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).

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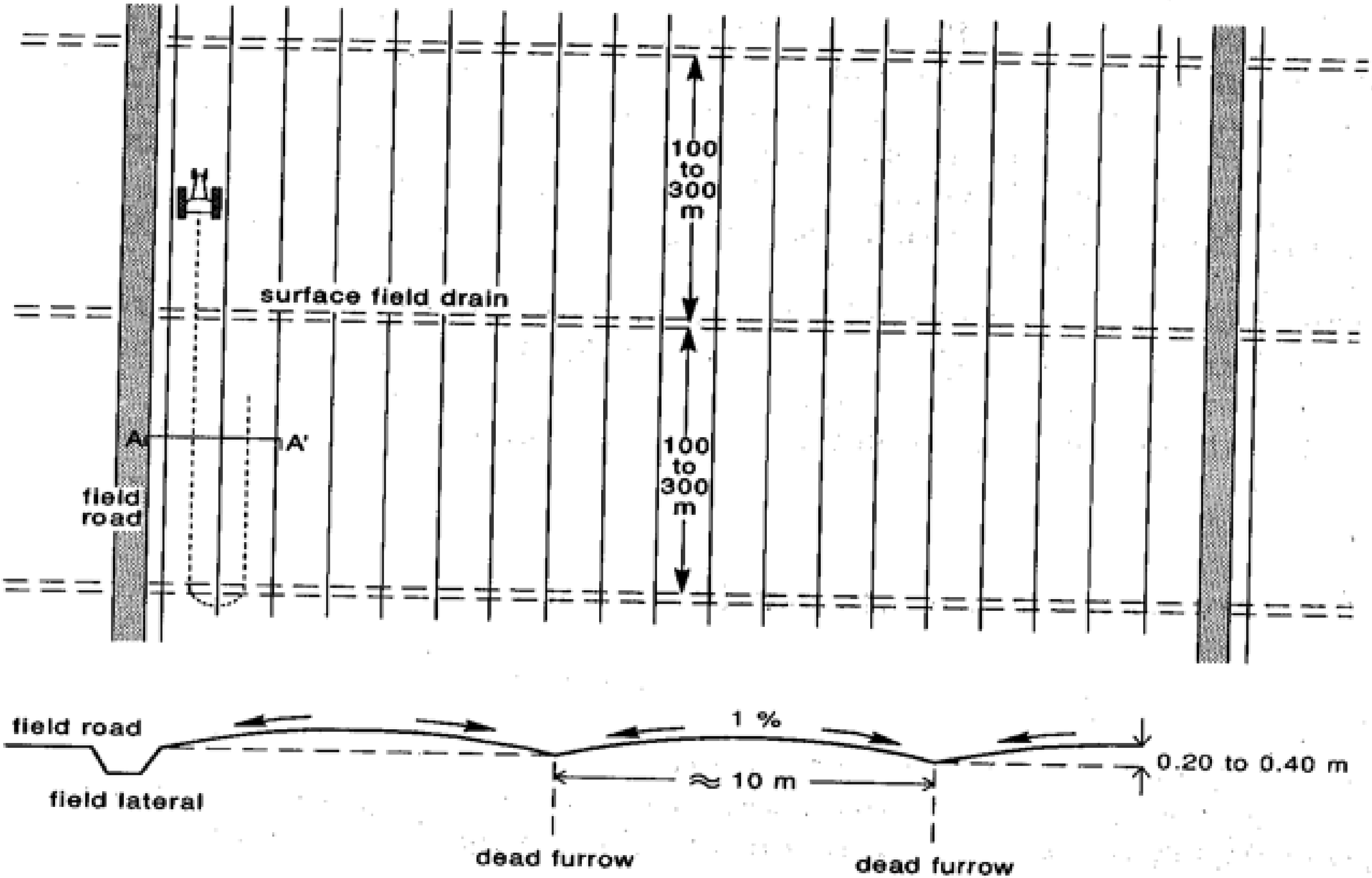
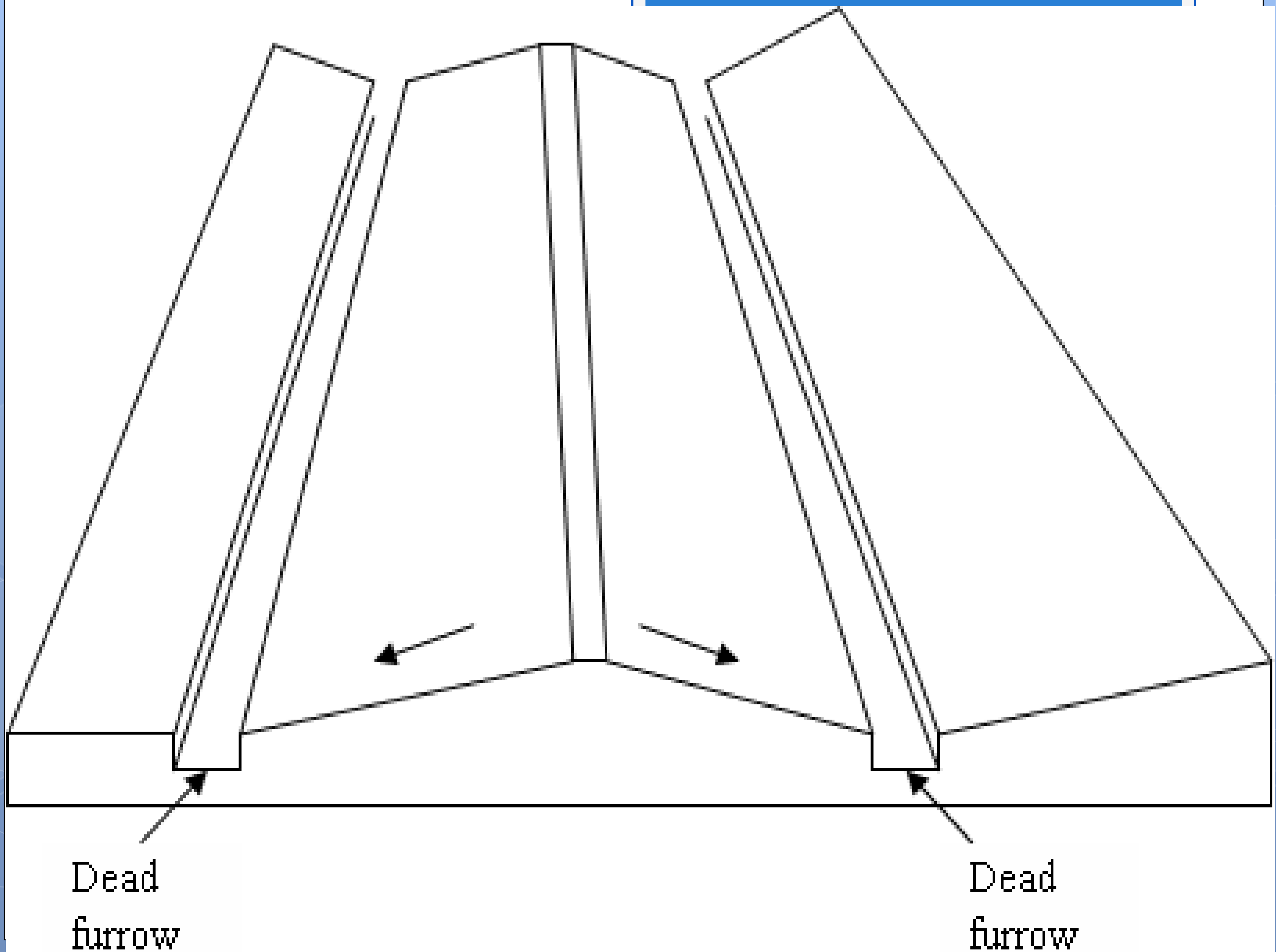


DETAIL CROSS-SECTION A - A'



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.

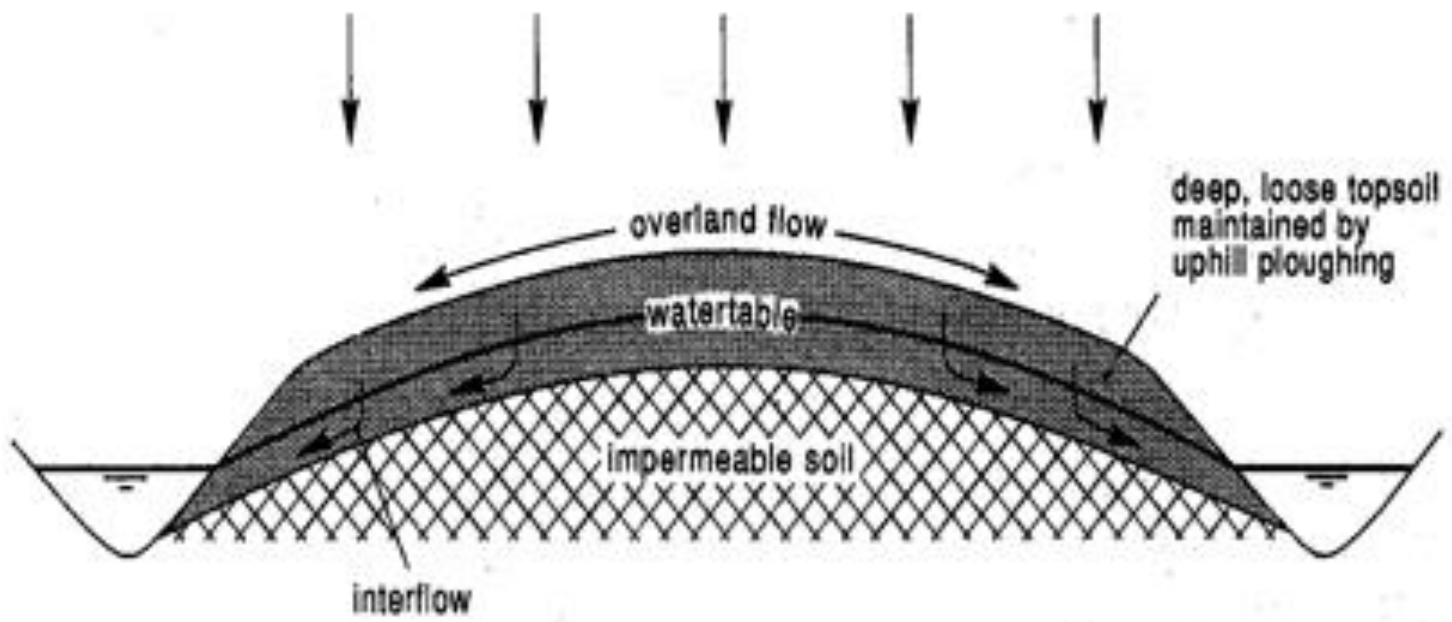


Fig: Drainage by overland flow and perched groundwater flow (interflow) in bedding system

- 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:

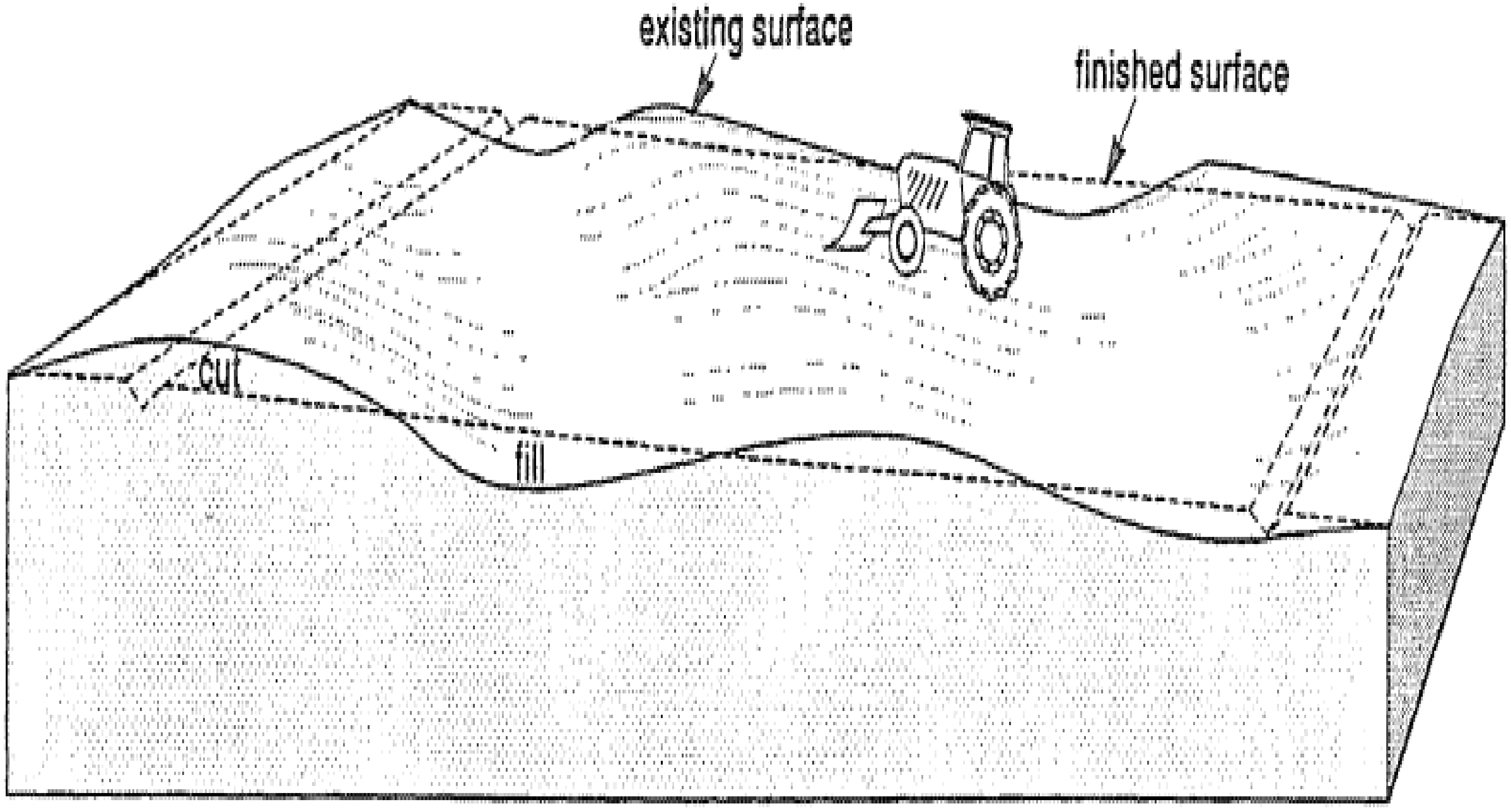
- Top soil is moved from the sides of the bed to the middle
- The system restricts mechanized farming
- The dead furrows require regular maintenance to prevent weed growth
- The slope of the dead furrows, is often insufficient resulting in ponded water.

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:

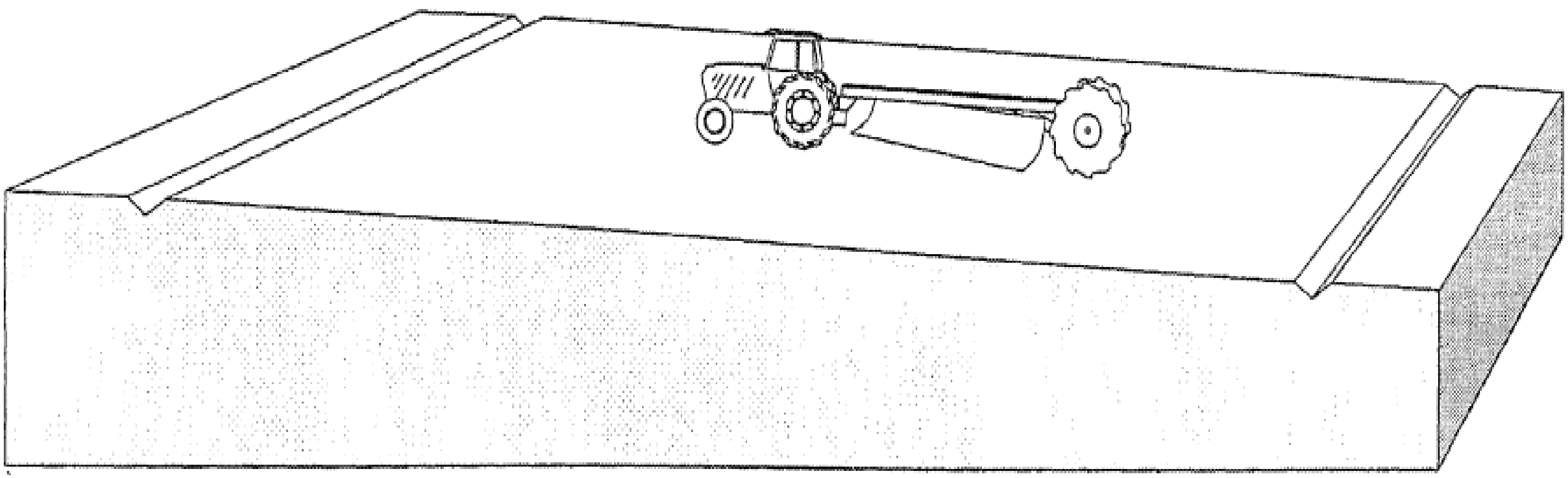
- Land grading for surface drainage consists of forming the land surface by **cutting, filling and smoothing it to predetermined grades,** so that each row or surface slopes to a field drain.



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.

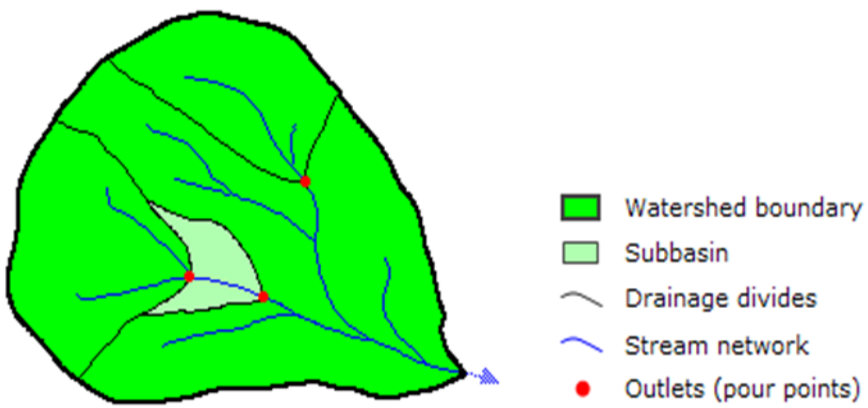


Figure :Time of concentration

- 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.

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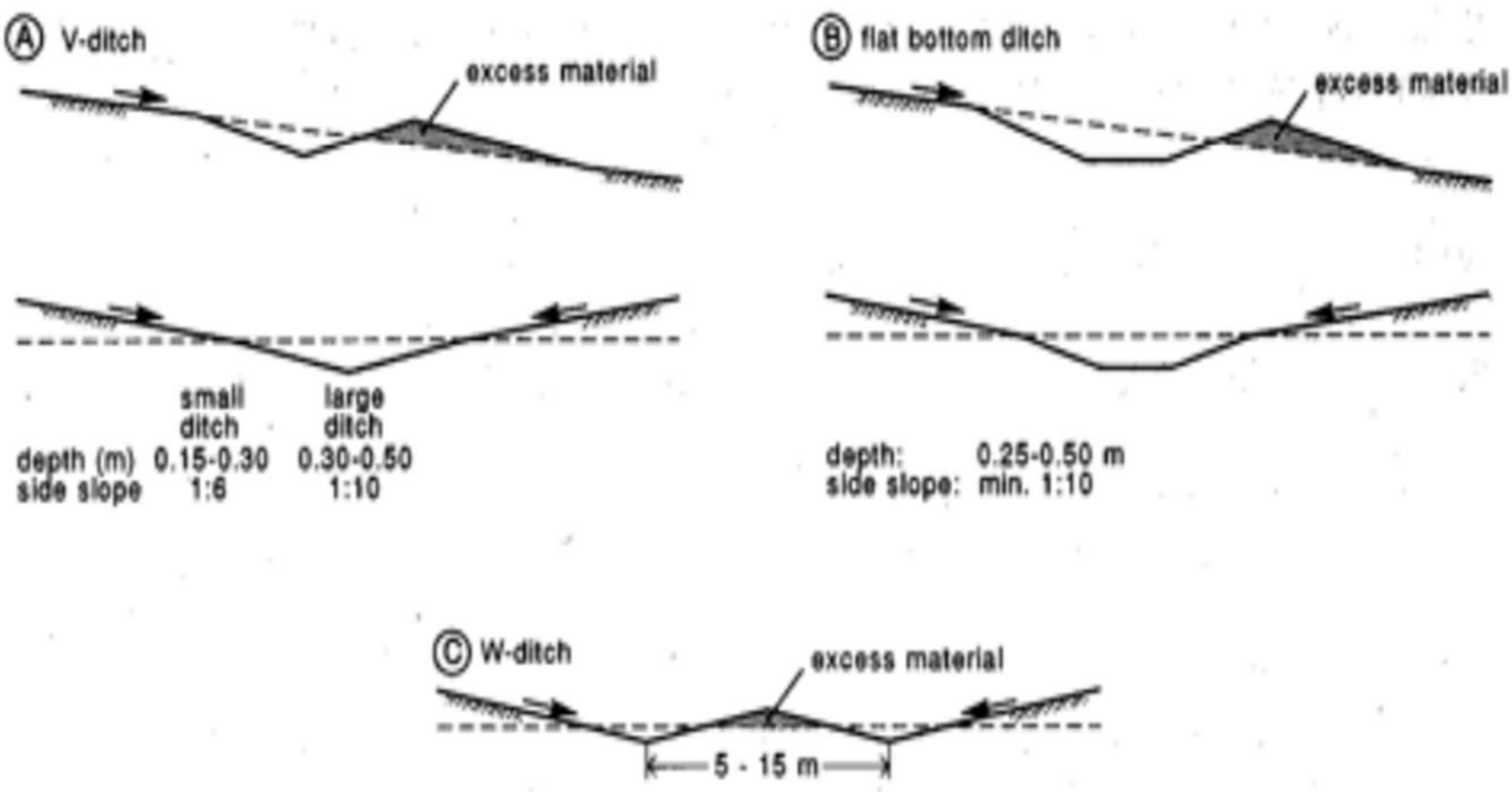
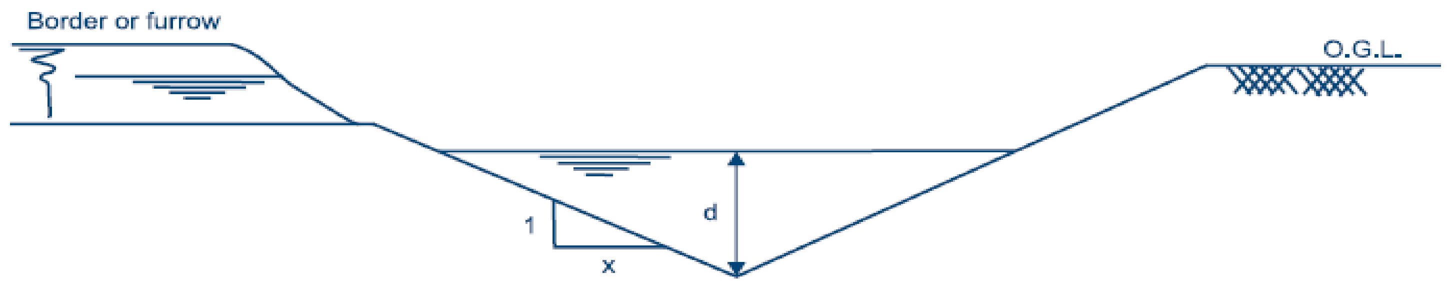


Fig: Types of passable field and collector ditches (Smedema and Rycroft, 1983)

- 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 ….).

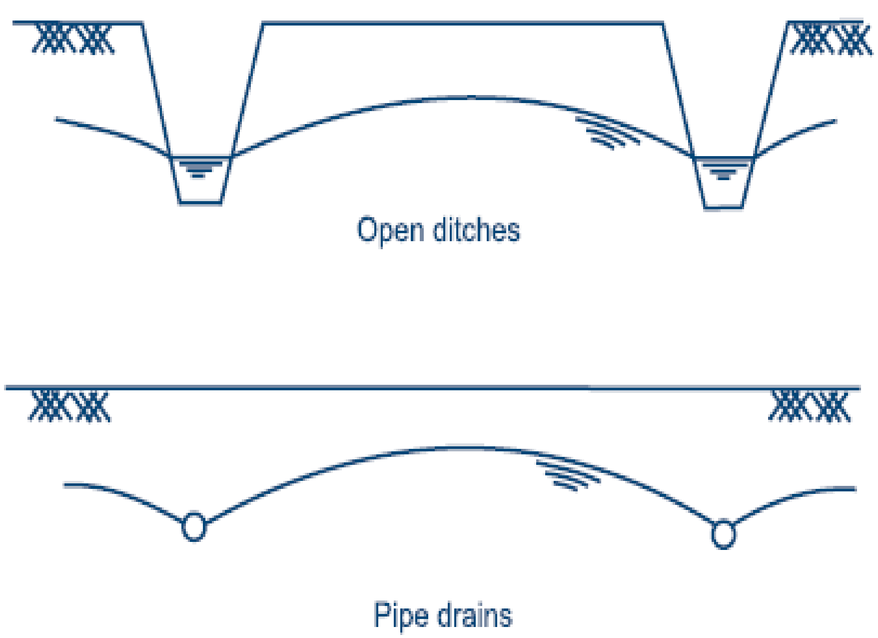
There are three main phases in implementation of pipe drainage system:

- Design
- Installation
- Operation & maintenance

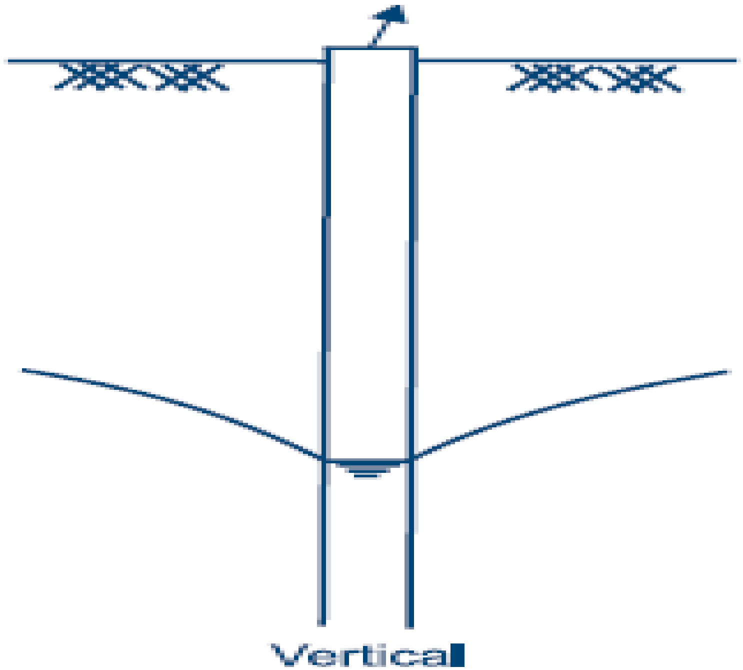
- Subsurface drainage is used to control the level of groundwater.

  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

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.).

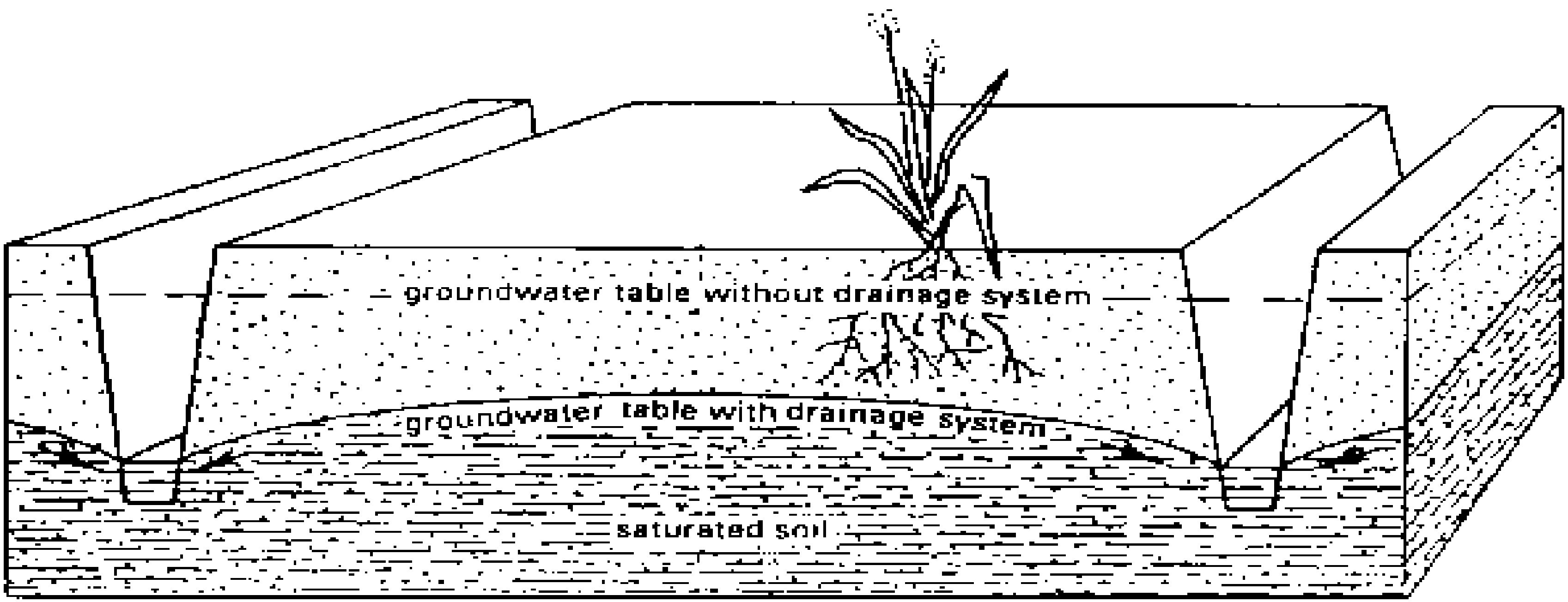
Pipe Drains

- 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

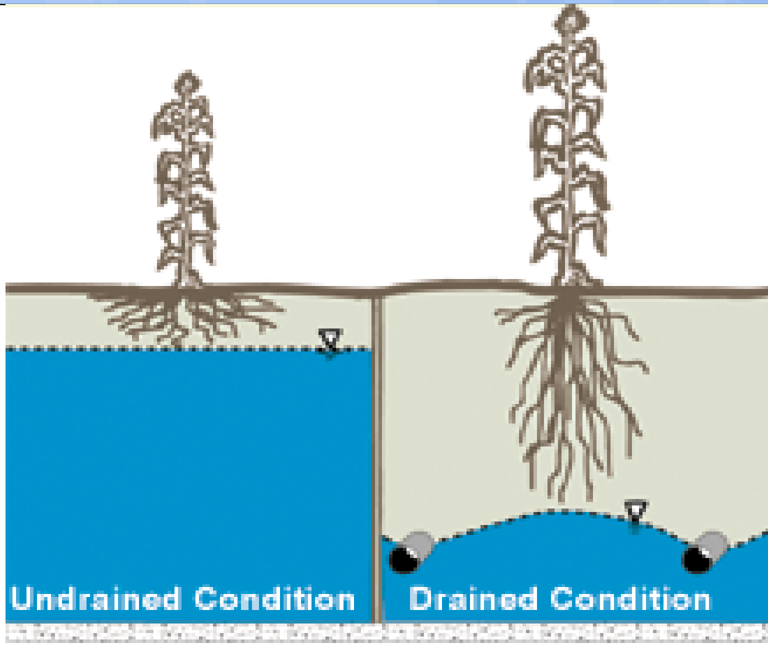
- Instead of open drains, water table control is usually done using field pipe drains.
- The materials used for pipe drain preparation are:

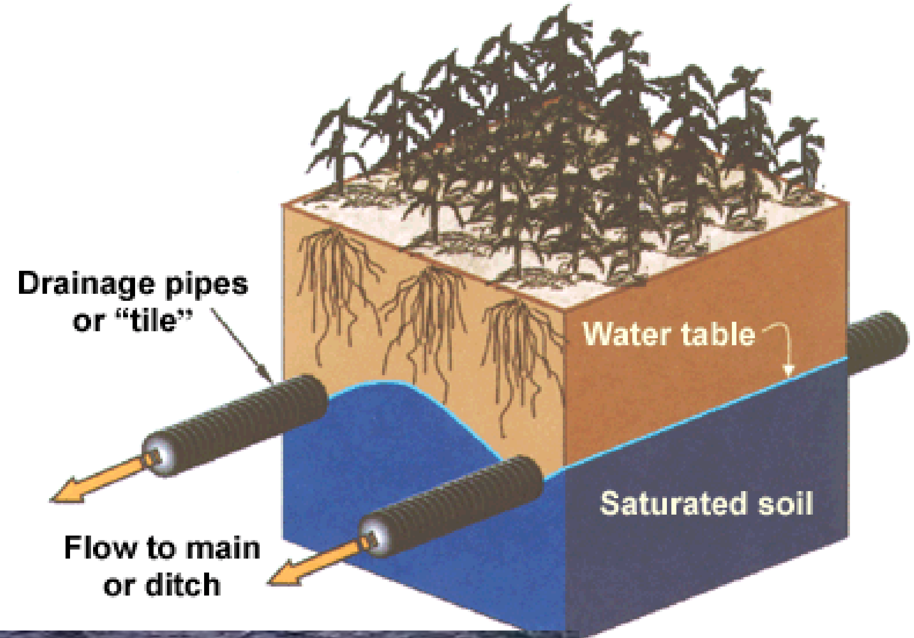
Clay pipes, concrete pipes and Plastic pipes .

- 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

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

d using Manning's equation.

('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".**

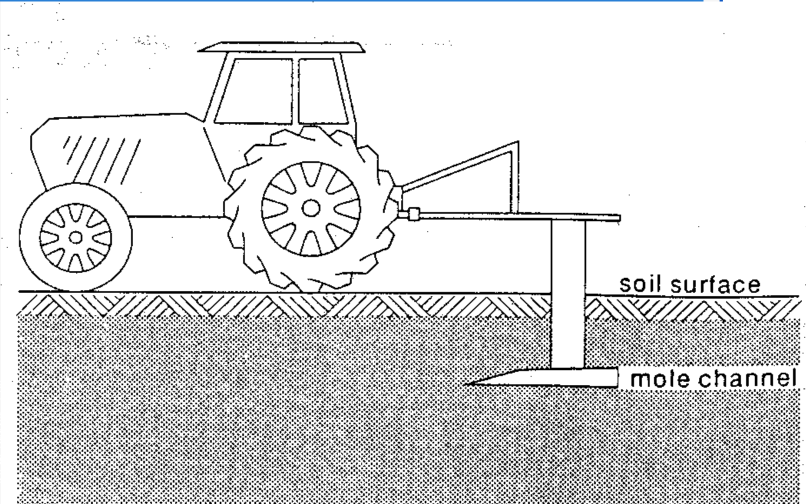
- Mole channels are susceptible to deterioration/errosion.

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.

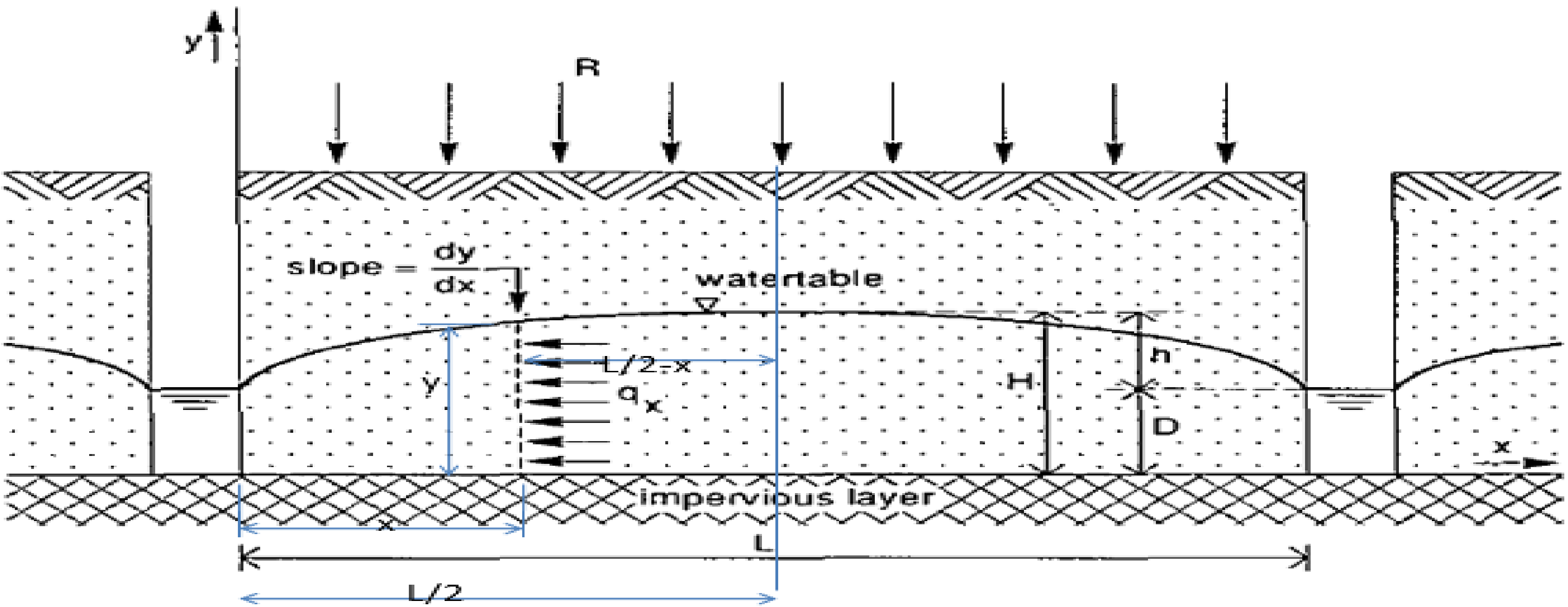
- If impervious layer does not coincide with the bottom of the drain, the flow in the vicinity of drain will be radial & **D-F** assumption can not be applied.
- **Under this condition**, **Hooghoudt** solved the problem by introducing an imaginary impervious layer to take into account the extra head 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 (½ L – x)

K y dy = R (½ 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)

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

$q = (8 K D h + 4 K h^2) / L^2$ …………………(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.

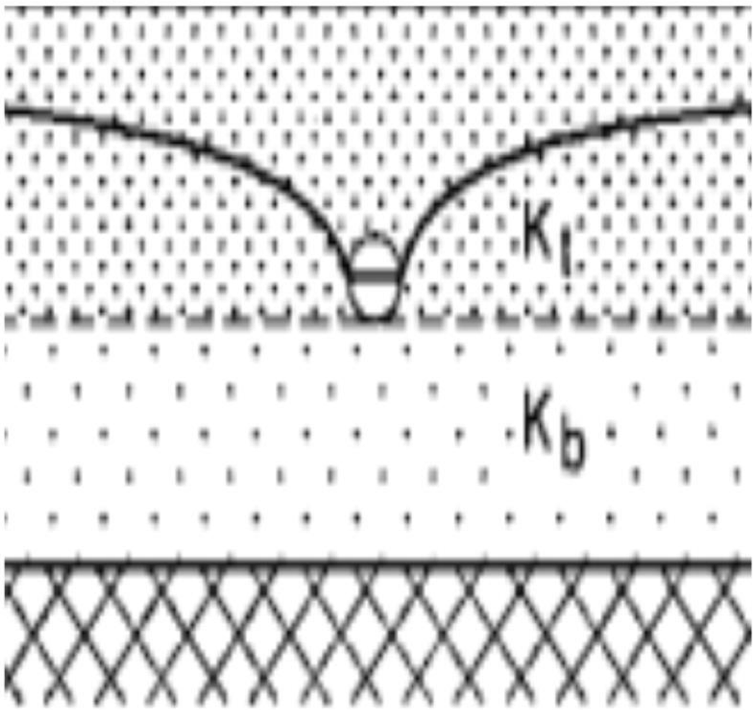
Case II: If the impervious layer is far below the drain level, i.e $D >> h$, then the second term in the equation becomes

$q = 8 K D h / L^2$ …………..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:

$$q = (8\ K_b\ D\ h + 4\ K_t\ h^2) / L^2 \quad \text{…………(4)}$$



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.

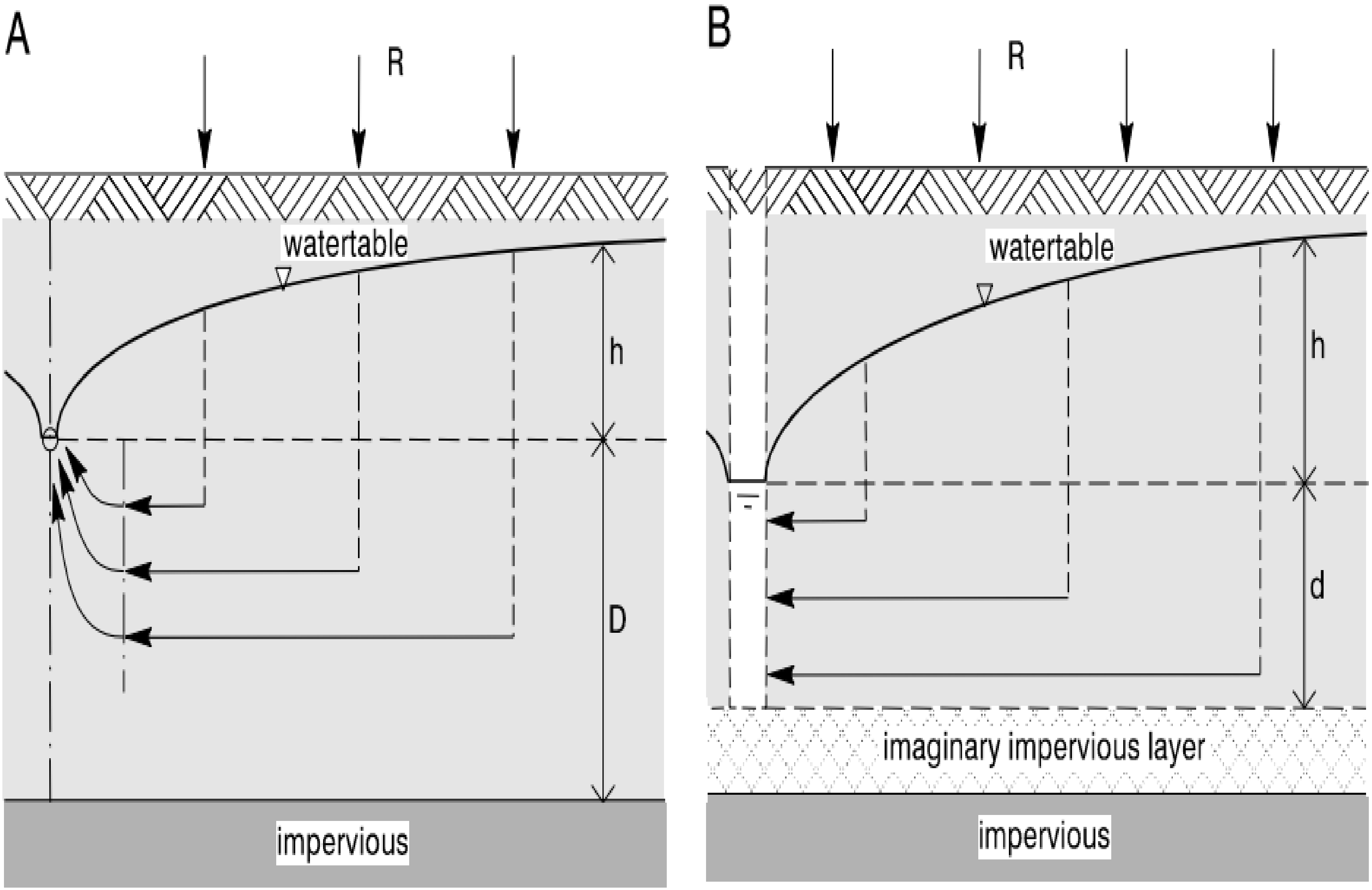
- Pipe or open drains do not reach impervious layer,
- Flow lines will converge towards drain and will thus no longer be horizontal.
- Actual depth to impervious layer (D) replaced with a smaller equivalent depth (d).
- Under these assumptions, still equation(3):

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

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.

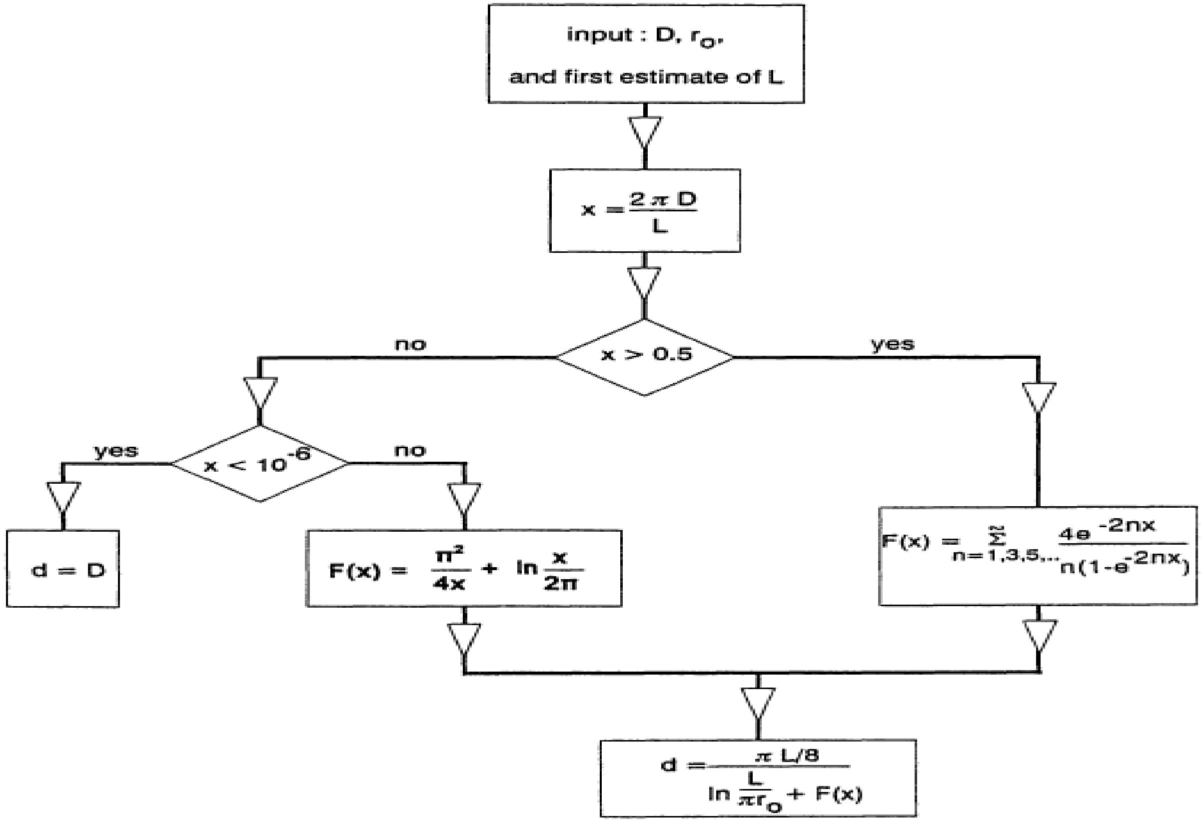
Table: Values for the equivalent depth d of Hooghoudt for r_o=**0.1** m, D and L in m (Hooghoudt 1940)

D ↓ / L →	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

D ↓ / L →	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

- 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



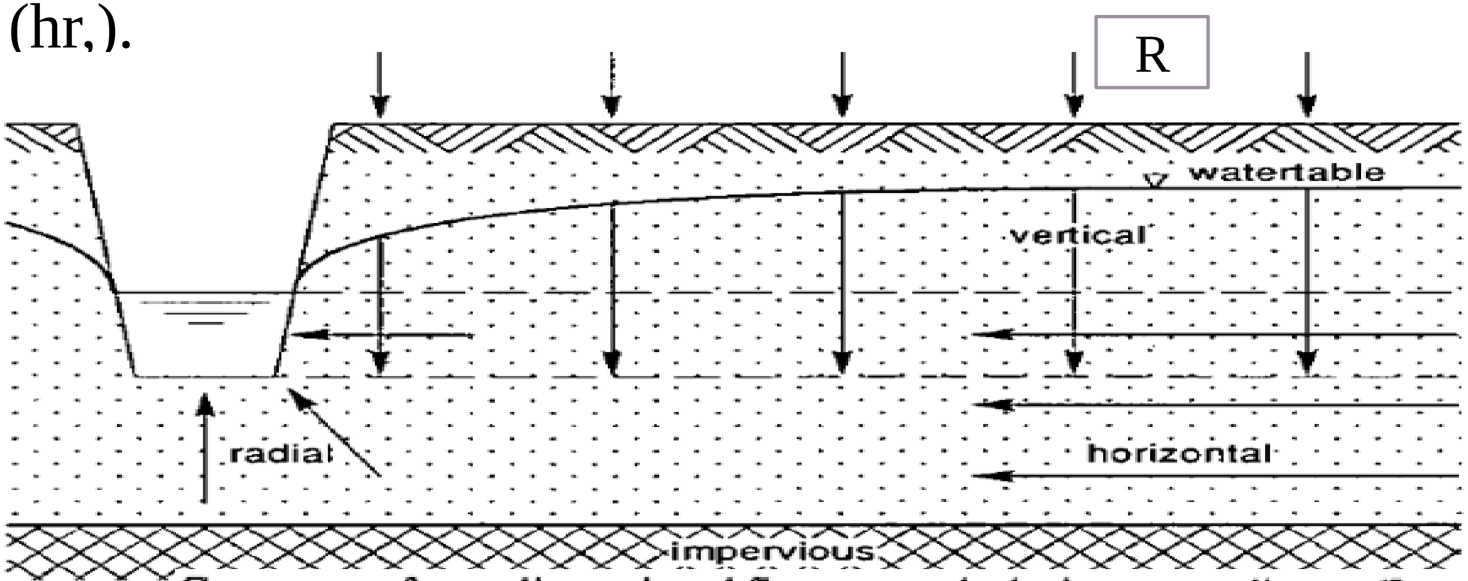
THE ERNST EQUATION

- 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.

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

$$\Rightarrow h_V = q \frac{d_v}{k_v} \ldots\ldots\ldots\ldots\ldots 5$$

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:

  $$h_h=q\ (L^2/8\sum(KD)_h)\ldots\ldots\ldots\ldots\ldots\ldots\ldots.6$$

- 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:

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

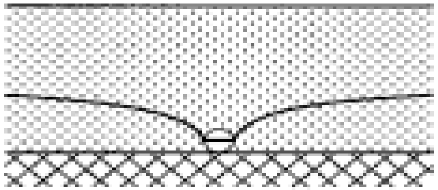
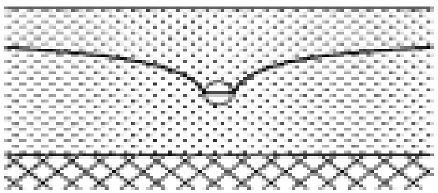
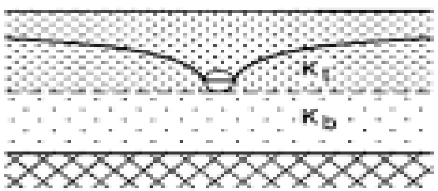
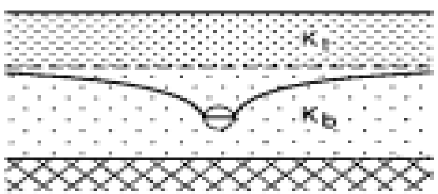
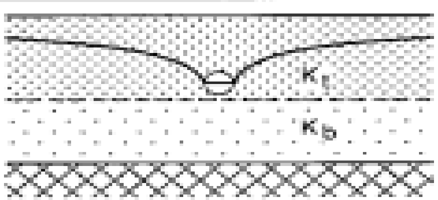
or

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

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:

$$S^2 = \frac{(4k_1z^2)+(8k_2dh)}{q}$$

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)

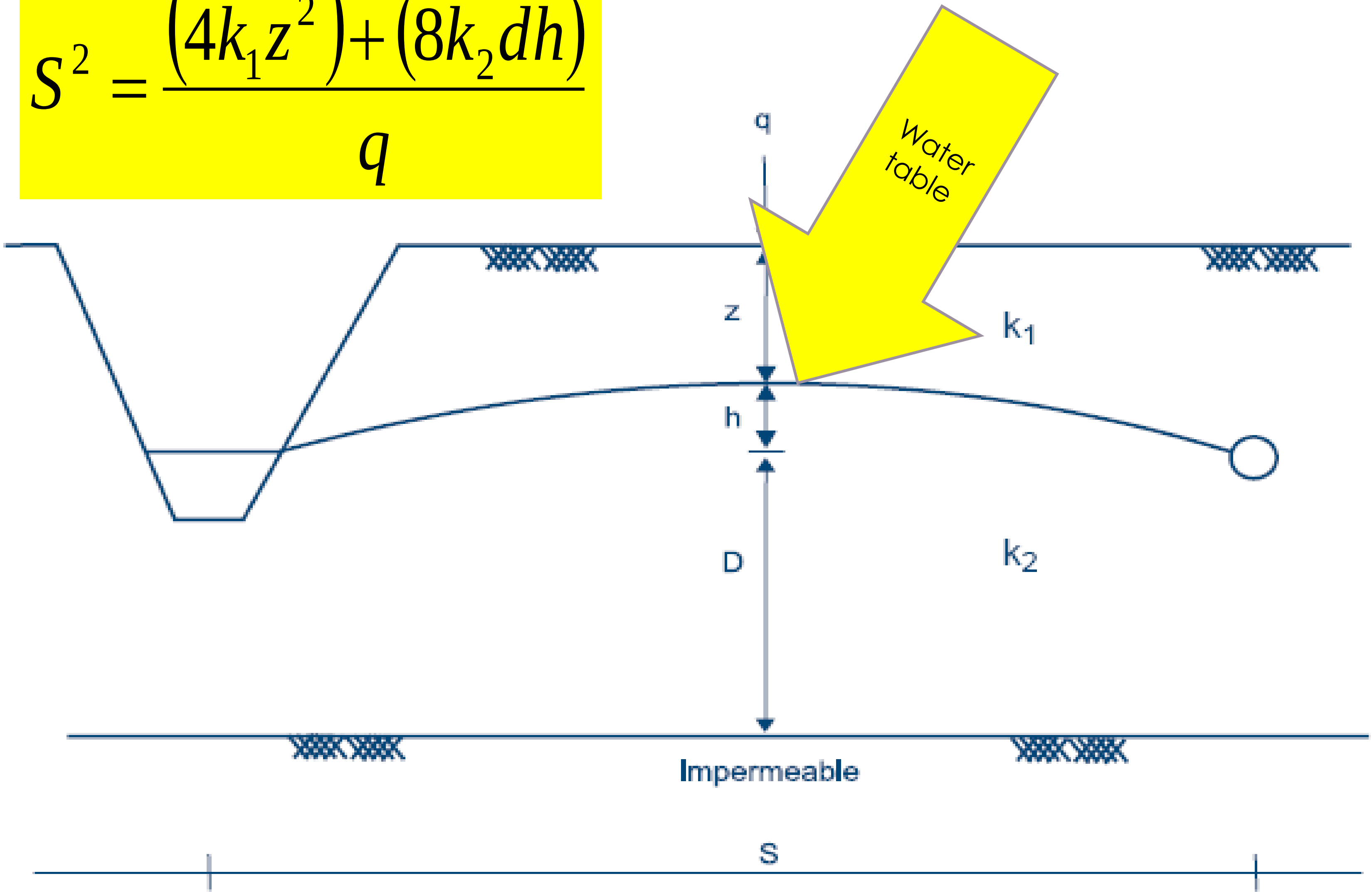
h = Hydraulic head of maximum groundwater table elevation above drainage level (m)

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

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

Con’d…

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



Subsurface drainage parameters

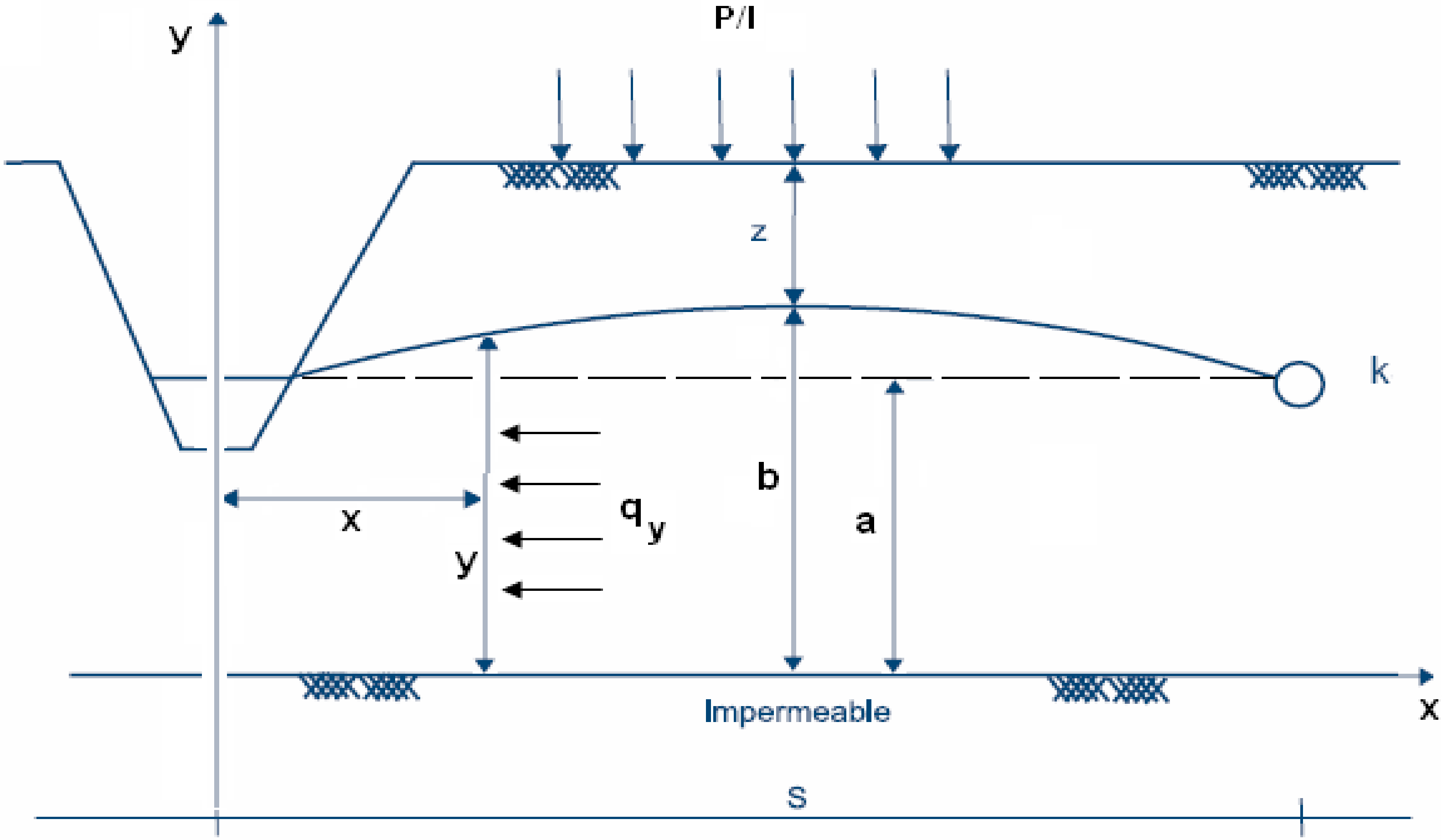
- In reality, the head losses due to horizontal and radial flow to the pipe should be considered, which would result in complex equations as shown below.
- The equivalent flow is essentially horizontal and can be described using the Hooghoudt formula.
- The equivalent depth, d is found by the equation:

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

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

- 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,

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

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

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

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