ARBA MINCH UNIVERSITY
Water Technology Institute
Faculty of Meteorology and Hydrology

Course Name:-Irrigated Lands Hydrology
Course Code:- MHH1403

CHAPTER FOUR

DRAINAGE OF IRRIGATED LANDS

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Objectives of the chapter

- By the end of the session, the student will able to:
  - Understand what we mean by Agricultural drainage
  - Understand causes of excess water in agricultural lands
  - Know Problems and effects of poor drainage
  - Understand need of drainage
  - Know different types of drainage

4.1 Definition of Drainage

- Good water management of an irrigation scheme not only requires proper water application but also a proper drainage system.

- Agricultural drainage can be defined as the removal of excess surface water and/or the lowering of the groundwater table below the root zone in order to improve plant growth.

Cont…

Class activity

- Be in group and discuss on following topics
  - Causes of excess water or rise of water table
  - What are the effects of poor drainage
  - Why drainage is needed?

Causes of excess water or rise of WT:

- **Natural Causes:**
  - Poor natural drainage of the subsoil
  - Submergence under floods
  - Deep percolation from rainfall
  - Drainage water coming from adjacent areas.
- **Artificial Causes:**
  - High intensity of irrigated agriculture irrespective of the soil or subsoil
  - Heavy seepage losses from unlined canals
  - Enclosing irrigated fields with embankments
  - Non-maintenance of natural drainages or blocking of natural drainages channels by roads.
  - the extra water applied for the flushing away of salts from the root zone.

4.2 Problems and effects of poor drainage

- **Drainage problem could be:**
  - Surface drainage problem ---- when excess water builds up the water table and reaches to the ground level (i.e. when the ground is water logged).
  - Subsurface drainage problem --- when the water table builds up and comes up to the root zone. Also, the rising water table brings up harmful salts to the root zone.
- **Effects of poor drainage:**
  - Inundation of crops resulting in deficient growth
  - Lack of oxygen in the root zone, hampering germination and the uptake of nutrients;
  - Insufficient accessibility of the land for farming operations like tillage.
  - Low soil temperatures (the major problem in temperate regions)
  - Continued irrigation over a large number of years without adequate drainage facilities is resulting in large tracts of irrigated areas becoming unproductive.

Problems of poor drainage:

FIGURE 1
Drainage can reduce or eliminate (a) waterlogging and/or (b) salinity

Impacts of Poor drainage –yellow plants

Poorly drained area damages yield

Cont…

Poorly drained agricultural land

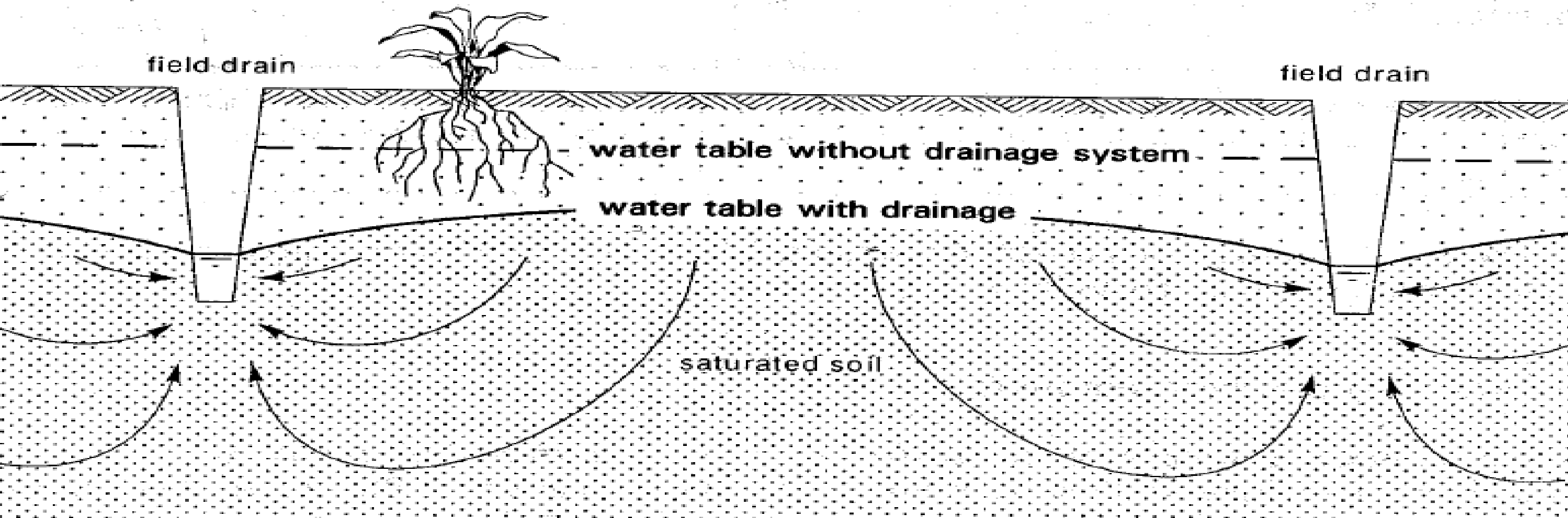
4.3 Need of Drainage

Drainage is needed in order to:

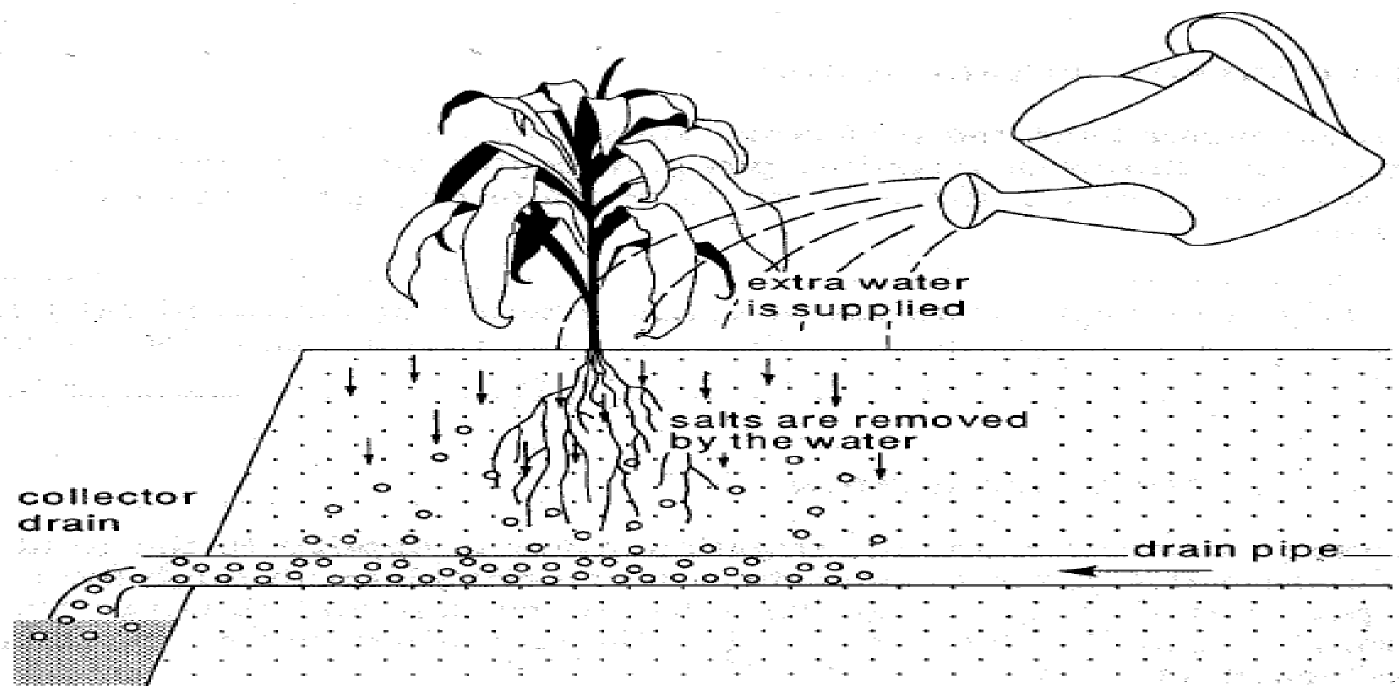
- Maintain the soil structure
- Maintain aeration of the root-zone, since most agricultural crops require a well aerated root-zone free of saturation by water; a notable exception is rice.
- Assure accessibility to the fields for cultivation and harvesting purposes
- Drain away accumulated salts from the root zone

- Therefore, drainage is necessary not only for removal of excess water but also for removing salts from the root zone.

Subsurface drainage to control the water table and to remove excess water and dissolved salts from the root zone



Extra irrigation water is applied to remove salts from the root zone



4.4 Types of drainage System

- Solution to drainage problems consists of both controlling the sources of excess water as well as adequate provision for the removal of excess water that is likely to occur.

- Drainage systems are broadly classified as:
  - Surface drainage system
  - Sub-surface drainage system

4.4.1 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.

Cont…

- 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
  - 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 irrigation.

Cont…

- 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 → Outlet

Cont…

- Types of surface drainage system (for flat areas):
  i. Bedding system
  ii. Random drain system
  iii. Parallel field drain system

Cont…

i. 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, which discharge into a field drain constructed at the lower end of the field and perpendicular to the dead furrows.
- 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).

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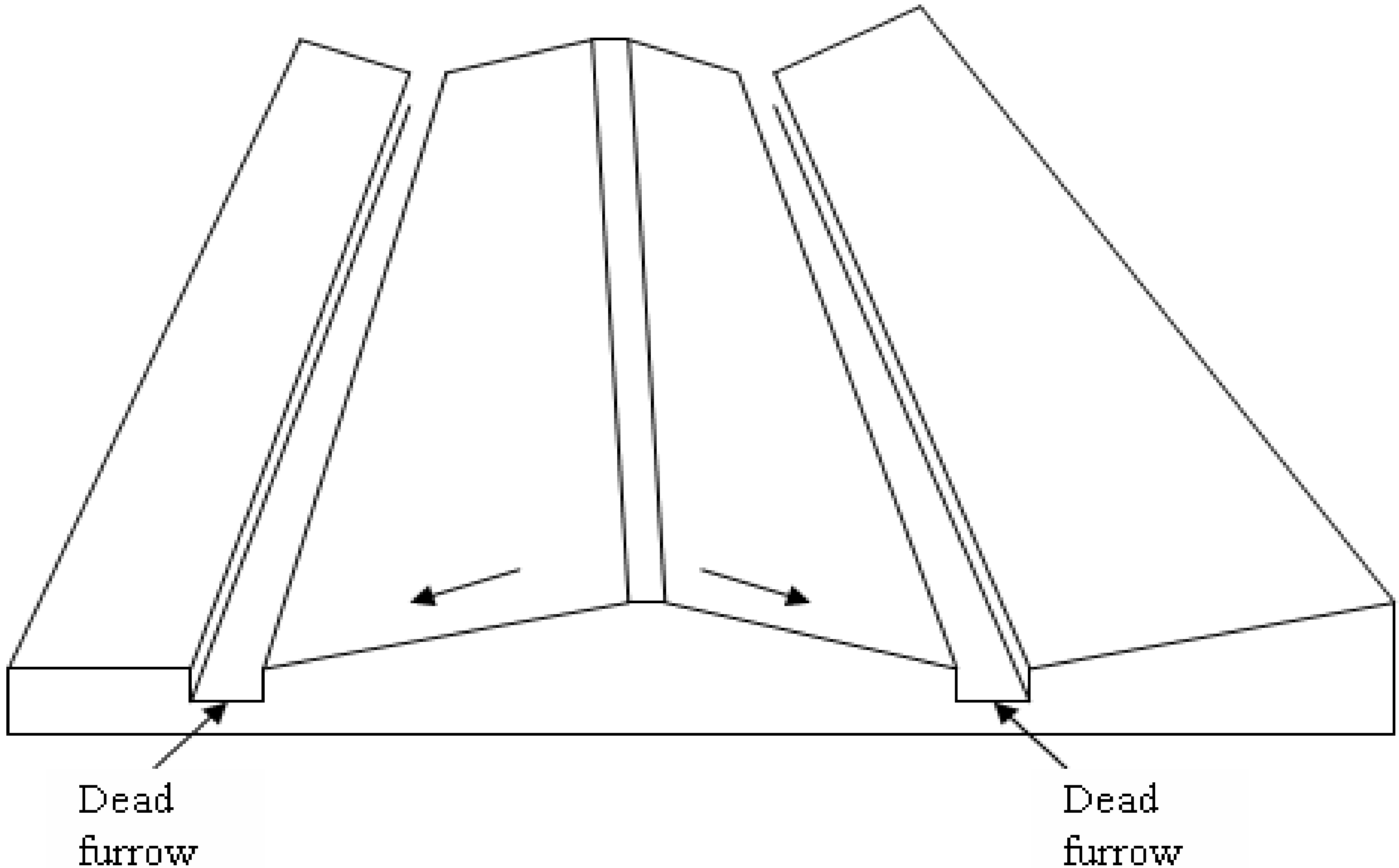

Bedding system

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- The bed width depends upon the land use, 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

Cont…

- Some disadvantages of bedding system:
  - The system is not satisfactory if the crops are grown parallel to the furrows and on the ridges. E.g row crops
  - The furrows require regular maintenance.
  - Due to movement of top soil from the sides of the bed to the middle, some reduction in yields nearer the dead furrows could occur
  - The slope of the furrows may not be enough for drainage, resulting in ponded areas.
  - System restricts mechanized farming

Cont…

ii. Random drain system –

- Used where small scattered depressions to be drained occur over the area.
- Often these depressions are large but shallow, and a complete land-forming operation is not considered as economically feasible.
- The depression are connected by means of a field drain and evacuates the stagnant water into a field lateral or conveyed to an outlet.
- The field drains are made shallow not to interfere in farming operations.
- The system is often applied in situation where farm operations are limited, for example on pasture land or farm operation is by means of small equipment.

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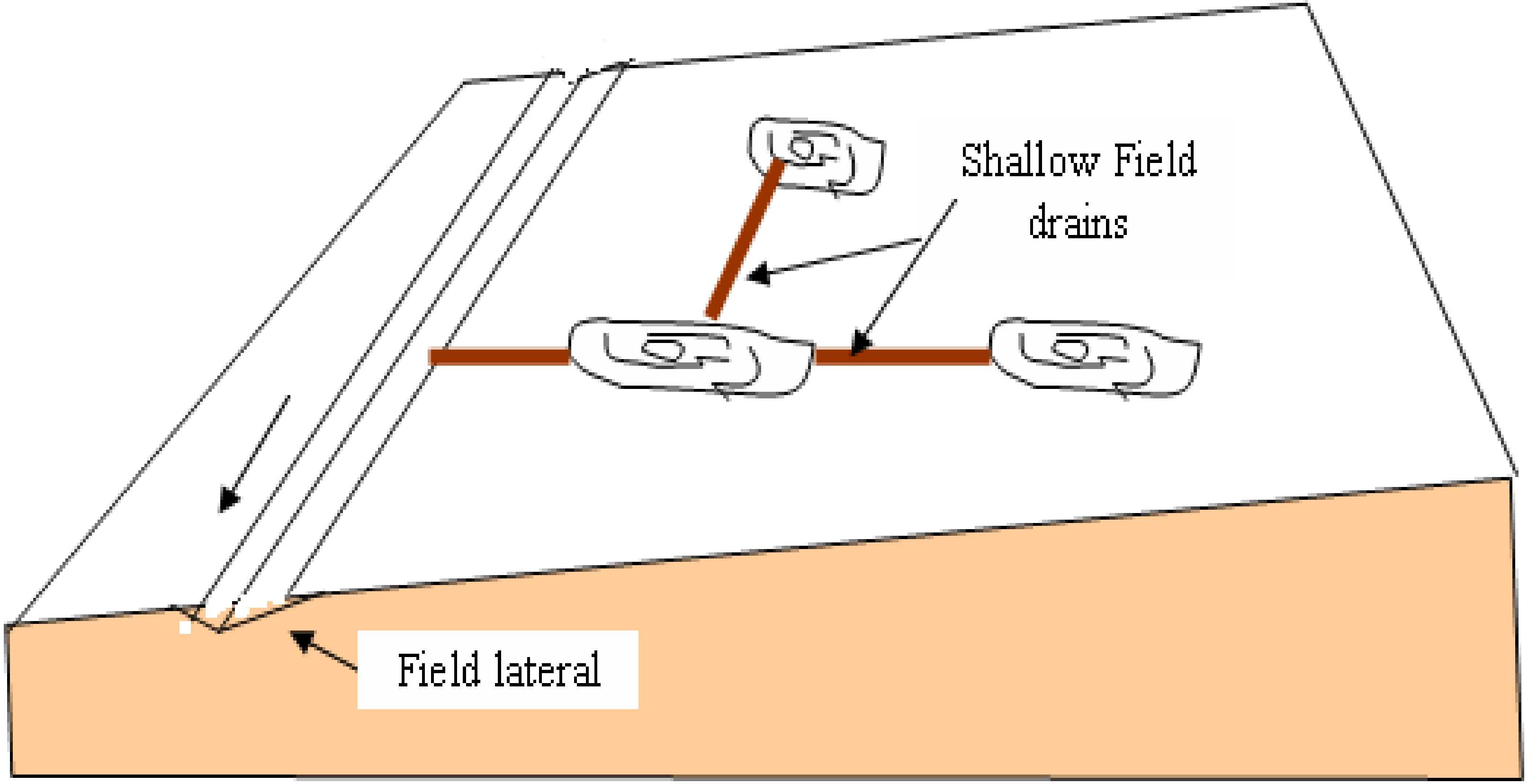
Land smoothing operations to remove the minor humps and depression is the first step for efficient surface drainage.



Random field drainage system

Cont…

iii. Parallel drain system/ field ditch system

- The most effective method of surface drainage and is well suited both for irrigated and rain-fed areas
- The system is applicable in flat areas with an irregular micro-topography and where farm operations require regular shaped fields.
- In this system, individual fields are properly graded such that they discharge into field drains.
- The parallel ,but not necessarily equidistant, field drains collect the surface runoff and discharge it into the field lateral, through which the water flows towards the main drainage system.
- Laterals and mains should be deeper than field ditches to provide free outfall.

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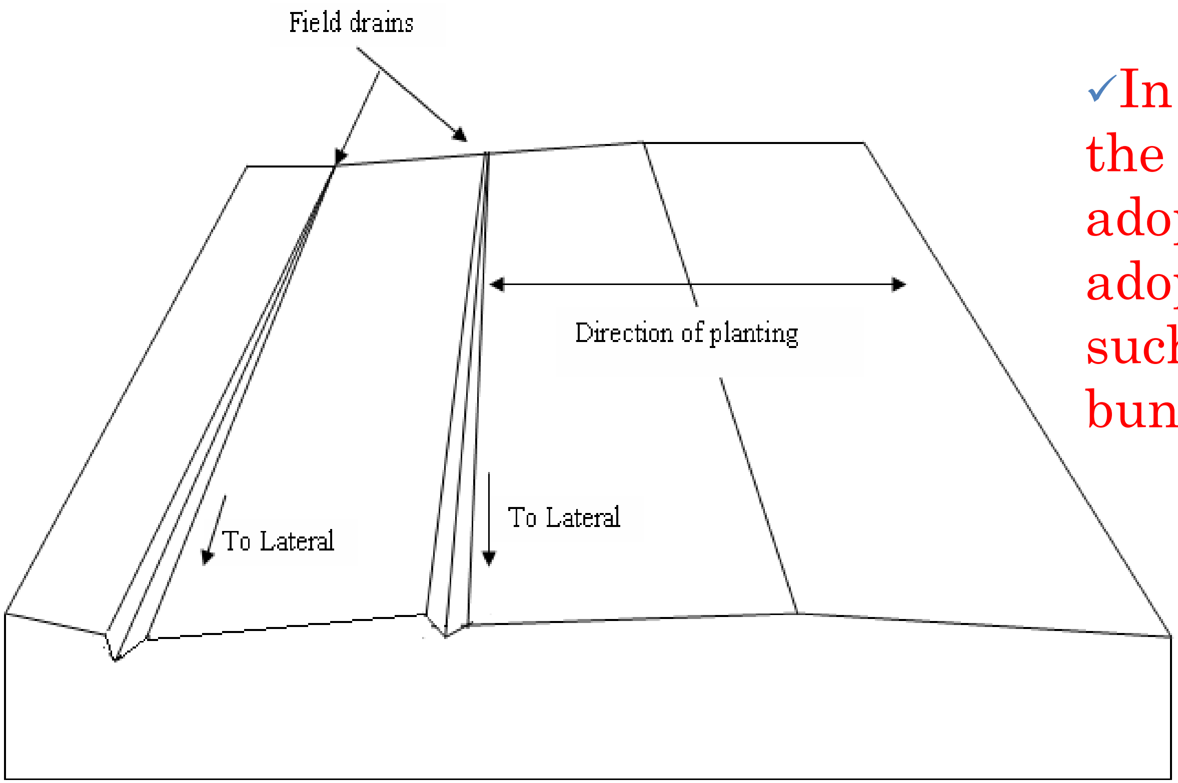
- The spacing of the field drains depends on
  - The size of lands that can be prepared
  - The water tolerance of crops
  - The amount and cost of land forming



✓In sloping areas (>2% slope), the surface drainage system adopted is the same as those adopted for erosion control such as construction of graded bunding

Parallel field drainage system

Surface drains – Design considerations

Runoff from Field → Field drains → Field laterals → Drainage Outlet

Field drains-are shallow and have flat side slopes (3:1 or flatter)

- They allow farm equipment to cross them and are easy to maintain with ordinary mowers.
- They are often V-shaped and their dimensions are determined by the construction equipment, maintenance needs, and cross ability for farm equipment.
- Larger field drains (which collect runoff in both direction) could have trapezoidal shape.

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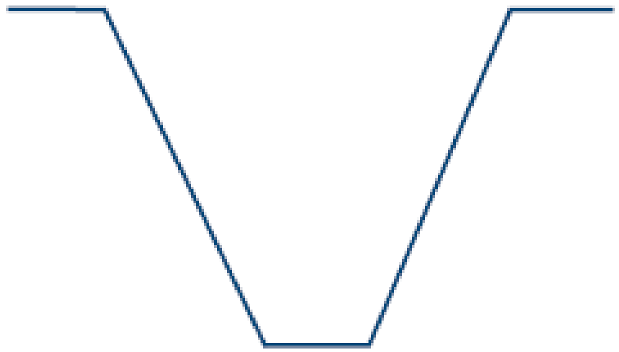
Passable

V-shaped

Impassable



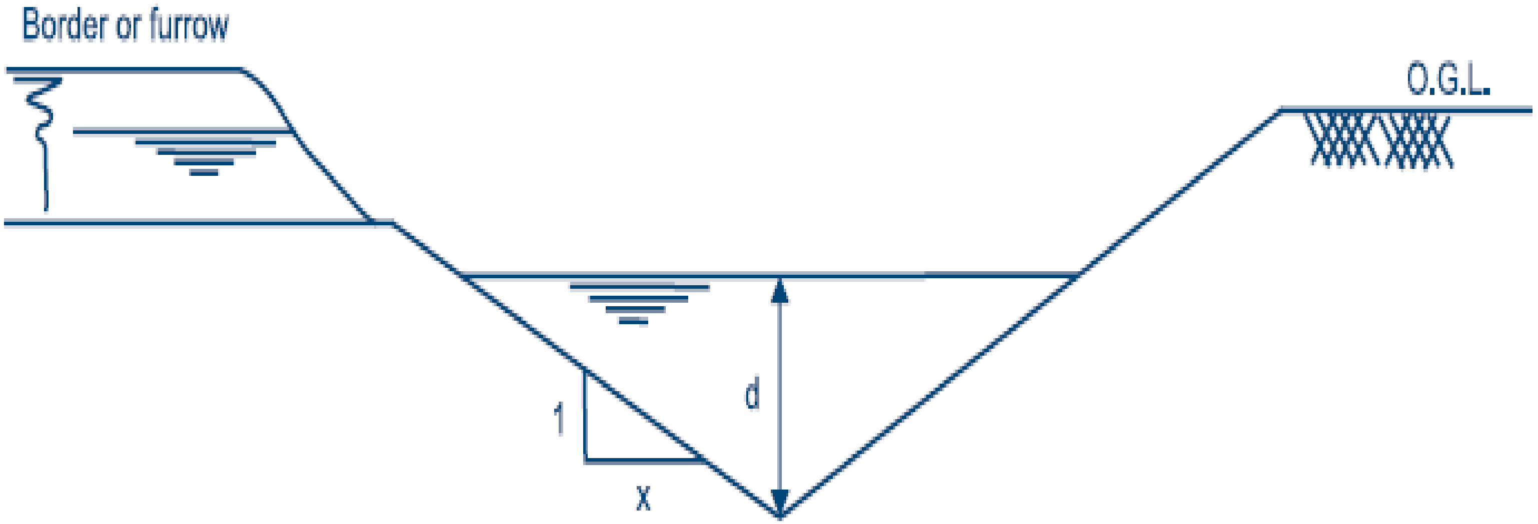
Trapezoidal

- Field laterals and higher orders 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.

Cont…

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



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- The design of drain dimensions should be based on a peak discharge.
  - It is usually impractical, in developing countries, to attempt to provide drainage for the maximum rainfall that would likely occur within the lifetime of a scheme.
  - It is also not necessary for the drains to instantly clear the peak runoff from the selected rainfall because almost all plants can tolerate some degree of water logging for a short period.
  - Therefore, drains must be designed to remove the total volume of runoff within a certain period.

Cont…

- If, for example, 12 mm of water (= 120 m^3/ha) is to be drained in 24hours, the design steady drainage flow of approximately 1.4 lit/sec per ha (= $(120 \times 10^3)/(24 \times 60 \times 60)$) should be employed in the design of the drain.

- If rainfall data are available, the design drainage flow, also called the drainage coefficient, can be calculated more precisely for a particular area.

Cont…

- The following method is usually followed for flat lands.
  - The starting point is a rainfall-duration curve.
  - This curve is made up of data that are generally available from meteorological stations.
  - The curve connects, for a certain frequency or return period, the rainfall with the period of successive days in which that rain is falling.

  - Often a return period of 5 years is assumed in the calculation.
  - It describes the rain which falls in X successive days as being exceeded once every 5 years.

  - For design purposes involving agricultural surface drainage systems X is often chosen to be 5 days.

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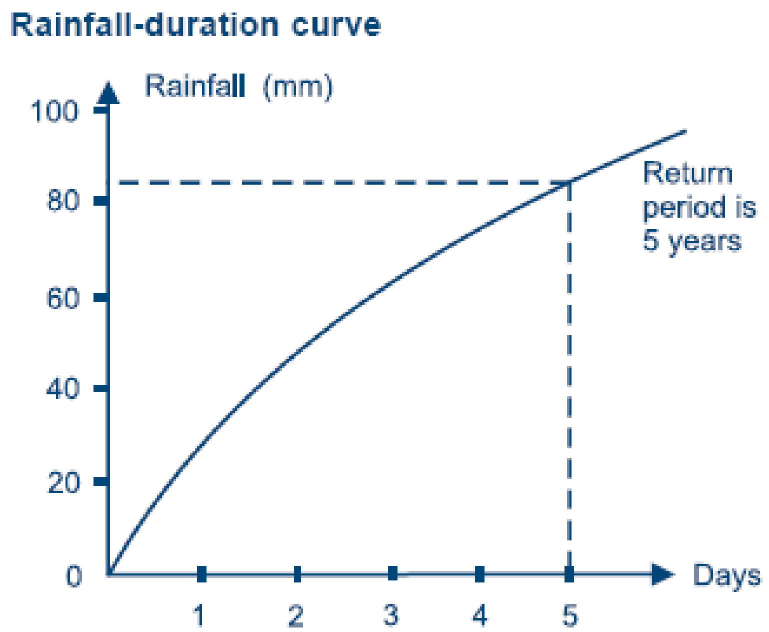
- Example:



- From the figure,
  - the rainfall falling in 5 days is 85mm.
  - this equals a drainage flow (coefficient) of:

    = $(85 \times 10^4)/(5 \times 24 \times 60 \times 60)$).

    = 1.97 l/sec per ha

Cont…

- Then, the design discharge can be calculated, using the equation:

  $$Q = (q \times A)/1000$$

  Where:

  Q = Design discharge (m3/sec)

  q = Drainage flow (coefficient) (l/sec per ha)

  A = Drainage area (ha)

- It would seem contradictory to take 5 days rainfall, when the short duration storms are usually much more intensive.
- However, this high intensity rainfall usually falls on a restricted area, while the 5 days rainfall is assumed to fall on the whole drainage area under consideration.
- It appears from practice that a drain designed for a 5 days rainfall is, in general, also suited to cope with the discharge from a short duration storm.

Cont…

- But this is not necessarily true in small irrigation schemes, especially on sloping lands (with slopes exceeding 0.5%), which may cover an area that could entirely be affected by an intense short duration rainfall.
- The design discharge could then be calculated with empirical formulas:
  - The rational formula
  - The curve number method
- The rational formula is the easier of the two and generally gives satisfactory results, and is also widely used.
- The formula reads:

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

Where:

  - Q = Design discharge (m^3/sec)
  - C = Runoff coefficient
  - I = Mean rainfall intensity over a period equal to the time of concentration (mm/hr)
  - A = Drainage area (ha)

Cont…

- The time of concentration, Tc --- defined as the time interval between the beginning of the rain and the moment when the whole area above the point of the outlet contributes to the runoff.

- The time of concentration can be estimated by the formula:

  $Tc = 0.0195\ K^{0.77}$

  Where:
  - Tc = Time of concentration (minutes)
  - $K = (L/\sqrt{S})$ and $S = H/L$
  - L = Maximum length of drain (m)
  - H = Difference in elevation over drain length (m)

Cont…

- Example 1: An irrigation scheme of 100ha arable land 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:

$S = H/L = 10/2500 = 0.004$ or0.4%

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

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

Cont…

- The runoff coefficient, C --- represents the ratio of runoff volume to rainfall volume. Its value is directly dependent on the infiltration characteristics of the soil, slope and land use.

	Slope (%)	Sandy loam	Clay silty loam	Clay
Forest	0-5	0.10	0.30	0.40
	5-10	0.25	0.35	0.50
	10-30	0.30	0.50	0.60
Pastures	0-5	0.10	0.30	0.40
	5-10	0.15	0.35	0.55
	10-30	0.20	0.40	0.60
Arable land	0-5	0.30	0.50	0.60
	5-10	0.40	0.60	0.70
	10-30	0.50	0.70	0.80

- The rainfall intensity, I --- can be obtained from a rainfall amount whose duration at least equal to the time of concentration.

Cont…

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

Cont…

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

$$V = \frac{1}{n} R^{2/3} S^{1/2}$$

– For full pipe flow, R can be replaced by the diameter D/4.
– Area A= $\pi D^2/4$ and perimeter P= πD, R=D/4,. Then the diameter can be determined from:

Cont…

$$D = 4 * \left(\frac{nV}{S^{1/2}}\right)^{3/2}$$

The *Chezy* equation is rewritten as $V = C\sqrt{RS_f}$

S*f* = *hf/L*, hf is the head loss and L is the length of channel/pipe

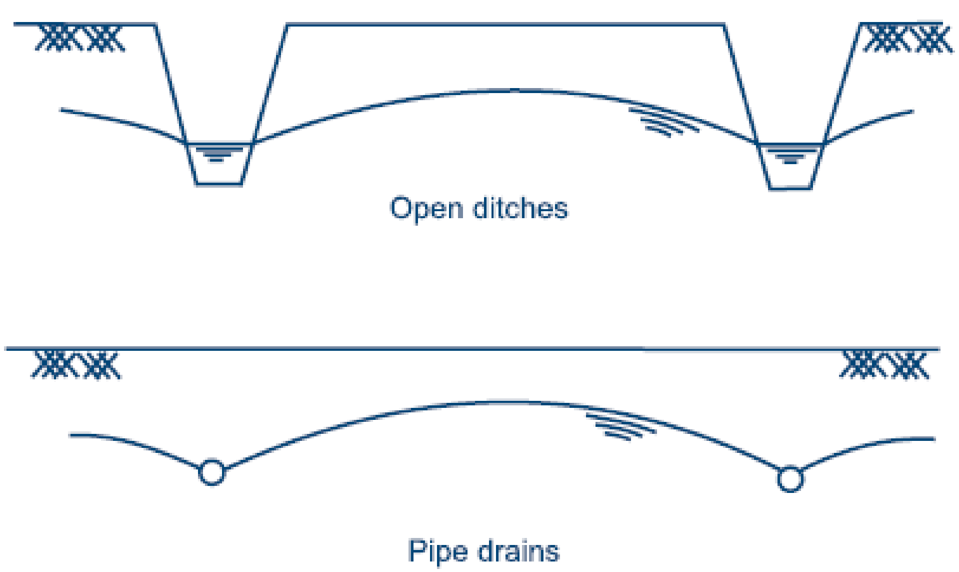
✓Which is *Chezy's equation* for open channel flow.

Note:

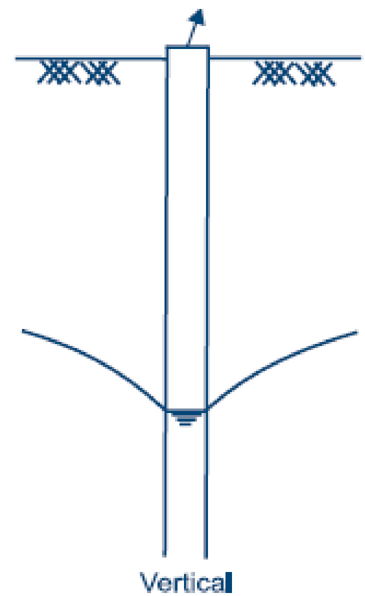
Higher order canal design should not only depend on the design discharge, but also on the need to collect water from all lower order drains. Therefore, the outlets of the minor drains should preferably be above the design water level of the collecting channel.

4.4.2 Subsurface drainage System:

- Subsurface drainage systems are used when the drainage problem is mainly that of shallow water tables.
- Subsurface drainage is thus used to control the level of groundwater so that 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

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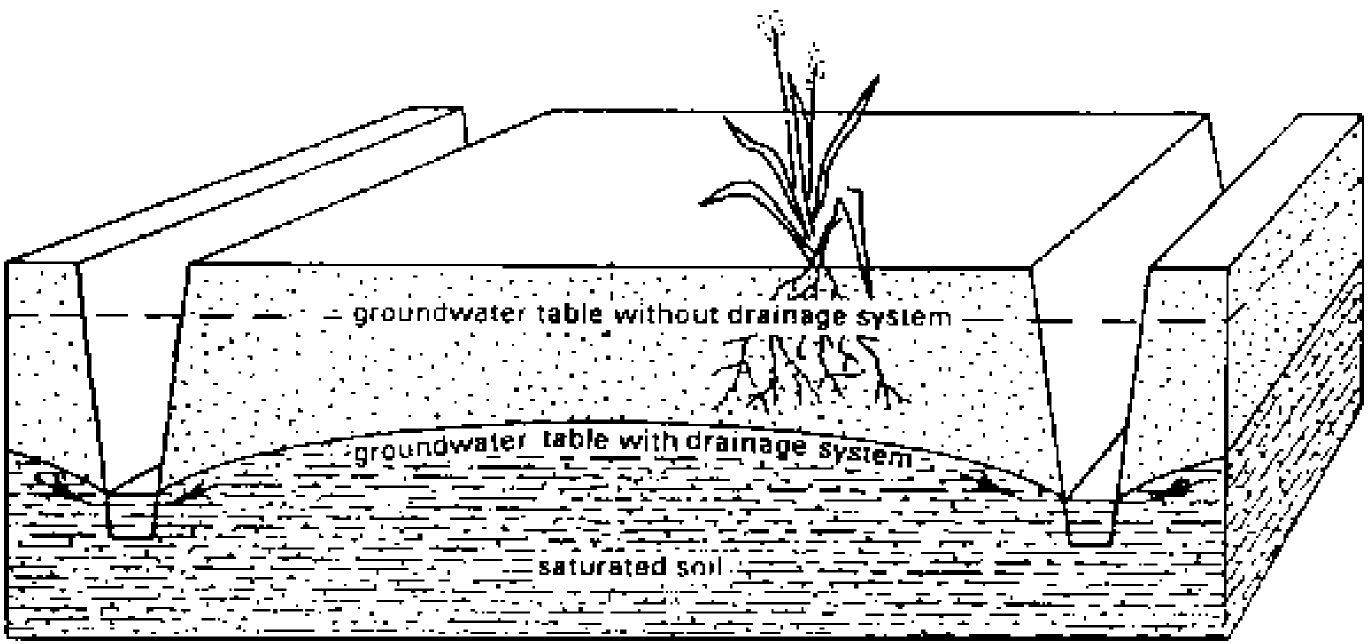
i) Deep open drains

- 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 because of the resulting small plots, especially where mechanized equipment has to be used.



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ii. Pipe drains

- Instead of open drains, water table control is usually done using field pipe drains.
- Pipe drains are buried pipes with openings through which the soil water can enter.
- The pipes convey the water to a collector drain, which is usually an open ditch.
- The materials used for pipe drains are ***clay pipes, concrete pipes and Plastic pipes (uPVC, PE)***
  - In clay and concrete pipes(usually 30cm long and 5-10cm in diameter), drainage water enters the pipes through the joints.

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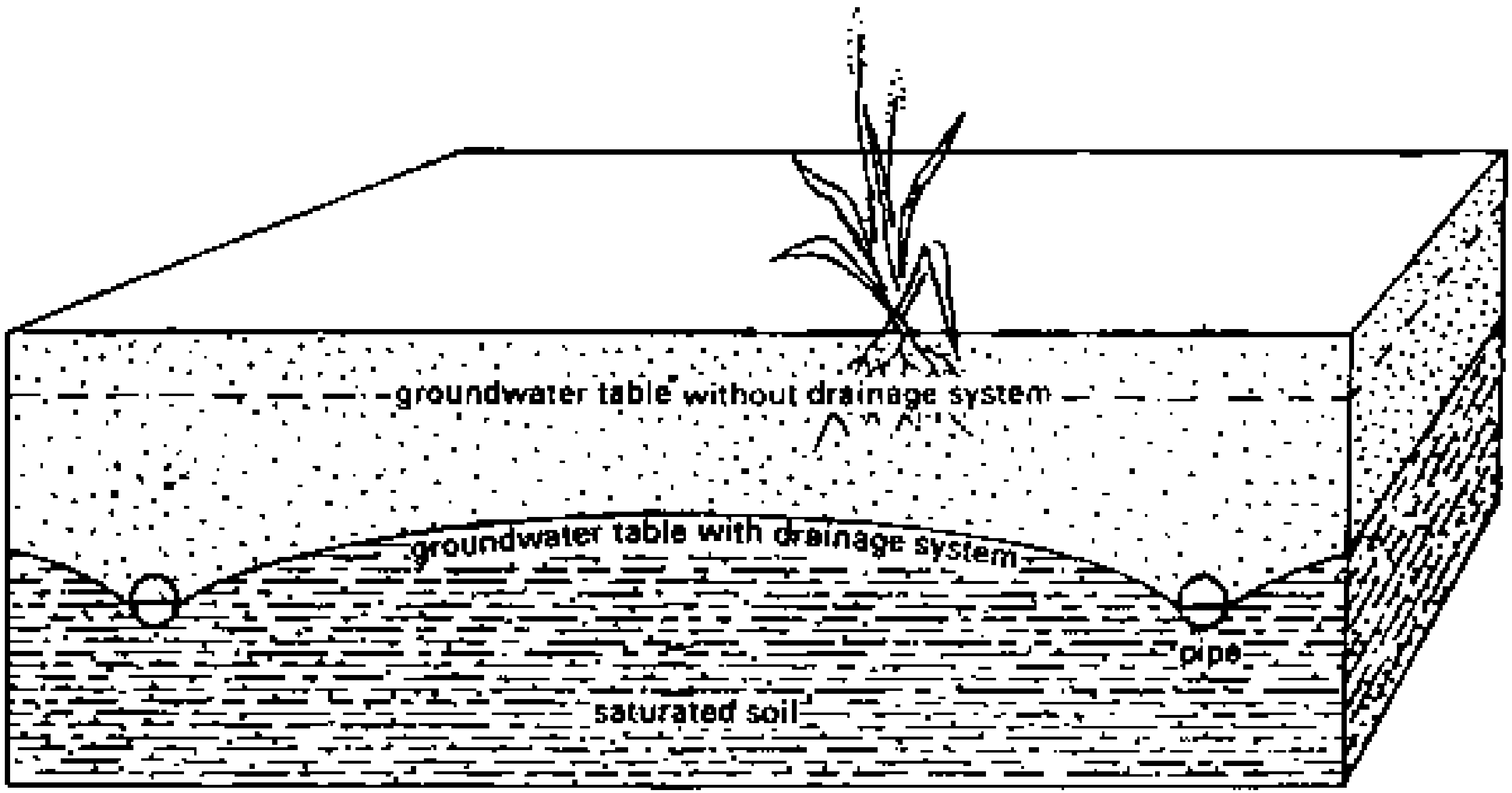
- Flexible plastic pipes are much longer (up to 200m) and the water enters through perforations distributed over the entire length of pipe.



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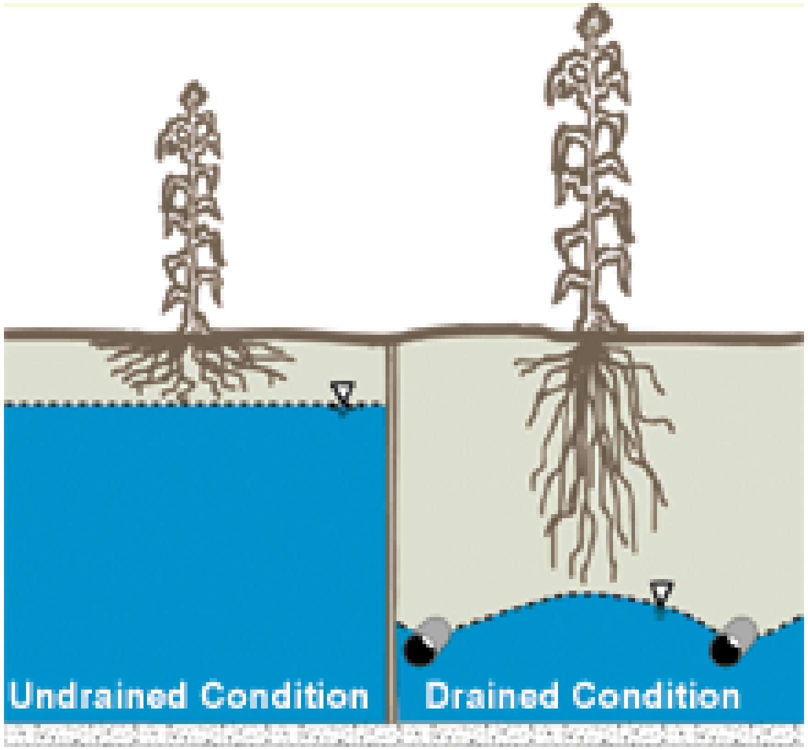

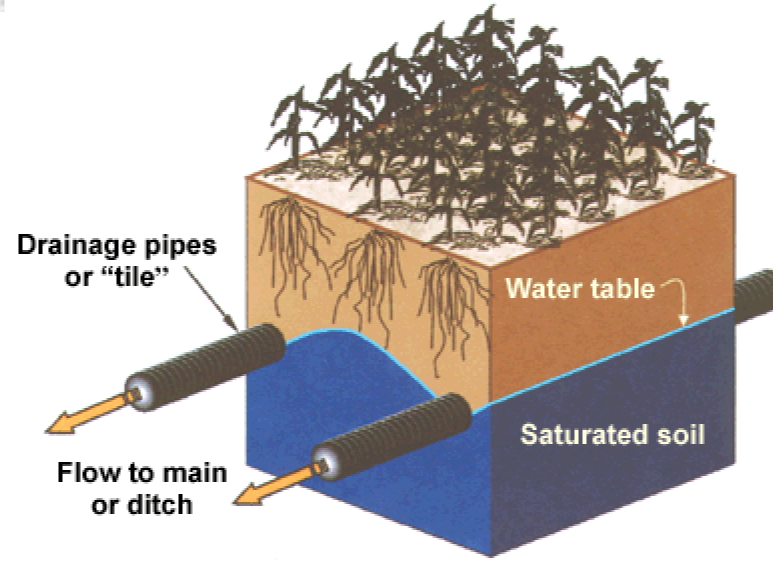

Drain tile outlet to a drainage ditch

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- 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

Types of Subsurface drainage System:

Open drains-*CURRR*

1. *Can receive surface runoff directly*
2. *Use land that otherwise could be used for crops.*
3. *Restrict the use of machines*
4. *Require a large number of bridges and culverts for road crossings and access to the fields*
5. *Require frequent maintenance (weed control, repairs, etc.).*

Pipe drains-*CNNMI*

- *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.*

Subsurface Drainage – Design considerations

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:**

$$S^2 = \frac{\left(4k_1h^2\right) + \left(8k_2dh\right)}{q}$$

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)

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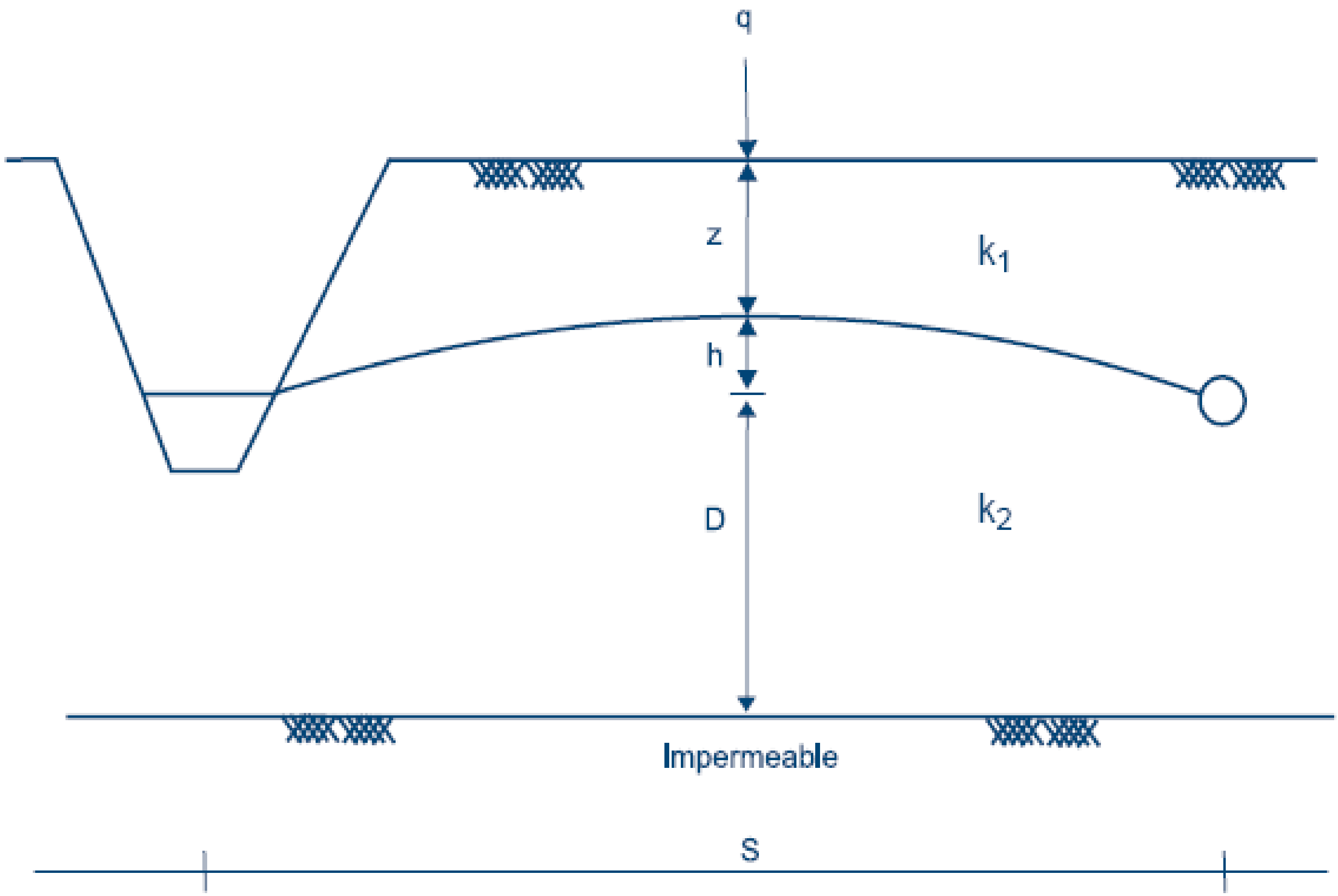

Subsurface drainage parameters

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- *In reality, the head losses due to horizontal and radial flow to the pipe should be considered, which would result in complex equations.*
- *To simplify the equation, a reduced depth (d) was introduced to treat the horizontal/radial flow to drains as being equivalent to flow to a ditch with the impermeable base at a reduced depth, equivalent to d.*
- *The equivalent flow is essentially horizontal and can be described using the Hooghoudt formula.*
- The equivalent depth, d is found by the equation:

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

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

Cont…

- *Since d is a function of the unknown drain spacing, S, the calculation requires several trials to come to the solution*
- Example 1: A drain pipe of 10cm diameter should be placed at a depth of 1.80m below the ground surface. Irrigation water is applied once every 7 days. The irrigation water losses, recharging the already high groundwater table, amount to 14mm per 7 days and have to be drained away. An average water table depth, z of 1.20 m below the ground surface has to be maintained. k1 and k2 are both 0.8m/day (uniform soil). The depth to the impermeable layer D is 5 m. What should be the drain spacing?

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Solution:

- $q = 14/7 = 2$ mm/day or 0.002 m/day and $h = 1.80 - 1.20 = 0.60$ m
- The calculation started by initially assuming the drain spacing.
- After determining d, the assumed S should be checked with the calculated S from the Hooghoudt Equation.
- Let us assume S = 90 m.
  - Thus, D/S = 5/90 = 0.056, substituting in the equation, d = 3.42.
  - Substitution of all known parameters in the Hooghoudt Formula gives:

$$S^2 = \frac{\left(4k_1h^2\right)+\left(8k_2dh\right)}{q} = \frac{\left(4\times 0.8\times 0.6^2\right)+\left(8\times 0.8\times 3.42\times 0.6\right)}{0.002}$$

• Thus, S = 84.5m, which means that the assumed drain spacing of 90 m is different from calculated.

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- Assume now 84.5m and find d, then S until they will acceptably be equal. Now, new d=3.35 and then new S=83.7.
- With further Assumption of S=83.7, d=3.34, S=83.6m

- Drainage coefficient, q – the rate at which the water is removed by a drain which is usually expressed in m/day (depth of water to be removed in 24hrs).
  - It is a function of the rainfall/irrigation, type of soil, type of crop, etc.
  - In rain-fed agriculture, the recommendation is 1% of the average rainfall to be removed per day
  - In irrigated area, with no available information, the recommendation is 1 to 2.5cm/day for mineral soils and 1.25 to 10cm/day for organic soils.

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- Example: A tile drainage system draining 12ha flows at a design capacity for two days, following a storm. If the system is designed using a DC of 1.25cm/day, how many cumec of water will be removed during this period?

- Solution:
  - Volume of water entering the drain = (0.0125m/day)x ($12 \times 10^4 m^2$) = $1500 m^3$/day
  - In two days, V = 2x1500 = $3000 m^3$

THANK YOU!!!