ARBAMINCH UNIVERSITY

WATER TECHNOLOGY INSTITUTE

FACULITY OF WATER RESOURCES AND IRRIGATION

ENGINEERING

DRAINAGE ENGINEERING

For G3WRIE-STUDENTS

By : Melkamu Ateka And Lijalem Agegn

1. INTRODUCTION

What is drainage?

Drainage: *Is the removal of excess water and dissolved salts from the surface and subsurface of the land in order to enhance crop growth.*

- Land drainage plays an important role in maintaining and improving crop yields
- It prevents a decrease in the productivity of arable land due to rising water tables and the accumulation of salts in the root zone
- **A** large portion of the land that is currently not being cultivated has problems of waterlogging/ponding and salinity. Drainage is the only way to reclaim such land.

Con’d…

- **Surface Drainage :** The removal of excess water from the surface of the land by diverting it into improved natural or constructed drains.
- **Subsurface Drainage :** Is the removal of excess water and dissolved salts from soils via groundwater flow to the drains, so that the water table and root-zone salinity are controlled.
- **Ponding :** The accumulation of excess water on the soil surface.
- **Waterlogging** : The accumulation of excess water in the root zone of the soil.
- **Salinization :** The accumulation of soluble salts at the soil surface, or at some point below the soil surface, to levels that have negative effects on plant growth and/or on soils.

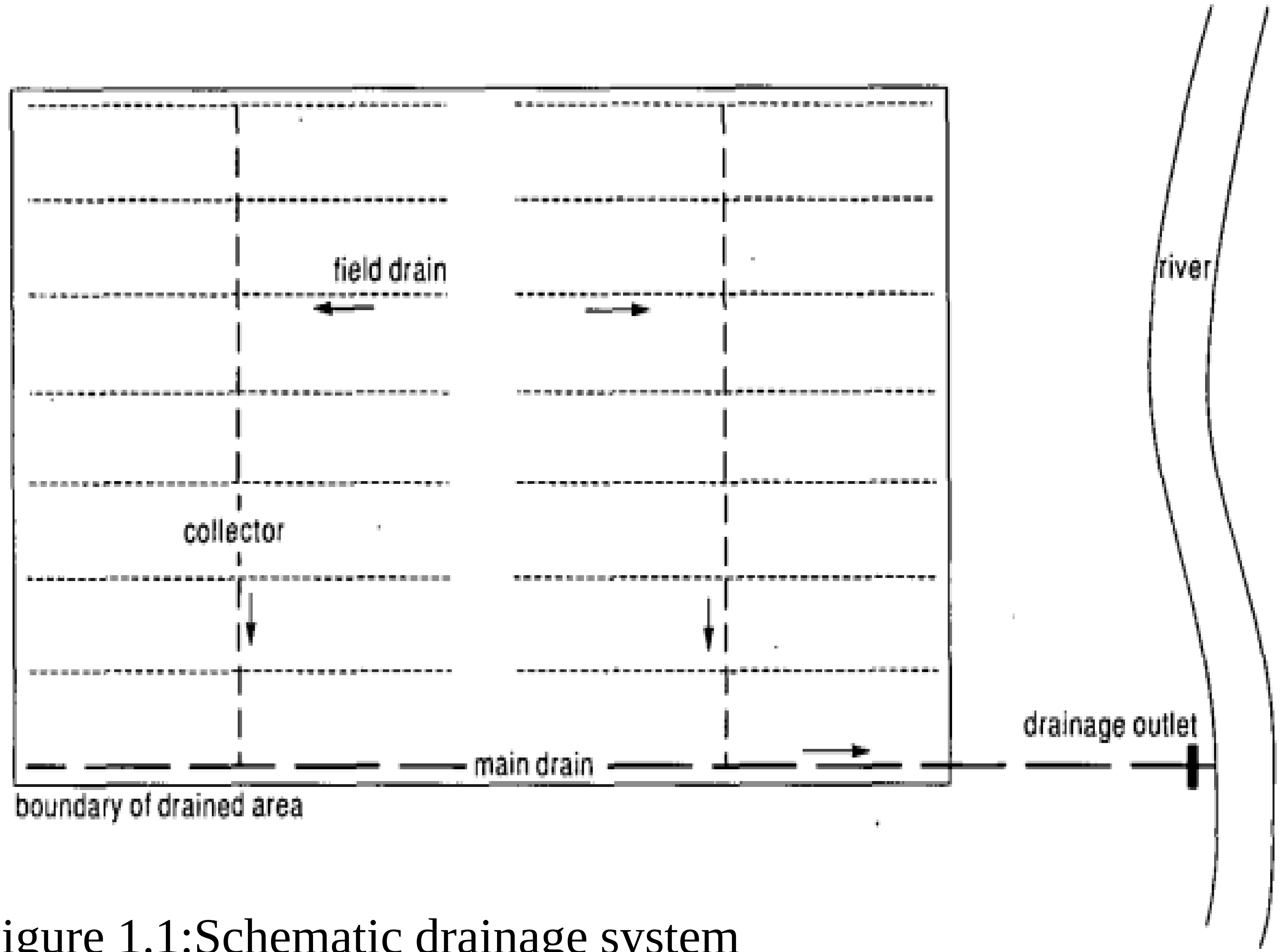
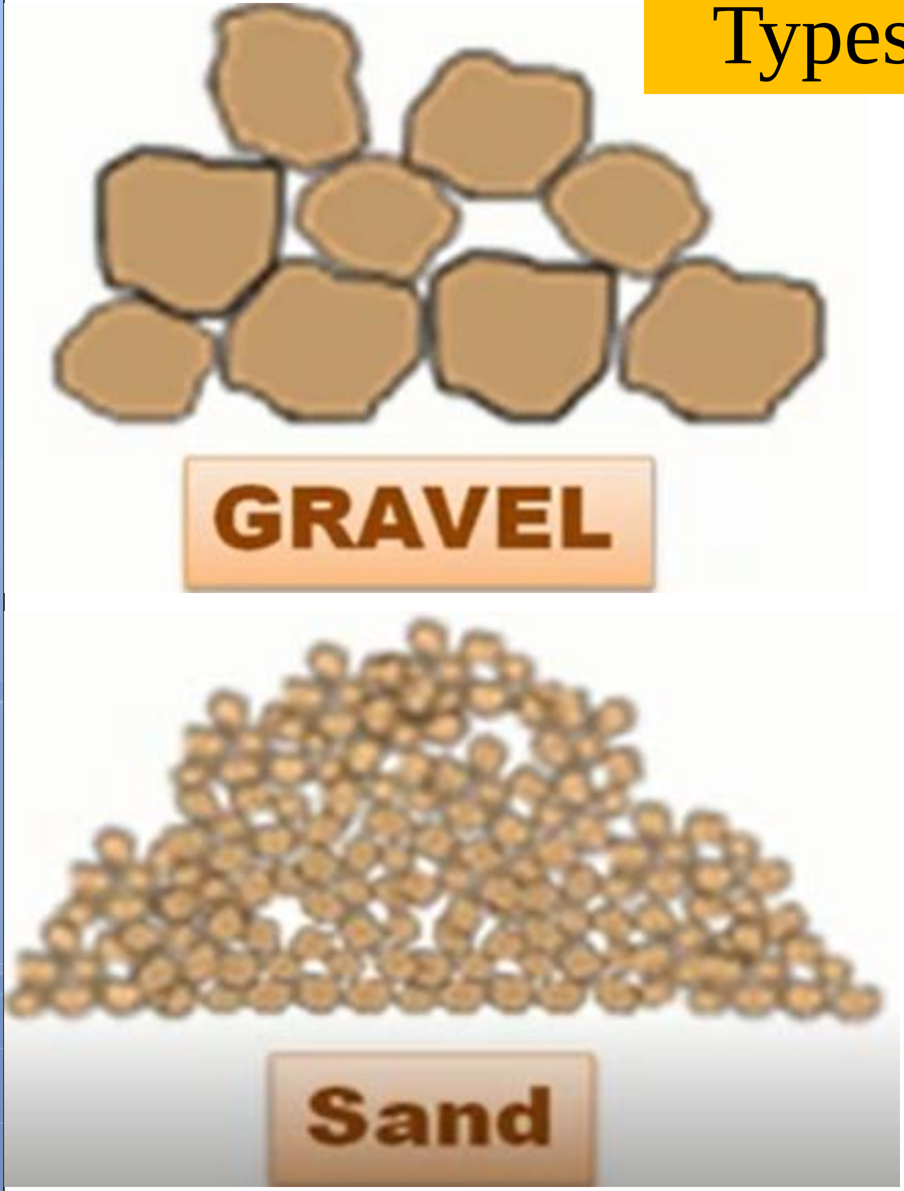


Figure 1.1:Schematic drainage system

Types of Soil



Types of Soil Water

Soil contains

- 25% Water
- 25% Air
- 5% Organic Matter and
- 45% Minerals.

Soil Pores Are of Two Types:

- Macrospores (size greater than 0.006mm)
- Microspores (size less than 0.006mm)

Con't…

- The water added to a soil mass during irrigation or otherwise is held in the pores of the soil which is termed as soil water or soil moisture.
- The soil water may exist in the soil in various forms, ***it can be classified in three categories as:***
  - ✓ **Hygroscopic water**
  - ✓ **Capillary water, and**
  - ✓ **Gravitational water**

I. Hygroscopic Water

- Is the water which is absorbed by the particles of dry soil from the atmosphere **(water sources…).**
- Is held as a very thin on the surface of the soil particles due to adhesion or attraction between surface of particles and water molecules.
- Below the permanent wilting point the soil contains only hygroscopic water.
- It is not available to the plant.

Con’d…

II. Capillary Water

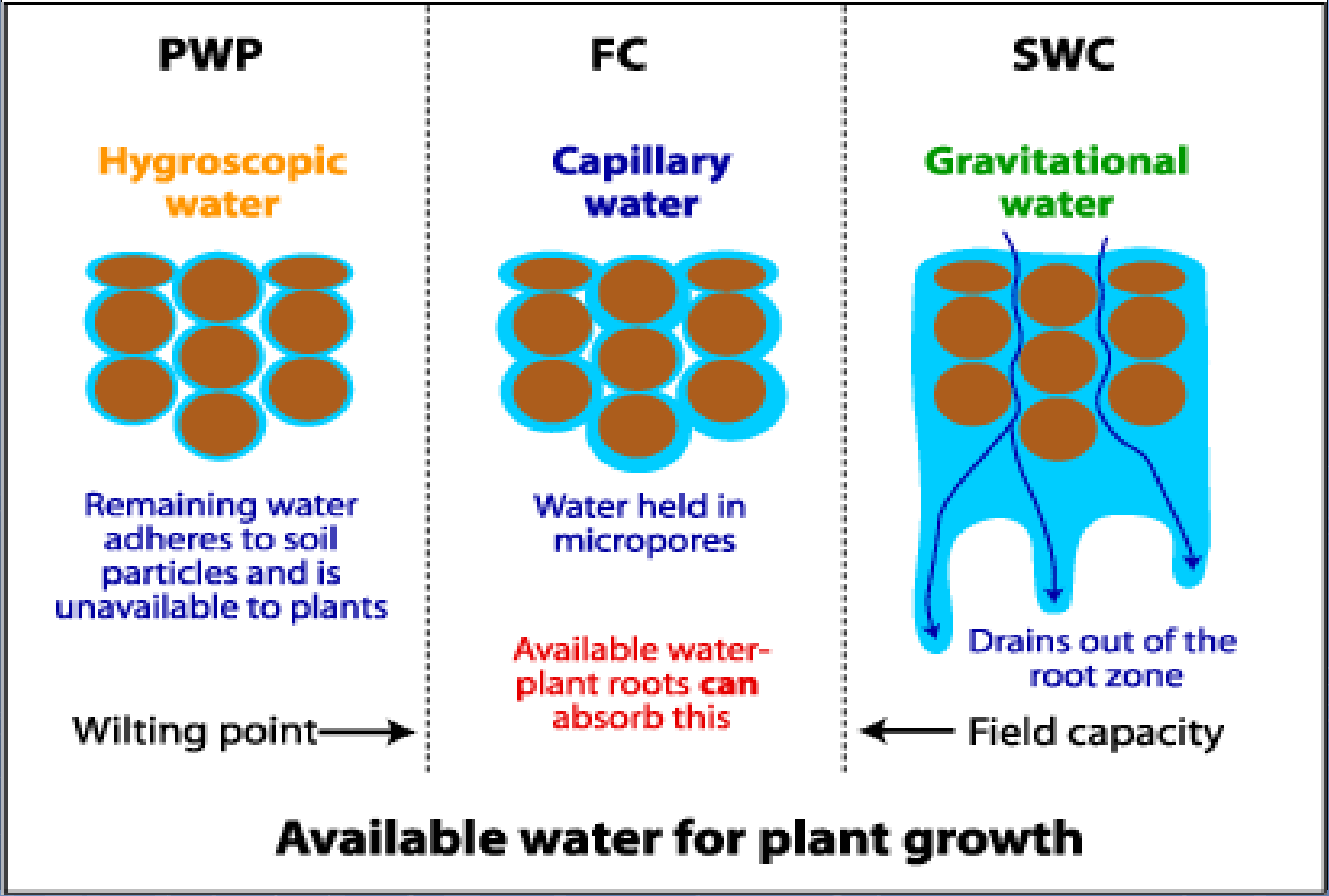
- The water content retained in the soil after the gravitational water has drained off.
- It is held in micropores of the soil due to surface tension properties of the soil (microspores are stronger than the force of gravity).
- It is the main water that is available to plants as it is trapped in the soil solution.
- Thus, it constitutes the principal source of water for plant growth.
- Main factors that influence the amount of capillary water in the soil are the:

(Structure, Texture and Organic matter content of the soil)

III. Gravitational Water (Sat=100%)

- Within the adhesion of water to the soil during irrigation or otherwise, the water content of the soil is raised to a state of saturation.
- At this point the soil pores are completely filled with water and the soil contains the maximum possible water content, which thus constitutes the upper limit of the gravitational water.
- It is free water moving through soil by the force of gravity.
- Largely found in macropores of soil and very little gravitational water is available to the plants as it drains rapidly down the water table in all except the most compact of soils.
- *It is that water which is not held by the soil but drains out freely under the influence of gravity.*

Con’d…


PWP
FC
SWC
Hygroscopic water
Capillary water
Gravitational water
Remaining water adheres to soil particles and is unavailable to plants
Water held in micropores
Drains out of the root zone
Available water- plant roots can absorb this
Wilting point
Field capacity
Available water for plant growth

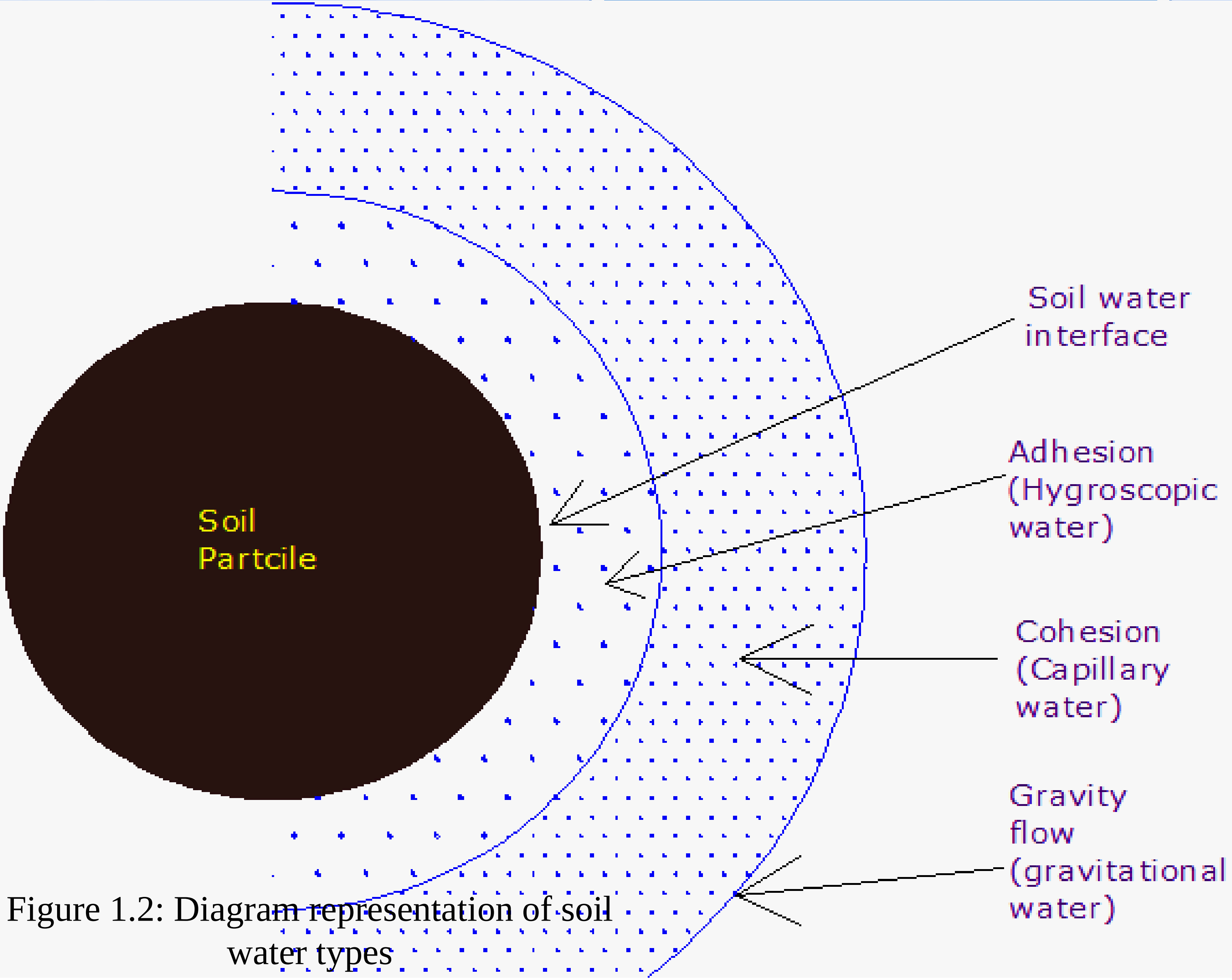


Figure 1.2: Diagram representation of soil water types

SOIL MOISTURE CHARACTERISTICS

- Moisture extraction curves, also called moisture characteristic curves, which are plots of moisture content Vs moisture tension.
- Soil moisture tension depends on the texture, structure and other characteristics of the soil.

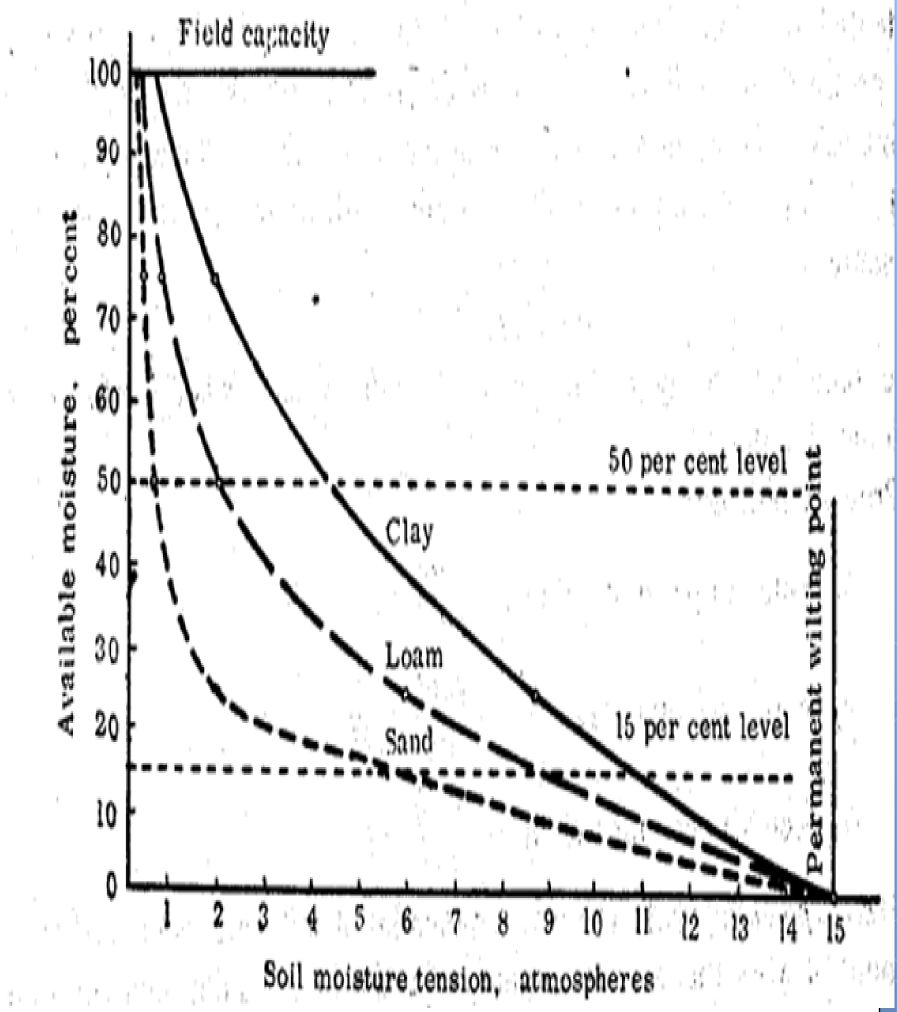


Figure 1.3 : Typical moisture characteristics curves of clay, silt loam and sand soils (From USDA, SCS).

Table 1: Generalized influence of soil separates on other soil properties and behavior

Property/behavior	Sand	Silt	Clay
Water-holding capacity	Low	Medium to High	High
Aeration, when moist	Good	Medium	Medium to poor
Hydraulic (water) conductivity	High	Slow to Medium	Slow to very slow
Soil organic matter level	Low	Medium to High	High to Medium
Decomposition of organic matter	Rapid	Medium	Slow
Warm-up in spring	Rapid	Moderate	Slow
Compactability	Low	Medium	High
Susceptibility to wind erosion	Moderate (high if fine sand)	High	Low
Susceptibility to water erosion	Low (unless fine sand)	High	Low if aggregated, High if not
Shrink-swell potential	Very low	Low	Moderate to very high
Sealing of ponds and dams	Poor	Poor	Good
Suitability for tillage when wet	Good	Medium	Poor
Pollutant leaching potential	High	Medium	Low (unless cracked)
Cation exchange capacity (CEC)	Low	Medium	High
Resistance to pH change	Low	Medium	High

SOIL MOISTURE CONSTANTS

Field capacity (FC):

- Is the amount of water remaining in the soil after the large pores have drained.
- The optimum water content for plant growth is considered to be close to field capacity.
- Plants continuously take this up until there is no more water available for crop growth and wilting occurs

Permanent welting point (PWP)

- Is the moisture content level at which the plants are water stressed and irreversibly wilt.
- The soil is said to be at the permanent wilting point when plants can no longer exert enough force to extract the remaining soil water.

con’d…

- The plant will wilt and may die later if water is not available.
- Water tension of soil at PWP is generally taken as **15 bars**.

Saturation capacity

- When all pores of soil are filled with water, it drains out so fast that it is not available to the crops.
- The time of draining out varies from sandy soils to clay soils.

Available Water (AW):

- The soil moisture between field capacity and permanent wilting point is referred as available moisture.

Readily Available Water (RAW):

- This is the level to which the available water in the soil can be used up without causing stress in the crop.
- For most crops, 50 to 60% available water is taken as readily available.

Con’d…

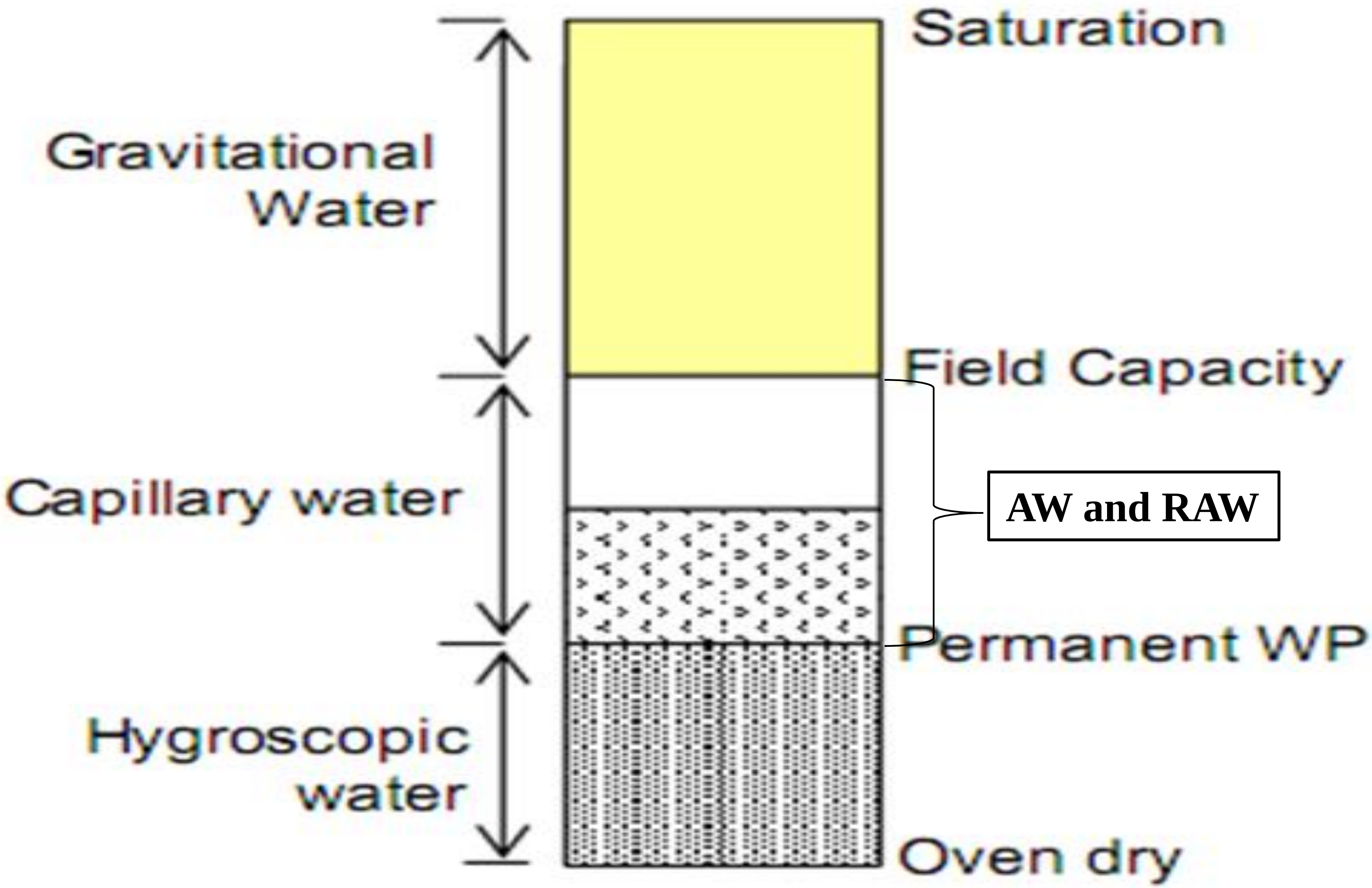


Fig 1.3 Classification of soil water

Water Movement in the Soil

- Water movement in the soils is quite simple and easy to understand.
- Mass of water tends to move from an area of higher potential energy to one of lower potential energy.

SOIL WATER POTENTIAL

Soil-water potential is defined as the work expended on or by the soil water during the transfer of an infinitesimal quantity of water from point A to a reference pool or point B in the soil.

- The total potential energy of water is the sum of the potentials from all sources.

$$\boldsymbol{\varphi T = \varphi m + \varphi g + \varphi p + \varphi o}$$

Where, $\boldsymbol{\varphi}$ (psi)= symbol for water potential

$\boldsymbol{\varphi m}$= matric potential, $\boldsymbol{\varphi g}$= gravitational potential

$\boldsymbol{\varphi p}$= pressure potential, $\boldsymbol{\varphi o}$= osmotic/solute potential

Gravitational Potential

- It was determined by the height of water above reference level
- Water moves downward under gravity.
- It is zero at reference level and positive above RL & negative below RL.
- According to principle of energy, water moves from points with higher energy status to points with lower energy status.
  - ***N.B Differences in head determine the direction and the magnitude of soil - water flow.***

pressure potential(φp,+ve/-ve)

- The pressure potential is a measure of the ***positive pressure*** potential and is measured in ***saturated soil conditions***.
- The ***negative pressure potential*** has been referred to as ***capillary potential, tension, suction, and matric potential.***
- φp is zero above and at level of water in the pizeometer.
- These forces bind the water to the soil matrix and lower the potential.
- ***The matric potential is a negative pressure and is measured in unsaturated soil.***

Matric potential (φm,-ve)

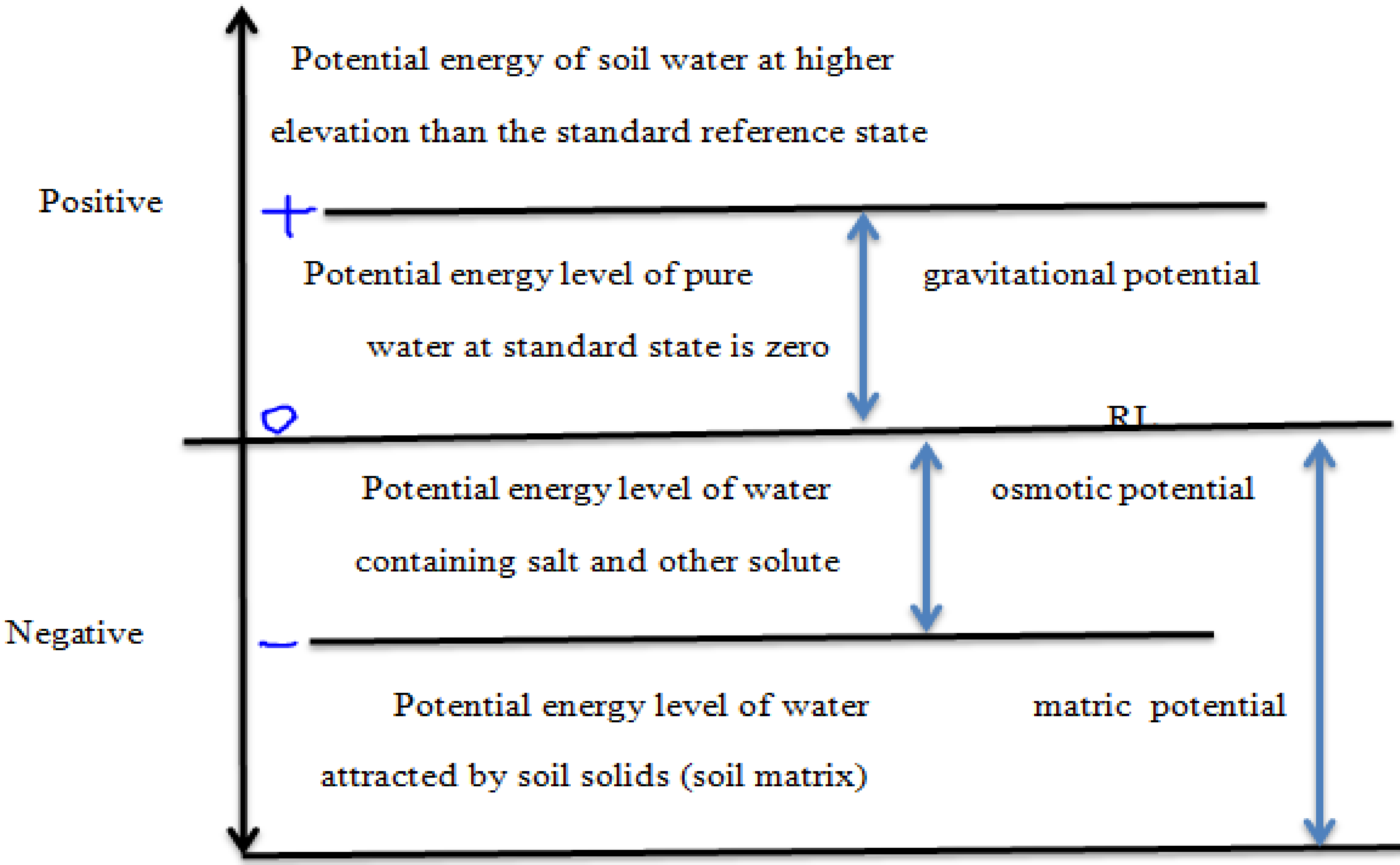
- It was determined by the strength of the ***attraction of water*** to the ***soil particle***.
- It is the most important part for the unsaturated flow(dry soil) Water flows from zone of wet soil to zone of dry soil (less negative to more negative).
- It is zero for saturated cause (***at and below water table***).
- The matric potential is a negative pressure and measured in unsaturated soil.

Solute or osmotic pressure (φo,-ve)

- Presence of solutes in soil water decreases the potential energy of water in the soil.
- The potential energy of water in the solution is lower than that of pure water.
- It was determined by the concentration of solutes in the soil water.
- It is more negative for high solute concentration. ***Water moves from zone of low solute to high solute concentration***.

con’d…

Water movement in unsaturated zone



Con't…

Components of Soil Water Potential

Factor affecting Potential Energy	Component name	Reference State	Sign
Adsorption of water to soil	Matric Potential	Free Water	**neg** "-"
Dissolved solutes	Osmotic or Solute Potential	Pure Water	**neg** "-"
Elevation in gravitational field	Gravitational Potential	Reference Elevation	**pos** "+" (above ref. elev.) or **neg** "-" (below ref. elev.)
Applied pressure	Pressure Potential	Atmospheric Pressure	**pos** "+" (applied pressure) or **neg** "-" (applied suction)

Darcy's Law and Richard's Equation

- **Darcy's Law and Richard's Equation**

A. Darcy's Law

- Darcy's law can be Validated for **Saturated** ,unsaturated and ***laminar*** flow conditions.
- Darcy's law says that the ***discharge rate q*** is proportional to the ***gradient in hydraulic head and the hydraulic conductivity*** or
- It states that volume of water flowing through a unit cross-sectional area per unit time (flow flux density) is proportional to the hydraulic gradient i.e.

$$(q = Q/A = -K * \dot{\Delta} h / \dot{\Delta} L)$$

- The proportionality factor, K, is called the hydraulic conductivity.

Con't...

(1). Q was directly proportional to the difference in water levels from inlet to outlet, $h_1 - h_2 = \Delta h$:

$$Q \propto \Delta h$$

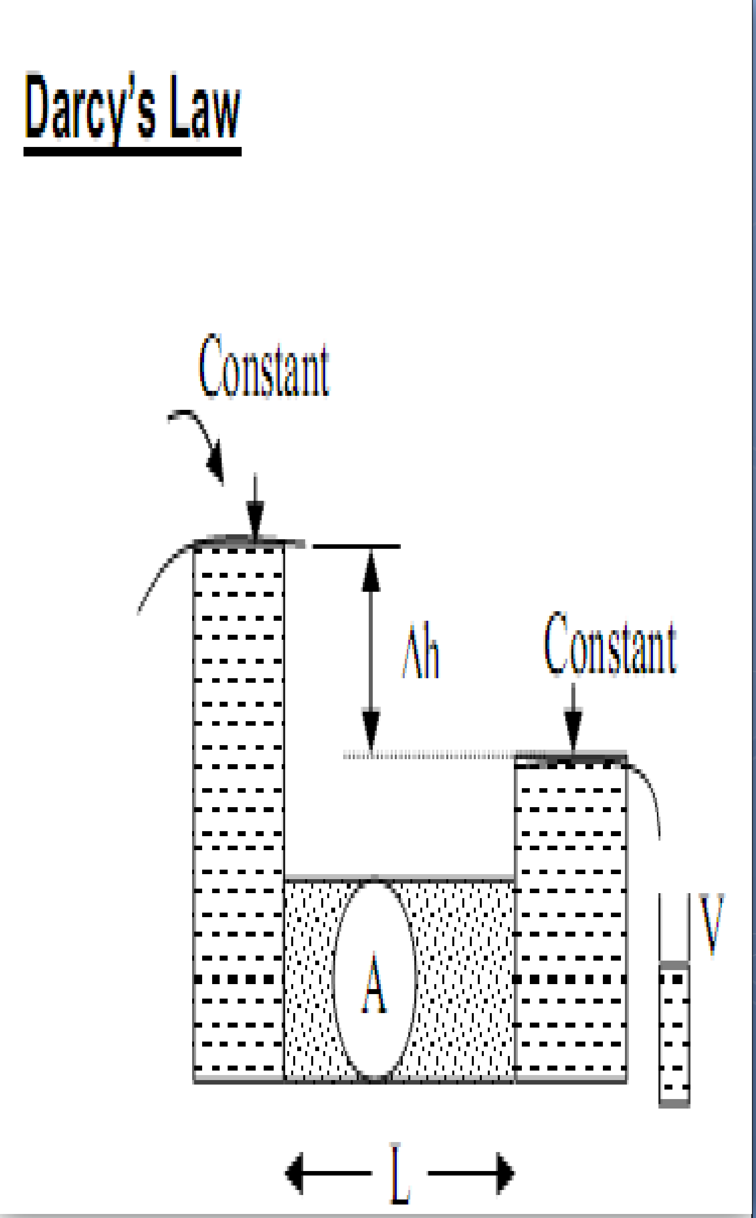
(2). Q was directly proportional to the cross sectional area of the tube:

$$Q \propto A$$

(3). Q was inversely proportional to the length of the column:

- .

$$Q = KA(\Delta h/\Delta L)$$



Con't…

- The above equation can also be recast in terms of:

- *The water volume flux per unit area, Q/A (also called "Darcy flux" or "Darcy velocity" with units of length per time):*

$$Q/A = -K(\Delta h/\Delta L)$$

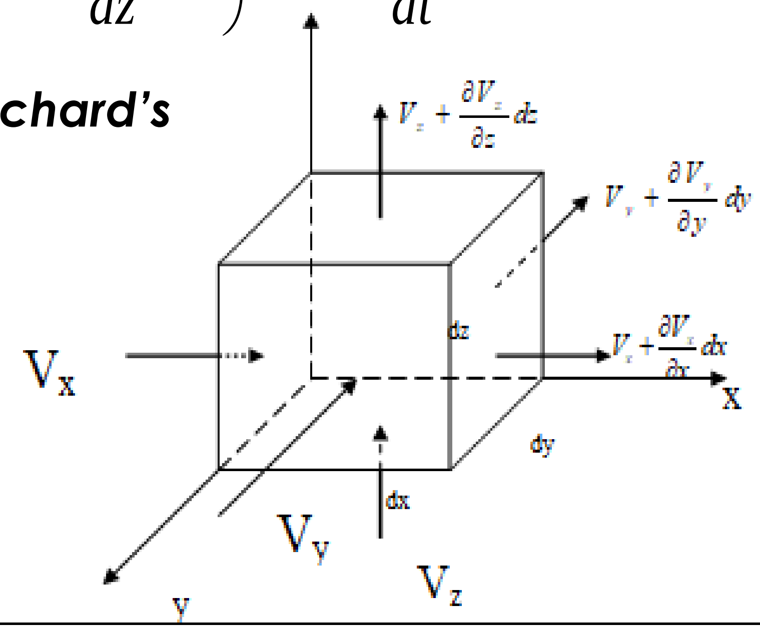
- *The negative sign in the above equations means that water flows in the direction of decreasing potential or against the positive direction of **z**.*

Richard’s Equation

- Consider a volume element of soil in the shape of cubic parallelepiped inside a space defined by a set of the rectangular coordinates x, y, z as shown in the figure below; profe the equation given below using the figure.

$$\frac{\partial}{dx}\left(K(h)\frac{dh}{dx}\right)+\frac{\partial}{dy}\left(K(h)\frac{dh}{dy}\right)+\frac{\partial}{dz}\left(K(h)(\frac{dh}{dz}+1)\right)=C_{(h)}\frac{dh}{dt}$$

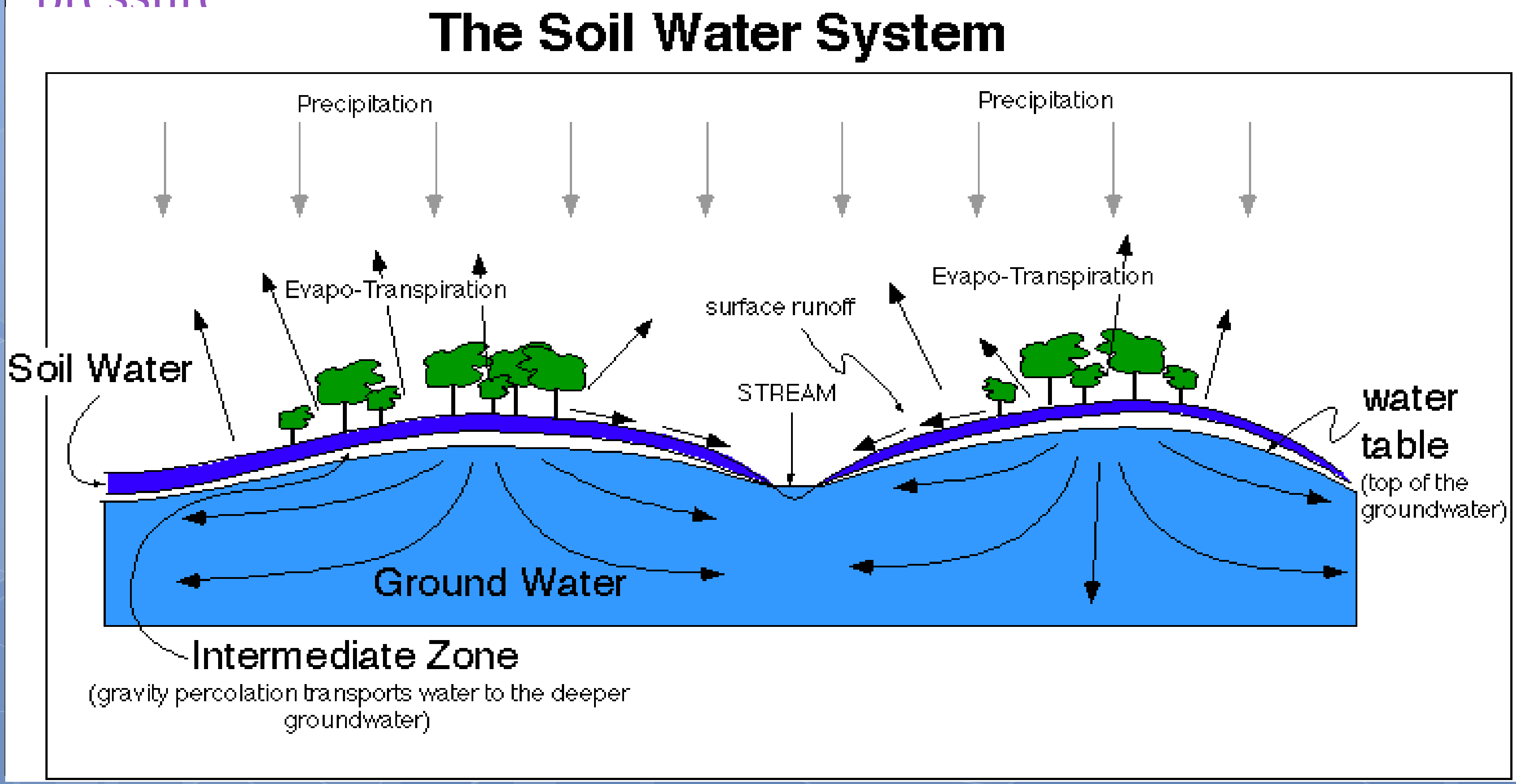
This expression is known as ***Richard’s equation***



Soil Water Movement Above Water Table

- The **Water Table** is the upper surface of the zone of saturation.

Where, the water **pressure head** = The atmospheric pressure



Con'd…

- Sometimes the natural drainage is inadequate to remove the extra water or salts brought in by irrigation; in such a case, an artificial or man-made drainage system is required.

CHAPTER TWO: DRAINAGE AND CROP PRODUCTION

THE NEED FOR DRAINAGE

- In the field, irrigation water, together with any rainfall ,will be partly stored on the soil surface and will partly infiltrate into the soil .
- If rain or irrigation continues for long periods, pools may form on the soil surface.
- This excess water on the soil surface is called ***ponded*** water.

  and hence, It needs to be removed or drained.
- **A** large portion of the land that is currently not being cultivated has problems of :

✓ ponding,

✓ waterlogging and salinity.

Drainage is the only way to reclaim such land.

- *Land drainage, as a tool to manage groundwater levels, plays an important role in maintaining and improving crop yields.*

Con’d…

The main objectives of Land drainage includes:

- To bring soil moisture down from saturation to field capacity.
  - *At field capacity, air is available to the soil.*
- Drainage helps *to improve soil hydraulic conductivity*
  - *Soil structure can collapse under very wet conditions and so also engineering structures.*
- In some areas with salt disposition, especially in arid regions, drainage is used ***to leach excess salt***.
- In irrigated areas, drainage is needed due to poor application efficiency which means that a lot of water is applied.
- Drainage can shorten the number of occasions when cultivation is held up waiting for soil to dry out.

Drainage to control water ponding

Water ponding:

- When rain or irrigation continues, pools may form on the soil surface, and this excess water needs to be removed.
- This standing water on the soil surface is called ponding water.
- ***(Ponding is the accumulation of excess water on the soil surface)***
- To remove excess (ponding) water from the surface of the land, we use surface drainage system.
- This is normally accomplished by shallow open field drains.
- In order to facilitate the flow of excess water towards these open drains, the field is usually given an artificial slope by means of ***land shaping*** *or* ***grading***

con'd…

- Surface drainage is the diversion or orderly removal of excess water from the surface of the land by means of improved natural or constructed drains.
- when necessary by the shaping and grading of land surfaces to such drains.

Drainage to control waterlogging

- When the percolating water reaches that part of the soil which is saturated with water, the water table will rise.
- If the water table reaches the root zone, the plants may suffer, and The soil has become waterlogged.
- ***Waterlogging:*** *is the accumulation of excess water in the root zone of the soil.*

con’d…

- To remove excess water from the root zone we use subsurface drainage.
- By subsurface drainage we control the water table, and excess water is removed from the underground by gravity through open or pipe drains installed at depths varying from 1 to 3 m.
- Subsurface drainage is the removal of excess water and dissolved salts from soils via groundwater flow to the drains.

  so that the water table and root zone salinity are controlled.

Drainage to control salinization

- Drainage is needed to remove the excess water and to control the rise of the Water table.
- Even in irrigation water of very good quality there are salts, thus bringing irrigation water to a field means also bringing salts to the same field.
- The irrigation water is used by the crop or evaporates directly from the soil. The salts, however, are left behind. This process is called salinization.
- ***Salinization*** *is the accumulation of soluble salts at the surface, or at some point below the surface of the soil profile, to levels at which they have negative effects on plant growth and/or soils.*

con’d…

- To remove salts from the soil, water is used as a vehicle: more irrigation water is applied to the field than is required for crop growth.
- This additional water infiltrates into the soil and percolates through the root zone.
- During percolation the water takes up part of the salts from the soil and removes these through the subsurface drains.
- This process, in which the water washes the salts out of the root zone, is called ***leaching***.

con'd…

- The additional water required for leaching must be removed from the root zone by means of drainage
- Otherwise the water table will rise and this will bring the salts back into the root zone.
- Thus salinity control is achieved by a combination of irrigation and drainage measures

Benefits of drainage

- *One of the benefits of installing a drainage system to remove excess water is that the soil is better aerated.*

This leads to a higher productivity of crop land because:

- *The crops can root more deeply*
- *The choice of crops is greater*
- *There will be fewer weeds*
- *Fertilizers will be used more efficiently*
- *The land is more easily accessible*
- *The land has a greater bearing capacity*
- *The soil has a better workability and tilth*
- *The period in which tillage operations can take place is longer*
- *It prevents increases in soil salinity in the root zone*
- *By removing salts, it allows salt-sensitive crops, or a wider range of crops, to be grown.*

CHAPTER THREE: DRAINAGE SYSTEMS

Drainage System:

- Is a system by which water is drained on or in the soil to enhance agricultural production of crops.
- It may involve any combination of storm water control, erosion control, and water table control.
- Drainage can be either natural or artificial.
- Many areas have some natural drainage; this means that excess water flows from the farmers' fields to swamps or to lakes and rivers.
- A drainage system is an artificial system of land forming, surface and/or subsurface drains, related structures, and pumps (if any), by which excess water is removed from an area when
- Natural drainage is often inadequate and artificial or man-made drainage is required.

Types of Artificial Drainage Systems

1. Surface Drainage and

2. Subsurface Drainage

Surface drainage:

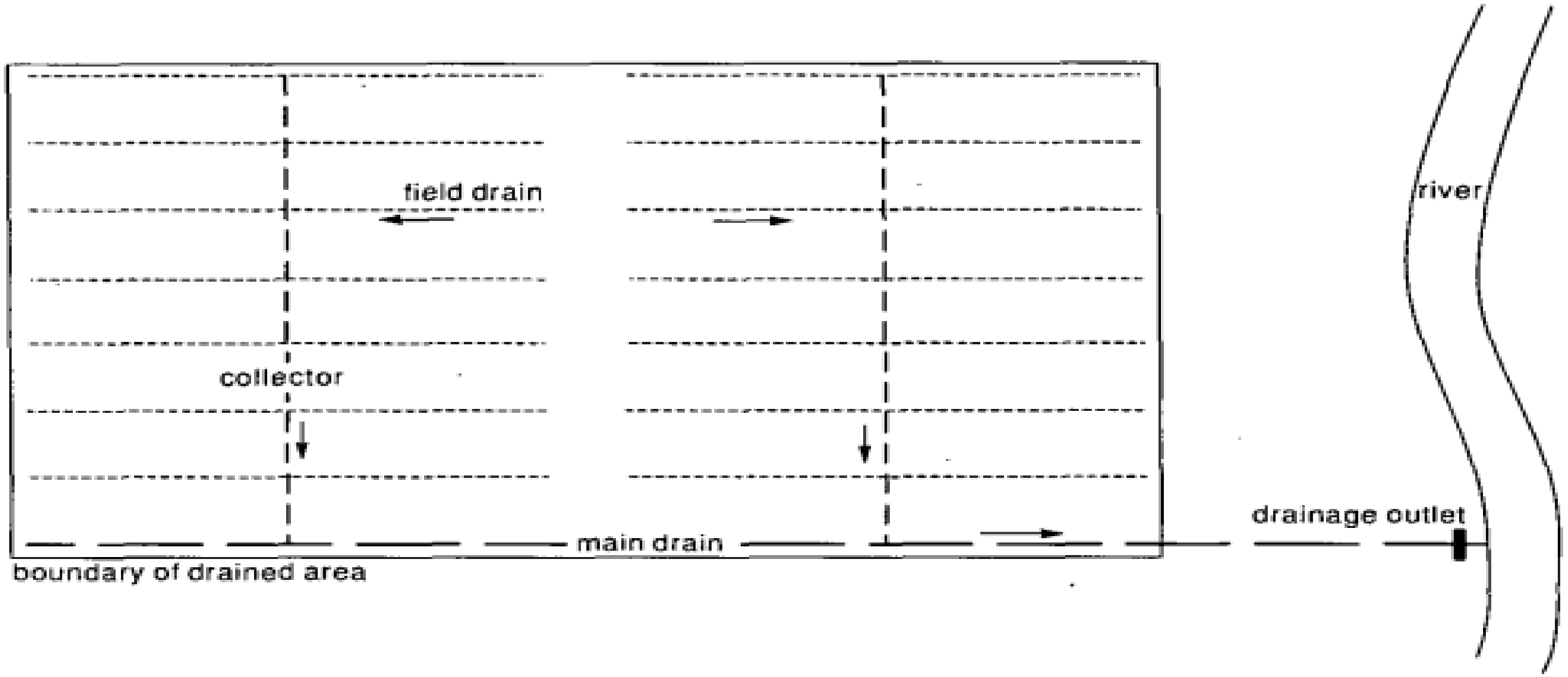
- Is a system of drainage measures, such as open drains and land forming, to prevent ponding by diverting excess surface water to a collector drain.
- This is normally accomplished by shallow ditches, also called open drains.
- The shallow ditches discharge into larger and deeper collector drains.
- In order to facilitate the flow of excess water toward the drains, the field is given an artificial slope by means of land grading.

A surface drainage system always has two components:

1. Open field drains to collect the ponding water & divert it to the collector drain.

2. Land forming to enhance the flow of water towards the field drains.

1. Open field drains



2. Land forming

- It is the change of surface of the land to meet the requirements of surface drainage or irrigation.
- There are three land-forming systems:
- *bedding,*
- *land grading and*
- *land planning.*
- **Bedding:** is a surface drainage method achieved by ploughing land to form a series of low beds, separated by parallel field drains.
- **Land grading:** Land grading for surface drainage consists of forming the land surface by:
- cutting, filling and smoothing it to predetermined grades so that each row or surface slopes to a field drain.
- **Land planning:** Land planning is the process of smoothing the land surface to eliminate minor depressions and irregularities, but without changing the general topography

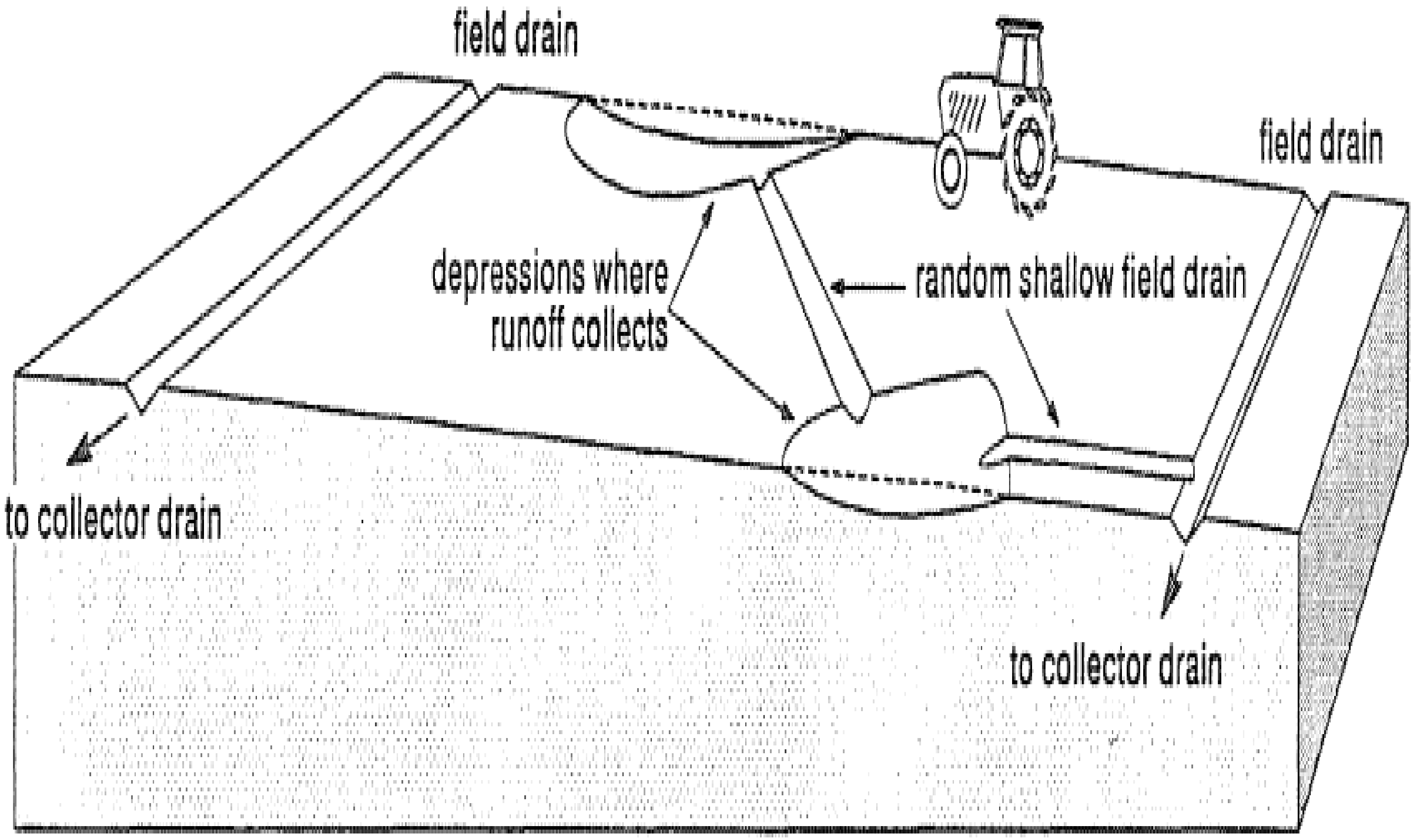
Surface Drainage System

surface drainage systems have two different layouts:

- **The random field drainage system and**
- **The parallel field drainage system**
- ***Random Field Drainage System***

- This type system is adapted to drainage systems on undulating land where only scattered wet areas require drainage.
- Applied where there are a number of large but shallow depressions in a field.
- Connects the depressions by means of a field drain and evacuates the water into a collector drain.
- The system is often applied on land which does not require intensive farming operations.

con’d…

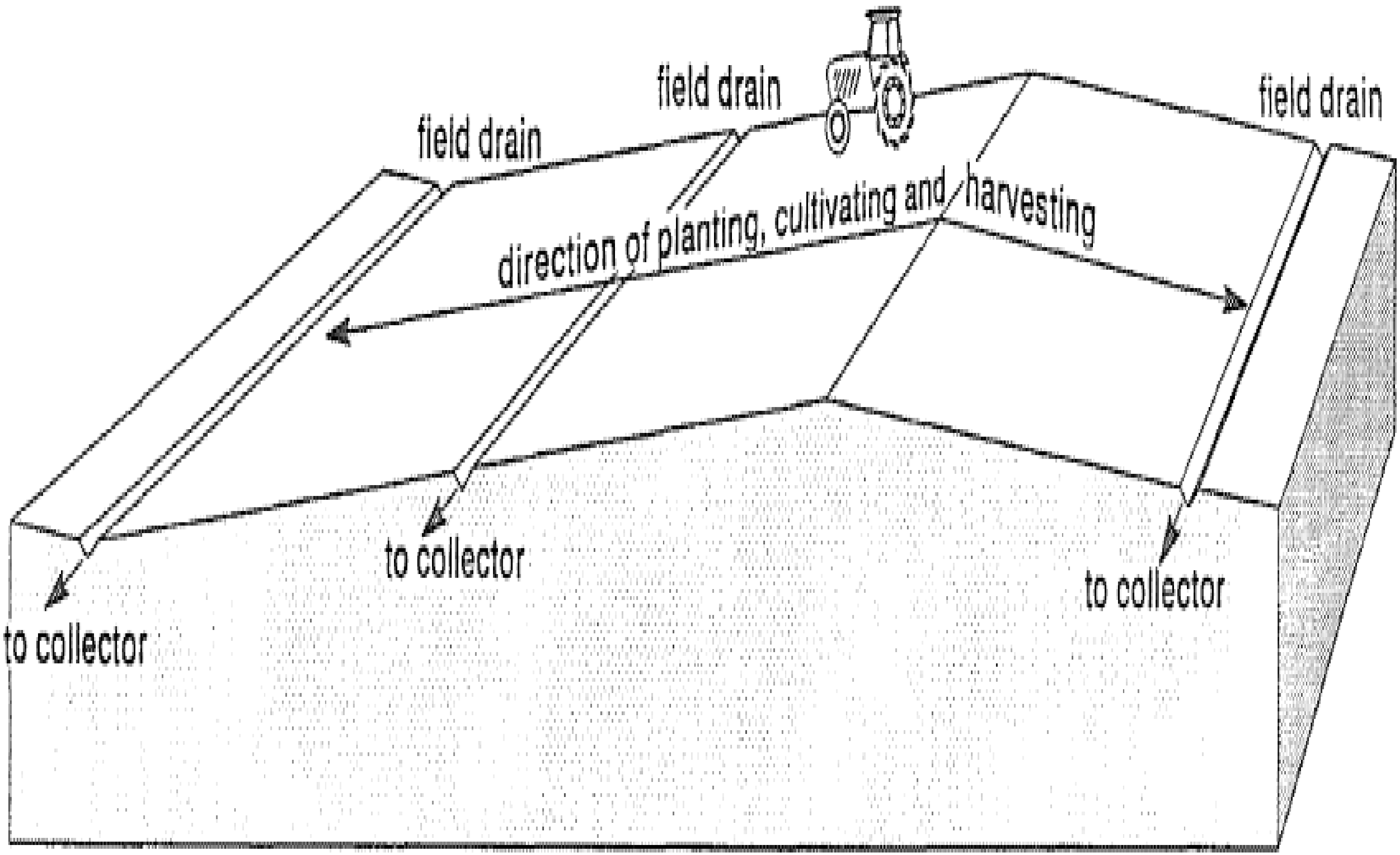


Random field drainage systems

Parallel field drainage system

- This type system is applicable to land where the topography is flat and regular and where uniform drainage is needed.
- The parallel field drainage system in combination with proper land forming, is the most effective method of surface drainage.
- The parallel field drains collect the surface runoff and discharge it into the collector drain.
- The ditches are established parallel but not necessarily equidistant.
- The system is suitable in flat areas with an irregular micro-topography.

con'd…



The parallel field drainage system

Subsurface Drainage

- Removal of excess water and dissolved salts from the soil
- It is accomplished by deep open drains or buried pipe drains.

Deep open drains

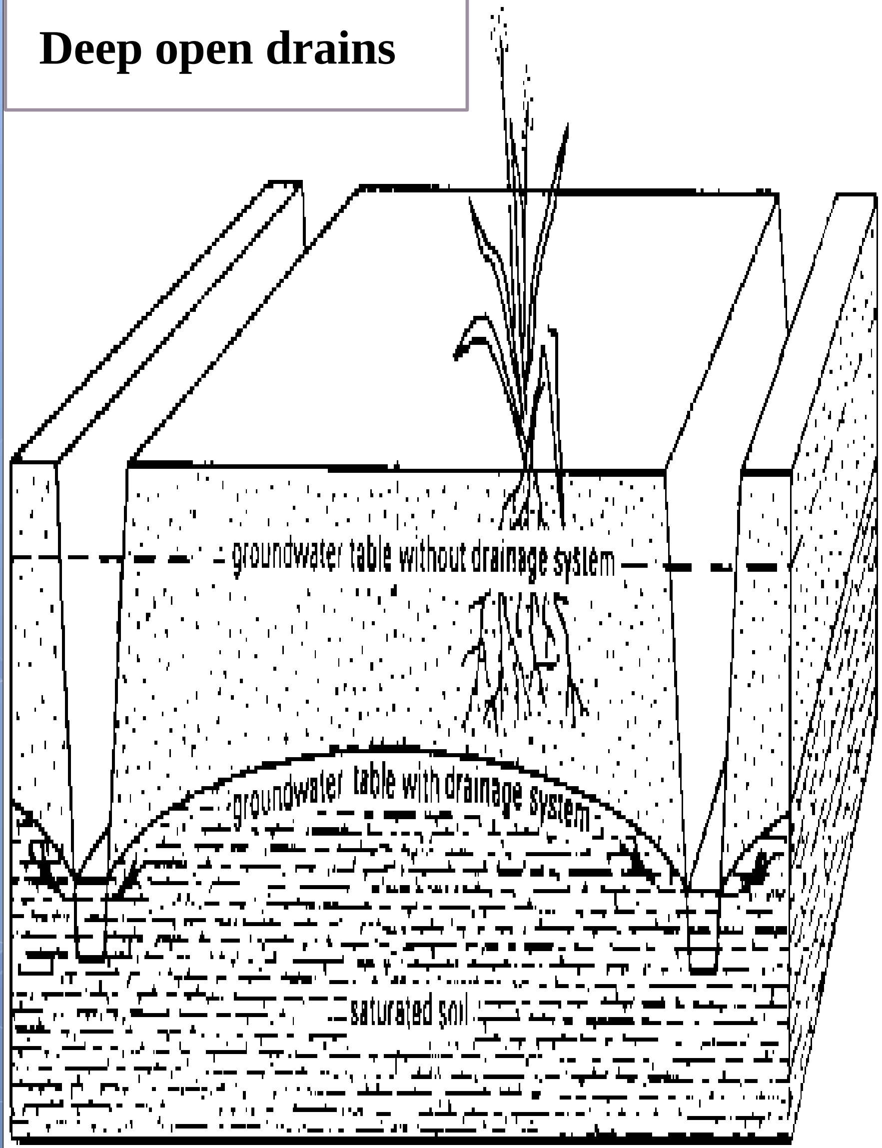
- The excess water from the root zone flows into the open drains.
- The disadvantage of this type of subsurface drainage is that it makes the use of machinery difficult (not easily avail).

Buried pipe drains

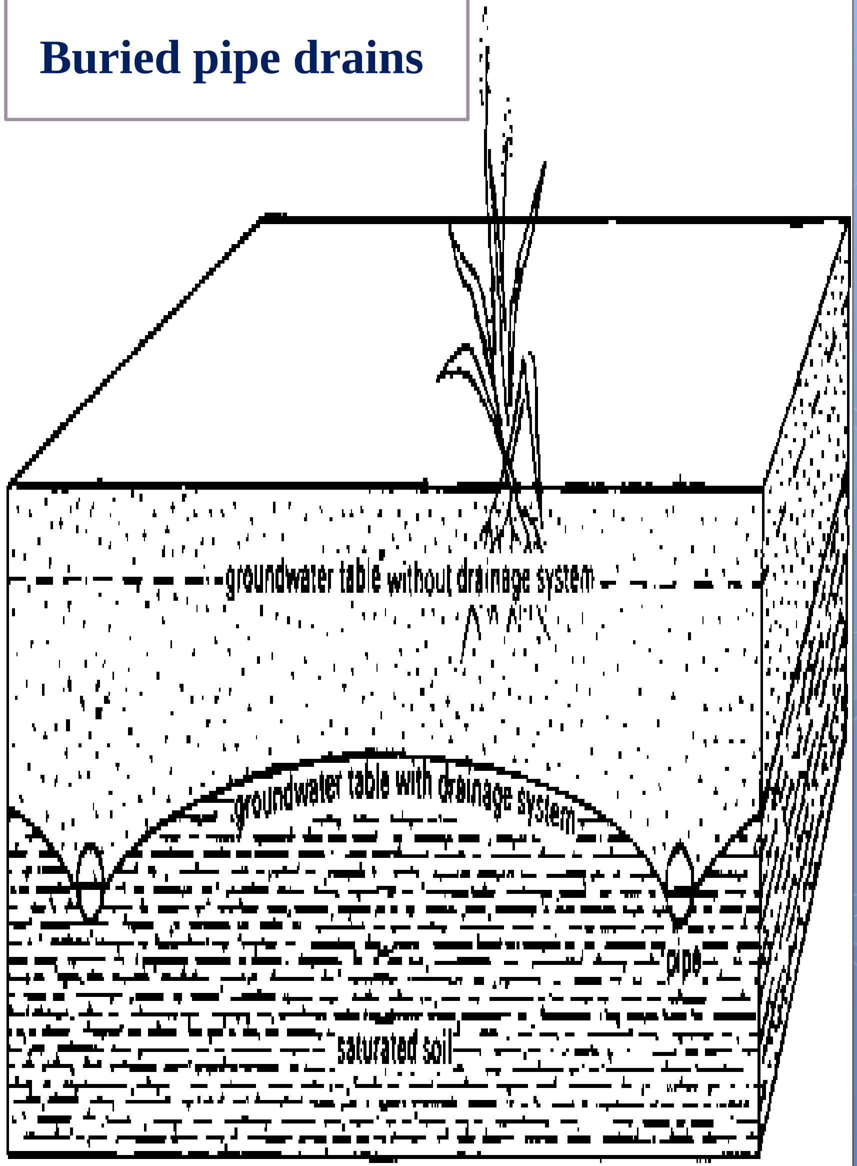
- Buried pipes with openings through which the soil water can enter
- The pipes convey the water to a collector drain

Con'd…

Deep open drains



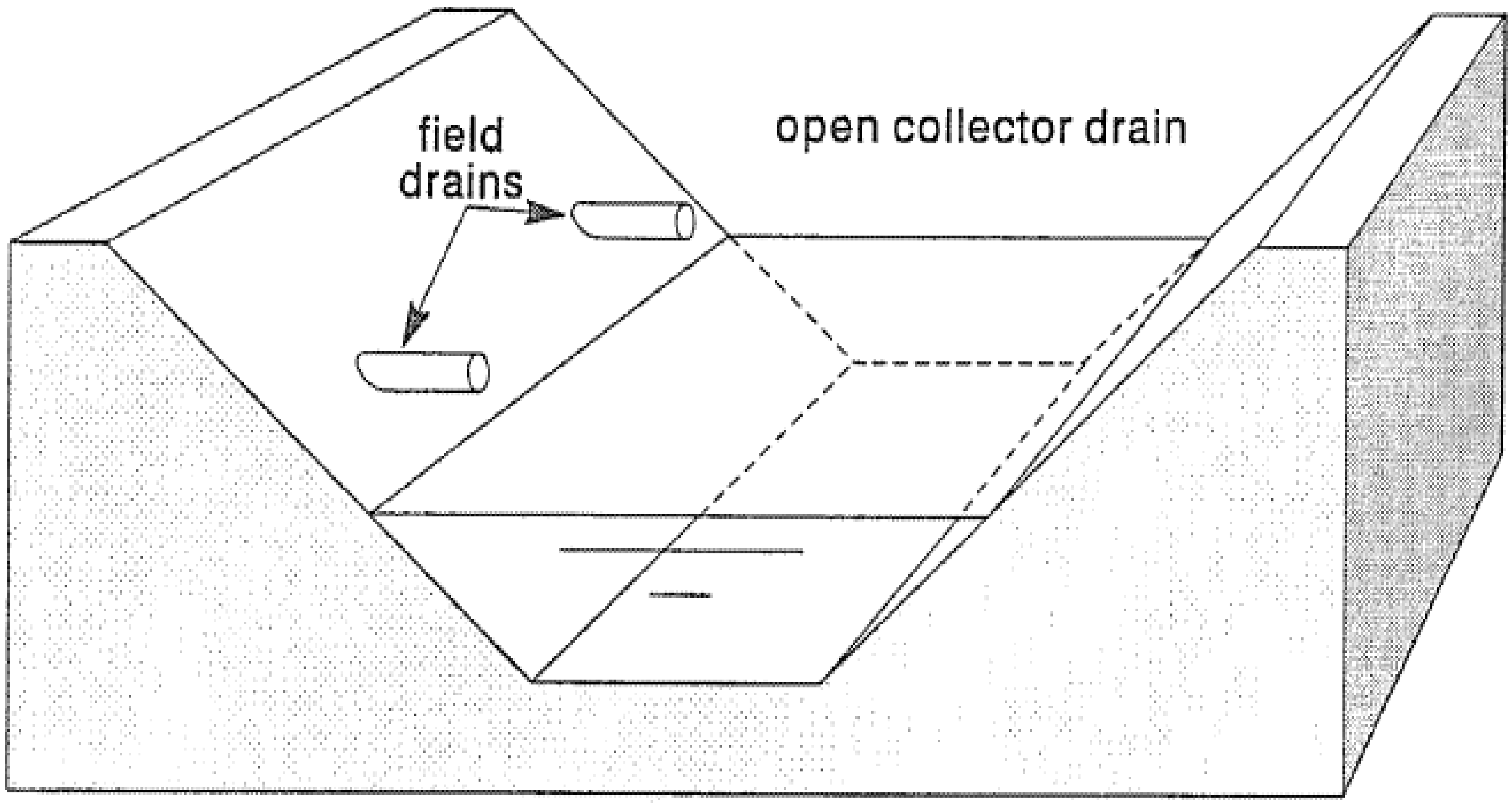
Buried pipe drains



con'd…

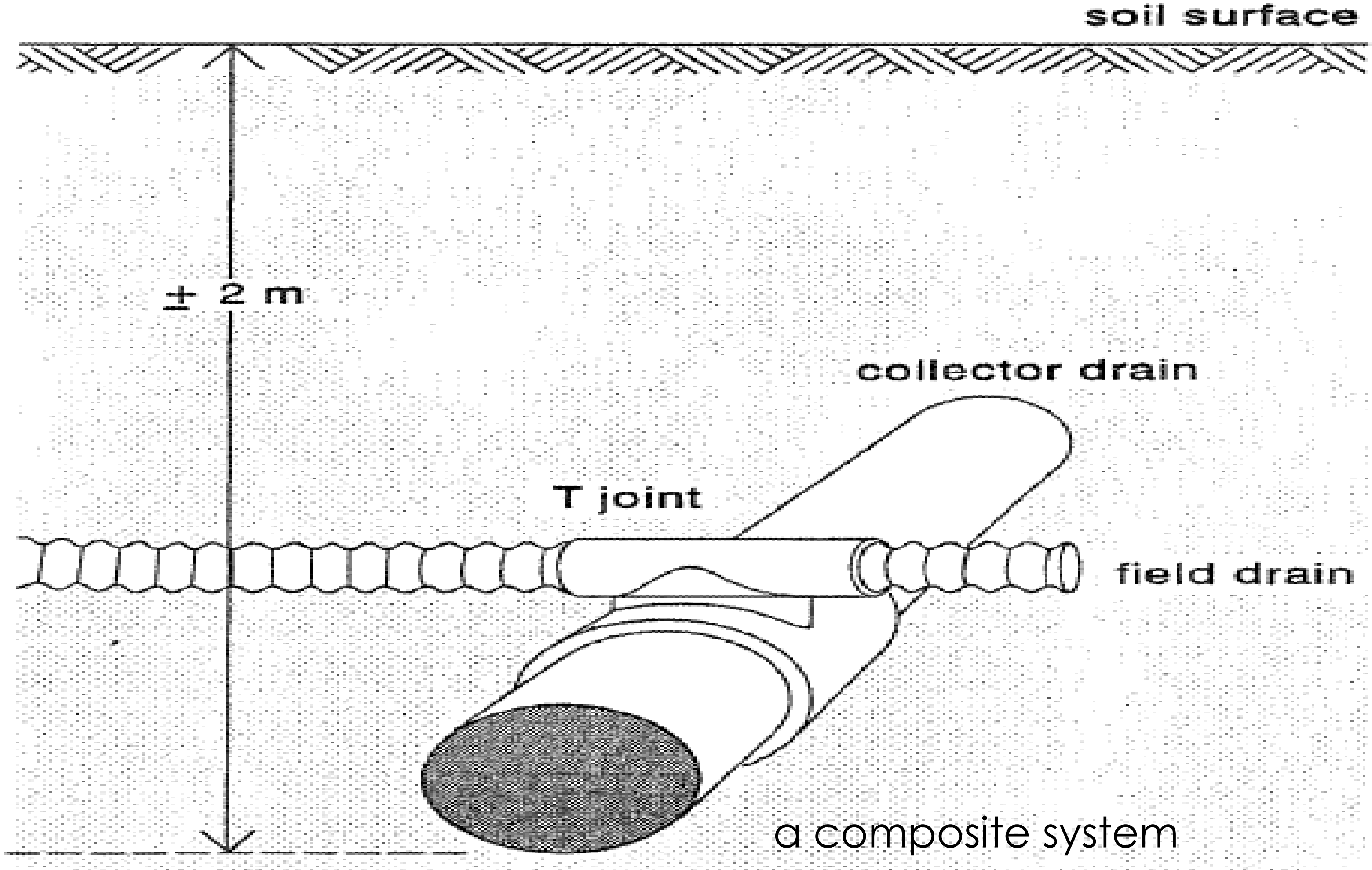
- The choice between open drains or pipe drains has to be made at two levels:
  - For field drains and
  - For collector drains.
- If the field drains are to be pipes, there are still two options for the collectors:
  - ***open drains***, so that there is a singular pipe drainage system.
  - ***Pipe drains***, so that there is a composite pipe drainage system.
- In a singular pipe drainage system, each field pipe drain discharges into an open collector drain

- A **singular drainage system:** A drainage system in which the field drains are buried pipes and all field drains discharge into open collector drains.



a singular pipe drainage system

- A **composite drainage system:** A drainage system in which all field drains and all collector drains are buried pipes



Components of a Drainage System

- ***A drainage system has three components***:
  - ***Field drainage system***
  - ***Main drainage system***
  - ***An outlet***

The field drainage system

- is a network that gathers the excess water from the land by means of field drains, possibly supplemented by measures to promote the flow of water to these drains.
- The *field drains* (or *laterals*) discharge their water into the collector or main system either by *gravity* or by *pumping*.
- The field drainage system is the most important component for the farmers.

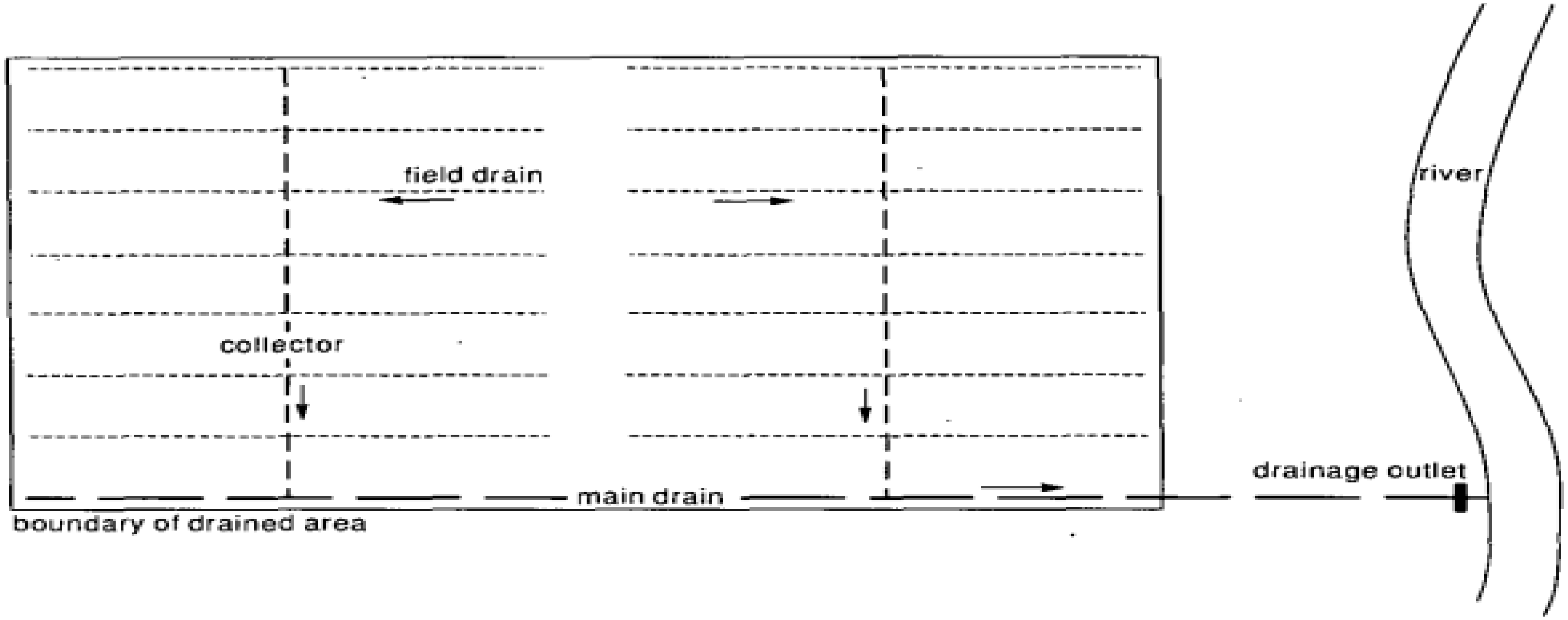
Main Drainage System

- **It** is a water-conveyance system that receives water from the field drainage systems; surface runoff and groundwater flow, and transports it to the outlet point.
- A collector drain collects water from the field drains and carries it to the main drain for disposal.
- The main drainage system consists of some collector drains and a main drainage canal.
- Collector drains can be either open drains or pipe drains.
- The main drain is the principal drain of an area.

outlet

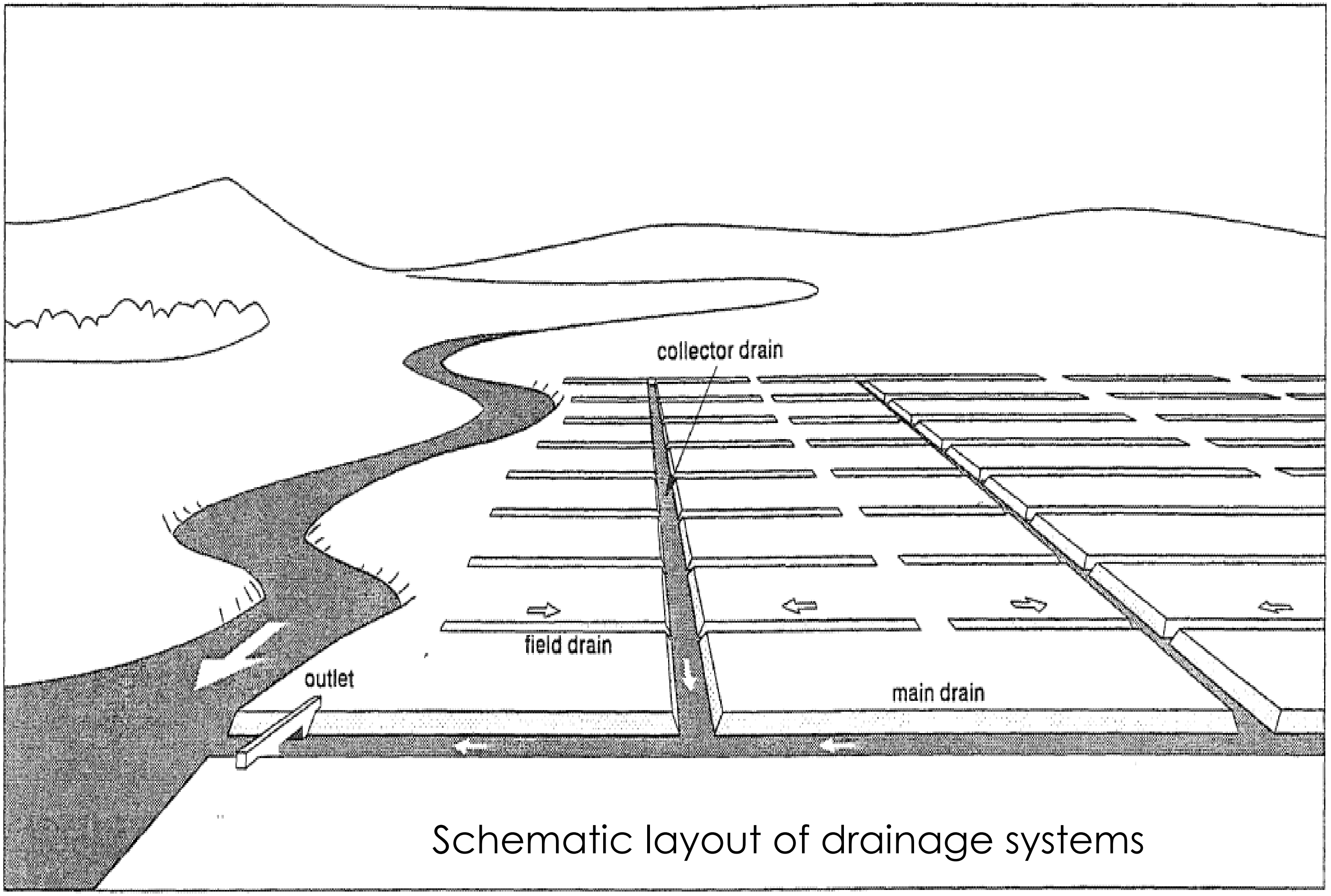
- It is the terminal point of the entire drainage system, from where the drainage water is discharged into a river, a lake, or a sea.
- It can be one of two kinds: a gravity outlet or a pumping station.
- A gravity outlet is a drainage structure in an area which has outside water levels that rise and fall.
- The drainage water can flow out when the outside water levels are low.

- A pumping station is needed in areas where the water levels in the drainage system are lower than the water level of the river, lake or sea.



Components of a Drainage System

Con'd…



Schematic layout of drainage systems

Compound Drainage Systems

- Sometimes, combined surface and subsurface drainage systems are used.

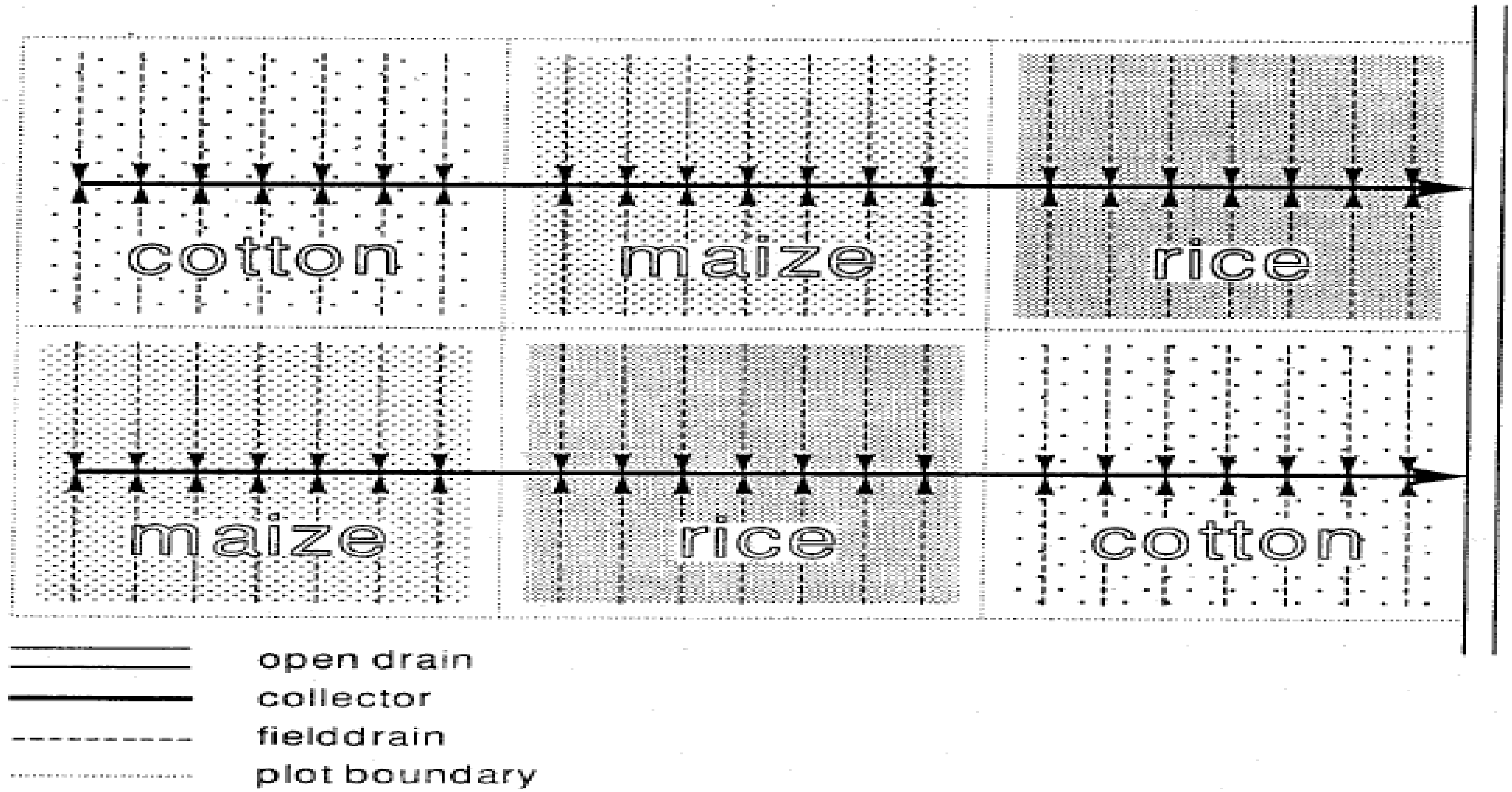
Whether this is needed or not depends on a combination of factors:

- The intensity and duration of the rainfall
- Surface storage
- The infiltration rate
- The hydraulic conductivity and
- The groundwater conditions.

- Sub-surface drainage is needed to control salinity for the dry-foot crops (e.g. maize and cotton), whereas surface drainage is needed to evacuate the standing water from the rice fields (e.g. before harvest).

- Areas with occasional high-intensity rainfall, which causes water to pond at the soil surface,even when a subsurface drainage system has been installed.

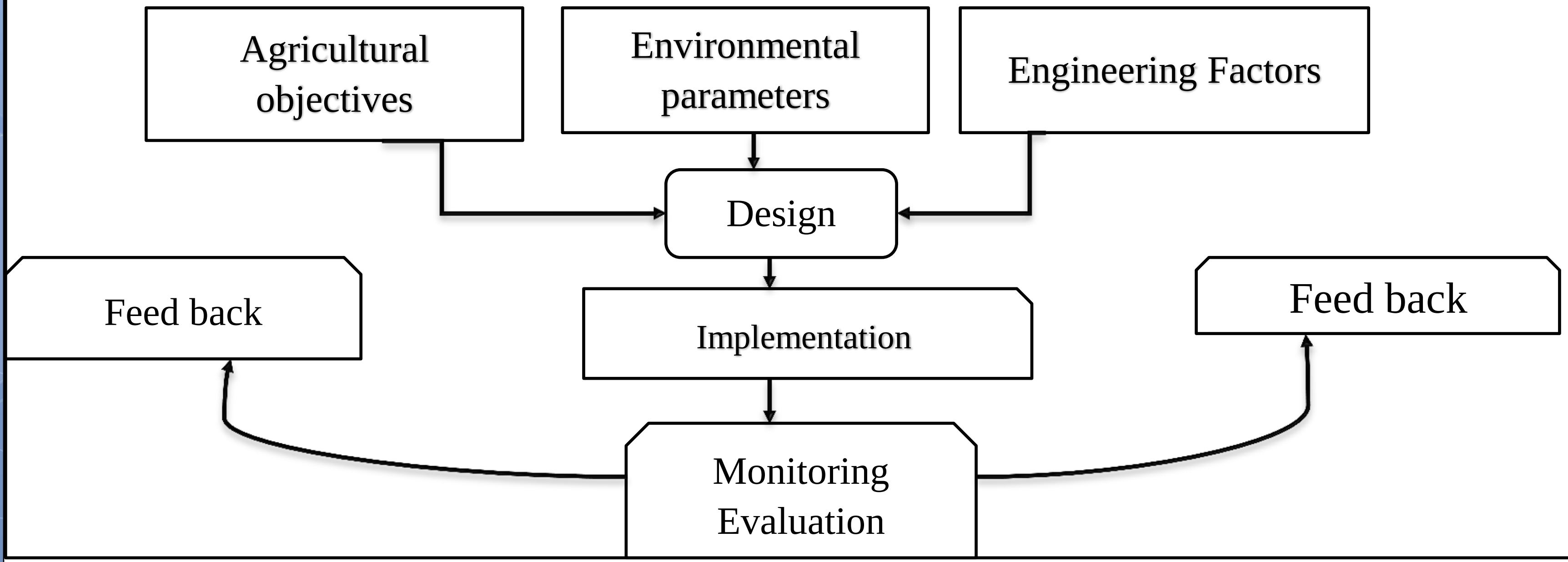
Rice is cultivated alongside "dry-foot" crops



CHAPTER FOUR:FACTORS RELATED TO DRAINAGE

Factors Related to Drainage

- For the design of agricultural drainage systems we group all these disciplines together in three types of input factors:
- The agricultural factors,
- The environmental factors (parameters) and
- The engineering factors



1. Agricultural factors of Drainage

1. Objectives And Effects

Main Objectives of Agricultural Drainage Are:

- Prevention or reduction of ponded or waterlogged condition,
- Salinity control and
- Making new land available for agriculture

Effects of Agricultural Drainage Are:

- Reduction of amount of water stored on or in the soil
- Discharge of water through the system

2. Field Drainage Systems and Crop Production

Land drainage directly increases yield of crops due to more favorable soil profile created as a result of drainage.

3. Water Table and Crop Production

- Optimum water table depth is required for best soil-water-air relationships
- It should be controlled within close limits of the root zone throughout the crop growing season
- If ground water is free from salts, maintain water table level up to root zone depth (as deep as required)
- If ground water is with salts, water table level should be deep enough to prevent capillary flow from bringing dissolved salts.

Recommended Depths of Water Table by FAO (1980)

For Irrigation Season

- ✓ Field crops and vegetables --- Depth between 1.0 & 1.2 m
- ✓ For fruit crops --- Depth between 1.2 & 1.6 m

- ❖ Lower range values (1 & 1.2 m) are best to coarse textured soils greater range depths (1.2 & 1.6 m) are best to fine textured soils)

4. Water Table and Soil Condition

A good soil structure favours both the soil aeration & storage of soil water.

2. Environmental Factors of Drainage

When we introduce drainage system into an area, we are manipulating the environment

I. Side Effects Inside the Project Area

- Loss of wetland
- Change of habitat
- Lower water table
- Subsidence
- Erosion
- Seepage
- Leaching of nutrients, pesticides and other elements

2. Side effects outside the project area

- Disposal of drainage effluent (liquid wastes)
- Seepage from drainage canals
- Lower upstream water table

3. Engineering Factors of Drainage

Table: examples of **Engineering Factors** by type of drainage system

Type of drainage system	Enigineering factor
Surface drainage system	Length and slope of the fields, dimensions of beds, terraces and open drains
Subsurface drainage system	Depth, spacing, and dimensions of open or pipe drains
Tubewell drainage system	Depth, spacing, and dimensions of wells, pump capacity
Main drainage system	Depth, width, cross-section, and slope of drains, spacing of the network

- **SOIL AND HYDROLOGICAL CONDITIONS**

1. Drainage surplus

drainage surplus is based on:

1. The maximum duration and frequency of surface ponding
2. Maximum height of the water table
3. The minimum rate at which water table is lowered

2. Dissolved Salts in the Ground Water

Accumulation of salts in the soils leads to:

- Unfavorable soil-water-air relationships
- Decrease in crop production
- Chief causes for salt build-up
- Poor water management practices
- Land goes out of order unless remedial measures are taken up.

3. **Hydraulic Conductivity**

- It can be correlated with the soil texture or the pore size distribution.

Hydraulic conductivity of some soil types

Soil type (texture)	Hydraulic conductivity (m/d)
Dense clay (no cracks, pores)	< 0.002
Clay loam, clay (poorly structured)	0.002 - 0.2
Loam, clay loam, clay (well-structured)	0.5 - 2.0
Sandy loam, fine sand	1 - 3
Medium sand	1 - 5
Coarse sand	10 -50
Gravel	100 - 1000

4. **Drainable Porosity**

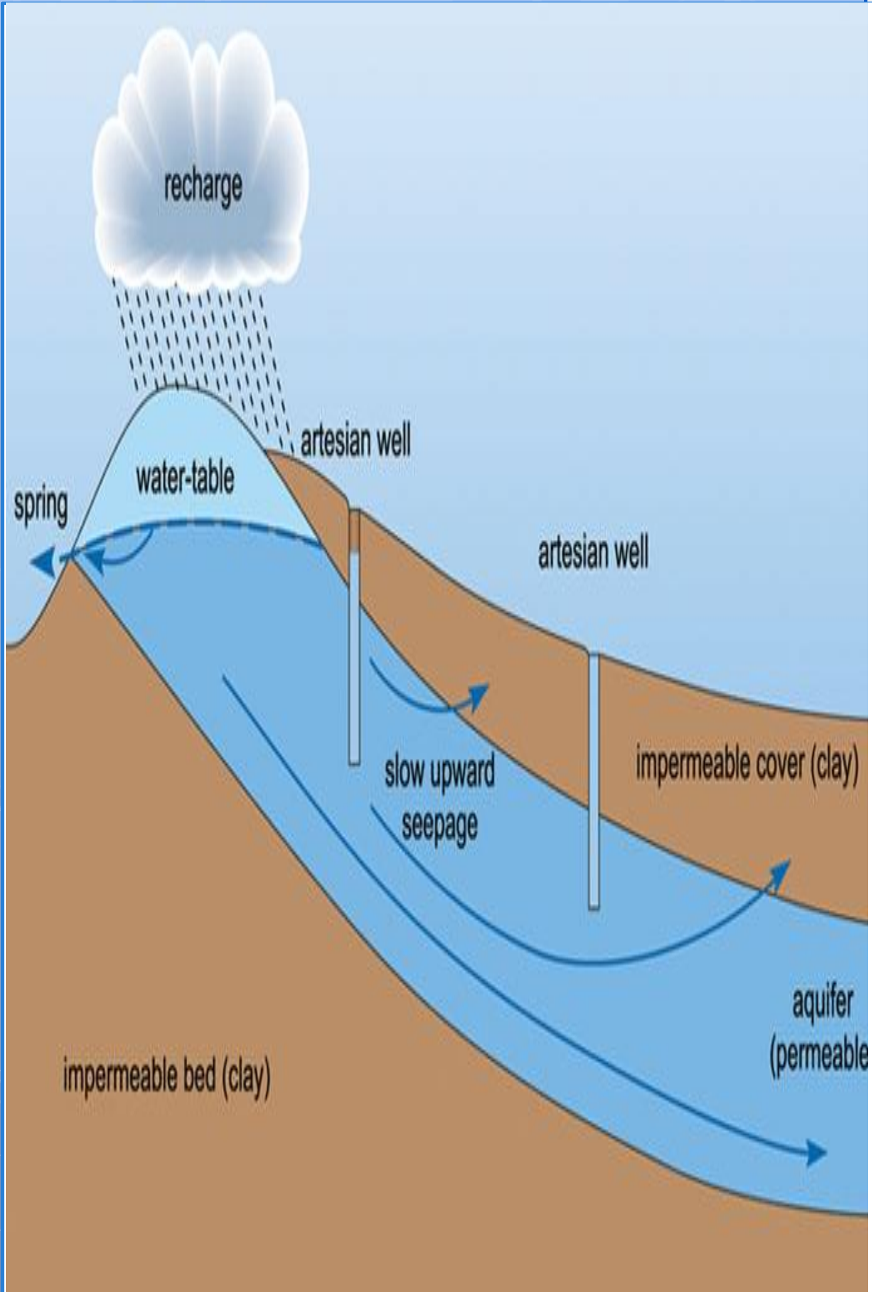
- Called as effective porosity
- It is the volume of water drained (or taken up) by unit volume of soil when water table drops (or rises) over a unit distance
- It is related to rate of fall of water table
- The quantity of water released by an incremental fall of water table is equal to the volume of voids are emptied
- In general two types of pores exist
    - capillary or small pores: induce greater holding capacity (poor drainage in clay soils) .
    - No-capillary or large pores-induce drainage and aeration.

Concept of Impermeable Layer

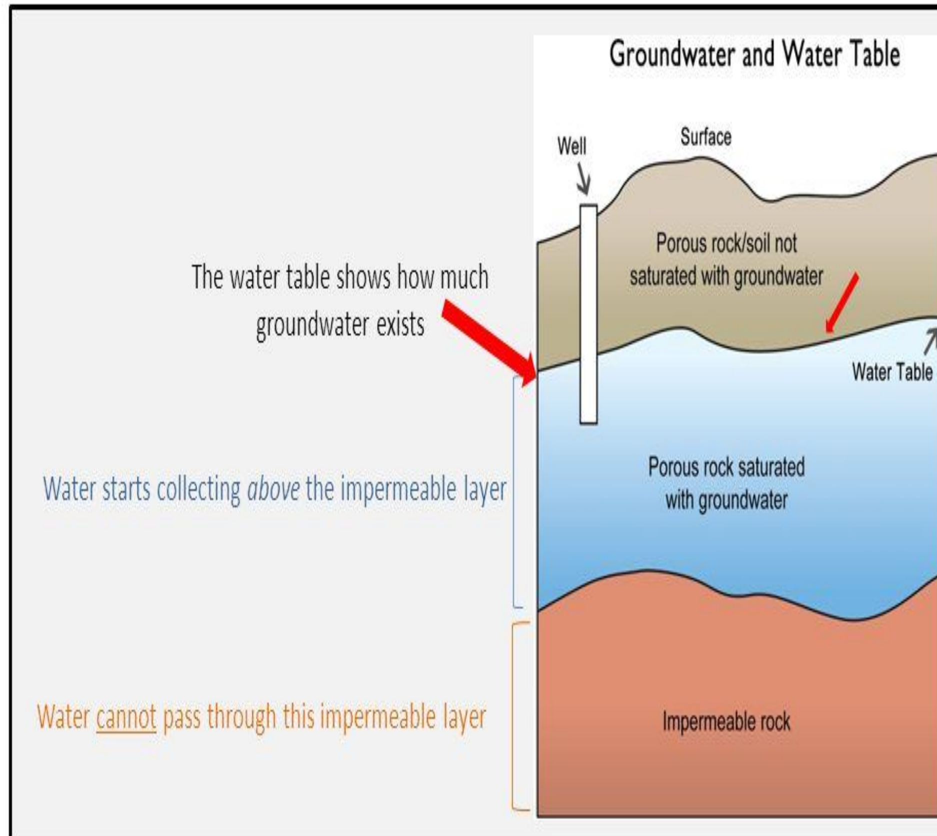
- It is a layer of material (such as clay) in an aquifer through which water does not pass or passes extremely slowly.

(**Flow of water from the land surface into the subsurface**)

- It has great bearing on the **spacing of field drains.**
- For fine textured soils, the layer cannot always be considered as impervious layer, because, sometimes, its permeability differs only little from permeable layer, hence contributes to the discharge of drainage water. *Hence the layer is semi-permeable*.
- Generally, riverbed deposits, show impermeable layer b/n 2 to 4 m.



There is a layer of <u>impermeable</u> *(does **not** allow passage of liquids)* rock below ground at the base of an aquifer which stops the flow of water.



Drainage Coefficient

- Is the design capacity of the drainage system.
- Is typically expressed as a depth of water removed in 24 hours (one day)
- The concept of drainage coefficient is used for the design of drainage systems for agricultural lands.
- 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:

Con'd…

- Rainfall and Size of the drainage area
- Characteristics of the drainage area and
- Nature of the crops grown and the degree of protection required for them from waterlogging.

Drainage coefficient can be calculated:

Discharge rate; $Q = D_c \times A$

Where,

A = Area in ha ,

D_c = Drainage coefficient

Q = Discharge from the field

Methods for Estimation Drainage coefficient

1. Empirical methods:

- 1% MAR (mean annual Rainfall in mm)
- Hudson’s (1983) method
- Mazumdar’s (1983) method

2. Frequency Analysis method

3. USSCS (1972) method

4. Actual measurement of out flow from the surrounding area

- **The empirical methods are explained with the help of the following solved example:**

Examples: Determine the Drainage coefficient and the discharge for the following data by using the three empirical methods:

Arba Minch & Mean Annual Rainfall(MAR)=790 mm & Area =110 ha.

Determine:

a). Dc and b). Q

Solution:

(i) 1% of MAR method:

1% of MAR = 0.01 * 790 = 8 mm/day

DC = 8 mm/day ……. ***Ans***

Q = discharge of the drain = Area of the watershed * DC

$$\therefore \; Q = 110 \text{ ha} * 8 \text{ mm/day}$$

$$= \frac{110 * 100 * 100 * 8}{24 * 60 * 60 \; 1000} \text{ m}^3\text{/sec}$$

$$= 0.102 \text{ m}^3\text{/sec} \quad \text{or}$$

$$= 102 \; \ell\text{/sec}$$ **…….Ans**

(ii) Hudson (1983)'s method:

if MAR ≤ 1000 mm , DC = 10 mm/day

if MAR ≥ 1000 mm , DC = $\frac{MAR}{100}$ mm/day

$\therefore$ In this case: MAR = 790 mm $\angle$ 1000 mm

Therefore; ***DC = 10 mm/day ……Ans***

Note : If MAR =1500 mm which is greater than 1000 mm

Therefore ;DC = $\frac{1500}{100}$ =***15 mm/day***

Since Area = 110 ha

$$\therefore Q = \left(\frac{10}{1000} * \frac{110 * 10^4}{86400} \right) * 1000\ \ell/sec$$

$= 127\ell$/sec ….**Ans.**

($1m^3 = 1000$ Litters)

(iii) **Mazumdar's method (Class Activity)**:
Determined drainage coefficient by using the following table

MAR (mm)	< 750	750 - 1000	1000-1250	1250-1500	> 1500
DC(mm/day)	5-7.5	7.5-9	9-12	12-25	>25

CHAPTER FIVE: SURFACE DRAINAGE SYSTEM

- **Surface drainage** is the removal of excess water from the land surface through land shaping and improved or constructed channels.
- It is needed to remove the excess rainfall as well as collection and disposal of excess surface irrigation water wherever it occurs.
- Surface drainage systems are usually applied:
  - ✓ In flat land and nearly flat lands that have soils with a low or medium infiltration capacity, or
  - ✓ In lands with high-intensity rainfalls that exceed the normal infiltration capacity,
  - ✓ In uneven land surfaces with depressions or ridges preventing natural runoff

Con'd…

- ✓ In areas without any outlet
- ✓ In lands where frequent water logging occurs on the soil surface
- ✓ In arid climate where the main aim of drainage is to dispose of excess surface runoff, resulting from the high-intensity precipitation.

- Surface drainage is normally accomplished by shallow ditches, also called open drains or field drains.
- Then, the shallow ditches discharge into larger and deeper collector drains.
- In order to facilitate the flow of excess water toward the drains, the field is given an artificial slope by means of land grading.

Field → Field drains → Collector drains → Main drain → Outlet

Criteria to design surface drainage system

It should be based on:

- Agricultural constraints (Eg. Severity of crop to ponded water & saturated soils)
- Engineering considerations of flow through channels & structures

As surface drainage is aimed at the orderly removal of excess water from the land surface, it has its nature and effect on environment of the area.

The design of Surface drainage system has two components

1. Shaping the surface by land forming :defines as " Changing the micro-topography of land to meet the requirements of surface drainage or irrigation

2. Construction of open drains to the main outlet

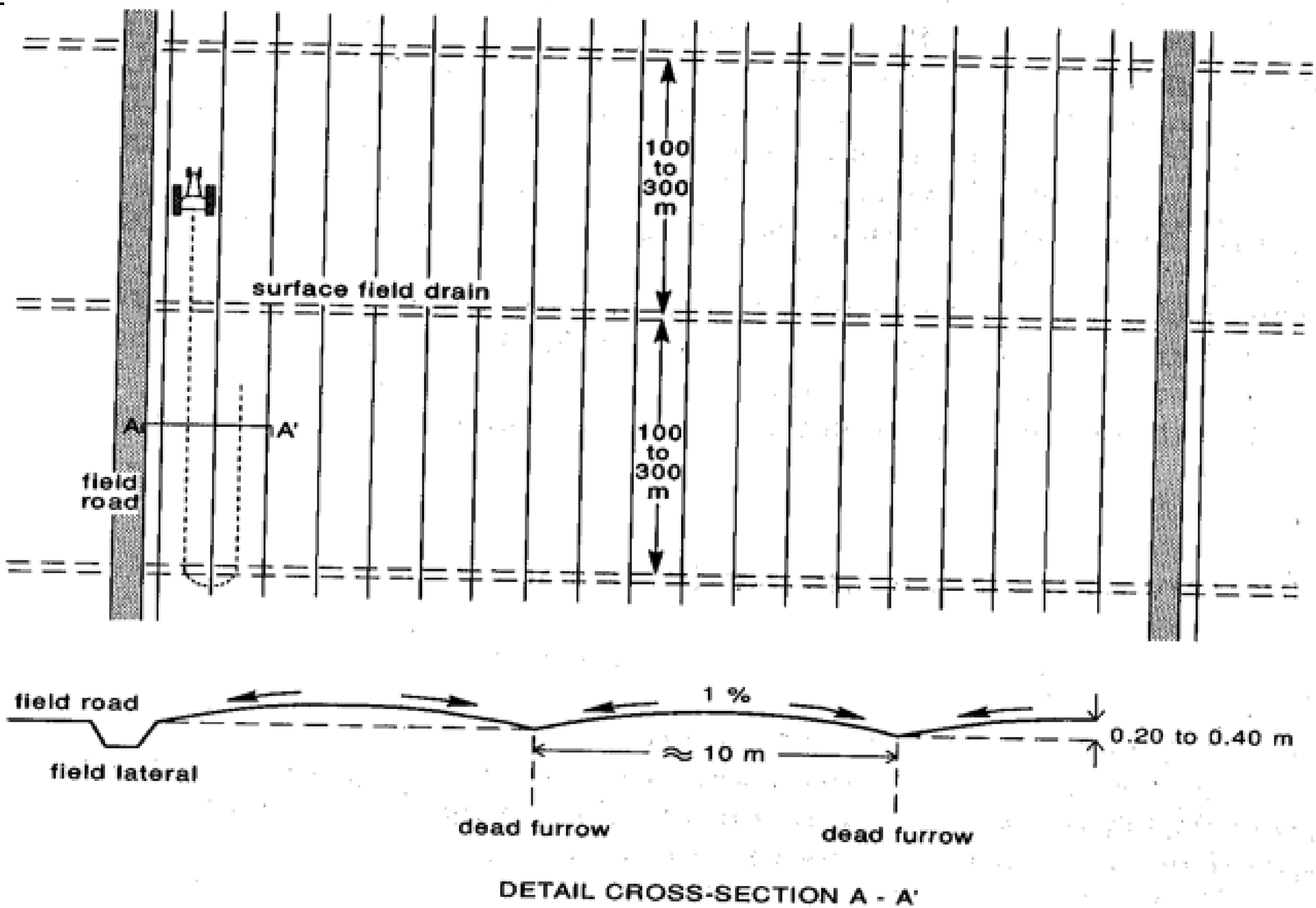
Under Land forming: There are three types of surface drainage system:

1. **Bedding**
2. **Land grading & Land planning**

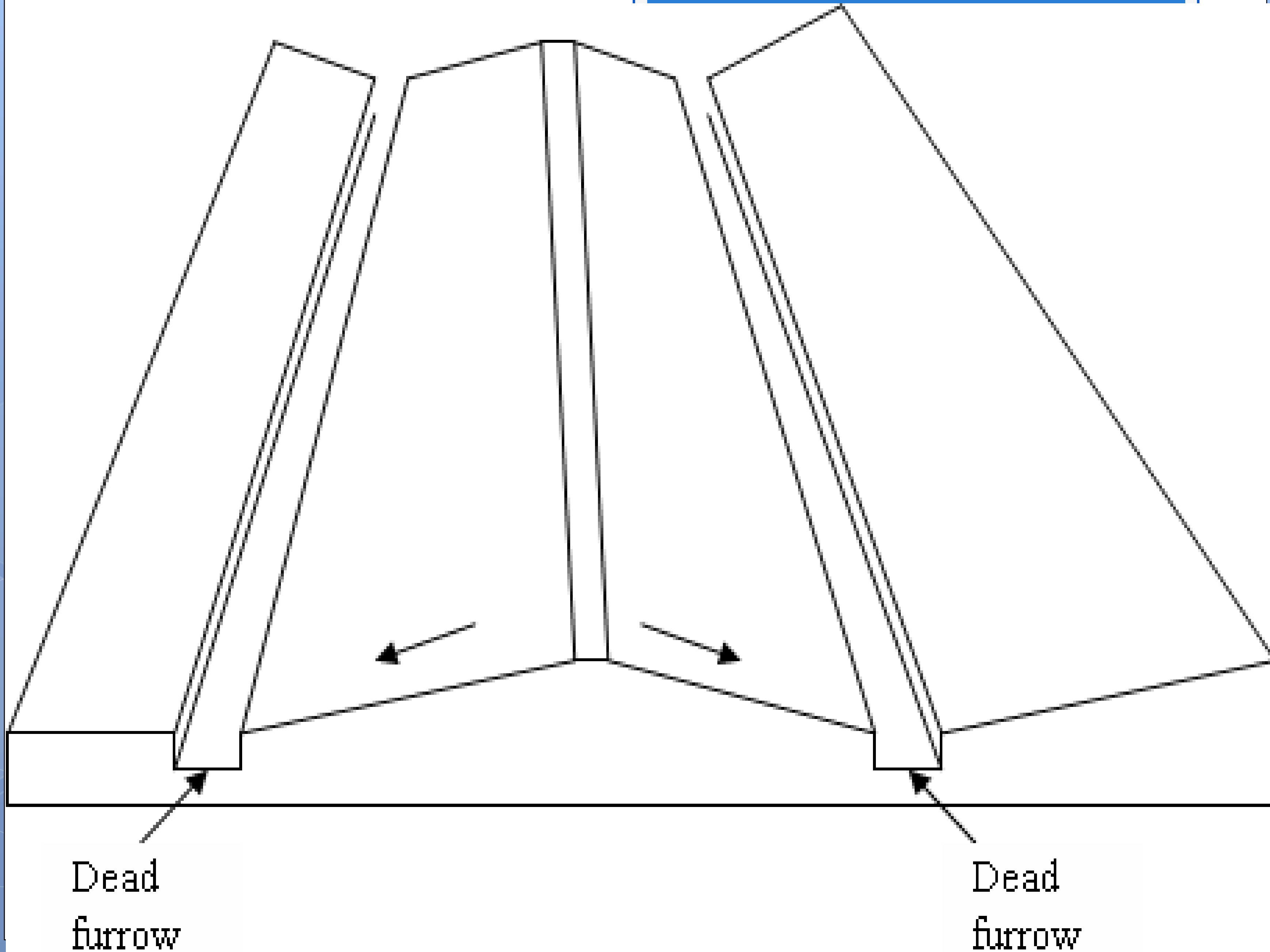
1. ***Bedding system***

- The oldest surface drainage practice and it is essentially a land forming process.
- The land is ploughed into beds, separated by dead furrows which run in the direction of prevailing slope.
- The water drains from the beds into the dead furrows.
- Farming operations on beds: Ploughing, planting, and cultivating should fit the width of a bed (10m bed width).
- The field drains discharge into field laterals and ultimately to the main drains.
- Bedding is proved to be successful on poorly drained soils and on flat and nearly flat lands (i.e. 1.5% or less).

Con’d…



100 to 300 m
surface field drain
A
A'
100 to 300 m
field road
field road
1 %
0.20 to 0.40 m
field lateral
≈ 10 m
dead furrow
dead furrow
DETAIL CROSS-SECTION A - A'



Bedding system

- Because of land preparation and construction of beds, the top soil of the bed has better hydraulic properties than the **'impermeable soil'**.
- A large part of the excess rainfall will therefore flow over the impermeable layer by 'inter flow' & as overland flow towards the dead furrow.

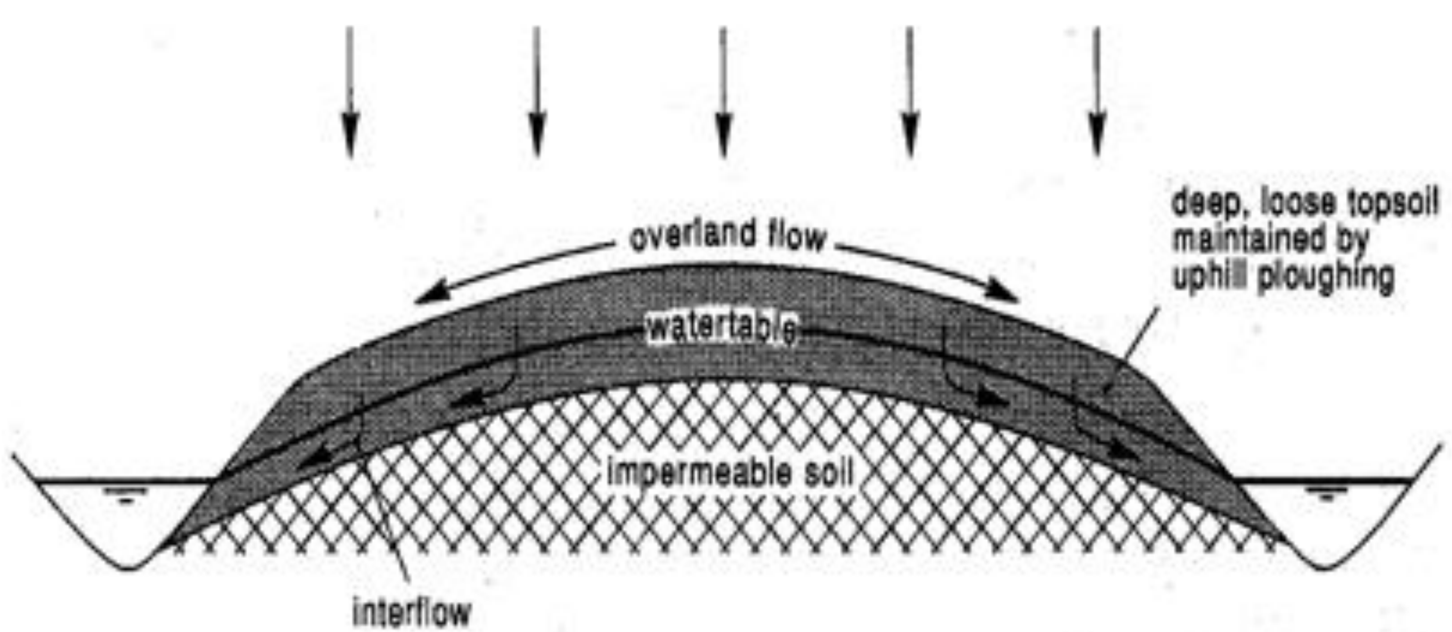


Fig: Drainage by overland flow and perched groundwater flow (interflow) in bedding system

Con’d…

- In areas where high ground water level occurs (in rice growing areas):
  - bedding system is applied to grow vegetables, tree crops & maize etc.
- The bed width depends upon the land use (like crop type), slope of the field, soil permeability, and farming operations.
- The length of the bed depends on field conditions and may vary from 100 to 300m.
- The maximum bed height is 20-40cm.
- Table : Recommended bed width

Permeability (K in cm/day)	Bed width (m)
0.5 (very low)	8-12
5 to 10 (low)	15-17
10 to 20 (good)	20-30

Limitation of bedding system:

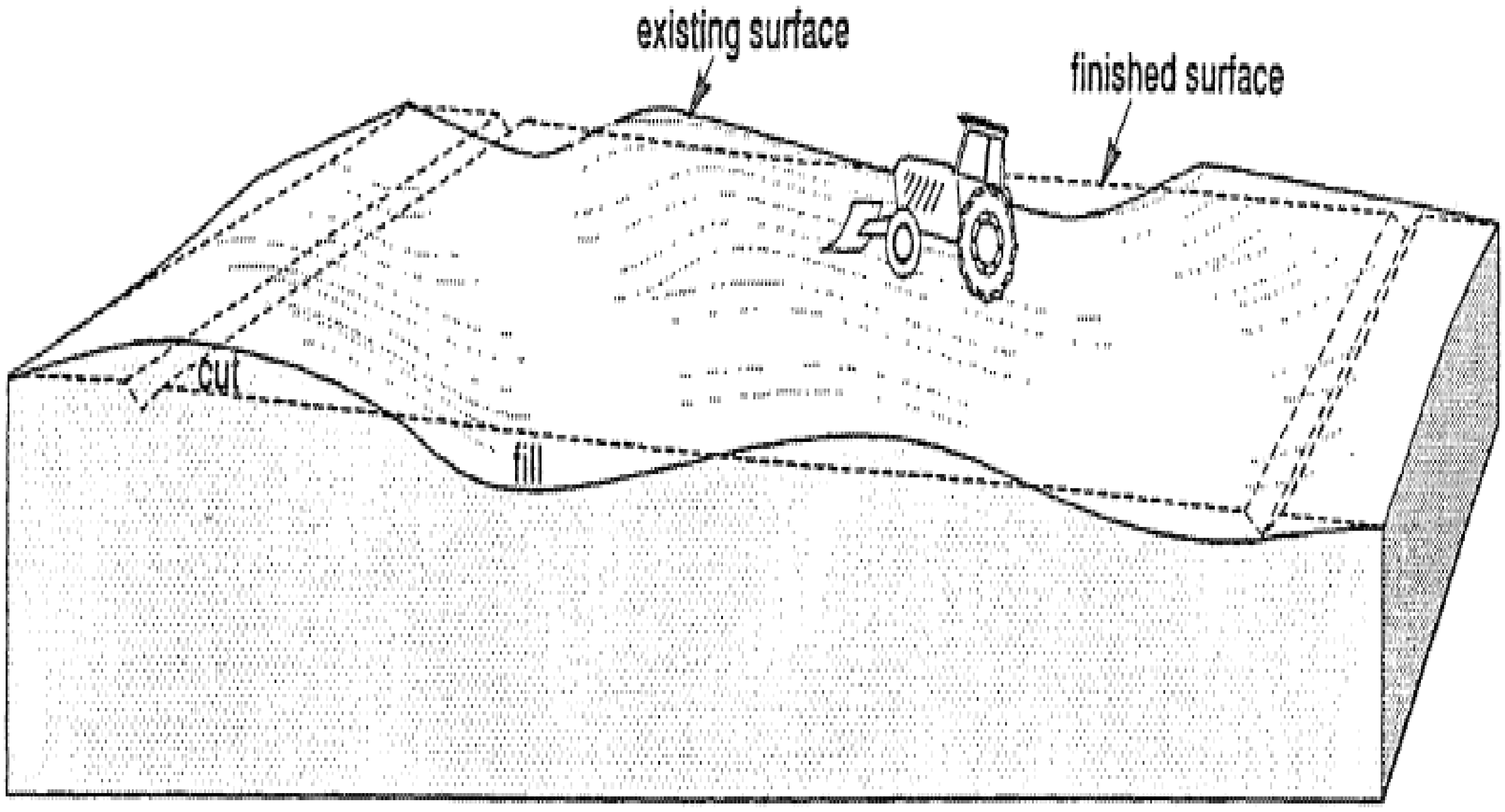
- Top soil is moved from the sides of the bed to the middle
- The system restricts mechanized farming
- The dead furrows require regular maintenance to prevent weed growth
- The slope of the dead furrows, is often insufficient resulting in ponded water.

Land crowning:

- **It is an** improved bedding system in which **earth moving machinery** is used to make the wider beds of **20 to 30 m.**
- **Crowning** is the process of forming the surface of land into series of broad low beds separated by parallel field ditches.

2. Land grading:

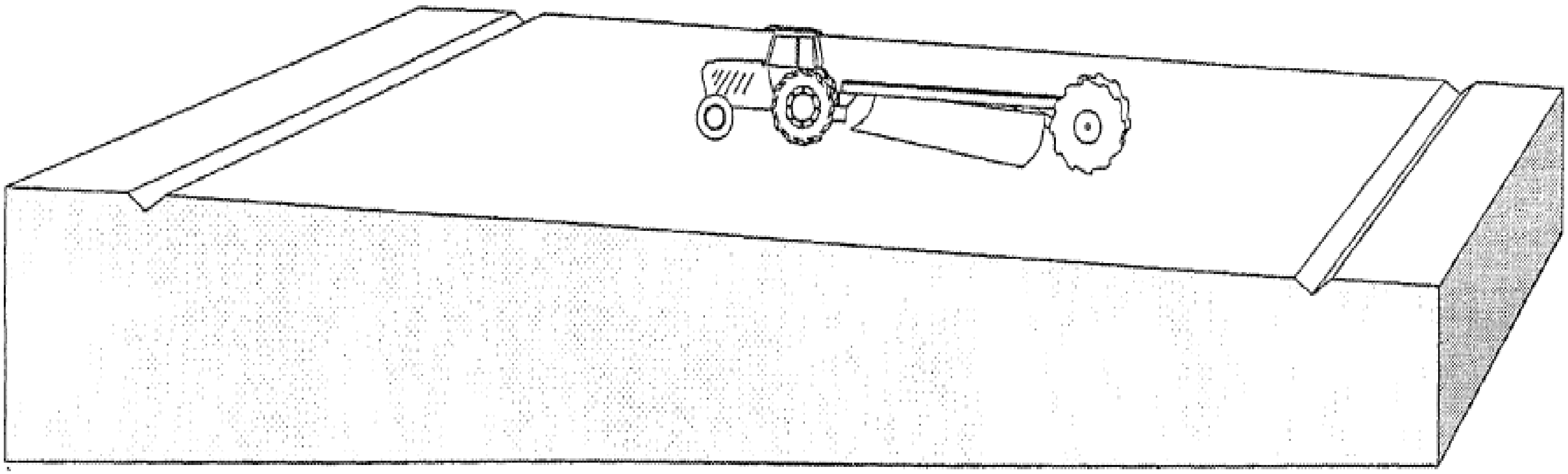
- Land grading for surface drainage consists of forming the land surface by **cutting, filling and smoothing it to predetermined grades,** so that each row or surface slopes to a field drain.



Land grading

3. Land planning:

- It is often done after land grading, because irregular micro-topography in a flat landscape, in combination with heavy soils, can cause severe crop losses.
- Land planning is the process of smoothing the land surface to ***eliminate minor depressions and irregularities***, but without changing the general topography .



In the field, surface drainage systems can have two different layouts**:**
The random field drainage system, and the parallel field drainage system

Cont'd…

- The design of land grading should be consider the type of crops that will be grown.
- Three main situations can be distinguished:

1. Crops will be planted in rows & the field surface is shaped into small furrows.
2. Crops will be planted by broadcast sowing or in rows.
3. Crops will be planted in basins designed for controlled inundation

Design Of Surface Drainage Systems

- Hydraulic design is similar to the design of irrigation canals
- The design of drain dimensions should be based on ***a peak discharge.***

Design Criteria

- Criteria for design of drainage systems are essentially the specifications for different conditions.

Design criteria consist of two parameters:

1.The rate of water removal necessary to provide a certain degree of crop protection.

2. The optimum depth to water table.

- Several factors must be considered in selection of design criteria for a particular project.

For example:

- Crop types (eg. Crop season drainage for aeration…)
- Soil types (eg. Heavy, light soils…)
- Climate (eg. Humid, Temperate…)
- Type of drainage (eg. Pipe drains, open ditches…)
- Economic considerations

Drainage Design Equation

Design discharge can be calculated using:

$Q = Dc \times A$; where, A = Area in ha,

D_c = Drainage coefficient

Q = Discharge from the field

Con’d…

- But this is not necessarily true in small irrigation schemes, especially on sloping lands (with slopes exceeding 0.5%) then design discharge can be calculated using:
- The rational formula
- The curve number method

The rational formula

- It is the easier of the two and generally gives satisfactory

$Q = (C \times I \times A)/360$

Where: Q = Design discharge (m3/sec)

C = Runoff coefficient

I = Mean rainfall intensity over a period equal to the time of concentration (mm/hr)

A = Drainage area (ha)

The time of concentration (Tc):

- It is a concept used in hydrology to measure the response of a watershed to a rainfall event. It is defined as **the time** needed for water to flow from the most remote point in a watershed to the watershed outlet.

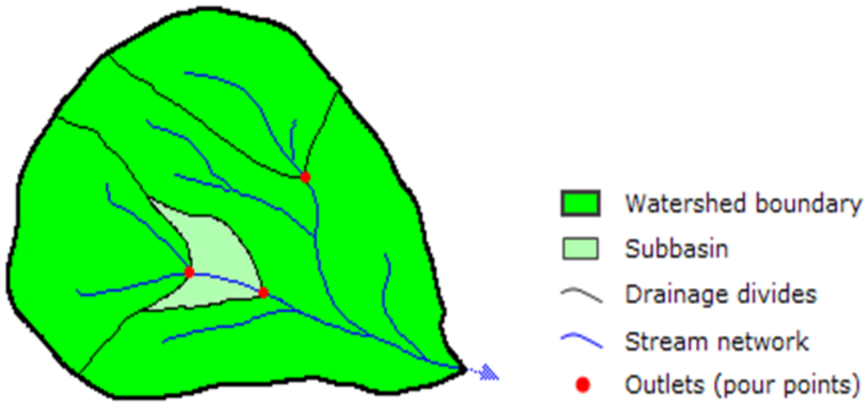


Figure :Time of concentration

- It can be estimated by the formula: $Tc = 0.0195\ K^{0.77}$

  Where, Tc = Time of concentration (minutes)

  $K = (L/\sqrt{S})$ and $S = H/L$=slope ;L = Maximum length of drain (m)

  H = Difference in elevation over drain length (m)

The hydraulic design of the drainage channels are normally designed using the Manning equation.

$$Q = AV = \frac{1}{n} A R^{\frac{2}{3}} S^{\frac{1}{2}}$$

Where; Q = Design discharge ($m^3 s^{-1}$)

V = Velocity of flow (m s^{-1})

n = Manning's coefficient

R = Hydraulic radius (m)

A = Cross sectional area (m^2)

S = Longitudinal slope

Hydraulic Design of Surface Drains and its Related Structure Construction

Field surface drain : Is a shallow **graded** channel with relatively flat slope**,** collects water within a field.

Field lateral :collect water from field drains & transport it to the main drainage system.

Field Drains : Field drains are shallow & have flat side slopes.

- Simple field drains are V-shaped.
- Dimensions of V-shaped drains, also applies to W-shaped drains.
- Field drains (which collect runoff in both direction) could have trapezoidal shape.

Con’d…

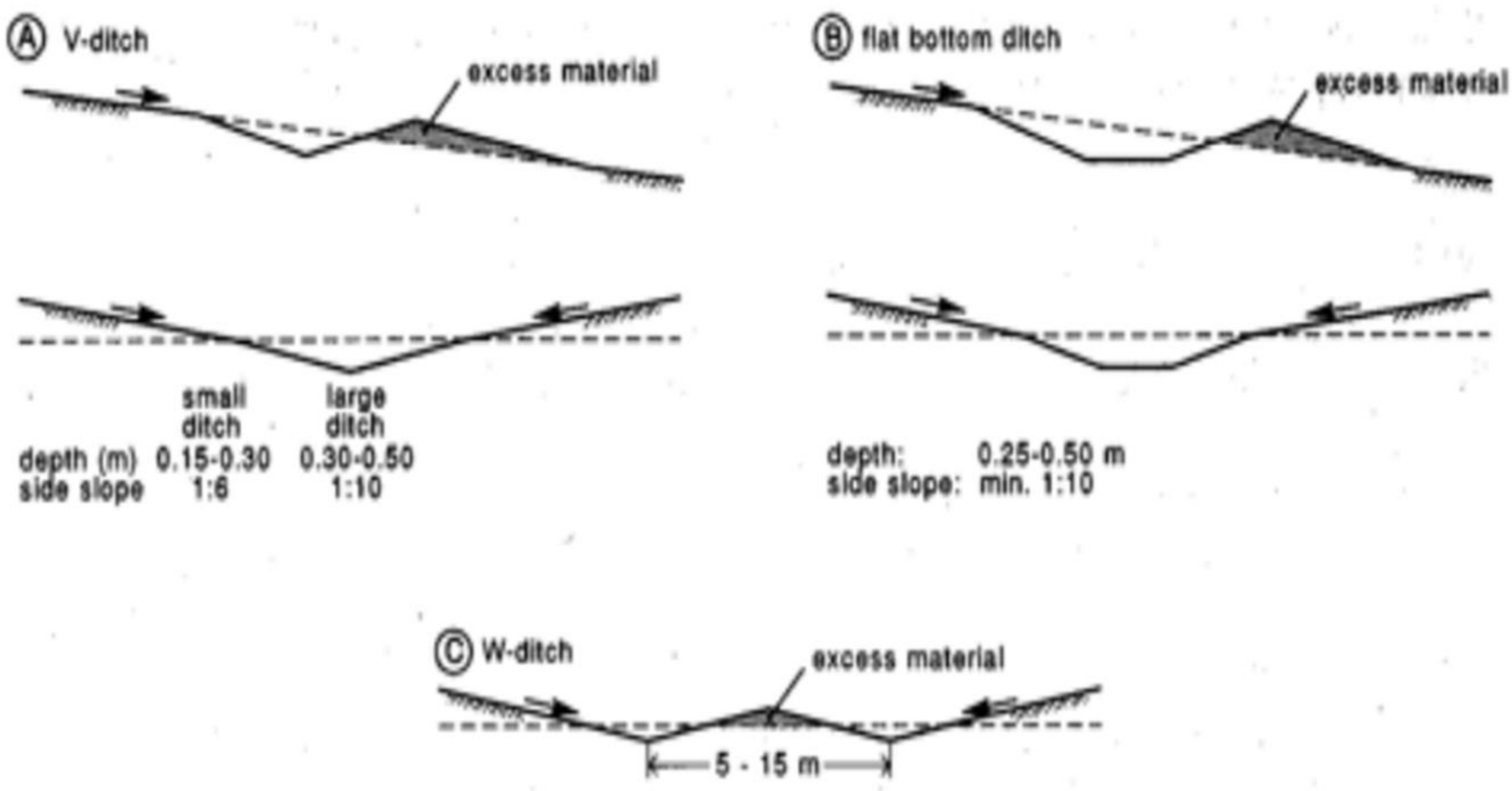
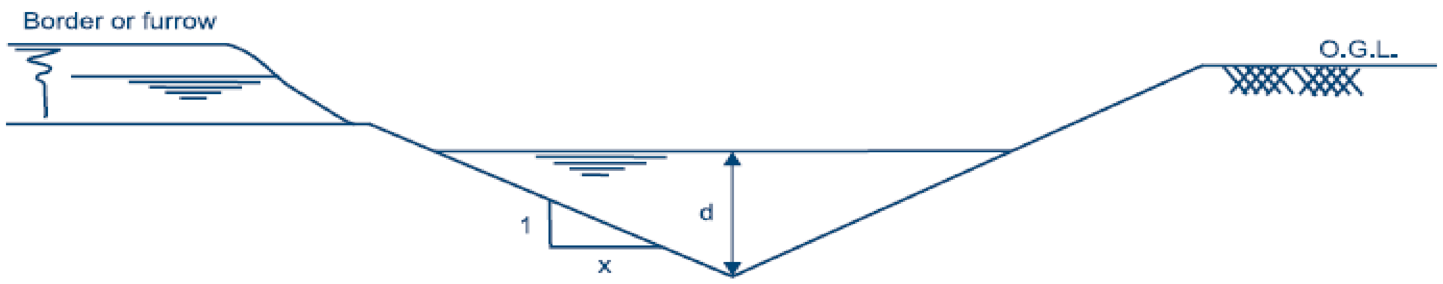


Fig: Types of passable field and collector ditches (Smedema and Rycroft, 1983)

- Field laterals and drains usually have a trapezoidal cross-section and
- Their cross-sections are designed to meet the required discharge capacity.
- The water level in the drain at design capacity should ideally allow free drainage of water from the fields.

Recommended values for the given cross-sections

Type of drain	Depth (m)	Recommended side slope (x:1)	Maximum side slope (x:1)
V-shaped	0.3 to 0.6	6:1	3:1
V-shaped	>0.6	4:1	3:1
Trapezoidal	0.3 to 1.0	4:1	2:1
Trapezoidal	>1.0	1.5:1	1:1



Surface Drainage Systems for Sloping Areas

- It is applied in sloping areas (slopes > 2 %).
- It comprises the creation of suitable conditions to regulate the overland flow before it becomes hazardous as an erosion force.

Sloping lands are terraced for the following reasons:

- Drainage
- Erosion Control
- Water conservation

Terraces applied for the above purposes are basically of two types:

1. Cross slope drainage system
2. Standard erosion control terrace

Water Disposal in Sloping Areas

- The water must be disposed by a drainage channel which runs down slope.
- Slope is usually steep such that channels will have to be lined or fitted with drop structures to prevent scouring.

Diversion or Interceptor Drains

- To protect flat areas from flooding, a diversion or interceptor drain can be constructed at the foot of upland areas.
- To prevent diversion or interceptor drains from silting up, a filter strip can be constructed on the upside of the ditch.

Drainage Canals

- Drainage canals are used to prevent damage to crops by carrying away the excess water.

Two types of drainage canals can be visualized:

A canal system (steep slope land):

- Intercept,collect,carry away water from sloping land adjacent to an agricultural area.
- Most of the water in the system originates from surface run-off.

A Canal System (Flat slope land):

- collect & carry water from a relatively flat agricultural area.
- The main source of water is the precipitation on the area or irrigation.

An Open Ditch Properly Designed Should Have

- sufficient capacity to carry the design flow.
- water surface elevation low enough to drain the land.
- side slopes be selected such a way that neither cave-in nor slide.
- velocity of flow is such that it is neither scouring nor silting.

- *The followings are recommended values of slope and velocity*.

Type soil	Max.Veli (m /sec)	Soil types	Allow.slop e
Sandy& sandy loam	0.75	Clay soil	1:1
Silt loam	0.90	Silt loam	1.5:1
Sandyclay loam	1.00	Sandy loam	2:1
Clay loam	1.20	Loose sandy soils	3:1
Stiff clay	1.50		

Ditch cross section

- Are usually designed with trapezoidal cross section
- Manning's equation is used for the design
- The size of ditch vary with:
  - The velocity
  - Quantity of water removed
- ***Bottom Width***
- For the most efficient cross section & for minimum volume of excavation, the bottom width is determined by:

$$b = 2\,d\,\tan\,\theta/2$$

Where, b = bottom width(m);

d = depth (m);

θ = side slope angle

Maintenance of surface drains

- The **benefits** derived from land grading depend on **good maintenance**
- Unless properly maintained, ditches will rapidly lose their effectiveness owing to weed growth and accumulation of sediments.

In general maintenance includes:

- Weed control
- Although weeds must be controlled, a vegetative cover of the banks is often necessary:
  - to provide stability for the side slopes of the ditch.
- Removal of soil & mud

Sub-surface drain- Design considerations

Example 1:

An irrigation scheme of 100ha with sandy loam soils and a general slope of less than 5% has a main drain of 2.5km long with a difference in elevation of 10m. What is the time of concentration?

Solution:

$S = H/L = 10/2500 = 0.004$ or 4%

$K = (L/ \sqrt{S}) = (2500/ \sqrt{0.004}) = 39.528$

$Tc = 0.0195\ K^{0.77} = 0.0195 \times (39,528)^{0.77} = 68$ min.

Surface drains – Design considerations

Example 2: In example 1, the 68minutes rainfall with a return period of 5 years is estimated at 8.5mm. What is the design discharge of the drain?

Solution:

- The mean hourly rainfall intensity = (60/68)x 8.5 = 7.5mm/hr
- The runoff coefficient for sandy loam arable land with a slope of less than 5% = 0.30
- Thus, design discharge for the scheme, Q = CIA/360 = (0.30x7.5x100)/360

  = 0.625 m^3/sec or 6.25 lit/sec/ha

Once the design discharge has been calculated, the dimensions of the drains can be determined using the Manning's Formula.

Note:

Higher order canal design should not only depend on the design discharge, but also on the need to collect water from all lower order drains. Therefore, the outlets of the minor drains should preferably be above the design water level of the collecting channel.

CHAPTER SIX : SUBSURFACE DRAINAGE SYSTEM

TYPES OF SUBSURFACE DRAINAGE SYSTEMS

- *Subsurface drainage:* aims to control the water table

that can be **achieved** or controlled by:

- Tube well drainage,
- Open drains, or
- Subsurface drains (pipe drains ….).

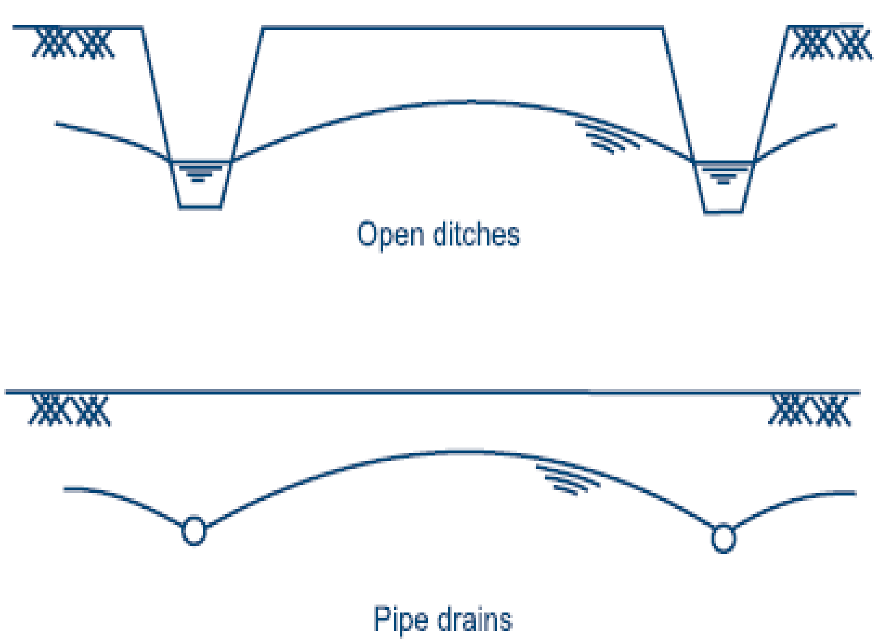
There are three main phases in implementation of pipe drainage system:

- Design
- Installation
- Operation & maintenance

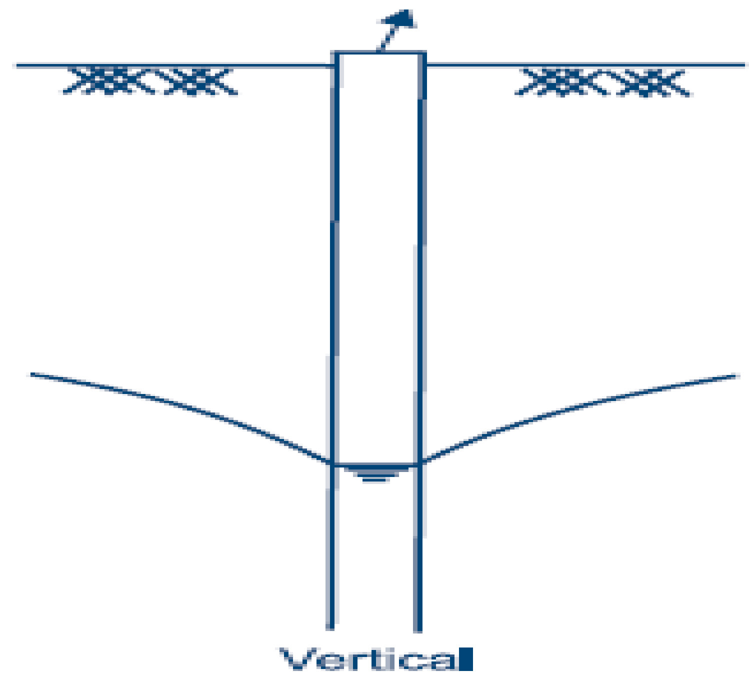
- Subsurface drainage is used to control the level of groundwater.

  As a result air remains in the root zone.

- It is accomplished by deep open drains or buried pipe drains (Horizontal drainage) or by using tube wells (vertical drainage).



Horizontal drainage



Vertical Drainage

Con’d…

Open Drains

- Can receive surface runoff directly.
- Restrict the use of machines.
- Require a large number of bridges and culverts for road crossings and access to the fields.
- Open drains require frequent maintenance (weed control, repairs, etc.).

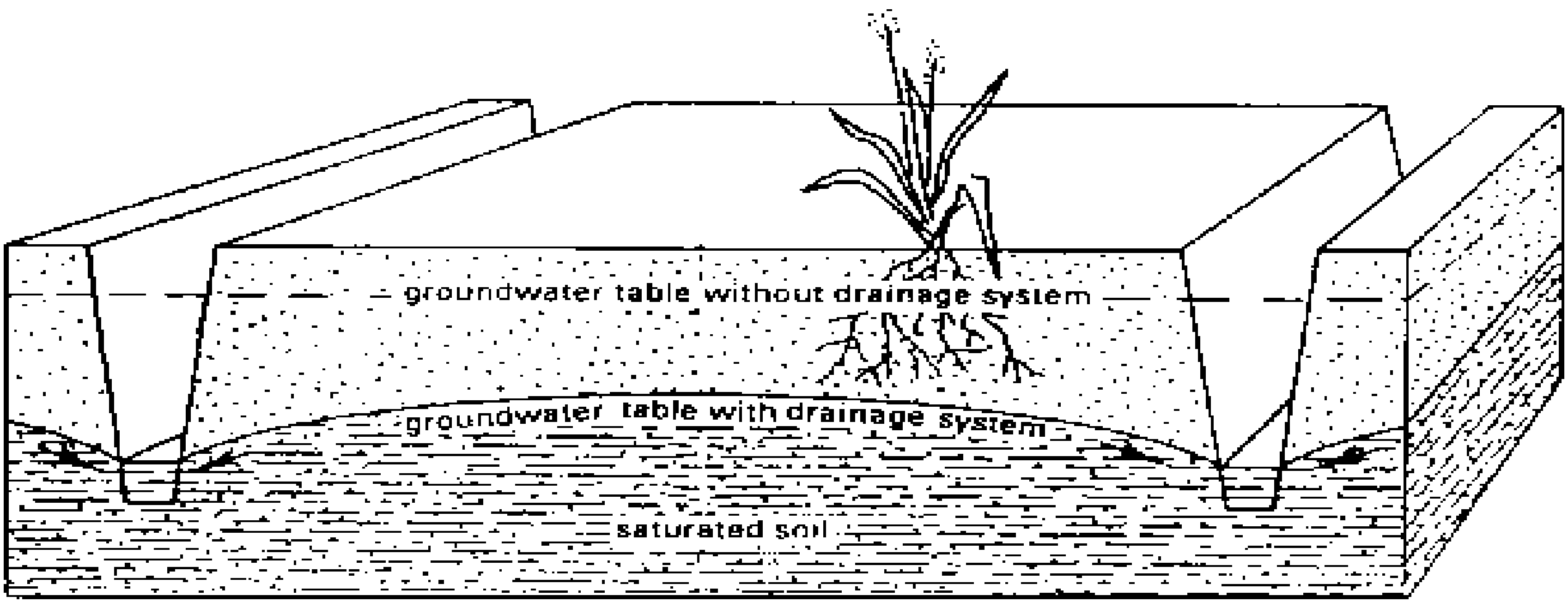
Pipe Drains

- Cause no loss of cultivable land
- No restriction to the use of machines
- No requirement for access to fields
- Maintenance requirements are very limited.
- The installation costs, however, may be higher due to the materials, the equipment and the skilled manpower involved.

I. Deep open drains

- The excess water from the root zone flows into the open drains.
- Open drains can only be justified to control groundwater if the permeability of the soil is very high and the ditches can consequently be spaced widely enough.
- Otherwise, the loss in area is too high and proper farming is difficult.

Especially where mechanized equipment has to be used.



ii. Pipe drains

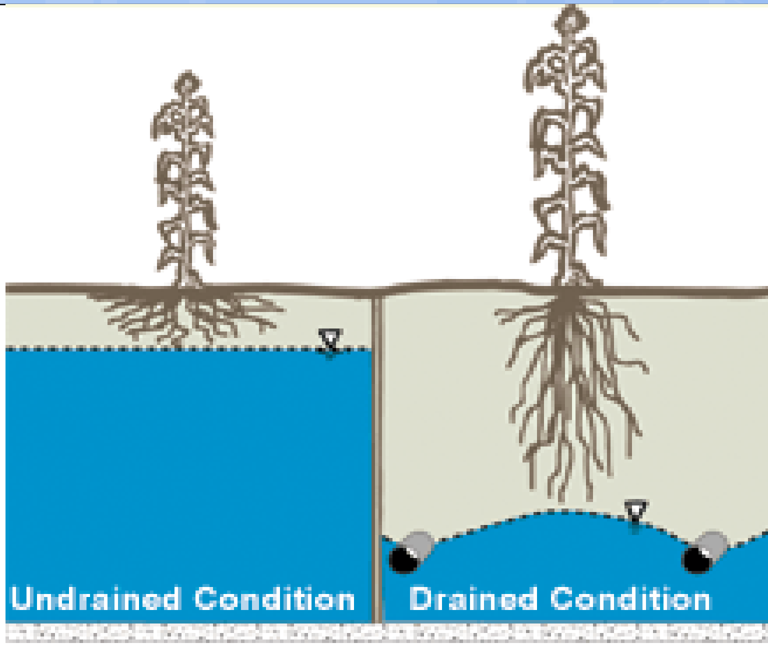
- Instead of open drains, water table control is usually done using field pipe drains.
- The materials used for pipe drain preparation are:

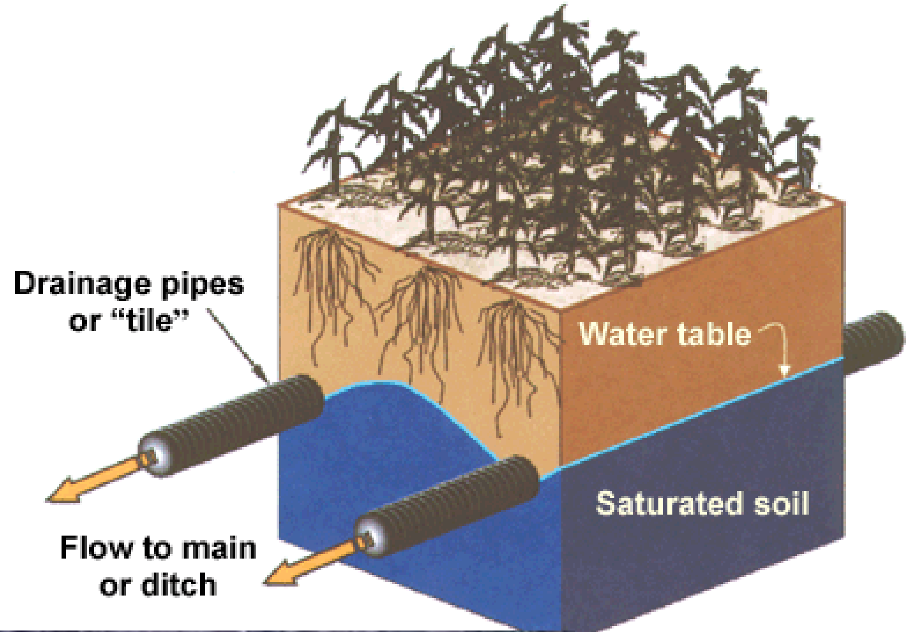
  Clay pipes, concrete pipes and Plastic pipes .

- Plastic pipes are the most preferred choice nowadays, because of lower transport costs and ease of installation,

Although this usually involves special machinery.

- In clay and concrete pipes (usually 30m long and 5-10cm in diameter), drainage water enters the pipes through the joints.
- Flexible plastic pipes are much longer (up to 200m) and the water enters through perforations/any openings distributed over the entire length of pipe.





Drain tile outlet to a drainage ditch

MATERIALS

The materials used in manufacture of drain pipes are:

- clay tiles or clay pipes
- concrete pipes
- plastic pipes

The important **criteria** for pipe quality and for selection of the most suitable type of pipe is:

- Resistance to mechanical & chemical damage.
- Longevity.
- Costs (include the cost of purchase/pay for, transport, handling & installation).

1.Clay tiles (pipe)

- These are comparatively cheap in cost and easy to manufacture.
- The diameter of the tile has to be designed based on the discharge using Manning's equation.

$$Q = AV = \frac{1}{n} A R^{\frac{2}{3}} S^{\frac{1}{2}}$$

('n' value for tile can be taken as 0.0108 or 0.011)

Factors to be considered in selection of tiles:

- Climatic conditions (Freezing & thawing conditions)
- Chemical characteristics of soils (acids &sulphate existence)
- Depth requirements (strength aspects)
- Installation cost (a big factor)

2. Concrete pipes

- Used as field drains & collector drains.
- Large size diameter pipes (up to 0.40 m) still commonly used as collector drains.
- Easy to manufacture.

Possible drawbacks

- Susceptibility for acid & sulphates.
- Heavy to transport: hence, damage may be more.

3. Plastic Pipes

- Plastic pipes are the most preferred choice nowadays,

Because of: Lower transport costs and ease of installation.

Although this usually involves special machinery.

Pipes are usually installed in trenches by machines

Quality standards

- Quality standard for drain pipes have been specified on *a national basis and thus differ between countries.*

Items specified under quality standard are:

- General *material test* as an indicator of chemical properties
- Dimensions of the pipes (with tolerances)
- Auxiliary materials (couplings & end plugs)
- Size, number & pattern of perforations

Other specifications are:

- Pipe stiffness
- Impact strength
- Possible creep (deformation with time under a give stress)
- Flexibility

Mole Drain

- Mole drains are unlined underground channels, formed by a mole plough without trenching.
- The attraction of the method lies in its **low installation costs** as compared with those of pipe drainage.
- Mole drainage may be effective in case where pipe drains are physically not feasible.
- This type is particularly appropriate in **dense, poorly pervious clay** soils which have general slope.
- Its primary aim is not to control the ground water table, **which may be very deep,** but to remove excess water from the field surface or from the top soil, where it may constitute “**Perched Water Table”.**

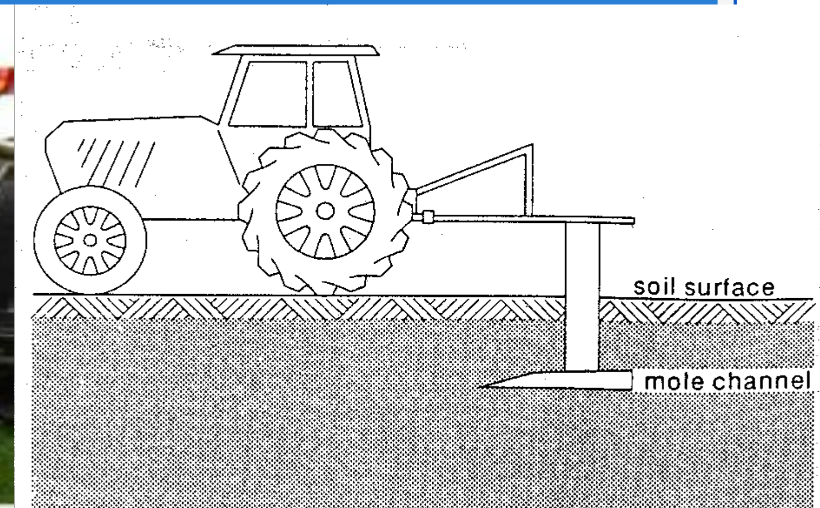
- Mole channels are susceptible to deterioration/errosion.

The rate of deterioration, consequently their effective life time, is governed by number of factors

- Soil properties (decide their stability)
- Moisture conditions during construction
- Flow velocities in the channel (High velocities cause scouring and Inundation may result in collapse)
- Method of construction : Soils should have a certain **“Plasticity “**to allow the mole channels to be shaped and also stable enough.
- Mole drains should have continuous slope in the direction of outlet.

Flat lands with irregular topography are less suitable.


Vertical bar
Mole opener


soil surface
mole channel

DESIGNS OF SUBSURFACE DRAINAGE SYSTEMS

- Improved subsurface drainage is necessary to optimize the crop environment and reduce production risks by controlling:
  - the depth of water table
  - salinity in the crop root zone.
- To assure an effective and profitable system, it's important to couple a good design process with the thorough evaluation of such on-site factors: such as soil type, topography, outlet placement and existing wetlands.
- This, and a quality installation will ensure a drainage system that will effectively perform for many years to come.

Assumptions

- *The drain discharge equals to the recharge to the ground water either by irrigation or rainfall.*
- *Consequently, the ground water remains in the same position.*
- *Recharge is uniform over the drainage area,*
- *Considered as two dimensional flow i.e., flow is considered identical in any cross-section perpendicular to the drains.*
- *Homogeneous & isotropic soils.*
- *Ignore if any spatial variation is observed in the hydraulic conductivity.*
- *The drain discharge* ***equals*** *to the recharge to the ground water either by irrigation or rainfall.*

Most important one is **Dupuit -Forchhmiemer assumption (D-F Assumption)**

- It says: The flow pattern is steady state.

  Uniform flow of recharge, steady b/n the drains

  Homogeneous and isotropic soil; Darcy's flow equation is applicable.

  Hydraulic gradient between two sections is constant.

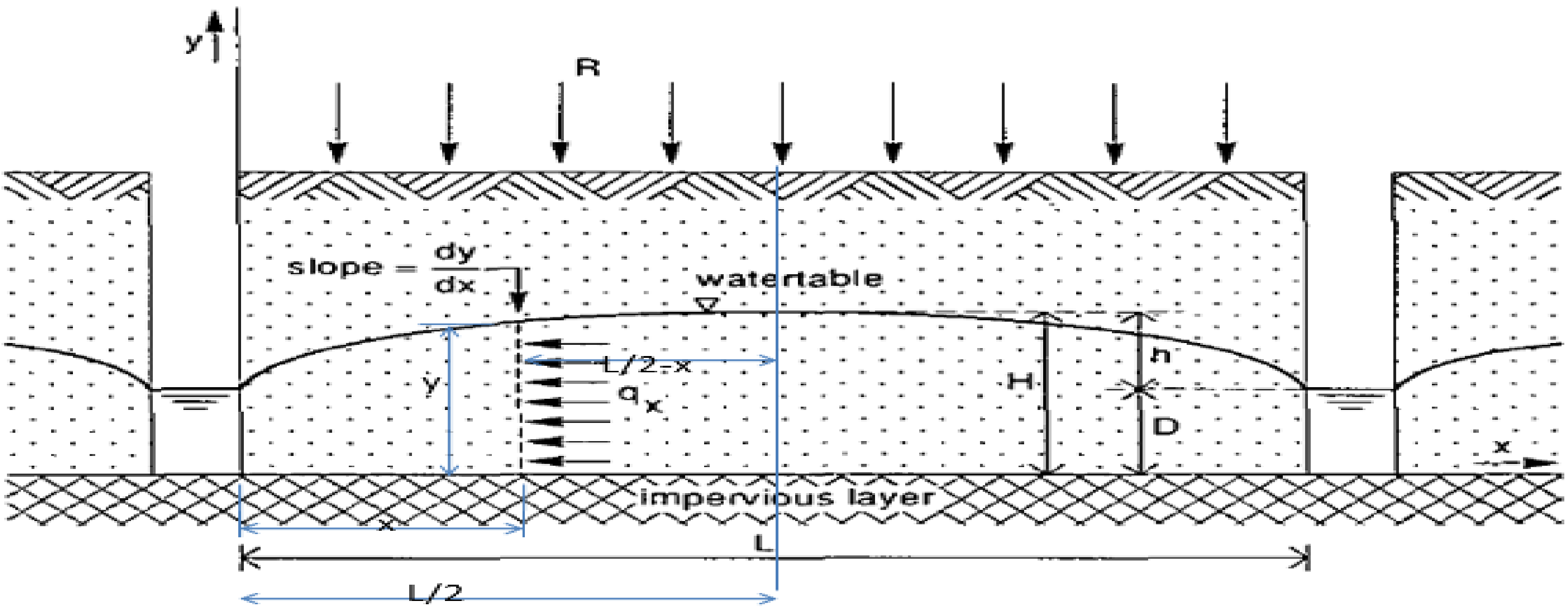
- If impervious layer does not coincide with the bottom of the drain, the flow in the vicinity of drain will be radial & **D-F** assumption can not be applied.
- **Under this condition**, **Hooghoudt** solved the problem by introducing an imaginary impervious layer to take into account the extra head loss caused by the radial flow.

Hooghoudt’ Equation:

- *For determining the spacing of drains is based on the above assumptions.*

Hooghoudt Equation:

- *Consider a steady state flow to vertically walled open drains*



Flow to vertically-walled drains reaching the impervious layer

According to D-F theory, Darcy equation can be applied to describe the flow of the ground water (qx):

- Through a vertical plane (y)
- At a distance (x) from the ditch:

q_x = K y dy/dx……………………….(1)

Where, qx = 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), Dy/dx = Hydraulic gradient at x

The continuity principle stats that all the water entering the soil in the surface area midway between the drains, must pass through the vertical plane (y) at distance (x) on its way to the drain.

If R is the rate of recharge per unit area, then the flow per unit time through plane (y) is:

q_x = R(½ L–x)……………………(2)

Where, R = Rate of recharge per unit surface area, m/day

L = Drain spacing, m

Since flow in the above two cases must be equal. Equate the right side of the equations, then:

$$K\, y\, dy/dx = R\,(\tfrac{1}{2} L - x)$$

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

The limit of integration of this differential equation is

When x = 0, y = D and when x = ½ L, y = H

Where, D = Elevation of water level in the drain (m)

H = Elevation water table midway between the drains (m)

Integrating the differential equation & substituting the limits

$$L^2 = 4\,K\,(H2 - D^2) / R$$ **OR**

$$q = R = 4\,K\,(H^2 - D^2) / L^2$$

Where, q = drain discharge (m /day)

(Assume, the Recharge per unit area is equal to drain discharge per unit area. therefore, q is equated to R).

- The above equation is derived by Hooghoudt in 1936, is also known as Donnan equation (Donnan 1946).

The above equation can be re-written as:

(Since from fig. $H – D = h$ & $H + D = 2d + h$)

$$q = 4\,K\,(H + D)\,(H – D) / L^2 = 4\,K\,(2\,D + h)\,(\,h\,) / L^2$$

$$q = (\,8\,K\,D\,h + 4\,K\,h^2\,) / L^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Conditions considered based on 'D' values

Case I: If the water level in the drain is very low i.e $D \approx 0$, then the above equation changes to $q = 4\,K\,h^2 / L^2$……This eq. describes the flow above the drain level.

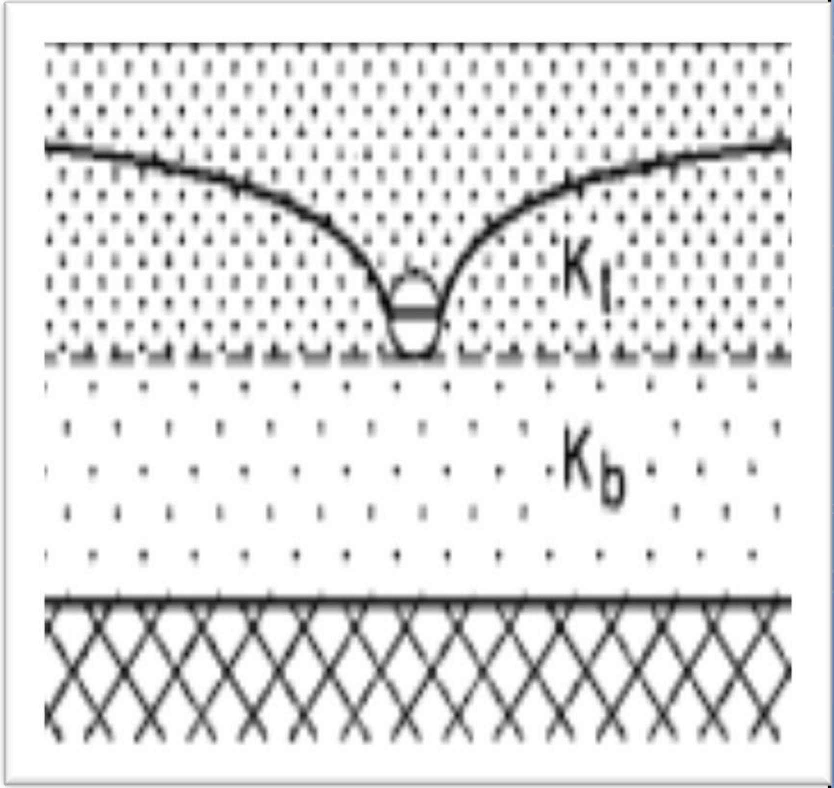
Case II: If the impervious layer is far below the drain level, i.e $D >> h$, then the second term in the equation becomes

$q = 8\,K\,D\,h / L^2$ …………..This equation describes the flow below the drain

The above two considerations lead to the following conclusion:

- If the soil profile consists of two layers with different hydraulic conductivities and
- If the drain level is at interface between the soil layers, **eq. (3)** can be written as:

$$q = (8\ K_b\ D\ h + 4\ K_t\ h^2) / L^2 \quad \ldots\ldots\ldots\ldots(4)$$



Where,

Kb = Hydraulic conductivity of the layer below the drain level (m/day)

Kt = Hydraulic conductivity of the layer above the drain level (m/day)

Case III: If pipe or open drain do not reach the impervious layer:

Hooghoudt (1940),Introduced the following points:

- He assumed **an imaginary impervious layer** above the real one
- He replaced the drains by imaginary ditches with their bottoms on the imaginary impervious layer.

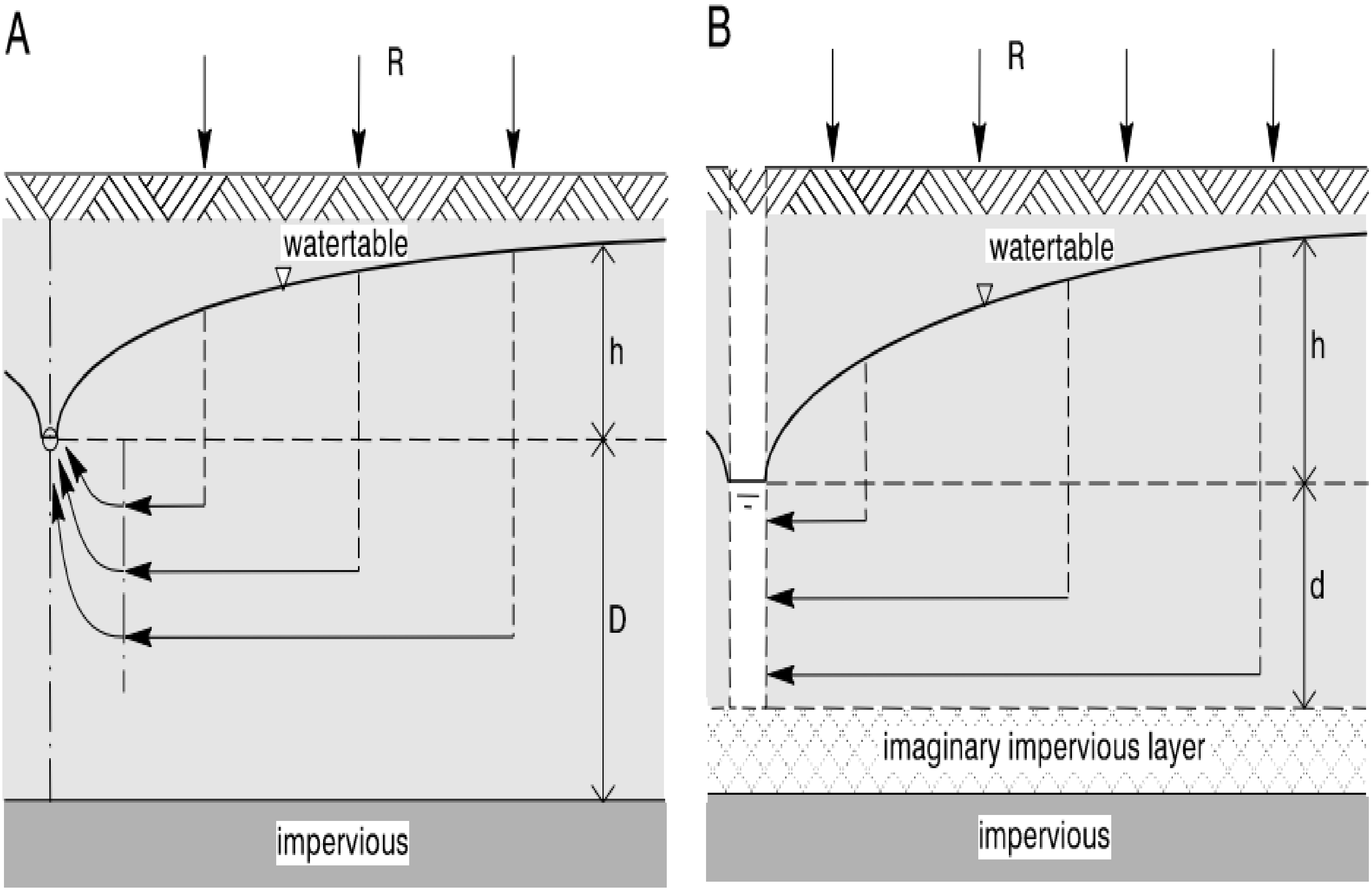
- Pipe or open drains do not reach impervious layer,
- Flow lines will converge towards drain and will thus no longer be horizontal.
- Actual depth to impervious layer (D) replaced with a smaller equivalent depth (d).
- Under these assumptions, still equation(3):

$$q = (8\,K\,D\,h + 4\,K\,h^2) / L^2$$

can be used to express the flow towards the drains.

- *This equivalent depth, d represents the imaginary thinner soil layer through which the same amount of water will flow per unit time as in the actual situation.*

- The flow lines will converge towards the drain and thus, no longer be **horizontal.**



Con’d…

- On the basis of the method of "mirror images", Hooghoudt derived a relation between
- The equivalent depth (d) and
- The spacing (L)
- The depth to the impervious layer (D)
- And the radius of the drain (r)

Therefore, Hooghoudt prepared tables for the most common sizes of drainpipes, from which the equivalent depth d can be read directly.

An example of such a table (for r = 0.1m) is given in the Table provided next slide.

Table: Values for the equivalent depth d of Hooghoudt for r_o=**0.1** m, D and L in m (Hooghoudt 1940)

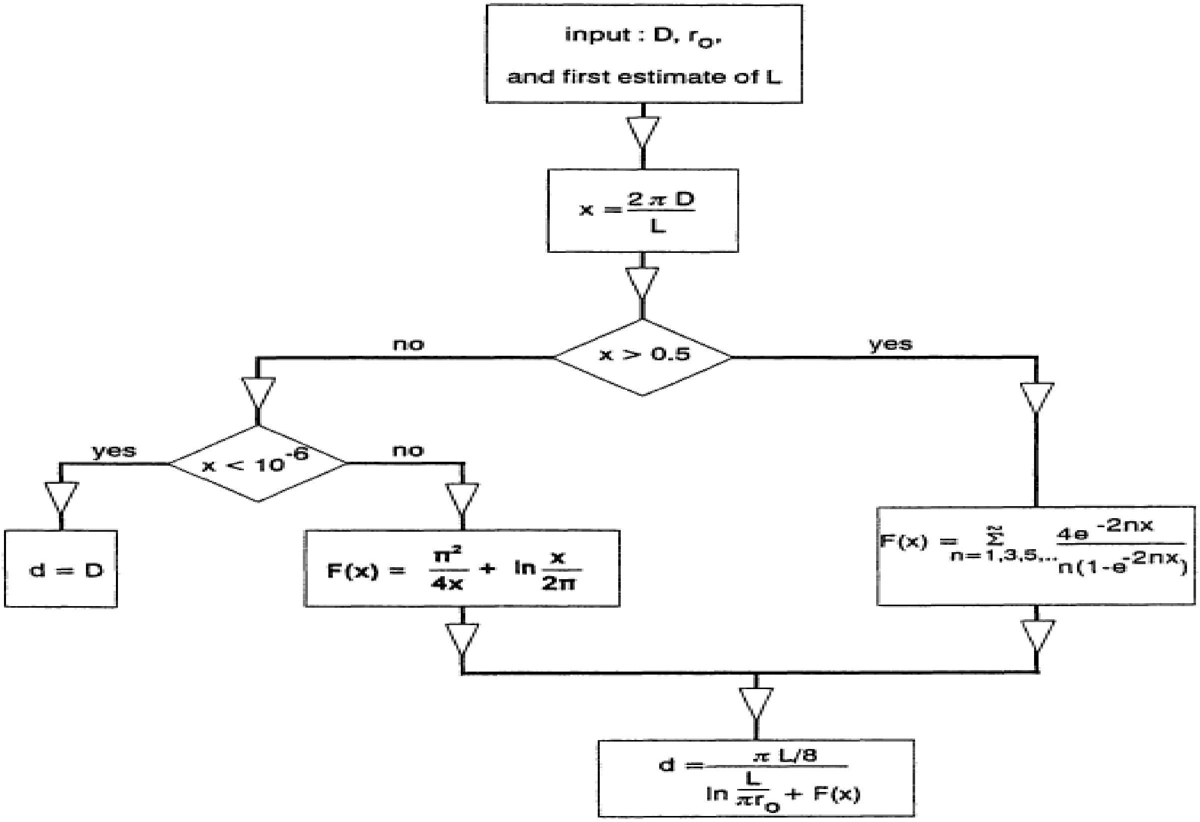
L → / D	5 m	7.5	10	15	20	25	30	35	40	45	50
0.5 m	0.47	0.48	0.49	0.49	0.49	0.50	0.50	0.50	0.50	0.50	0.50
0.75	0.60	0.65	0.69	0.71	0.73	0.74	0.75	0.75	0.75	0.76	0.76
1.00	0.67	0.75	0.80	0.86	0.89	0.91	0.93	0.94	0.96	0.96	0.96
1.25	0.70	0.82	0.89	1.00	1.05	1.09	1.12	1.13	1.14	1.14	1.15
1.50	0.70	0.88	0.97	1.11	1.19	1.25	1.28	1.31	1.34	1.35	1.36
1.75	0.70	0.91	1.02	1.20	1.30	1.39	1.45	1.49	1.52	1.55	1.57
2.00	0.70	0.91	1.08	1.28	1.41	1.5	1.57	1.62	1.66	1.70	1.72
2.25	0.70	0.91	1.13	1.34	1.50	1.69	1.69	1.76	1.81	1.84	1.86
2.50	0.70	0.91	1.13	1.38	1.57	1.69	1.79	1.87	1.94	1.99	2.02
2.75	0.70	0.91	1.13	1.42	1.63	1.76	1.88	1.98	2.05	2.12	2.18
3.00	0.70	0.91	1.13	1.45	1.67	1.83	1.97	2.08	2.16	2.23	2.29
3.25	0.70	0.91	1.13	1.48	1.71	1.88	2.04	2.16	2.26	2.35	2.42
3.50	0.70	0.91	1.13	1.50	1.75	1.93	2.11	2.24	2.35	2.45	2.54
3.75	0.70	0.91	1.13	1.52	1.78	1.97	2.17	2.31	2.44	2.54	2.64
4.00	0.70	0.91	1.13	1.52	1.81	2.02	2.22	2.37	2.51	2.62	2.71
4.50	0.70	0.91	1.13	1.52	1.85	2.08	2.31	2.50	2.63	2.76	2.87
5.00	0.70	0.91	1.13	1.52	1.88	2.15	2.38	2.58	2.75	2.89	3.02
5.50	0.70	0.91	1.13	1.52	1.88	2.20	2.43	2.65	2.84	3.00	3.15
6.00	0.70	0.91	1.13	1.52	1.88	2.20	2.48	2.70	2.92	3.09	3.26
7.00	0.70	0.91	1.13	1.52	1.88	2.20	2.54	2.81	3.03	3.24	3.43
8.00	0.70	0.91	1.13	1.52	1.88	2.20	2.57	2.85	3.13	3.35	3.56
9.00	0.70	0.91	1.13	1.52	1.88	2.20	2.57	2.89	3.18	3.43	3.66
10.00	0.70	0.91	1.13	1.52	1.88	2.20	2.57	2.89	3.23	3.48	3.74
∞	0.71	0.93	1.14	1.53	1.89	2.24	2.58	2.91	3.24	3.56	3.88

L → / D	50	75	80	85	90	100	150	200	250
0.5	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
1	0.96	0.97	0.97	0.97	0.98	0.98	0.99	0.99	0.99
2	1.72	1.80	1.82	1.82	1.83	1.85	1.00	1.92	1.94
3	2.29	2.49	2.52	2.54	2.56	2.60	2.72	2.70	2.83
4	2.71	3.04	3.08	3.12	3.16	3.24	3.46	3.58	3.66
5	3.02	3.49	3.55	3.61	3.67	3.78	4.12	4.31	4.43
6	3.23	3.85	3.93	4.00	4.08	4.23	4.70	4.97	5.15
7	3.43	4.14	4.23	4.33	4.42	4.62	5.22	5.57	5.81
8	3.56	4.38	4.49	4.61	4.72	4.95	5.68	6.13	6.43
9	3.66	4.57	4.70	4.82	4.95	5.23	6.09	6.63	7.00
10	3.74	4.74	4.89	5.04	5.18	5.47	6.45	7.09	7.53
12.5	3.74	5.02	5.20	5.38	5.56	5.92	7.20	8.06	8.68
15	3.74	5.20	5.40	5.60	5.80	6.25	7.77	8.84	9.64
17.5	3.74	5.30	5.53	5.76	5.99	6.44	8.20	9.47	10.4
20	3.74	5.30	5.62	5.87	6.12	6.60	8.54	9.97	11.1
25	3.74	5.30	5.74	5.96	6.20	6.79	8.99	10.7	12.1
30	3.74	5.30	5.74	5.96	6.20	6.79	9.27	11.3	12.9
35	3.74	5.30	5.74	5.96	6.20	6.79	9.44	11.6	13.4
40	3.74	5.30	5.74	5.96	6.20	6.79	9.44	11.8	13.8
45	3.74	5.30	5.74	5.96	6.20	6.79	9.44	12.0	13.8
50	3.74	5.30	5.74	5.96	6.20	6.79	9.44	12.1	14.3
60	3.74	5.30	5.74	5.96	6.20	6.79	9.44	12.1	14.6
∞	3.88	5.38	5.76	6.00	6.26	6.82	9.55	12.2	14.7

Con'd…

- Since the drain spacing L depends on the equivalent depth d, which in turn is a function of L.
- The Hooghoudt Equation can only be solved by iteration.

Flow chart for the calculation o Hooghoudt's equivalent depth using an exact solution



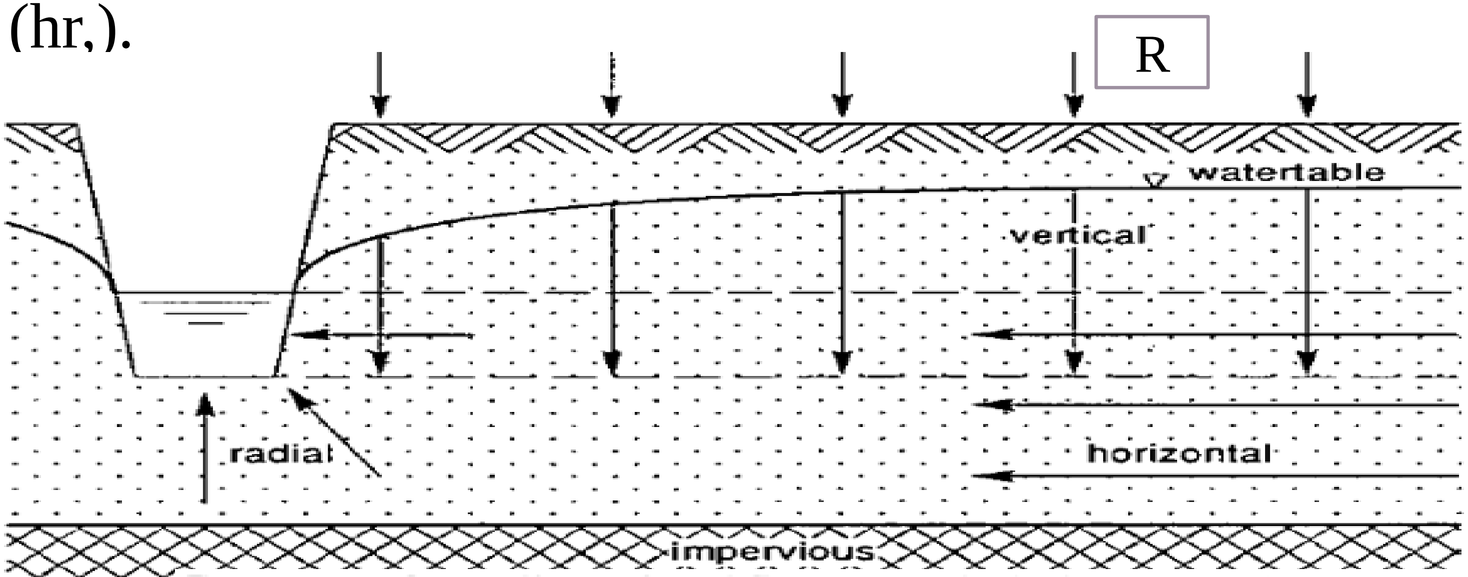
THE ERNST EQUATION

- So far, we have discussed solutions that can be applied for a homogeneous soil profile or two layered soil profile provided that the interface between the two layers coincides with the drain level.
- The Ernst equation is applicable to **any type of two layered soil** profile.
- It has the advantage over the Hooghoudt equation that the interface between the two layers can be either above or below the drain level.
- It is especially useful when top layer has a considerably lower hydraulic conductivity than the bottom layer.
- To obtain a generally applicable solution for soil profiles consisting of layers with different hydraulic conductivities.

Ernst divided the flow into the following three parts(layers):

1. A vertical (hv) component
2. A horizontal (hh) component
3. A radial (hr) component

- Total available head (h) can be divided into a head loss caused by vertical flow (hv), horizontal flow (h_h), and radial flow (hr,).



Geometry of two-dimensional flow towards drains, according to Ernst

Vertical Flow

- It is assumed to take place in the layer between wt & the drain level.
- Therefore, we can apply Darcy's law to get the loss of head caused by vertical flow i.e.

$$q = k_v \frac{h_V}{d_v}$$

$$\Rightarrow h_V = q \frac{d_v}{k_v} \quad \text{.................5}$$

Where

dv =thickness of the layer in which the vertical flow is considered (m)

kv = Vertical hydraulic conductivity (m/day)

***Note* :** The vertical head loss, however, is generally small compared with the horizontal and radial head loss,

- So the error introduced by replaying kv with kh can be neglected.

Horizontal Flow:

- It takes place below the drain level:

  $q = 8\,KD\,h / L^2$;For single homogeneous layer

- But for two layers having different H.C.

  $$q=8\sum(KD)_h\, h_h/L^2$$

- Horizontal head loss h_h, can be described as:

  $$h_h=q\,(L^2/8\sum(KD)_h)\ldots\ldots\ldots\ldots\ldots\ldots6$$

- Where; $\sum(KD)_h$ =transmissivity of the soil layers through which water flows horizontally (m^2/day)
- When considering the horizontal flow, however, we cannot neglect the transmissivity of the top layer, and $\sum(KD)h = KbDd, + KtDt$, $in\ which\ Dt = Dr + \frac{1}{2} * h$
- If impervious layer is very deep, the value of $\sum$(KD) is infinity;
- consequently the horizontal head loss decreases to zero.
- To prevent this, the maximum thickness of the soil layer below the drain level through which flow is considered ($\sum D_h$)is restricted to L/4 where L is the spacing of the drain.

Radial Flow:

- It is also assumed to take place below drain level.
- The head loss caused by the radial flow can be expressed as:

$$h_r = q \frac{L}{\Pi K_r} \; In \frac{a.Dr}{u} \ldots\ldots\ldots\ldots\ldots\ldots\ldots 7$$

Where; Kr = radial hydraulic conductivity (m/day)

a = geometry factor of the radial resistance (-)

Dr =Thickness of the layer in which the radial flow is considered (m)

u=πro =Wetted perimeter of the drain (m)

The geometry factor depends upon:

Soil profile & Position of the drain

- For homogeneous soil, a=1,
- Layered Soil drain in bottom layer, a =1
- For layered Soil and drain in Top layer, a =f(K_b/K_t)
- (K_b /K_t) <0.1, a =1; (K_b /K_t) > 50, a=4
- 0.1< (K_b /K_t) <50, a=f(K_b/K_t, D_b/D_t) ……………see Table

Table : the geometry factor (a) obtained by the relaxation method

$\frac{K_b}{K_t}$	$\frac{D_b}{D_t}$					
	1	2	4	8	16	32
1	2.0	3.0	5.0	9.0	15.0	30.0
2	2.4	3.2	4.6	6.2	8.0	10.0
3	2.6	3.3	4.5	5.5	6.8	8.0
5	2.8	3.5	4.4	4.8	5.6	6.2
10	3.2	3.6	4.2	4.5	4.8	5.0
20	3.6	3.7	4.0	4.2	4.4	4.6
50	3.8	4.0	4.0	4.0	4.2	4.6

Combining eq^n (5), (6) and (7) we get:

$$h = q\left(\frac{D_v}{K_v}\right) + q\,\frac{L^2}{8\sum(KD)_h} + q\,\frac{L}{\Pi K_r}\,\ell n\left(\frac{a.D_r}{u}\right)$$

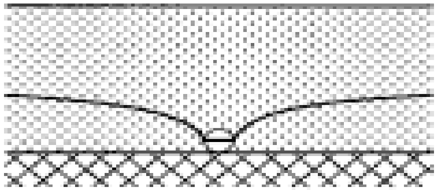
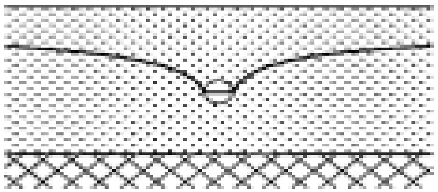
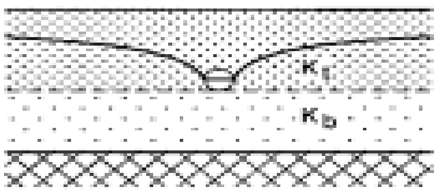
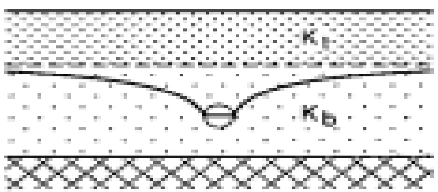
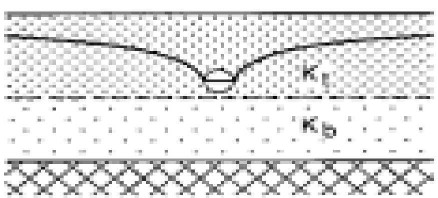
or

$$h = q\left[\frac{D_v}{K_v} + \frac{L^2}{8\sum(KD)_h} + \frac{L}{\Pi K_r}\,In\left(\frac{a.D_r}{a}\right)\right]$$

is known as Ernst Equation

If the design discharge (q) and the available total hydraulic head (h) are known, the quadratic equation for L can be directly solved

Steady-state equations

SCHEMATIZATION	SOIL PROFILE	POSITION OF DRAIN	THEORY	EQUATION
	homogeneous	on top of impervious layer	Hooghoudt/ Donnan	$q = \frac{4K(H^2 - D^2)}{L^2}$
	homogeneous	above impervious layer	Hooghoudt with equi- valent depth	$q = \frac{8Kdh + 4Kh^2}{L^2}$
	two layers	at interface of the two soil layers	Hooghoudt	$q = \frac{8K_b dh + 4K_t h^2}{L^2}$
	two layers $(K_t < K_b)$	in bottom layer	Ernst	$h = q\left(\frac{D_v}{K_t} + \frac{L^2}{8K_b D_b} + \frac{L}{\pi K_b} \ln \frac{D_r}{u}\right)$
	two layers $(K_t < K_b)$	in top layer	Ernst	$h = q\left(\frac{D_v}{K_t} + \frac{L^2}{8(K_b D_b + K_t D_t)} + \frac{L}{\pi K_t} \ln \frac{aD_r}{u}\right)$

Drainage design procedures:

- The principal design parameters for both open trenches and pipe drains are spacing and depth.
- The most commonly used equation for the design of a subsurface drainage system is the Hooghoudt Equation:

$$S^2 = \frac{(4k_1 z^2) + (8k_2 dh)}{q}$$

Where:

S = Drain spacing (m)

k_1 = Hydraulic conductivity of soil above drain level (m/day)

k_2 = Hydraulic conductivity of soil below drain level (m/day)

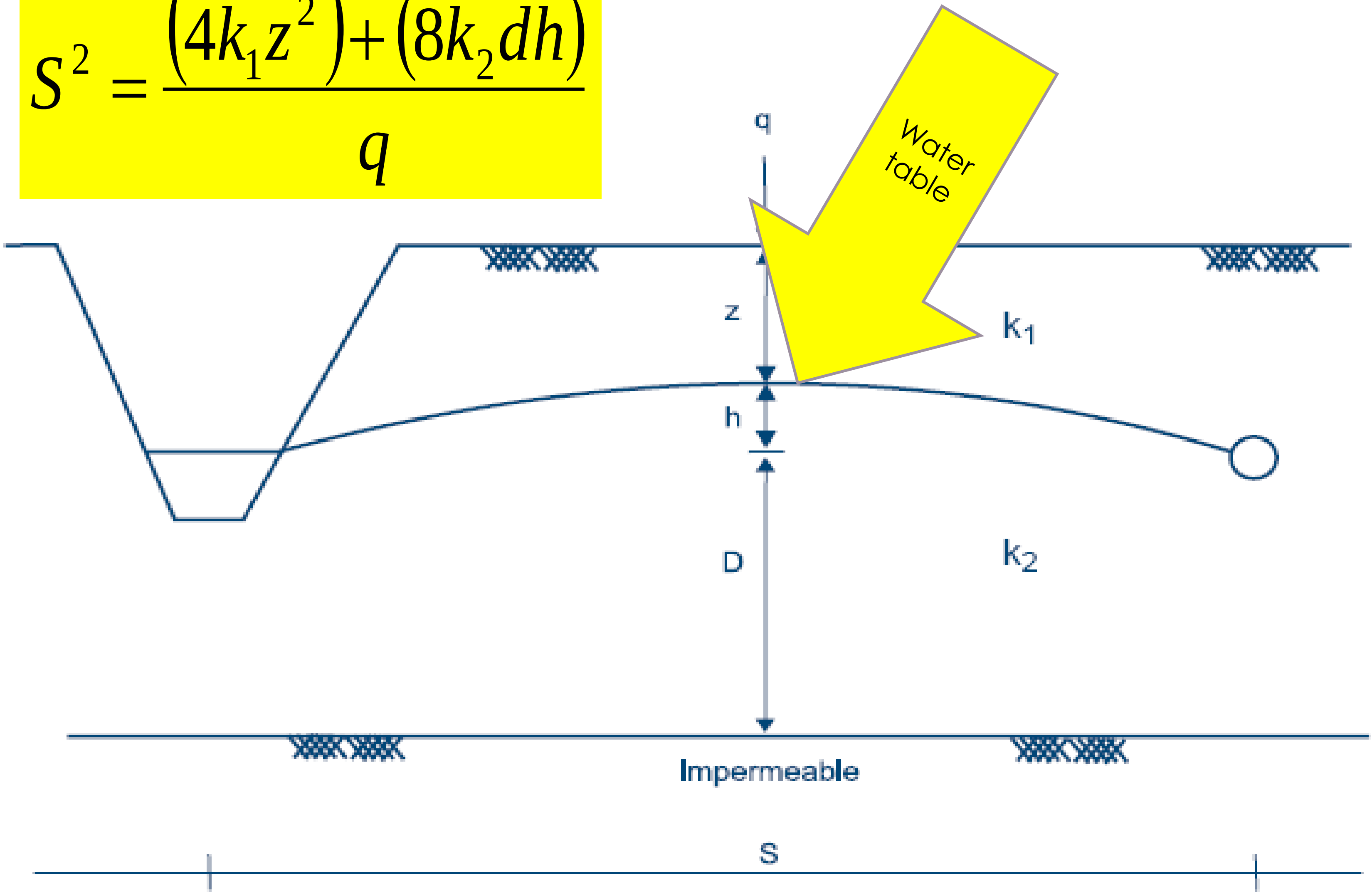
h = Hydraulic head of maximum groundwater table elevation above drainage level (m)

q = Discharge requirement expressed in depth of water removal (m/day)

d = Equivalent depth of substratum below drainage level (m)

Con'd…

$$S^2 = \frac{(4k_1 z^2) + (8k_2 dh)}{q}$$



Subsurface drainage parameters

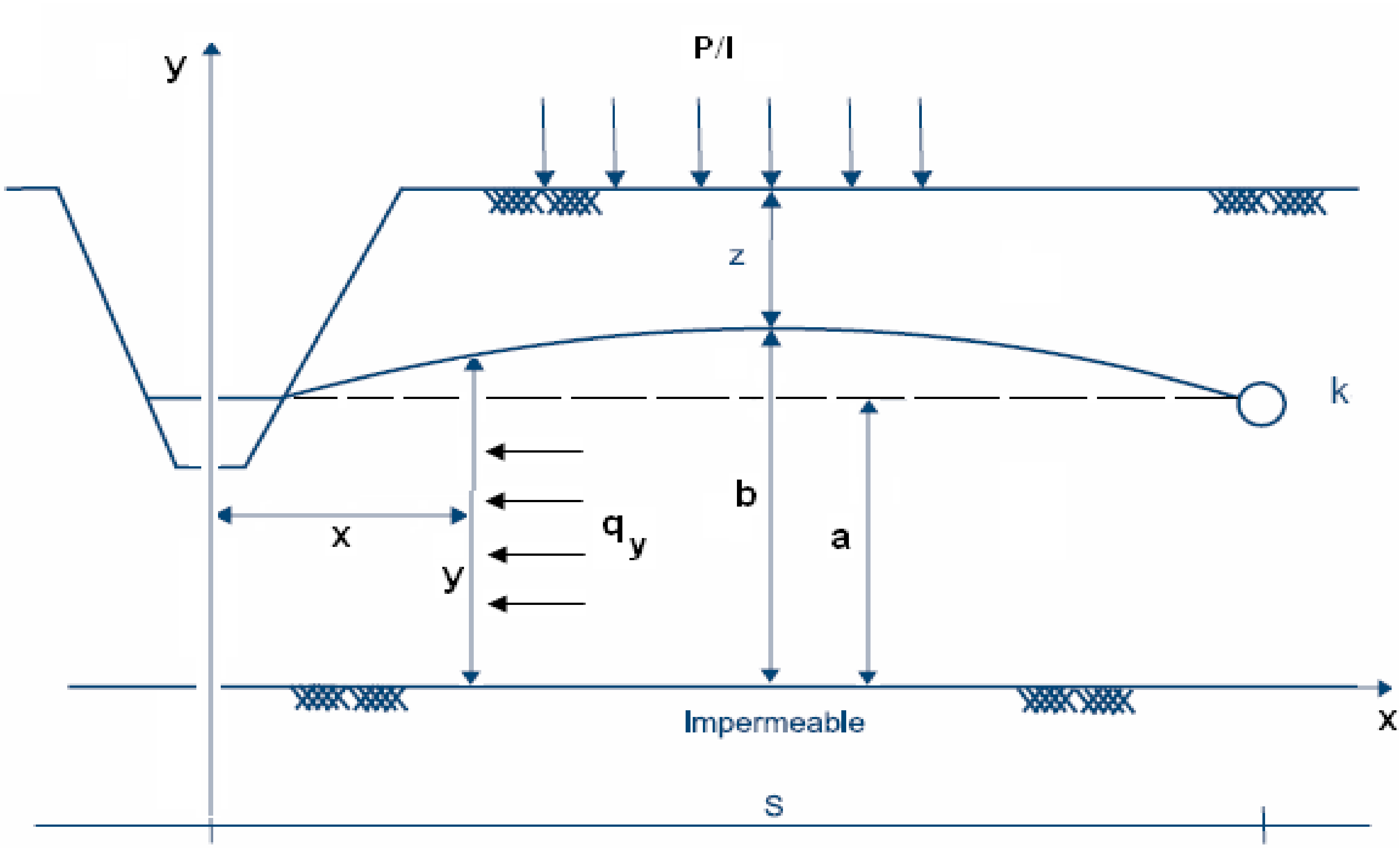
- In reality, the head losses due to horizontal and radial flow to the pipe should be considered, which would result in complex equations as shown below.
- The equivalent flow is essentially horizontal and can be described using the Hooghoudt formula.
- The equivalent depth, d is found by the equation:

$$d = \frac{D}{1 + (D/S)\left[(8/\pi)\ln(D/r_o) - 3.4\right]} \quad for \quad 0 < D/S \leq 0.3$$

$$d = \frac{S}{(8/\pi)\left[\ln(S/r_o) - 1.15\right]} \quad for \quad D/L > 0.3$$

- Since d is a function of the unknown drain spacing, S, the calculation requires several trials to come to the solution.

- Sometimes, the spacing of tile drains for homogenous soil may be found by an approximate equation as follows.



Con'd…

- According to Darcy's law, $Q = kiA$
- Discharge per unit length of the drain passing the section at y,will be:
  - $q_y = k(dy/dx)y$ ……………….(x)
- But when x =S/2 , q_y = 0 and when x= 0, q_y = q/2
- Thus, assuming that q is inversely proportional to distance, then q_y may be expressed as

Equating (x) and (x), rearranging and integrating,

$$qy = \frac{1}{2}q - \frac{1}{2}q\frac{x}{S/2} = \frac{1}{2}q\left(1 - \frac{x}{S/2}\right) = \frac{q}{2S}(S - 2x) \ldots\ldots\ldots\ldots\ldots xx$$

$$\int \frac{q}{2Sk}(S - 2x)dx = \int ydy$$

$$\frac{q}{2Sk}\left(Sx - \frac{2x^2}{2}\right) = \frac{y^2}{2} + C$$

Con'd…

$$\frac{q}{2Sk}\left(Sx-\frac{2x^2}{2}\right)=\frac{y^2}{2}+C$$

- When x= 0, y = a. Therefore, C = $-a^2/2$

Substituting for C,

$$\frac{q}{2Sk}\left(Sx-\frac{2x^2}{2}\right)=\frac{y^2-a^2}{2}$$

- Also, when x=S/2, y=b. Thus, finally,

$$S=\frac{4k}{q}\left(b^2-a^2\right)$$

Con'd…

- The layout of pipe drainage system is determined by the *drain spacing* along with the consideration *of the capacity* and *length of the drain pipes* for various *diameters and slopes*.
- The amount of water to be conveyed by a pipe drain is from a design drainage coefficient and the area covered by the pipe. i.e.

$$Q = Dc.A = Dc.WB$$

Where, Q = pipe discharge(m3 /d) ; Dc= drainage coefficient (m /d)

A = drainage area (m2); W = width of area to be drained (or pipe spacing) (m)

B = length of pipe line (m)

- But from Manning's equation, $Q = (1/n)\, R^{2/3} S^{1/2}$
- For full flow pipe, $R = (0.25\pi d^2)/(\pi d) = d/4$
- Therefore, $Q = 0.312(1/n)d^{2.67}s^{1/2})$
- For selected diameter and slope, Q can be known from eqn.(2) and
- Then, the length of the pipe can be known, for pipe spacing obtained from Hooghoudt equation, using equation (1).

Con’d…

- The hydraulic design of drainpipes is based on formulae that relate to:
  - The discharge of water to the pipe diameter,
  - The hydraulic roughness of the pipe wall and
  - The hydraulic gradient.
- Different formulae are used for smooth and corrugated pipes.
  - Clay,
  - concrete and
  - smooth plastic

  } pipes are considered hydraulically smooth pipes.
- Their discharge capacities can be calculated from the Darcy-Weisbach equation.
- The discharge capacity of corrugated pipes can be calculated from the Chézy-Manning equation.

Con'd…

- In the Chézy-Manning equation, the hydraulic roughness (or 'friction resistance') of the pipe wall is expressed as
  - Manning's coefficient, n, or
  - its reciprocal parameter, kM.
- For drainpipes with diameters ranging from 50 to 200mm and small corrugations;

roughness coefficient $n = 0.0143\ s\ m^{-1/3}$ *or the reciprocal value* $kM = 70\ m^{1/3}\ s^{-1}$

- kM-value of larger diameter pipes with large corrugations can be expressed as:
- $$\mathbf{kM = 18.7}\boldsymbol{d}^{\mathbf{0.21}}\boldsymbol{S}^{\mathbf{-0.38}}$$

where; d =internal pipe diameter (m) and

S =ditch length(m)

- For most pipes with large corrugations, a roughness coefficient

$n = 0.02\ s\ m^{-1/3}$ $(or\ km = 50\ m^{1/3}\ s^{-1})$ can be accepted.

Transport Vs drainage principle in drainage pipe design

- The ***type of pipe*** and the ***hydraulic gradient*** *determine* the discharge capacity of drainpipes (*as shown in the next slide*, *table*).
- The calculation of the discharge capacity of drainpipes may be based upon two principles (Wesseling and Homma, 1967; Wesseling, 1987):
- ***The transport principle*** *with* ***uniform flow***, whereby a drainpipe is assumed to transport a fixed discharge along its length, while the pipe itself is flowing full; and
- *The drainage principle with non-uniform flow*, whereby a constant inflow of groundwater into the drain along its length results in a discharge which increases along the length of the pipe.

Material type	Transport principle	Drainage principle
Clay, concrete and smooth plastic pipes	$Q = 50\, d^{2.714}\, s^{0.572}$	$Q = 89\, d^{2.714}\, s^{0.572}$
Small corrugated pipes (50 to 200mm)	$Q = 22\, d^{2.667}\, s^{0.5}$	$Q = 38\, d^{2.667}\, s^{0.5}$
Large corrugated pipes more than 200mm	$Q = 15\, d^{2.667}\, s^{0.5}$	$Q = 27\, d^{2.667}\, s^{0.5}$
Where Q= discharge(m^3/s), d= internal diameters(m), and s- hydraulic gradient(-)		

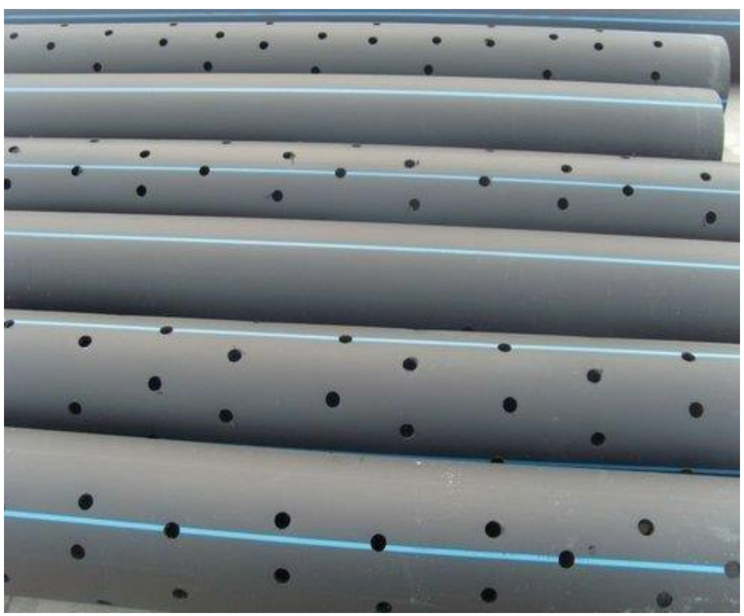
- ❖ Comparison of these equations reveals that the assumption of the transport principle for the determination of the diameter of drainpipes implies that a safety factor is automatically incorporated in the design.
- ❖ The equations based upon the drainage principle yield larger discharge capacities, and, as such, larger surfaces that can be drained with a given pipe diameter.
- ❖ Adoption of some safety factor is indeed required to incorporate the risk of possible mineral and/of chemical clogging of the pipe in its hydraulic design.

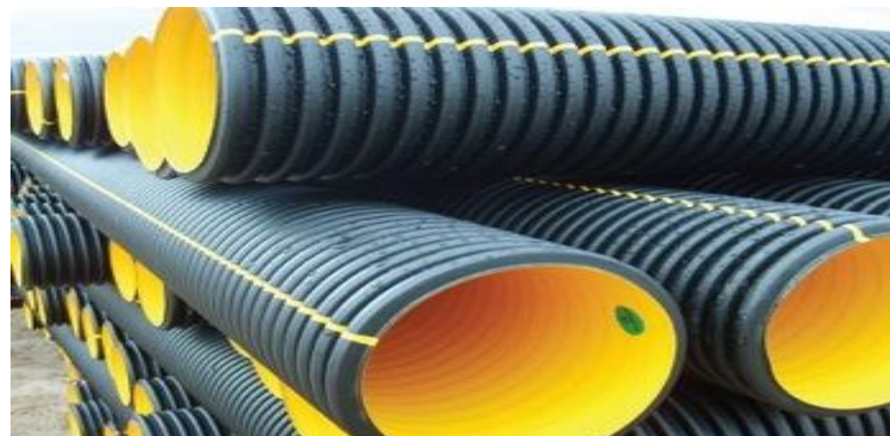
CHOICE OF TYPE OF SUBSURFACE DRAINAGE SYSTEM

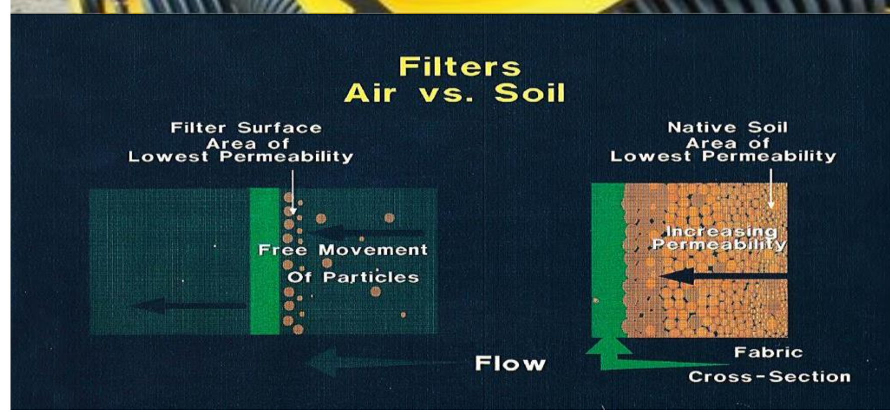
- If one has decided to install a subsurface drainage system, he/she has to make a subsequent choice b/n:
- Tube well drainage or open drainage or
- Pipe drain or mole drains
- The mole drainage is mainly aimed at rapid removal of the excess surface water rather than at controlling the water table.
- The usual choice is therefore, between:
- *open drains & pipe drains*.

Corrugated, Perforated and envelope

- A corrugated pipe is surrounded by ridges and furrows on its surface.
- Perforated Pipe is a pipe which has small slots through which water can flow through them.
- Small particles of soil material suspended in water moving toward a drain will actually pass through a properly selected drain envelope without causing clogging







CHAPTER SEVEN: SALINITY CONTROL

SALINITY CONTROL

SALINITY

- Irrigation water even of excellent quality, it is a major source of soluble salts.
- The presence of soluble salts in the soil solution can affect plant growth, depending on the salt concentration and susceptibility of plant or crop.
- **Soil salinity** is appraised by measuring the **electrical conductivity or salt concentration** in soil water extracts.
- The soluble salts present in the soils are mainly chlorides, sulphates and sometimes nitrates of Na, Ca, Mg and K.
- In addition to readily available salts, saline soils may contain relatively insoluble salts such as **calcium sulphate** (**gypsum**) and **calcium and magnesium carbonates**.

Cont…

- In addition to readily available salts, saline soils may contain relatively insoluble salts such as calcium sulphate (gypsum) and calcium and magnesium carbonates
- In order to reclaim saline soils, it is necessary to reduce soluble salt concentration to acceptable limits and
- This can be done by leaching,provided there is adequate drainage either natural or artificial.

Sodicity: refers to the presence of sodium (Na) ions in the soil solution.

Soil acidity & Alkalinity :Acidity is general term that refers to the amount of hydrogen ions in the soil solution.

Crop growth affected by Salinity & Sodicity

1. *Effect of Salinity on Crop growth*

- **Osmotic effect**
- As salinity of solution increases, its osmotic potential increases too and reduces the availability of water for crop.

2. *Effect of Sodicity on Crop Growth*

Exchangeable sodium affects plant growth in two ways

- It causes nutritional problems
- Poor soil structure

With the breakdown of soil structure, plant growth is effected by:

- Poor aeration in the root zone
- Reduced water movement
- Water logging in the root zone or on the soil surface

Causes for Salt build-up in Irrigated Soils

The following factors either singly or in association with other factors are responsible for the development of Saline and Alkaline soils

- Use of Saline Irrigation Water
- Deposition of salts on the soil surface from high sub-soil water table
- Seepage from canals
- Arid climate
- Poor drainage
- Back water flow / Intrusion of sea water

SALT BALANCE

- The relation b/n the quantity of soluble salts brought into an area by the irrigation water and
- The quantity removed from the area by the drainage water has been called **" the Salt Balance "** of the area.

- The ***salt balance in the soil*** is influenced by ***the quantity and quality*** of irrigation water and the effectiveness of leaching and drainage.
- The salt balance of soil is expressed by the following relationship.

$$V_iC_i+S_m-V_dC_d+S_p-S_c=0$$

where;

V_i = Volume of irrigation Water

C_i =Salt content of irrigation water

S_m = amount of salt dissolved from soil minerals

V_d = Volume of drainage water

C_d = Salt content of drainage water

Sp = Amount of salt precipitated over the soil surface

S_c = The amount salt removed by the crop

Cont…

- If D_d & D_i are volumes per unit area of equivalent depths of drainage and irrigation waters respectively, the above equation may be written as

D_d/D_i=Ci /Cd Where;

Dd=volume per unit area of equivalent depth of drainage

Di= volume per unit area of irrigation waters

C_d = Salt content of drainage water

C_i =Salt content of irrigation water

Leaching Requirement

Leaching is the process of: dissolving and transporting soluble salts by downward movement of water through the soil.

1.The depth of irrigation water per unit depth of soil, required to produce any specified increase in soil salinity for any given conductivity of irrigation water, can be calculated using the equation

$D_i/Ds=ds/d_w * SP/100 * \Delta EC_e/Ec_i$

D_i=Depth of irrigation water ;D_d=Depth of soil

d_s=Density of soil (bulk density); $d_{w\ =}$ Density of irrigation water

SP=Saturation Percentage of soil ; ΔEC_e=Increase in EC of saturation extract

EC_i=Electrical Conductivity of irrigation water

2. Under High Water Table Conditions, the increase in salinity by the evaporation of ground water, can be determined by:

$\Delta\ EC_e = D_g/D_s x ECg\ /SP\ xdw/ds\ x\ 100$

Where;

D_g=Depth of ground water evaporated

EC_g=Electrical Conductivity of ground water

Cont…

3. The fraction of irrigation water that must be leached through the root zone to keep the salinity of the soil below a specific limit is termed as Leaching Requirement (LR)

$LR = D_d/Di = ECi / EC_d$ …….X

Where;

LR=Leaching requirement as a ratio or as a percent

Ec_i =EC of irrigation water

Ec_d = drainage water expressed in (mmhos /cm)

D_i=depth of irrigation

D_c = Consumptive use

D_d =equivalent depth of drainage water

- The depth of irrigation water, D_i is related to consumptive use, D_c and equivalent depth of drainage water, D_d by the equation:

$D_i = Dc + Dd$

Substitute D_d from eq.(X) into eq.

$LR = (D_i - D_c)/D_i$,

$LR = D_i / D_i - D_c / D_i$,

$LR = 1 - (D_c / D_i)$

$D_c / D_i = 1 - LR$,

Therefore, $Di = D_c / (1 - LR)$

Land reclamation techniques for salt affected soils

Reclamation measure: is a measurement to bringing saline and alkali soils into productive condition.

- In salt affected soils, a water table is often present at shallow depth.
- If so, **first measure** to be taken is to install a drainage system to control the water table.
- The **second measure** is to apply irrigation water to leach the salts from the soil.

THE END…

(OF THE COURSE)!!!

GOOD LUCK

TO ALL OF YOU!!!