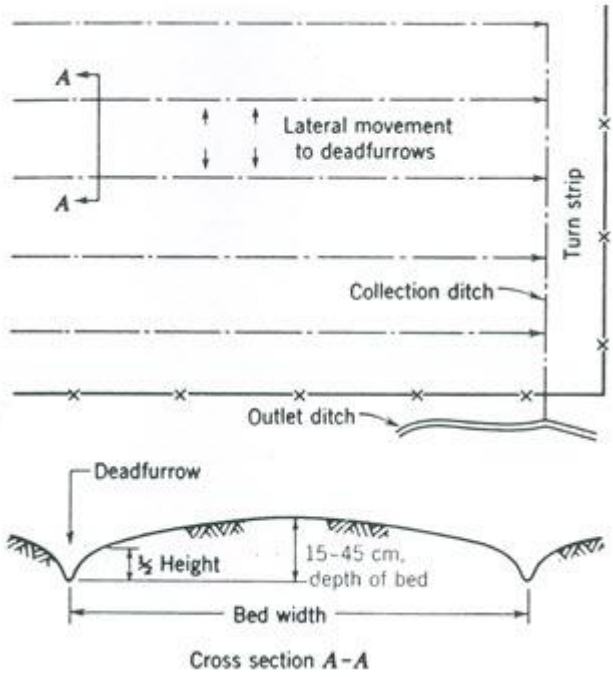


Fig. 12.2. Bedding field drain system. (Source: Schwab et al., 2005)

The design and layout of a bedding system involves the proper spacing of dead furrows, depth of bed, and grade in the channel. The depth and width of the bed depend on land slope, drainage characteristics of the soil, and cropping system. Bed widths recommended for the Corn Belt region of the United States vary from 7 to 11 m for very slow internal drainage from 13 to 16 m for slow internal drainage, and from 18 to 28 m for good internal drainage. The length of the beds may vary from 90 to 300 m. In the bedded area, the direction of farming operation may be parallel or normal to the dead furrows. Tillage practices parallel to the beds have a tendency to retard water movement to the dead furrows. Plowing is always parallel to the dead furrows.

12.3.1.3 Parallel Field Drain System

Parallel field drains are similar to bedding except that the channels are spaced farther apart and may have a greater capacity than the dead furrows. This system is well adapted to flat, poorly drained soils with numerous small depressions that must be filled by land grading (Schwab et al., 2005).

The design and layout are similar to those for bedding except that drains need not be equally spaced and the water may move in only one direction. The layout of such a field system is shown in Fig. 12.3. As in bedding, the turn strip is provided where ditches border a fence line. The size of the ditch may be varied, depending on grade,

soil, and drainage area. The depth of the ditch should be a minimum of 0.2 m and have a minimum cross-sectional area of 0.5 m^2. For trapezoidal cross sections, the bottom width should be 2.4 m (ASAE, 1986). The side slopes should be 8:1 or flatter to facilitate crossing with farm machinery. As in bedding, plowing operations must be parallel to the channels, but planting, cultivating, and harvesting are normally perpendicular to them. The rows should have a continuous slope to ditches. The maximum length for rows having a continuous slope in one direction is 180 m, allowing a maximum spacing of 360 m where the rows drain in both directions. In very flat land with little or no slope, some of the excavated soil may be used to provide the necessary grade; however, the length and grade of the rows should be limited so as to prevent damage by erosion. On highly erosive soils that are slowly permeable, the slope length should be reduced to 90 m or less.

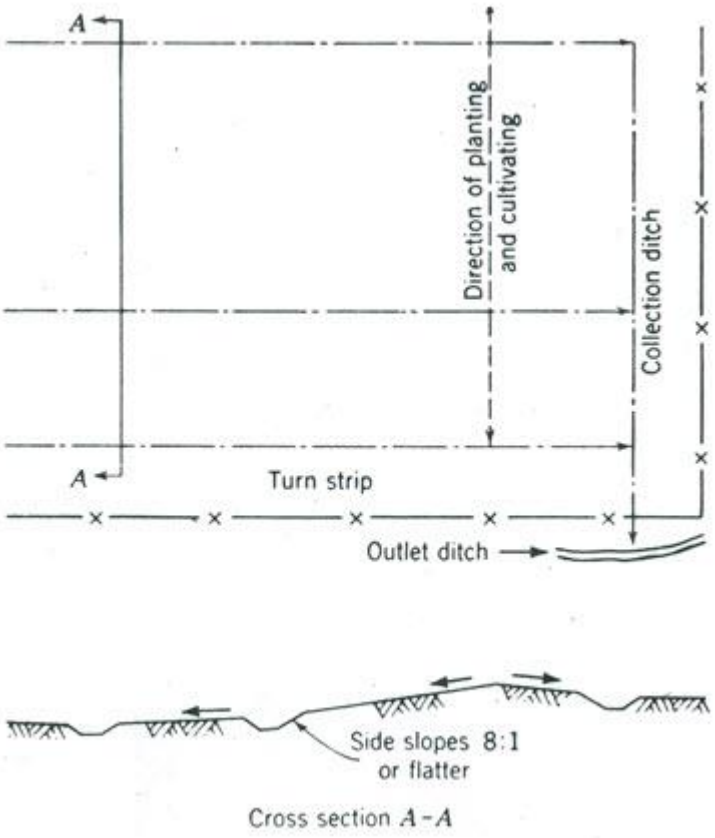


Fig. 12.3 Parallel field drain system. (Source: Schwab et al., 2005)

The cross section for field drains may be V-shaped, trapezoidal, or parabolic. The W-drain shown in Fig. 1.2.4 is essentially two parallel single ditches with a narrow spacing. All of the spoil is placed between the channels, making the cross section similar to that of a road. The advantages of the W-drain are that it: (i) allows better row

drainage because spoil does not have to be spread, (ii) may be used as a turn row, (iii) may serve as a field road, (iv) can be constructed and maintained with ordinary farm equipment, and (v) may be seeded to grass or row crops. On the other hand, the disadvantages of the W-drain are that: (i) the spoil is not available for filling depressions, (ii) a greater quantity of soil must be moved, and (ii) a larger area is occupied by drains. The minimum width for W-drains varies from about 5 to 30 m depending on the size. The W-drain is best adapted to relatively flat land where the rows drain from both directions.

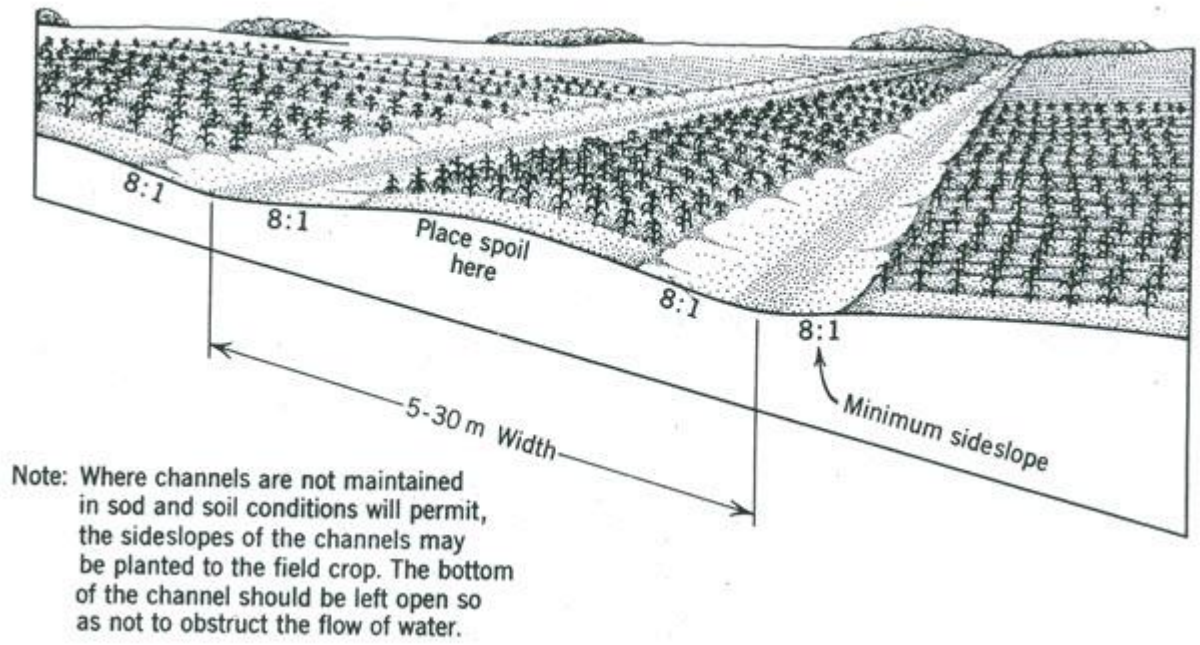


Fig. 12.4. W-drain or double field drain for surface drainage

12.3.1.4 Parallel Lateral Ditch System

The parallel lateral ditch system is similar to the field drain system except that the ditches are deeper. These drains shown in Fig. 12.5 cannot be crossed with farm machinery. For clarity, the minimum size for open ditches is 0.3 m deep and side slopes are steeper than 6:1. The purpose of lateral open ditches is to control the water table and to provide surface drainage. These ditches are applicable for draining peat and muck soils to obtain initial subsidence prior to subsurface drainage. For the same depth to water table, ditches provide the same degree of surface drainage as pipe drains.

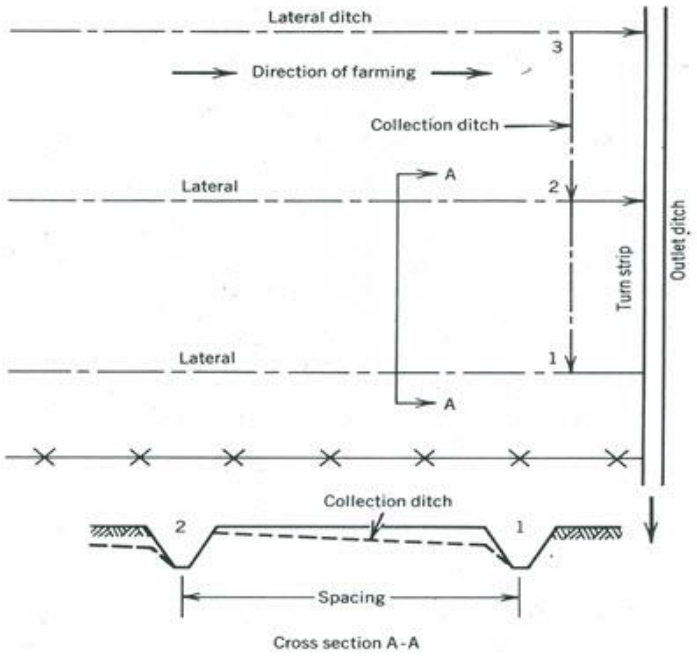


Fig. 12.5 Parallel lateral ditch system for water table control and surface drainage.

The design specifications for lateral ditches are given in Table 12.1. Since lateral ditches are considerably deeper than collection ditches, over fall protection must be provided at outlets 1 and 2 as indicated in Fig. 3.8. This protection may be obtained with a suitable permanent structure, by providing a gradual slope near the outlets, or by establishing a grassed channel. Since these ditches are too deep to cross with farm machinery, farming operations must be parallel to the ditches. A collection ditch, row drain, or quarter drain should be provided for row drainage. As in other methods of drainage on flat land, the surface must be graded and smoothed and large depressions filled or drained by random field ditches.

Table 12.1. Ditch specifications for water table control

Sl. No.	Parameter	Sandy Soil	Other Mineral Soils	Organic Soils, Peat and Muck
1	Maximum Spacing	200 m	100 m	60 m
2	Minimum Side Slope	1:1	:1	Vertical to 1:1[a]
3	Minimum Bottom Width	1.2 m	0.3 m	0.3 m
4	Minimum Depth	1.2 m	0.8 m	0.9 m

For water table control during dry seasons, dams with removable crest boards are placed at various points in the open ditches to maintain the water surface at the required level. During wet seasons, the crest boards are removed and the system provides surface drainage (Schwab et al., 2005). In highly permeable soils such as sands, peat, and muck, crop yields may be increased by controlled drainage. Deep permeable soils underlain with an impervious material provide the best conditions for successful water table control. The water level may be regulated by gravity, pumping, or a combination of gravity drainage and pumping. The depth at which the water table is to be maintained depends mainly on the crop to be grown, soil type, topography, seasonal conditions, and climatic conditions. Note that in organic soils, a high water table is desirable to provide water for plant growth, to control land subsidence, and to reduce fire and wind erosion hazards. In these soils, the water table should be maintained from 0.5 to 1.2 m below the soil surface depending on the crop type (Schwab et al., 2005).

12.3.1.5 Cross-Slope Ditch System

The drainage of sloping land may be feasible with cross-slope ditches. Such channels usually function both for surface drainage and for erosion control. Where designed specifically for the control of erosion, these drains are called terraces. Diversion ditches are sometimes used to divert runoff from low-lying areas, thereby reducing the drainage problem.

The cross-slope ditch system is adapted primarily to soils with poor internal drainage where subsurface drainage is not practicable and for land with slopes of 4% or less having numerous shallow depressions (Schwab et al., 2005). This land is generally too steep for bedding or field drains because farming up and down the slope results in excessive erosion.

12.3.2 Subsurface Drainage

Subsurface drainage is defined as ‘the removal of excess soil water in time to prevent damage to crops because of a high water table’. Subsurface drainage problems occur in the areas having shallow water table (e.g., canal commands), which occurs due to substantial groundwater recharge and sluggish subsurface outflow. Subsurface field drains can be either open ditches or pipe drains, but nowadays they are mostly pipe drains. Pipe drains are installed underground at depths normally ranging from 1 to 3 m

(Bos and Boers, 1994). Excess groundwater enters the perforated field drains and flows by gravity to an open or closed collector drain.

12.3.3 Vertical Drainage

Vertical drainage or tube well drainage can be defined as the ‘control of an existing or potential high water table or artesian groundwater condition’. It is accomplished using shallow or deep tube wells; sometimes open wells are also used. Most tubewell drainage systems consist of a group of wells spaced with a sufficient overlap of their cones of depression so as to control the water table at all points in an area. When draining newly-reclaimed clay soils or peat soils, the drainage engineer has to estimate land subsidence due to drainage of these soils, because this will affect the drainage design (Bos and Boers, 1994). The problem of land subsidence can also occur in the areas drained by tube wells.

Irrespective of the technique used to drain a given area, it is evident that the drainage technique must fulfill the local need to remove excess water. These days, the ‘need to remove the excess water’ is strongly influenced by a concern for the environment. The design and operation of all drainage systems must ensure sustainable agriculture in the drained area and must minimize the pollution of rivers and lakes from irrigation return flow or drainage effluent (Bos and Boers, 1994). The quality of drainage effluent is generally inferior because it often contains significant amounts of sediments, agricultural chemicals (fertilizers and pesticides) and other contaminants. Therefore, proper disposal of drainage effluents is a serious concern in most canal commands of the world, especially in developing countries.

12.4 DESIGN OF OPEN DITCHES (MANNINGS’S EQUATION)

Manning's formula is perhaps the most widely used empirical equation for estimating discharge since it relies solely on channel characteristics that are easily measured. Manning's formula is:

$$Q = VA = \left(\frac{1.00}{n}\right) AR^{\frac{2}{3}} \sqrt{S}$$

Where,

Q = discharge (m^3/s)

A = cross sectional area of the stream (m^2)

R = hydraulic radius (m), (area/wetted perimeter of the channel)

S = slope of the water surface

n = roughness coefficient of the channel.

LECTURE 13

Drainage coefficient and its importance in drainage design, Various methods to determine drainage coefficient – Cypress Creek Formula only and problems

13.1 DRAINAGE COEFFICIENT

The drainage coefficient for which the hydraulic section of the drain is determined is called the design drainage coefficient. Drainage coefficient is expressed in millimetres per day (mm/day) or in litres per second per hectare (lps/ha). The equivalence between the two is:

1 mm/day = 0.116 lps/ha or 1 lps/ha = 8.64 mm/day.

13.1.1 Concept of Drainage Coefficient

The concept of drainage coefficient is used for the design of drainage systems for agricultural lands; it is the key parameter needed for the hydraulic design of drainage systems. In agriculture lands, open ditches or drains are the most commonly used surface drainage structures.

The rate at which the open drains should remove water from a drainage area depends on: (i) rainfall, (ii) size of the drainage area, (iii) characteristics of the drainage area, and (iv) nature of the crops grown and the degree of protection required for them from waterlogging.

Drainage coefficient is defined as the amount of surplus water to be removed from the agricultural land in 24 hours so that the plants are not stressed due to surplus water. Alternatively, it is also defined as the depth of water to be removed in 24 hours from the entire drainage area. A commonly used unit of drainage coefficient is cm/day or mm/day. It is also expressed as the flow rate per unit area, i.e., m^3/s per km^2 or L/s per hectare (Lps/ha). Thus, for a 100 ha agricultural watershed, a drainage coefficient of 1 mm/day would lead to a discharge of 100 ´ 0.116 = 11.6 L/s at the outlet of the watershed (because 1 mm/day = 0.116 Lps/ha).

Drainage coefficient for an agricultural land is decided such that no appreciable damage is caused to the crops to be grown in that land. The intensity of rain and its duration are inversely proportional to the time allowed for removal of water (which

depends upon the type of crop). In deciding the drainage coefficient of an area past experience with similar soils, climatic conditions and crops is very useful. For open ditches for small agricultural areas, the value of drainage coefficient ranges from 0.6 to 2.5 cm, and in extreme cases up to 10 cm. Note that the drainage coefficient is an average rate and it does not take into consideration the runoff distribution with time. Conceptually, the drainage coefficient represents a flow rate lower than the peak of the hydrograph (as calculated by the rational formula). The flow rate corresponding to the drainage coefficient should be adjusted in such a way that the volume of water represented by the area of the direct runoff hydrograph above the drainage coefficient is able to flow out of the watershed within a duration during which it is not harmful for the plants.

Example 13.1 :

A watershed of 1500 hectares is discharging through a drain at an average ratio of 2.5 m^3/s. Calculate the drainage coefficient. If the drainage coefficient is 3 cm, what would be the discharge through the drain?

Solution:

Drain discharge in 24 hours = 2.5 ´ 60 ´ 60 ´ 24 m^3/day.

$$\therefore \text{ Drainage Coefficient} = \frac{2.5 \times 60 \times 60 \times 24}{1500 \times 10^4}$$

= 0.0144 m per day = 1.44 cm/day, **Ans.**

If the drainage coefficient is 3 cm, the rate of flow through the drain (Q) will be:

$$Q = \frac{3}{100} \times \frac{1500 \times 10000}{24 \times 60 \times 60} = 5.21 \text{ m}^3/\text{s}, \textbf{ Ans.}$$

13.2 DETERMINATION OF DRAINAGE COEFFICIENT

13.2.1 Cypress Creek Formula

An empirical relationship relating design drainage rate at the outlet of a watershed and the watershed area was developed in the USA based on the data from a large number of

watersheds. This relationship is popularly known as the Cypress Creek formula and is considered valid for a mean watershed slope of £0.45%. This relationship was developed based on the fact and observations that the unit drainage rate (discharge per unit area) reduces as the watershed area increases. Accordingly, an equation relating the runoff rate with the watershed area was obtained as follows:

$$Q = C \times A^{p}$$

Where,

Q = runoff rate (m^3/s), A = area of the watershed or agricultural land (km^2),

p = 5/6 (Approximate average value), and

C = (0.2098 + 0.0074Y),

Where,

Y is the direct runoff volume (mm) estimated by the CN method.

This formula is entirely empirical and has been derived upon a large number of observations carried out in the USA. The value of Q is not the same as peak discharge, and it may so happen that its value will be much less than the peak discharge as certain amount of flooding is allowed before the water is drained.

Since the value of p is less than 1, the rate of increase in the estimated design discharge will not be proportional to the increase in the drainage (watershed) area. This equation makes use of the CN-estimated runoff which is reflected in the coefficient 'C'. The value of p as 5/6 was standarised based on the analysis of the runoff data from the watershed of different sizes.

Assuming that above equation is applicable to the climatic conditions of India, a few average values of C in the equation for estimating a 5-year return period (recurrence interval) Q are given in Table . For obtaining the design runoff for a 2-year return period, the values of Q, calculated using Eqn. for the C values listed in Table 5.1, are to be multiplied by a factor varying between 0.79 and 0.84 for different regions of India. These values have been obtained from the drainage area-design discharge curves

for different regions of India and for three major groups of crops as developed by Gupta et al. (1971). The design discharge was calculated based on the volume of runoff estimated by the CN method for a constant I_a versus S relation of $I_a = 0.2S$. Equation is further used to proportion the design discharge based on the size of the contributing segments of a watershed at a given junction of two drains. Based on the field studies, it has been found that the Cypress Creek formula considerably over estimates the drainage coefficient for watershed areas up to about 100 km^2.

Table 5.1. Average values of the coefficient (C) appearing in the Cypress Creek formula (Gupta et al., 1971)

Sl. No.	Region	Values of 'C' for Different Crops		
		Vegetable Crops	Grain Crops	Rice
1	Punjab and Haryana Alluvial Soils	1.414	0.354	0.071
2	Indo-Gangetic Alluvial Soil (North)	3.084	1.050	0.421
3	Indo-Gangetic Alluvial Soil (South)	2.375	0.668	0.260
4	Indo-Gangetic Alluvial Soil (Central)	2.820	0.816	0.185
5	Black Soil (sub-humid)	4.454	1.113	0.890
6	Black Soil (arid and semi-arid)	2.970	0.519	0.372
7	Eastern Red Soils	3.396	1.050	0.734
8	Southern Red Soils	2.262	0.565	0.356
9	Assam Valley	2.970	0.927	0.446

LECTURE 14

Hydraulic Conductivity-Single auger hole method (Hooghoudt's equation only), Inverse auger hole method (equation only) & problems

Hydraulic conductivity is the coefficient k in the Darcy's law v = ki, where v is the velocity and i is the hydraulic gradient. Hydraulic conductivity values can be determined as shown Fig. 14.1.

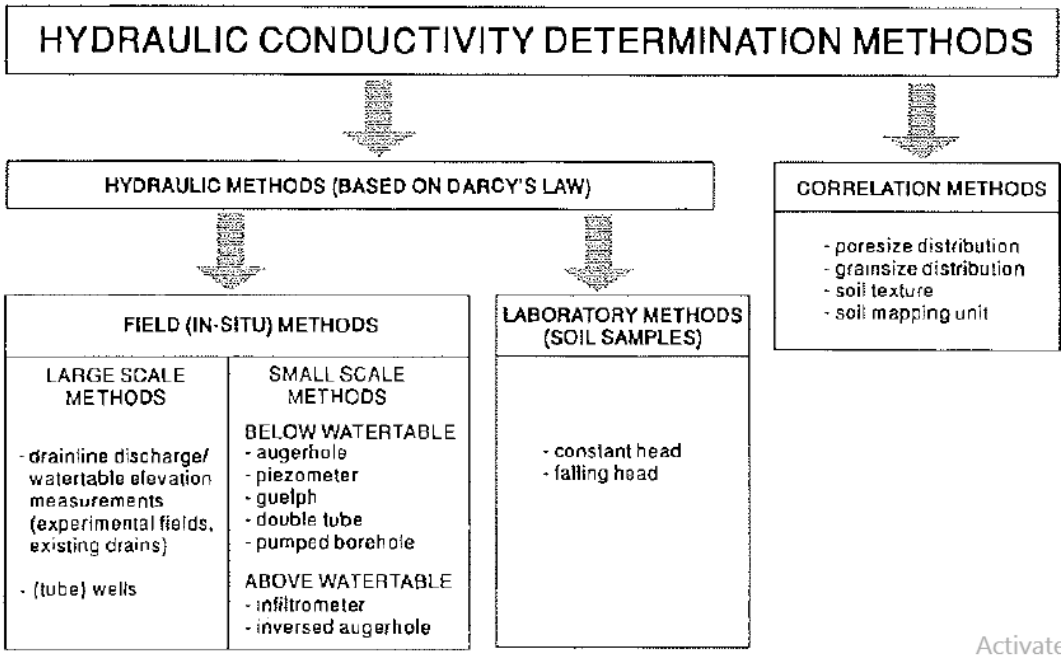


Fig. 14.1 Overview methods used for determination of hydraulic conductivity

14.1 SINGLE AUGER HOLE METHOD (HOOGHOUDT'S METHOD):

Description (principle): A hole is made to a certain depth below the groundwater table. The water table in the hole is lowered with a bailer and then the rate of rise of the water table is measured. From this and from the geometry of the auger hole, can be calculated the value of hydraulic conductivity. Use (application): Common procedure may be used in the field surveys for the design of subsurface pipe drainage system. Disadvantages (limitations): Mainly horizontal hydraulic conductivity is measured. This method is not suitable for strongly layered soils or for soils with irregular pore space distribution.

This method is used when the water table is present near the ground surface. This methods consists of drilling a hole extending into the water table. A casing pipe is installed to prevent the sides collapsing into the bore. Water is removed quickly from the bore either by using a pump or more conveniently using a bailer.

The equation used for calculating the hydraulic conductivity was derived by Hooghoudt and is known as the Hooghoudt's equation. Fig. 14.2 indicates the different terms involved in this equation

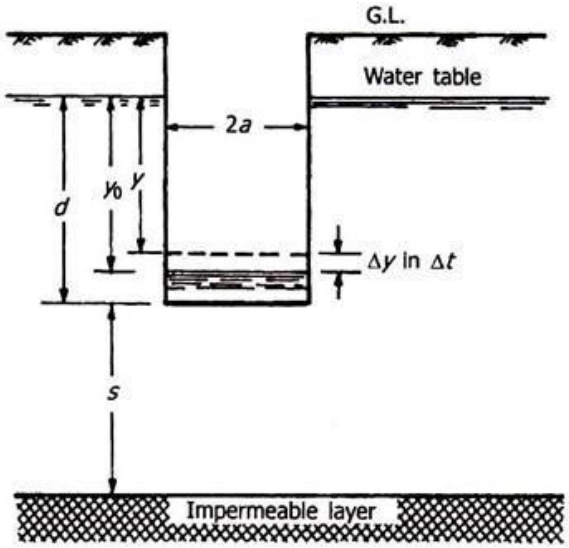


Fig. 18.5. Determination of hydraulic conductivity using single auger hole.

Fig. 14.2 Determination of hydraulic conductivity using single auger hole method

The assumptions in deriving the equation are as follows:

i. The water table around the auger hole is not lowered when water is removed from it. This condition is satisfied for a short while after the auger hole has been pumped. This condition will not be valid if the auger hole is repeatedly pumped.

ii. Water flows horizontally into the sides of the auger hole arid vertically up through the bottom of the hole.

Using the second assumption, it can be taken that the rate at which the auger hole is filled is directly proportioned to the circumference of the hole and is inversely proportional to the cross sectional area of the hole. The rate of rise of water in the hole at time t is now written as –

$$\frac{dy}{dt} = K \frac{2\pi ad}{\pi a^2} \cdot \frac{y}{S}$$

where K is the hydraulic conductivity (a constant) and S is another constant of proportionality.

The constant S depends upon the factors a, d, s and on the height of water in the hole at th time of measurement. Using controlled experiments in sandtank models, Hooghoudt determined th value of S as :

$$S = \frac{ad}{0.19}$$

(Note s and height of water in the hole however does not occur in the above formula).

If the auger hole is drilled upto the impermeable layer, the vertical flow of water through the bottom is zero and the above equation becomes

$$K = \frac{2.3aS}{(2d+a)\Delta t} \log \frac{y_0}{y_1}$$

Substituting the value for $S = \frac{ad}{0.19}$

and expressing K in m/day, we have, $K = \frac{(2.3)(a^2)86400}{2\times(0.19)} \frac{\log y_0/y_1}{\Delta t}$

$$= \left(523{,}000\, a^2 \log \frac{y}{y_1}\right)\frac{1}{\Delta t}$$

In this equation, a is measured in m and Δt in seconds.

14.2 INVERSE AUGER HOLE METHOD

A hole is augered to a certain depth well above the groundwater table. Water is flowed into the dry hole, and then the rate of lowering of the water table is measured. From this rate of decreasing and from the geometry of the borehole, is calculated the value of hydraulic conductivity. Use (application): Common procedure in field surveys for surface or subsurface drainage design, if groundwater table is not present. Disadvantages (limitations): As auger-hole method.

$$K = 1.15\, r \frac{\log(h_0 + \frac{1}{2} r) - \log(h_t + \frac{1}{2} r)}{t - t_0}$$

Where,

t = time since the start of measuring (s)
h_t = the height of the water column in the hole at time t (cm)
h_o = h_t at time t = 0

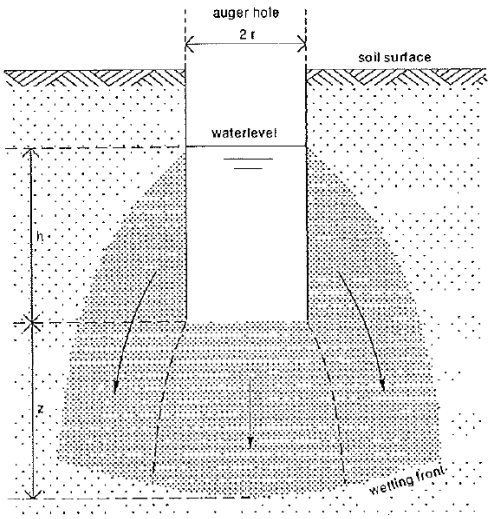


Fig. 14.3 Infiltration from a water filled auger hole into the soil (Inverse auger hole method)

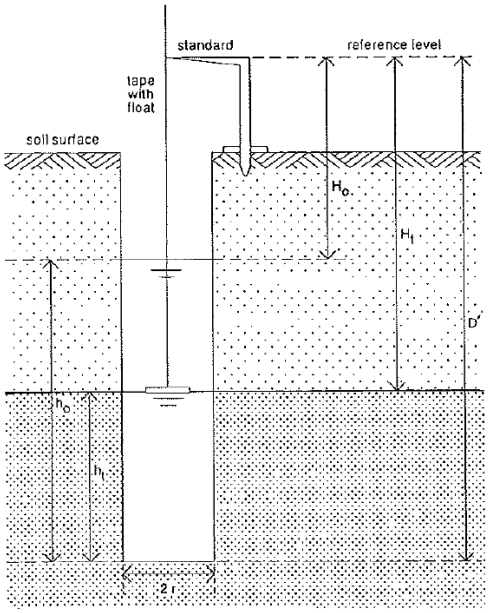


Figure 12.17 Measurements for the inversed auger-hole method

Fig.14.4 Measurements for the Inverse auger hole method

LECTURE 15

Sub surface drainage system – Purpose and benefits of sub-surface drainage, Investigation for subsurface drainage (list only), Layouts of tile drainage systems, Capacity of tile drains, grades, sizes and materials of tile drains including envelope materials

15.1 PURPOSE AND BENEFITS OF SUBSURFACE DRAINAGE

Subsurface drainage is the removal of excess water from the root zone. It is accomplished by deep open drains or buried pipe drains (FAO, 1985). Subsurface drainage is an important conservation practice. Poorly drained lands are usually topographically situated so that when drained, they may be farmed with little or no erosion hazard. Many soils having poor natural drainage are, when properly drained, rated among the most productive soils in the world.

Specific benefits of subsurface drainage are: (i) aeration of the soil for maximum development of plant roots and desirable soil microorganisms; (ii) increased length of growing season because of earlier possible planting dates; (iii) decreased possibility of adversely affecting soil tilth through tillage at excessive soil water levels; (iv) improvement of soil water conditions in relation to the operation of tillage, planting and harvesting machines; (v) removal of toxic substances, such as salts, that in some soils retard plant growth; and (vi) greater storage capacity for water, resulting in less runoff and a lower initial water table following rains. Through these benefits drainage enhances farm productivity by: (a) adding productive land without extending farm boundaries, (b) increasing yield and quality of crops, (c) permitting good soil management, (d) ensuring that crops may be planted and harvested at optimum dates, and (e) eliminating inefficient machine operation caused by small wet areas in fields. In arid regions irrigation and drainage are complementary practices.

In some areas leaching of soluble salts through a drainage system is essential before the land can be developed. Drainage is often a necessity as a result of excess water that accumulates from low efficiencies in the conveyance and application of water for irrigation. Although these losses can be reduced, they cannot be entirely eliminated. The benefits of drainage can be realized only when the soil is potentially productive if

drained. Government regulations may require leaving soil undrained as a range land or as a recreation and wildlife area.

15.2 TYPES OF SUBSURFACE DRAINAGE SYSTEMS

If one has decided to install a subsurface drainage system, one has to make a subsequent choice between well drainage, open drains, pipe drains, and mole drains. Well drainage and mole drainage are applied only in very specific conditions. Also, mole drainage is mainly aimed at a rapid removal of excess surface water, not controlling water table. Therefore, the usual choice is between open drains and pipe drains (Cavelaars *et al.*, 1994).

This choice has to be made at two levels: (a) for field drains, and (b) for collectors. If the field drains are to be pipe drains, there are still two options for the type of collectors: (i) they can be open drains so that we have a 'singular pipe-drain system', or (ii) they can be pipe drains so that we have a 'composite pipe-drain system'.

Open drains have the advantage that they can receive overland flow directly, but the disadvantages often outweigh the advantages. The main disadvantages are: loss of land, interference with the irrigation system, splitting-up of the land into small parcels that hamper mechanized farming operations, and the burden of maintenance. Nevertheless, there are cases where open drains are used exclusively, e.g., peat soils and very saline land under a monoculture of rice.

Moreover, a combined system of surface and subsurface drainage may be more appropriate in certain field situations. Salient examples are as follows:

i. A soil profile with a layer of low permeability below the root zone, but good permeability at drain depth: This is a soil profile that can be found in alluvial soils throughout the world. After a heavy rain, a perched water table forms in the root zone, which cannot be lowered rapidly enough without some form of surface drainage. Subsurface drainage subsequently lowers the water table to a normal depth. An alternative solution could be to break up the impeding layer by sub-soiling, especially if the impeding layer is less than about 0.3 m thick.
ii. Areas with deep frost penetration and snow cover during winter: When the snow melts and the topsoil thaws, but soil at some depth is still frozen, a

perched water table will form and will damage a crop of winter grain. The same measures as in the previous example are required here;

iii. Irrigated land in arid and semi-arid regions, where the cropping pattern includes rice in rotation with 'dry-foot' crops (e.g., as in the Nile Delta in Egypt): Subsurface drainage is needed for salinity control of the dry-foot crops, whereas surface drainage is needed to evacuate the standing water from the rice fields (e.g., before harvest).

iv. Areas with occasional high-intensity rainfall that causes water ponding on the land surface, even if a subsurface drainage system is present: The ponded water could be removed by the subsurface drainage, but this may either take too long time or require very narrow drain spacings. Under such circumstances, it would be more efficient to remove the ponded water by surface drainage.

15.3 TILE DRAIN SYSTEM DESIGN-LAYOUTS OF TILE DRAINAGE SYSTEMS, CAPACITY OF TILE DRAINS, GRADES, SIZES AND MATERIALS OF TILE DRAINS INCLUDING ENVELOPE MATERIALS

The design of a tile drain system consists in determining-

(1) Layout of the system;

(2) Depth and spacing of the drains;

(3) Size of the drains;

(4) Material of the tiles;

(5) Grade of the tile lines;

(6) Envelope materials and accessory structures; and

(7) Outlets.

15.3.1 Layout of Tile Drainage Systems:

The different types of tile drainage layout followed are –

a. Random or natural,

b. Herringbone,

c. Gridiron, and

d. The interceptor drains.

In an area it is possible to use one or a combination of the systems depending upon the site conditions.

The random or the natural system is used for draining isolated patches when the entire area does not need drainage. It is thus economical. The herringbone system is used in areas where a main line or sub-main could be laid in the low area and laterals could be drawn from both sides. The land in this system is well drained.

The gridiron system is similar to the herringbone system except that the laterals enter the main only from one side. The system could be more economical than the herringbone system as less number of junctions are used.

The interceptor or the cut-off drain is placed at the upper edge of a wet area to intercept the subsurface seepage. Open drains are also used for the purpose but require considerable land area.

15.3.2 Depth and Spacing of Tile Drains:

The depth and spacing of tile drains are closely interrelated and depend upon the hydraulic conductivity of the soil, kind of crop, extent of surface drainage, outlet conditions and the agronomic practices followed.

The depth of the tile drains should be such that midway between the drains the water table should be at a satisfactory depth. Where an impermeable layer is encountered the tiles should be placed above such layer, except when the impermeable layer occurs at very shallow depth. If the tiles are located below the impermeable layer, backfilling of the trenches should be done with permeable soil.

The depth and spacing are determined using different requirements in humid and arid regions. In humid areas, as during heavy rainfall water table will rise to near the surfaces the rate of drop of the water table is important. In arid regions under irrigation the consideration is to maintain a minimum depth of the water table for optimum crop growth.

In general, the deeper the drains the wider the spacing and less number of drains are needed. On the other hand, deeper drains will result in greater installation costs and may cause outlet problems.

The following table gives the general depth and spacing that could be adopted under different conditions:

15.3.3 Capacity of Tile Drains:

After the spacing of the tile drains is determined, the discharge through the tile drains can be calculated either by using the Hooghoudt's approach for steady state conditions or the USBR's approach for the unsteady state conditions.

In Hooghoudt's approach, the maximum rate of flow per unit length of the drain is given by-

The design flow of tile drains is estimated under humid and arid conditions using different approaches. Under humid conditions, the main purpose of the tile drains is to remove the excess rainfall appearing as subsurface flow.

In determining the capacity of the tile line the area actually drained by that particular line is to be considered. Additional allowance is to be made where there are surface inlets into the tile line or side hill seepage.

In irrigated conditions, an estimate of the deep percolation from irrigation and other sources like unlined canals etc. is to be made for determining the tile flow.

15.3.4 Grades of Tile Drains:

Tile drain grades should be such that no sedimentation occurs in the tiles. A minimum velocity of 45 cm per second is generally recommended. A desirable working grade is 0.2 per cent while higher grades can be adopted.

Higher grades result in higher velocities which may cause un-determining of the tiles. These recommendations are for the laterals. The grades of the main lines are to some extent depend upon the outlet selected. Grades upto 2 to 3 per cent were found to be satisfactory for the main lines.

15.3.5 Size of Tile Drains:

The size of the tile drains is determined using the maximum expected flow and the grade. Manning's formula is used for the design. The value of n in Manning's formula recommended is 0.011 for concrete tiles. Using Manning's formula, the following relationship is developed for the size of the tiles flowing full –

For practical purposes, the nearest available commercial size is selected. In order to take care of sedimentation and also of any misalignment during installation, a size slightly larger than the calculated size is selected. In case of concrete or clay tiles sizes of 10 cm, 12.5 cm and 15 cm are used.

15.3.6 Materials for Tiles:

Concrete, burnt clay and PVC are the materials used for tiles. As the tiles installed will be there once for all, good quality materials should be used for the tiles. Concrete tiles are easy to manufacture and can be transported without breakages.

Concrete tiles can also be locally made using simple moulds made of mild steel sheets. Concrete 1:2:4 proportions should be used and the tiles should be properly cured. If the concrete tiles are to be placed in acid or alkali soils, the tiles should be specially made using cement with specific chemical characteristics in order to prevent the decay of the tiles with time.

Clay tiles should be well burnt and without any defects. Good clay tiles have a distinct ring when lapped with a metal object. Clay tiles have the advantage of being cheaper than concrete tiles and also can be used in acid and alkaline soils. However they are difficult to transport without breakages and will not be able to withstand as much load as concrete tiles can take.

Plastic pipes introduced around 1960 are becoming increasingly popular for tile drainage. The common materials are the polyvinyl chloride (PVC) and polythelene, of which PVC is more popular. PVC pipes are somewhat more resistant to outside pressure than polythelene pipes and are also cheaper.

Plastic pipes come in both smooth and corrugated types. The smooth pipes are rigid and they come in standard lengths. The corrugated pipes are flexible and they

come in coils. The corrugated pipes require less plastic material per unit length and have greater resistance to outside pressure than smooth pipes.

They can conveniently be used with the tile laying machines. They however have greater hydraulic resistance than smooth pipes and hence larger sized pipes are needed to drain the same amount of water.

Circular holes in the corrugations allow the water enter into the tile drain. Around 20 holes per 30 cm length are generally provided. The use of envelope materials increases the effective diameter and hence fewer perforations per unit length will be needed to get the desired flow.

Loads on Drain Pipes:

Drain pipes have to bear the load of the soil above them. Drains located at shallow depths (less than 1 m) are subjected to both the soil weight and any other load resulting due to machinery. Drains located at deeper depths are subjected to soil loads only.

For estimating the loads on drain tiles, two formulae are in vogue. These are the Ditch Conduit Formula for the narrow trenches and the Projecting Conduit Formula for wide trenches. If the ditch is more than 2 or 3 times the outer diameter of the tile then it is considered as a wide trench and otherwise a narrow trench.

The Ditch Conduit Formula:

This formula is used for calculating the load on pipes in narrow trenches and is given by –

$$W_c = C_d W B_d^2$$

where, W_c = load on the pipe,
C_d = load coefficient,
W = unit weight of fill material, and
B_d = width of trench at the top of the pipe.

The projecting conduit formula for wide ditches is

$$W_c = C_c W B_c^2$$

Where Cc = load coefficient for project conduits and Bc = outside diameter of the conduit. The load coefficient Cd and Cc in the above formulae are functions of the frictional coefficients of the soil, the height of the fill (H) and the width of the ditch or the width of the conduit as the case may be.

In case of ditch conduits it is assumed that the density of the soil filled is less than that of the original soil. The sides of the ditch offer an upward frictional resistance to the fill material and as such the load on the conduit is less than the weight of the soil directly above it.

But in case of projecting conditions, the load on the conduit is greater than the weight of the soil directly above it, for the reason that the shearing forces due to greater settlement of soil on both sides are downward rather than upward.

Values of C_d and C_c are given in Fig. 18.15. Transition widths are those when the loads computed by both the equations are the same.

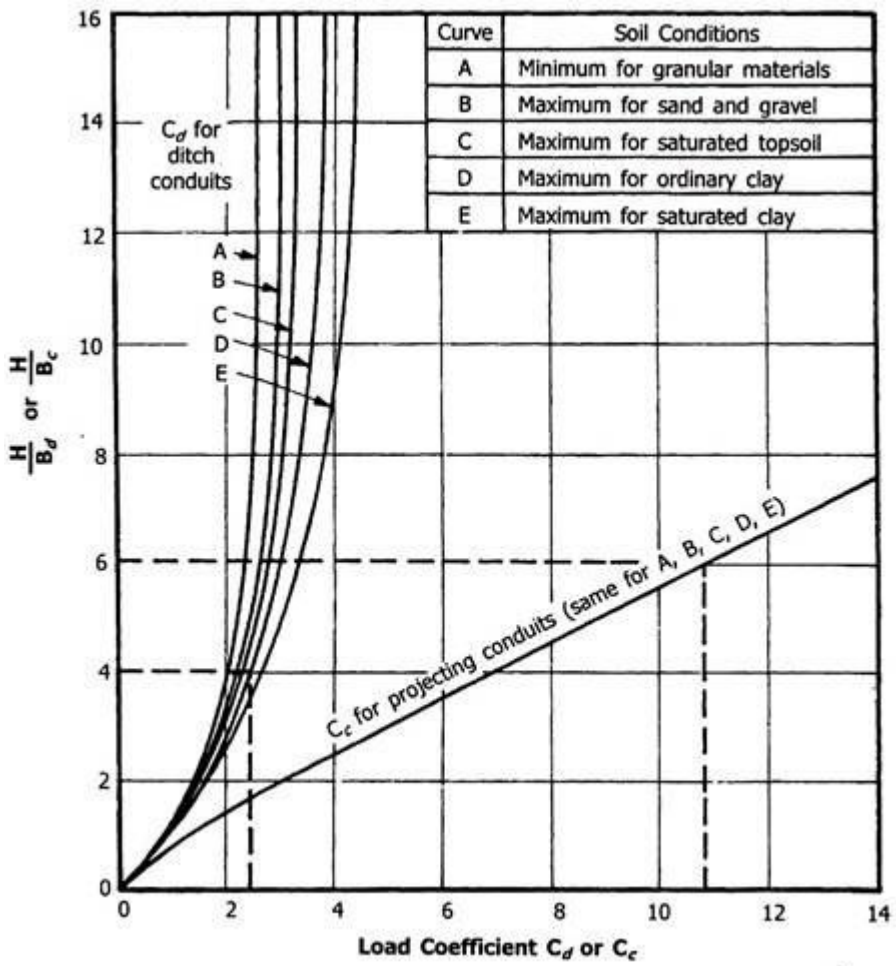


Fig. 18.15. Values of C_d and C_c in ditch conduit formula (Spangler, 1947).

Drain tiles should be installed such that the loads on them does not exceed their crushing strength.

Testing of Tiles:

There are two methods in use for testing the strength of concrete or clay tiles. The first one more commonly used is known as the three-edge bearing test. The equipment for this test consists of two wooden blocks on which the tile is placed.

A point load which can be increased is applied on top of the tile. This load is applied either by a mechanical jack or a hydraulic system. The load is gradually increased and the load at which the tile breaks is noted.

The second method is known as the sand bearing test in which the procedure is the same but the arrangement is different. In this method the bottom of the tile is supported by a bed of sand. This represents the conditions found under normal installation procedures more closely than the three edge bearing test.

The crushing strength found by the sand bearing method is nearly 1.5 times higher than the strength found by the three edge method.

The testing of plastic pipes used for tiles is done differently. Plastic pipes do not get crushed like clay or concrete tiles but instead get deformed under load. Deformation is the characteristic that is measured in case of plastic pipes.

15.3.7 Bedding Conditions for Tile Drains:

The bedding conditions of the tiles have an influence on the amount of load which the tiles can take. Fig. 18.17 shows the different bedding conditions and the load factors. The crushing strength as determined by the three edge tests is multiplied by the load factor to determine the load that could be supported. While calculating the loads a safety factor is taken into consideration. The calculated loads are increased by 50 per cent as a safety factor.

15.3.8 Accessories for Tile Drain Systems:

For the tile drainage systems to function satisfactorily several accessories are needed. These are:

15.3.8.1 Envelope Materials:

In soils where there is a chance of heavy movement of soil particles into the tile drains and consequently clogging them, filter materials are placed around the tiles. The filter or envelope materials prevent the entry of the relatively coarser particles into the tiles.

In addition, the envelope materials serve other purposes as well. They act as bedding material and thus allow the tiles to take greater loads. They also increase the effective diameter of the tiles and allow quantities of water to flow into the tiles.

A variety of materials have been used as envelope materials in tile drains. These consist of gravel, coarse sand, organic materials like corn cobs, straw etc. In case of continuous plastic tile lines in the Netherlands coir matting has also been used as envelope material. Among these, gravel has been the most widely used material because of its efficiency and also of permanent nature.

The gravel envelope provided should prevent the movement of the soil particles into the tile drains. The gravel envelope should be designed for this purpose taking into consideration the nature of the soil around the tile drains. The criteria followed for the design are based on the same principles followed for the design of gravel envelopes for wells.

However, the flow towards the well is faster than the flow towards drains and as such the design criteria are slightly different. The United States Bureau of Reclamation recommends the following criteria for the design of gravel envelopes –

For uniform soils, $\frac{D_{50} \text{ of envelope}}{D_{50} \text{ of soil}} = 5 \text{ to } 10$

For graded soils, $\frac{D_{50} \text{ of envelope}}{D_{50} \text{ of soil}} = 12 \text{ to } 58$

The gravel should be clean, free from organic matter and bentonite clays.

15.3.8.2 Manholes and Sedimentation Basins:

These are vertical structures installed at regular intervals along the tile lines to help in inspection of the tile lines and cleaning the accumulated sediment. These are constructed using either concrete or brick masonry and are of dimensions enough for a person to enter. These could be installed at junctions of tile lines. There are no general guidelines for their spacing but decided upon local conditions.

The top of the manhole or the sedimentation basin can be kept at ground level or below ground level. Ground level structures may interfere with farming operations. If the top of the manhole is located below the ground level, it is located about 60 cm below and covered by a concrete block. In this case it will not be obstruction to farming operations.

15.3.8.3 Inlet to Tile Drains:

Inlets to tile drains are used to admit surface runoff into the tile lines. These could also be used for flushing the tile lines. The two types of inlets which are used are the blind inlets and the surface inlets.

Blind inlets are cheaper and do not interfere with farming operations but they are likely to get clogged. Surface inlets have provision for preventing the trash and other suspended materials entering the tile drains.

15.3.8.4 Installation of Tile Drains:

Installation of the tiles consists in digging the trench, laying the tiles to the prescribed grade, putting the envelope material and backfilling the soil. Installation procedures depend upon the availability of labour, types of the tiles used and the soil conditions. Installation of the tiles should start from the outlet as this ensure disposal of the drainage water during installation.

Digging of the trenches can be done either by manual methods or by using trenching machines. Manual methods use ordinary excavating tools. After the trench is excavated tiles are laid manually.

In case of machines used for tile drain construction the operation of digging, laying the tiles, filling the envelope material and backfilling is done in one single operation. The operation of these machines is faster when continuous plastic pipes are laid as tiles.

Latest machines use laser techniques for maintaining the grades of tile lines. The tile lines used are continuous PVC pipes with slots. The excavation of the trench, laying the tile line and placing the envelope materials are carried out in one operation.

15.3.8.5 Establishing Grade:

Establishing the proper grade for laying the tiles is very important. The two methods that are used are the line and the sight method. In the line method a string or thin wire is used to set the grade whereas in sight method the grade is established by sighting over two targets.

The bottom of the trench should be dug parallel to the line of sight or the string which represents the required grade. Wooden frames are fixed on the ground at regular intervals to serve as lines of sight or measurement points.

15.3.8.6 Laying the Tile:

The concrete or clay tiles are laid at the bottom of the trench at the proper grade. In case the envelope material is used, it is partly filled in the trench, the tiles are put, the grade checked and rest of the envelope materials is filled in.

15.3.8.7 Blinding and Backfilling:

After the tiles and envelope material are put, the trenches are filled with top soil for about 15 to 20 cm carefully. This is known as blinding and helps in providing permeable soil around the tile and also keeps the tiles in position.

Backfilling of the trenches is done with the excavated soil either manually or by machines. When the soil contains stones care should be taken while blinding and backfilling operations so that the tiles do not get broken.

15.3.9 Outlets for the Drains:

Functioning of the tile drainage system depends on the proper functioning of the outlet.

The requirements of a satisfactory outlet are:

(1) Provide free flow of drainage water,

(2) Discharge the outflow without any damage to the tile or erosion,

(3) Prevent the entrance of flood waters,

(4) Protect the end or the tile line, and

(5) Keep out rodents.

The principle types of the outlets used are the gravity outlet and the pump outlet. The topography of the land is the main factor that dictates the choice of the outlet. In the

gravity outlet water flows out of the drainage system by gravity into an open drain, stream, a pond or any other facility that disposes the water.

When disposing the water the outlet pipe should be above the water level by about 30 cm so that there is a free fall. It should be ensured that the end of the pipe is not covered by water. Where gravity outlets are not possible, pumped outlets are used. In the pumped outlet, the tile drains lead to a sump and water is lifted from the sump and pumped into a drain or other water disposal facility.

Water level in the sump could be allowed to go above the level of the drains for a short while if crops are not affected consequently. The capacity of the sump and the pump depends upon the area that is being drained.

Evaporation ponds have been used as a means of disposing drainage water in areas where any types of outlets are not possible. They are also used in situations where the discharge of drainage water into streams is objectionable from water quality point of view.

Water is collected in ponds of suitable size and allowed to evaporate. Water quality aspects of subsurface drainage waters need to be monitored for their use and disposal.

15.3.10 Materials for Drain Pipe

The materials used for manufacturing drain pipes are clay, concrete, and plastics. Important criteria for pipe quality and for selecting the most suitable type of pipes are: resistance to mechanical and chemical damage, longevity, and costs (Cavelaars *et al.*, 1994). Mechanical damage and chemical deterioration may occur during transport and handling, or after the pipe has been installed. In addition, the lifetime of the pipes should not be excessively shortened by deterioration in mechanical or chemical properties in the course of time. The costs are the total costs for purchase, transport, handling, and installation.

15.3.10.1 Clay Tiles

Clay tiles used to be predominant type of drain pipes in Europe, from the first introduction of pipe drainage (before 1850), to about 1960-1970 (Cavelaars *et al.*,

1994). Clay tiles were made from clay, shale, fireclay or mixture thereof and burnt (IS, 1983). These clay tiles had common diameters of 0.05 to 0.15 m, and came in lengths of 0.30 to 0.33 m. Their ends were either straight or had a collar, with a less-than-perfect fit so that the water could enter through the joints. The chemical stability and longevity of good-quality pipes are excellent.

Criteria for testing the quality of clay pipes are (Cavelaars *et al.,* 1994): shape (they should be straight, with straight-cut ends), absence of fissures and cracks (which can be judged by the sound when the pipe is hit), and mechanical strength (breaking strength). Moreover, the tiles should be uniformly burnt and should be free from minerals and chemicals that are known to cause slaking or disintegration of tiles (IS, 1983). The manufacture of good-quality pipes requires considerable skill and a fairly large well-equipped production unit.

15.3.10.2 Concrete Pipes

Concrete pipes were used as field drains like clay tiles in various countries, until they virtually became obsolete with the introduction of plastic pipes (Cavelaars *et al.,* 1994). In larger diameters, concrete pipes are still commonly used as collectors. Concrete pipes (Fig. 9.1) can be manufactured in comparatively simple (mobile) production units that can easily be erected in the project area. There is practically no limit to their diameter, although for large diameters (i.e., >0.4 m), the concrete must be reinforced (Cavelaars *et al.,* 1994). Pipe ends are either straight, have a collar, or a spigot-and-groove. Water entry is almost exclusively through the joints between pipe sections. For larger diameters, openings at the joints may become rather large; this is the reason that some manufacturers supply rubber sealing rings.



Fig. 15.8 Reinforced concrete drain pipes.

Possible disadvantages of concrete pipes are their susceptibility to acidity and sulphate, which may be present in the soil. This susceptibility can be reduced to some extent with the use of sulphate-resistant cement, and by producing to a high manufacturing standard so that high-density concrete is formed which seals off the concrete from attack by soil chemicals (Cavelaars *et al.*, 1994).

15.3.10.3 Plastic Pipes

The introduction of plastic pipes for drainage started around 1960. Initially, straight-walled smooth pipes (Fig.15.9a) were used. Around 1970, corrugated pipes (Fig.15.9b) were introduced, which soon replaced the smooth pipes (Cavelaars *et al.*, 1994). The major advantages of plastic over clay or concrete are the much lower weight per meter of pipe, and the greater length of pipe (at least several meters). This makes transporting and handling the pipes a lot easier and cheaper, and it enables higher installation rates. A disadvantage is the environmental pollution caused by the raw material (resin). Ex-factory prices of plastic pipes may be higher than that for clay or concrete pipes, but the total costs may be lower because of a saving in the costs of transport, handling and installation.

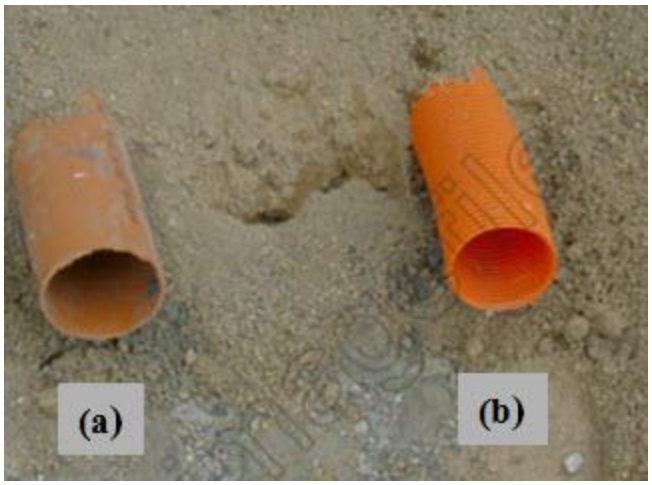


Fig. 15.9 Plastic drain pipes: (a) Smooth pipe; (b) Corrugated pipe.

The three predominant materials for plastic pipes are (Cavelaars *et al.*, 1994): polyvinyl chloride (PVC), high-density polyethylene (HDPE) (Fig. 15.10), and, to a minor extent, polypropylene (PP). When comparing PVC and HDPE, one can find that the dark-colored HDPE is more affected by high temperatures than the light-colored PVC. Consequently, the risk of deformation for HDPE pipes is greater than for PVC pipes.



Fig. 15.10. High-density polyethylene (HDPE) drain pipes.

(Source: http://www.marieturnerinc.com)

On the other hand, PVC, being more sensitive to low temperatures, becomes brittle when exposed to temperatures below freezing point. In addition, PVC is more sensitive to ultra-violet radiation (sunshine), which may cause irreversible deterioration of mechanical properties (brittleness). Therefore, PVC pipes should not be stored in bright sunlight. PVC has some environmental disadvantages also because it forms hydrochloric acid when burnt (FAO, 2005). Note that plastic pipes (PVC, HDPE, or PP) are resistant to all chemicals that may occur in agricultural soils.

15.3.11 Drain Envelopes

When a subsurface drain is installed, some soils may require measures to protect the drain pipe from soil particle entry. Due to the drag force of the water, soil particles or aggregates may be carried into the pipe through the perforations in the pipe wall. This process can never be prevented completely, but it may substantially be slowed down or partially stopped by the use of external porous material around the drain pipe. The porous material designed to do this job is called ‘drain envelope’ (FAO, 2005). A variety of terms are used for drain envelopes, reflecting its purpose and method of application. Commonly used terms are: filter, cover material, and permeable fill. However, the term ‘drain envelope’ has often erroneously been referred to as a ‘drain filter’ (FAO, 2005).

In the subsequent sub-sections, the discussion on drain envelopes is provided in terms of their requirement, functions, design criteria, and construction materials.

15.3.10.1 Requirement of Drain Envelopes

Qualitative guidelines for designing drain envelopes mainly consider soil texture. Straightforward rules can be given for fine-textured and coarse-textured soils. However, for soils in the intermediate texture classes, there is a considerable uncertainty.

Fine-textured soils with a clay content of more than about 0.25 to 0.30 are characterized by a high structural stability, even if being worked under wet conditions (Cavelaars *et al.*, 1994). Thus, with trencher-installed pipe drains, no problems are to be expected and a drain envelope is not required. However, with trenchless drainage, one can easily work below the critical depth, especially in wet conditions, resulting in a high entrance resistance. A drain envelope is not likely to be of any help. Clogging of the pipe is not to be expected.

On the other hand, coarse-textured soils free of silt and clay are permanently unstable, even if undisturbed. Thus, soil particles are likely to wash into the pipe, both from the trench backfill and from the undisturbed soil below the pipe. There is a need for a permanent drain envelope, completely surrounding the pipe, only as an effective filter, because there is no high entrance resistance. In this case, a thin geotextile envelope is probably the best solution (Cavelaars *et al.*, 1994).

Soils of intermediate texture are not so simple. In the finer-textured soils of this category (clay contents less than 0.25 to 0.30, but more than say 0.10 to 0.15), the trench backfill will remain stable and of good permeability, provided that pipe installation is done under dry conditions and in irrigated land, provided that the trench backfill is properly compacted (Cavelaars *et al.*, 1994). In these cases, even without an envelope, no problems will arise. However, if the pipes are installed under wet conditions, both drain sedimentation and a high entrance resistance can follow. Hence, a drain envelope is required in this case. A commonly applied guideline in The Netherlands is that the drain envelope should be ‘voluminous’ in order to fulfill its hydraulic function. Nevertheless, a thin filter sheet wrapped around a corrugated pipe will do the job equally well, because it ensures that water is conveyed towards the perforations (Cavelaars *et al.,* 1994). It should be noted that a drain envelope, in spite of

its general positive effect, is no guarantee against poor drain-line performance, especially when the pipes are installed under wet conditions.

15.3.10.2 Functions of Drain Envelopes

A drain envelope is defined as the material placed around pipe drains to perform one or more of the following functions (Cavelaars *et al.,* 1994):

- **Filter function:** to prevent or restrict soil particles from entering the pipe where they may settle and eventually clog the pipe;
- **Hydraulic function:** to constitute a medium of good permeability around the pipe and thus reduce entrance resistance;
- **Bedding function:** to provide-all-round support to the pipe in order to prevent damage due to the soil load. Note that large diameter plastic pipes are embedded in gravel especially for this purpose.

The first two functions provide a safeguard against the two main hazards of poor drain-line performance, viz., siltation and high flow resistance in the vicinity of drains.

15.3.10.3 Design Criteria

In view of drain-envelope functions, ideally, the drain envelope should be designed in such a way that it prevents the entry of soil particles into the pipe, though a limited flow of clay particles will do little harm, because they mainly leave the pipe in suspension. The filtering effect, however, should not be such that the envelope, while keeping the pipe free from sediment, itself becomes clogged. If this happens, the hydraulic function of the drain envelope is severely affected. Besides these conflicting filtering and hydraulic functions, the formulation of functional criteria for the design of envelopes is complicated by a dependence on soil characteristics (mainly soil texture) and drain installation conditions as mentioned earlier. In spite of considerable research efforts, firm quantitative criteria are still far from established. Instead, to a large extent, drainage practice works with qualitative, empirical guidelines (Cavelaars *et al.,* 1994).

The standard procedure for the design of gravel envelopes is to match the particle-size distribution of the soil with the particle-size distribution of the gravel. Several sets of design criteria to prevent base soil invasion into the drain envelope and the drain pipe have been developed such as Soil Conservation Services (SCS) and

United States Bureau of Reclamation (USBR) criteria (Cavelaars *et al.,* 1994). In these standards, the underlying requirements are that the drain envelope should fulfill both the filter and the hydraulic function, that particles from the drain envelope itself should not move through the perforations into the drain in significant amounts, and that the drain envelope should not contain very coarse particles which could possibly damage the pipe during placement. The general procedure for designing a gravel envelope for a given soil is as follows (FAO, 2005):

(1) Make a particle-size analysis of both the soil and the proposed gravel envelope;

(2) Compare the two particle-size distribution curves; and

(3) Decide, by some design criterion, whether the proposed gravel envelope material is suitable.

Gravel is available in many countries and has proven to be a suitable drain envelope if properly installed. Nevertheless, although modern drainage machinery has facilities to install gravel automatically under and around the pipe, it remains a costly and difficult operation (Cavelaars *et al.,* 1994).

15.3.11.4 Envelope Materials

A wide variety of materials are used as envelopes for drain pipes ranging from organic and mineral material to synthetic material and mineral fibers (Cavelaars *et al.,* 1994).

Organic material is mostly fibrous, and includes peat (the classical material used in Western Europe), coconut fiber (Fig. 15.11a), and various organic waste products like straw, chaff, heather, and sawdust.

Mineral materials are mostly used in a granular form; they may be gravel, slag of various kinds (industrial waste products), or fired clay granules.

Synthetic materials may be in a granular form (e.g., polystyrene) or in a fibrous form [e.g., nylon, acryl, and polypropylene (Fig. 15.11b)].

Mineral fibers such as glass fiber, glass wool, and rock wool, are also used.

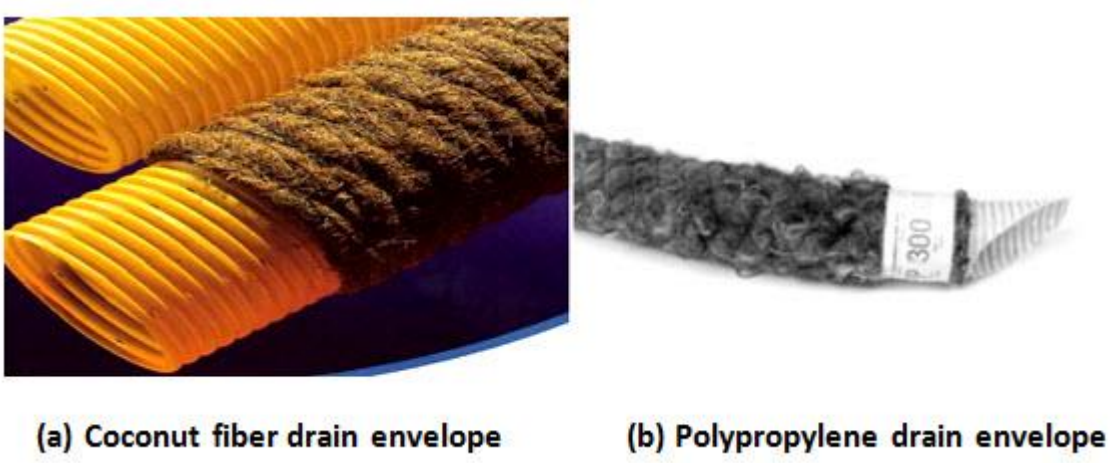


Fig. 15.11 Drain-envelope materials: (a) Coconut fiber; (b) Polypropylene. (Source: FAO, 2005)

Envelope materials are applied in bulk, as thin sheets (Fig. 15.12), or as more voluminous 'mats' (Cavelaars *et al.,* 1994). Bulk application is common for gravel, peat litter, various slags, and granules. The classical method is to spread the material after the pipe has been laid in the trench so that the material will protect the top and the sides of the pipe. A complete surround (e.g., with gravel) is achieved by first spreading gravel on the trench bottom, then lying the pipe, and again spreading gravel.

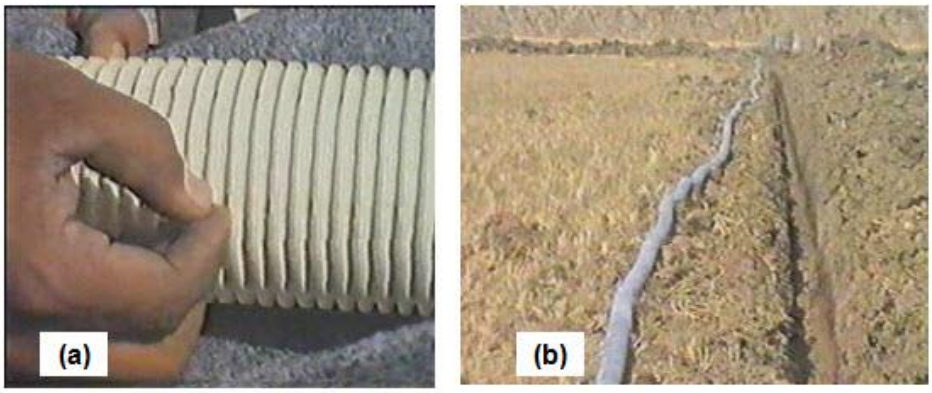


Fig. 15.12 Application of geo-textile envelope material: (a) Corrugated perforated PVC pipe being wrapped with geo-textile envelope material; (b) Lateral drain pipe wrapped with geo-textile envelope material is ready for installation.

Many of the drawbacks of gravel envelopes can be overcome with the use of synthetic envelopes. Thin sheets are commonly used with corrugated plastic pipe as a pre-wrapped envelope. They may consist of glass or synthetic fibres, which are also known as geotextiles. More voluminous mats of up to about 10 mm thick normally

consist of fibrous materials, whether they are organic materials, synthetic fiber, or mineral fiber (Cavelaars *et al.,* 1994). These mats are often used as pre-wrapped envelopes with plastic pipes, but they can also be used in the form of strips. One such a strip may be placed only on top of the pipe, or another strip may be placed below the pipe, thereby making it suitable in combination with any type of pipe (clay, concrete, or plastic).

INVESTIGATIONS FOR SUBSURFACE DRAINAGE

A. Surveys and investigations required

B. Topographic surveys

C. Soils investigations

D. Subsurface explorations

- ✓ Logging soils and subsurface materials
- ✓ Soil samples for laboratory testing
- ✓ Hydraulic conductivity
  - ➢ Auger-hole method Equipment for auger-hole method
  - ➢ Formulas for determination of HC by auger-hole method
  - ➢ Other methods for determining hydraulic conductivity

E. Ground-water investigations

i. Observation wells

- ➢ Size of wells and casing
- ➢ Spacing
- ➢ Depth
- ➢ Establishing well elevations
- ➢ Measuring water table levels and recording data
- ➢ Period of measurement

ii. Piezometers

- ➢ Installation by driving
- ➢ Installation by jetting
- ➢ Batteries of piezometers

iii. Salinity of ground water

F. Irrigation practices

G. Investigation of existing systems of buried drains

LECTURE 16

Tile Drainage- Depth and Spacing of tile drains, Hooghoudt's equation for spacing of tile drain under steady state flow conditions only & problems

In subsurface drainage, field drains are used to control the depth of the water table and the level of salinity in the rootzone by removing excess groundwater. In this module, we will discuss the flow of groundwater towards field drains. The discussion will be restricted to parallel drains, which may be either open ditches or pipe drains. Relationships will be derived between the drain properties (diameter, depth, and spacing), the soil characteristics (profile and hydraulic conductivity), the depth of the water table, and the corresponding discharge. To derive these relationships, several assumptions are to be made. Note that all the solutions are approximations. However, their accuracy is such that their application in practice is fully justified (Ritzema, 1994).

16.1 DEPTH AND SPACING OF TILE DRAINS

The depth and spacing of tile drains are closely interrelated and depend upon the hydraulic conductivity of the soil, kind of crop, extent of surface drainage, outlet conditions and the agronomic practices followed.

The depth of the tile drains should be such that midway between the drains the water table should be at a satisfactory depth. Where an impermeable layer is encountered the tiles should be placed above such layer, except when the impermeable layer occurs at very shallow depth. If the tiles are located below the impermeable layer, backfilling of the trenches should be done with permeable soil.

The depth and spacing are determined using different requirements in humid and arid regions. In humid areas, as during heavy rainfall water table will rise to near the surfaces the rate of drop of the water table is important. In arid regions under irrigation the consideration is to maintain a minimum depth of the water table for optimum crop growth.

In general, the deeper the drains the wider the spacing and less number of drains are needed. On the other hand, deeper drains will result in greater installation costs and may cause outlet problems.

16.2 HOOGHOUDT'S EQUATION FOR SPACING OF TILE DRAIN UNDER STEADY STATE FLOW CONDITIONS

Consider a steady-state flow to vertically-walled open drains reaching an impervious layer (Fig. 16.1). According to the Dupuit-Forchheimer assumptions, Darcy's equation can be applied to describe the flow of groundwater (q_x) through a vertical plane (y) at a distance (x) from the drainage ditch, which yields the following:

$$q_x = K\, y \frac{dy}{dx}$$

Where, q_x = unit flow rate in the x-direction (m^2/day), K = hydraulic conductivity of the soil (m/day), y = height of the water table at x (m), and $\frac{dy}{dx}$ = hydraulic gradient at x (dimensionless).

According to the law of conservation of mass, all the water entering the soil in the surface area midway between the drains and the vertical plane (y) at distance (x) must pass through this plane on its way to the drain. If R is the rate of recharge per unit area, then the rate of flow through the plane (y) is given as:

$$q_x = R\left(\frac{1}{2}L - x\right)$$

Where,

R = rate of recharge per unit surface area [L/T], and L = drain spacing [L].

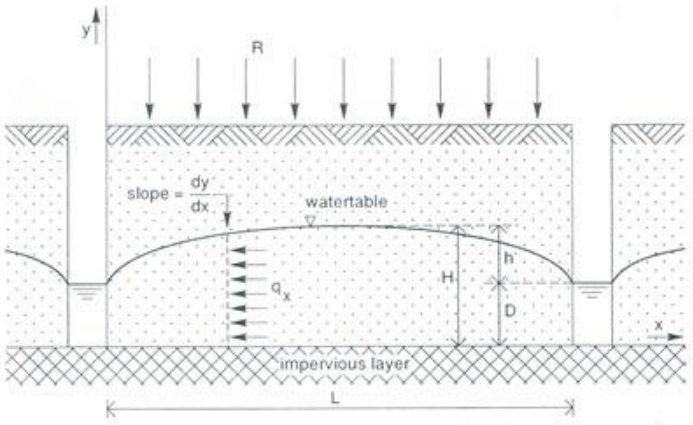


Fig.. 16.1 Flow to vertically-walled drains reaching the impervious layer.

Since the flow in the two cases must be equal, we can equate the right sides as follows:

$$K\,y\frac{dy}{dx} = R\left(\frac{1}{2}L - x\right)$$

$$\Rightarrow \quad K\,y\,dy = R\left(\frac{1}{2}L - x\right)dx$$

Integrating this differential equation [Eqn. (6.3)] with the lower and upper limits of x and y, we have:

$$\text{at x = 0, y = D; and at } x = \frac{L}{2}, y = H$$

Integrating Eqn. (6.3) within these limits, we have:

$$L^2 = \frac{4K\left(H^2 - D^2\right)}{R}$$

$$\text{or,} \qquad q = R = \frac{4K\left(H^2 - D^2\right)}{L^2}$$

Where,

D = elevation of the water level in the drain [L], H = elevation of the water table midway between the drains [L], q = drain discharge [L/T], and the remaining symbols have the same meaning as defined earlier.

Hooghoudt derived this equation by assuming constant and uniform rate of recharge and horizontal flow to vertical ditches. The Hooghoudt's theory also assumes that the drains (pipe or open drains) run half full and that the drains have no entrance resistance. The second assumption (no entrance resistance) suggests that the drain is ideal. To be an ideal drain, the hydraulic conductivity of the surround (drain trench) should be at least 10 times higher than that of the undisturbed soil outside the trench (Smedema and Rycroft, 1983). If the hydraulic conductivity of the surround is less, an envelope material can be used to minimize the entrance resistance, so that a greater part of the total head could be available for flow through the soil. In case, it is not possible to use an envelope material, the entrance resistance should be introduced into the Hooghoudt equations by replacing h with ($h - h_e$), wherein h_e is the entrance head loss in metres. Hence, the validity of Eqn. becomes better when the drains are of negligible width as compared to the drain spacing, shallow, fully penetrating and with a small difference between H and D such that the assumption of parallel flow is applicable. Also, homogeneous soil (constant hydraulic conductivity) is also an important pre-condition can be rewritten as:

$$q = \frac{4K(H+D)(H-D)}{L^2}$$

It is clear that H - D = h, and hence H + D = 2D + h, where h is the height of the water table above the water level in the drain. Consequently, Above equation can be written as follows:

$$q = \frac{8K\,D\,h + 4\,K\,h^2}{L^2}$$

If the water level in the drain is negligible (i.e., D » 0), Above Eqn. reduces to:

$$q = \frac{4 K h^2}{L^2}$$

Equation describes the flow above the drainage base (drain level)

If the impervious layer is far below drain level (D >> h), the second term in the enumerator of above equation can be neglected, yielding:

$$q = \frac{8 K D h}{L^2}$$

Above Eqn. describes the flow below the drain level.

Thus, if the soil above drainage base has a different hydraulic conductivity (say K_1) than the hydraulic conductivity of the soil below drainage base (say K_2), and the drain level is at the interface between the two soil layers, Eqn. (6.5) can be written as:

$$q = \frac{8 K_2 D h + 4 K_1 h^2}{L^2}$$

The situation of layered or stratified soil is quite common in the field. The soil above the drain level is often more permeable than that below the drain level because the soil structure above drain level gets improved by the periodic wetting and drying of the soil (resulting in the formation of cracks), and the presence of roots, micro-organisms, micro-fauna, etc.

Example 1:

In an agricultural area, high water table condition occurs. A subsurface drainage system is to be installed to control the water table under the following conditions:

(1) Agricultural drainage criteria:

- Design discharge rate is 1 mm/day
- The depth of the water table midway between the drains is to be kept at 1.0 m below the soil surface.

(2) Technical criteria:

- Drains will be installed at a depth of 2 m;
- PVC drain pipes with a radius of 0.10 m will be used.

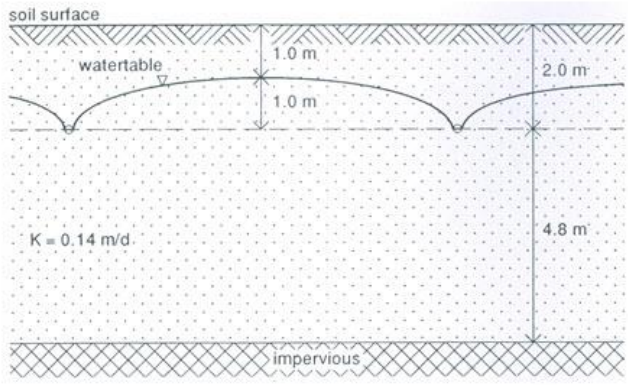


Fig. 16.2 Calculation of drain spacing in a one-layered soil profile.

Field investigation revealed that there is a layer of low conductivity at 6.8 m depth, which can be regarded as the base of the flow region (Fig. 6.6). Auger-hole method was used to calculate the hydraulic conductivity of the soil above the impervious layer and its average value was found to be 0.14 m/day. Calculate the spacing of pipe drains.

Solution:

If we assume a homogeneous soil profile, we can use the Hooghoudt formula [to calculate the drain spacing. We have the following data:

q = 1 mm/day = 0.001 m/day,

h = 2.0 – 1.0 = 1.0 m,

r_0 = 0.10 m,

K = 0.14 m/day, and

D = 6.8 – 2.0 = 4.8 m

Substitution of the above values into Equation (6.9) yields:

$$L^2 = \frac{8\,K\,d\,h + 4\,K\,h^2}{q} = \frac{8\times 0.14\times d\times 1.0 + 4\times 0.14\times 1.0^2}{0.001}$$

$$\Rightarrow \quad L^2 = 1120\,d + 560$$

As the equivalent depth, (d) is a function of L (among other factors), we can solve this quadratic equation for L by the trial-and-error method.

First Trial: Assume L = 75 m. We can read the equivalent depth, (d) from Table 6.1.

$$d_{75} = 3.04 + \frac{8}{10}(3.49 - 3.04) = 3.40 \text{ m}$$

Thus, L^2 = 1120 ´ 3.40 + 560 = 4368 m^2. This is not in agreement with the assumed value of L, because $L^2 = 75^2$ = 5625 m^2. Apparently, the drain spacing of 75 m is too wide.

Second Trial: Assume L = 50 m. In this case, d is obtained from Table 6.1 as:

$$d_{50} = 2.71 + \frac{8}{10}(3.02 - 2.71) = 2.96 \text{ m}$$

Thus, L^2 = 1120 ´ 2.96 + 560 = 3875 m^2. Again, this is not in agreement with the assumed value of L, because $L^2 = 50^2$ = 2500 m^2. Thus, a drain spacing of 50 m is very narrow.

Third Trial: Assume L = 65 m. In this case d is obtained as:

$$d_{65} = d_{50} + \frac{15}{25}(d_{75} - d_{50}) = 2.96 + \frac{15}{25}(3.40 - 2.96) = 3.22 \text{ m}$$

Thus, L^2 = 1120 ´ 3.22 + 560 = 4166 m^2. This is reasonably close to the assumed value of L because $L^2 = 65^2$ = 4225 m^2. Therefore, a drain spacing of 65 m can be selected.