# DRAINAGE & DESIGN OF DRAINAGE SYSTEMS

Drainage means the removal of excess water from a given place.

Two types of drainage can be identified:

**i)Land Drainage:** This is large scale drainage where the objective is to drain surplus water from a large area by such means as excavating large open drains, erecting dykes and levees and pumping. Such schemes are necessary in low lying areas and are mainly Civil Engineering work.

**ii)Field Drainage:** This is the drainage that concerns us in agriculture. It is the removal of excess water from the root zone of crops

## Need of Drainage

During rain or irrigation the fields become wet. The water infiltrate into the soil and is stored in its pores. When all the pores are filled with water, the soil is said to be saturated and no more water can be absorbed; when rain or irrigation continues, pools may form on the soil surface (as shown in Figure).

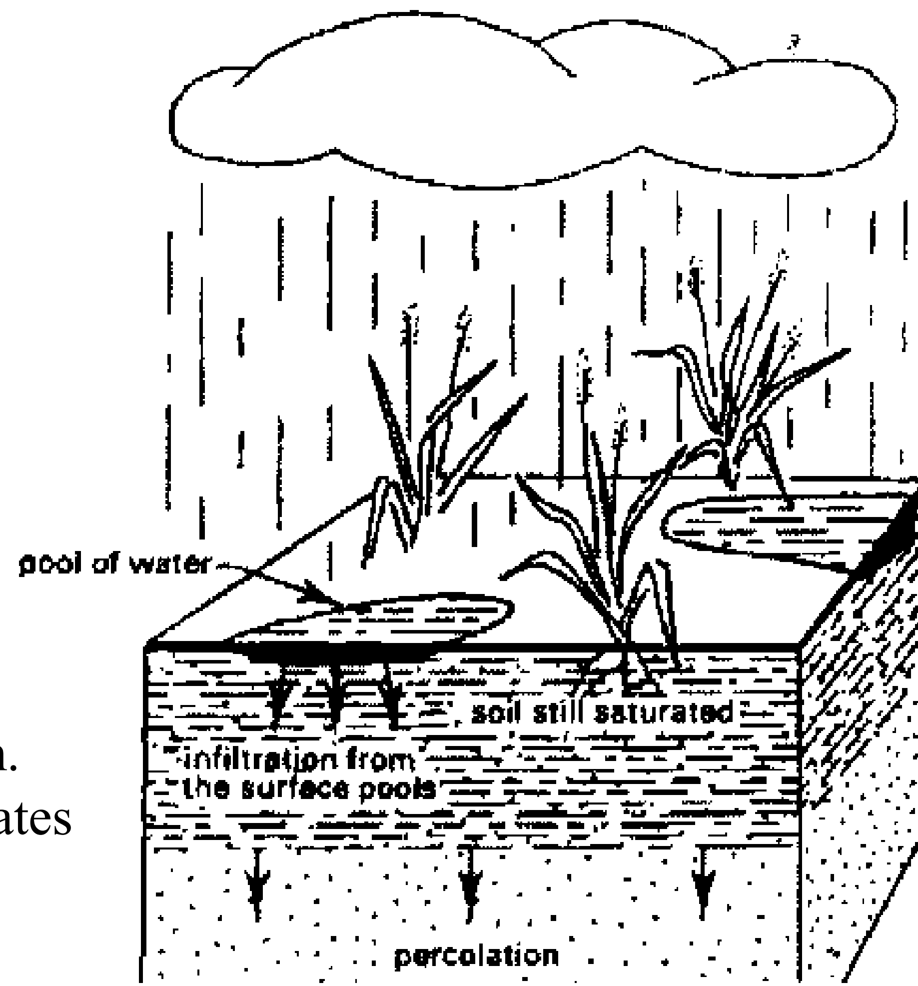
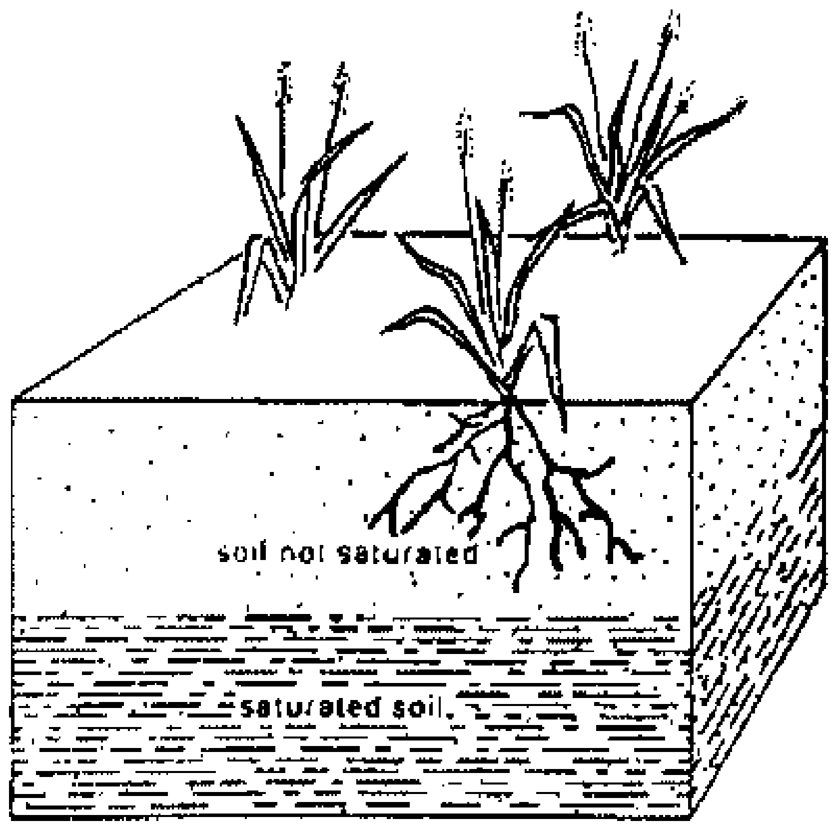
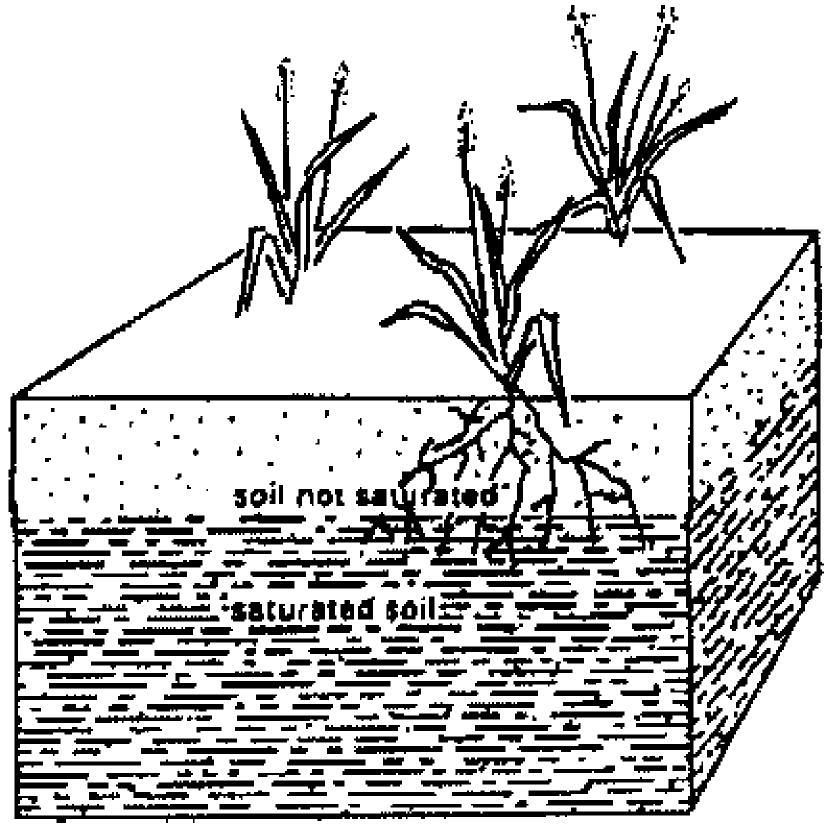



***Figure.*** During heavy rainfall the upper soil layers become saturated and pools may form. Water percolates to deeper layers and infiltrates from the pools

BEFORE HEAVY RAINFALL



# Water in Soil After Heavy Rain



## The main aims of Field drainage include:

i) To bring soil moisture down from saturation to field capacity. At field capacity, air is available to the soil and most soils like to grow at moisture less than saturation.

ii) Drainage helps improve hydraulic conductivity: Soil structure can collapse under very wet conditions and so also engineering structures.

iii) In some areas with salt disposition, especially in arid regions, drainage is used to leach excess salt.

iv) In irrigated areas, drainage is needed due to poor application efficiency which means that a lot of water is applied.

v) Drainage can shorten the number of occasions when cultivation is held up waiting for soil to dry out.

## TYPES OF FIELD DRAINAGE

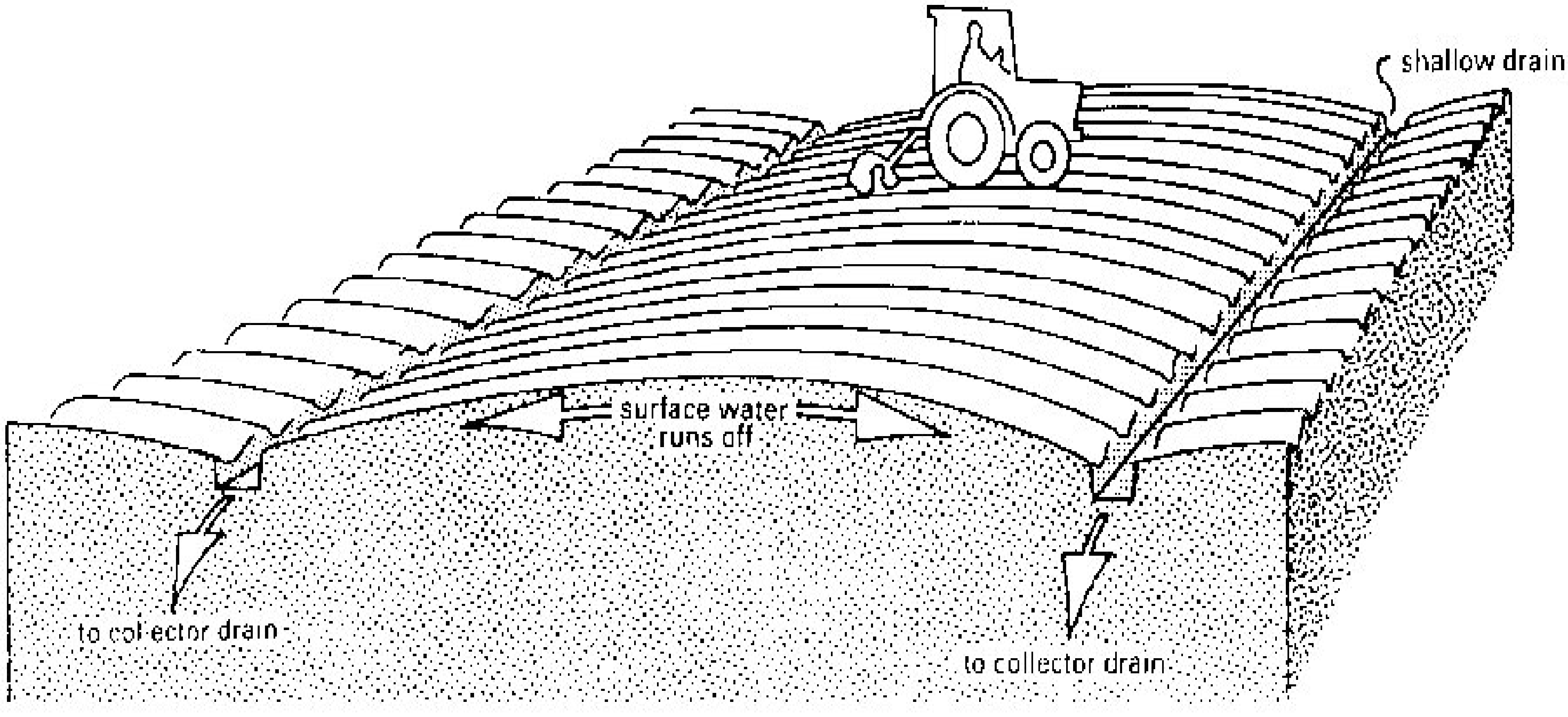
The different field drainage methods can be classified as:

1. Horizontal drainage
    - i. Surface drainage
    - ii. Sub-surface drainage
2. Vertical drainage i.e. Tube wells

# DESIGN OF SURFACE DRAINAGE SYSTEMS:

Surface drainage involves the removal of excess water from the surface of the soil.

This is done by removing low spots where water accumulates by land forming or by excavating ditches or a combination of the two.

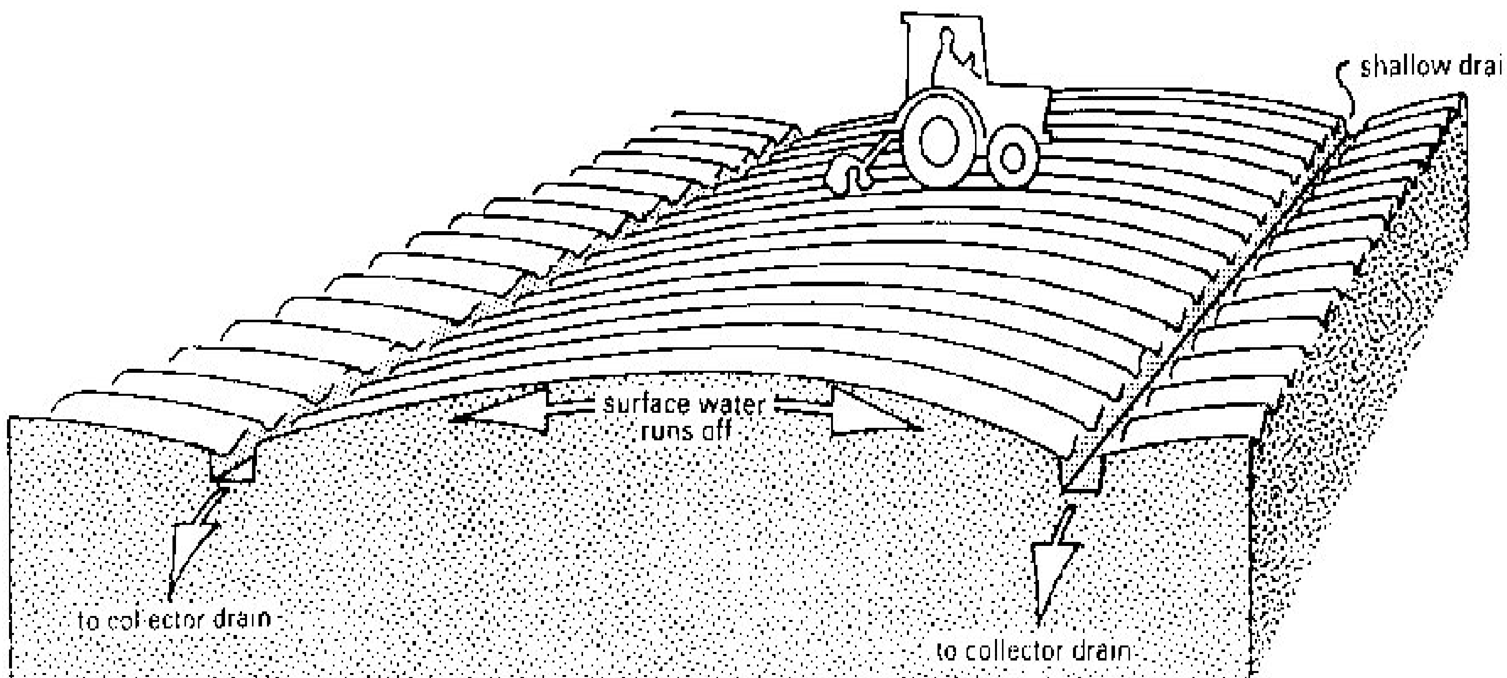


Land forming is mechanically changing the land surface to drain surface water.

This is done by smoothing, grading, bedding or leveling.

Land smoothing is the shaping of the land to a smooth surface in order to eliminate minor differences in elevation and this is accomplished by filling shallow depressions using bulldozers or scrapers.

There is no change in land contour.  Smoothing is done using land levelers or planes.



## Design of Drainage Channels or Ditches

***Estimation of Peak Flows:*** This can be done using the Rational formula, Cook's method, Curve Number method, Soil Conservation Service method etc.

Drainage coefficients (to be treated later) are at times used in the tropics especially in flat areas and where peak storm runoff would require excessively large channels and culverts.

This may not apply locally because of high slopes.

**a) The Rational Formula:**

It states that:

$$q_p = (CIA)/360$$

where

$q_p$ = peak flow ($m^3/s$);

C = dimensionless runoff coefficient;

I = rainfall intensity for a given return period.

(Return period is the average number of years within which a given rainfall event will be expected to occur at least once)

A = area of catchment (ha).

# Diagram Showing Two Catchments

## Using the Rational Method

i) Obtain area of catchment by surveying or from maps or aerial photographs.

ii) Estimate intensity using the curve in Hudson's Field Engineering, page 42.

iii) The runoff coefficient C is a measure of the rain which becomes runoff. On a corrugated iron roof, almost all the rain would runoff so C = 1, while in a well drained soil, nine-tenths of the rain may soak in and so C = 0.10. The table (see handout) from Hudson's Field Engineering can be used to obtain C value. Where the catchment has several different kinds of characteristics, the different values should be combined in proportion to the area of each.

# Runoff Coefficient, C



*Table 3.3*
*Values of run-off coefficient C*

| Topography and vegetation | Soil texture | | |
|---|---|---|---|
| | Open sandy loam | Clay and silt loam | Tight clay |
| **Woodland** | | | |
| Flat 0-5 per cent slope | 0·10 | 0·30 | 0·40 |
| Rolling 5-10 per cent slope | 0·25 | 0·35 | 0·50 |
| Hilly 10-30 per cent slope | 0·30 | 0·50 | 0·60 |
| **Pasture** | | | |
| Flat | 0·10 | 0·30 | 0·40 |
| Rolling | 0·16 | 0·36 | 0·55 |
| Hilly | 0·22 | 0·42 | 0·60 |
| **Cultivated** | | | |
| Flat | 0·30 | 0·50 | 0·60 |
| Rolling | 0·40 | 0·60 | 0·70 |
| Hilly | 0·52 | 0·72 | 0·82 |
| **Urban areas** | 30 per cent of area impervious | 50 per cent of area impervious | 70 per cent of area impervious |
| Flat | 0·40 | 0·55 | 0·65 |
| Rolling | 0·50 | 0·65 | 0·80 |

From Schwab, Frevert, Edminster, and Barnes, *Soil and water conservation engineering*, Wiley, New York.

**b) Cook's Method:**

Three factors are considered:

1. Vegetation,

2. Soil permeability and

3. Slope.

These are the catchment characteristics.

For each catchment, these are assessed and compared with Table 3.4 of Hudson's Field Engineering

# Table 3.4: Hudson's Field Eng'g (CC)

*Table* **Z**

*Catchment characteristics (CC)*

| Cover | | Soil type and drainage | | Slope | |
|---|---|---|---|---|---|
| Heavy grass | 10 | Deep, well drained soils | 10 | Very flat to gentle | 5 |
| Scrub or medium grass | 15 | Deep, moderately pervious soil | 20 | Moderate | 10 |
| Cultivated lands | 20 | Soils of fair permeability and depth | 25 | Rolling | 15 |
| Bare or eroded | 25 | Shallow soils with impeded drainage | 30 | Hilly or steep | 20 |
| | | Medium heavy clays or rocky surfaces | 40 | Mountainous | 25 |
| | | Impervious surfaces and waterlogged soils | 50 | | |

Select the most appropriate factor from each of these three lists and add them together.

*Example*

Heavy grass (10) on shallow soils with impeded drainage (30) and moderate slope (10):
CC = 10 + 30 + 10 = 50.

From Dept. of Conservation and Extension, Government of Rhodesia. *Handbook of basic instruction for dam construction.*

**Example**

A catchment may be heavy grass (10) on shallow soils with impeded drainage (30) and moderate slope (10).

Catchment characteristics (CC) is then the sum of the three i.e. 50.

The area of the catchment is then measured, and using the Area, A and the CC, the maximum runoff can be read from Table 3.5 (Field Engineering, pp. 45).

# Table 3.5: Hudson's Field Eng'g (Runoff Values)

*Table 3*
*Run-off from small catchments*

| A \ CC | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 0·2 | 0·3 | 0·4 | 0·5 | 0·7 | 0·9 | 1·1 | 1·3 | 1·5 | 1·7 | 1·9 | 2·1 |
| 10 | 0·3 | 0·5 | 0·7 | 0·9 | 1·1 | 1·4 | 1·7 | 2·0 | 2·4 | 2·8 | 3·2 | 3·7 |
| 15 | 0·5 | 0·8 | 1·1 | 1·4 | 1·7 | 2·0 | 2·4 | 2·9 | 3·4 | 4·0 | 4·6 | 5·2 |
| 20 | 0·6 | 1·0 | 1·4 | 1·8 | 2·2 | 2·7 | 3·2 | 3·8 | 4·4 | 5·1 | 5·8 | 6·5 |
| 30 | 0·8 | 1·3 | 1·8 | 2·3 | 2·9 | 3·6 | 4·4 | 5·3 | 6·3 | 7·3 | 8·4 | 9·5 |
| 40 | 1·1 | 1·5 | 2·1 | 2·8 | 3·5 | 4·5 | 5·5 | 6·6 | 7·8 | 9·1 | 10·5 | 12·3 |
| 50 | 1·2 | 1·8 | 2·5 | 3·5 | 4·6 | 5·8 | 7·1 | 8·5 | 10·0 | 11·6 | 13·3 | 15·1 |
| 75 | 1·6 | 2·4 | 3·6 | 4·9 | 6·3 | 8·0 | 9·9 | 11·9 | 14·0 | 16·4 | 18·9 | 21·7 |
| 100 | 1·8 | 3·2 | 4·7 | 6·4 | 8·3 | 10·4 | 12·7 | 15·4 | 18·2 | 21·2 | 24·5 | 28·0 |
| 150 | 2·1 | 4·1 | 6·3 | 8·8 | 11·6 | 14·7 | 18·2 | 21·8 | 25·6 | 29·9 | 35·0 | 40·6 |
| 200 | 2·8 | 5·5 | 8·4 | 11·7 | 15·3 | 19·1 | 23·3 | 28·0 | 33·1 | 38·5 | 45·0 | 52·5 |
| 250 | 3·5 | 6·5 | 9·7 | 13·2 | 17·2 | 21·7 | 27·0 | 32·9 | 39·6 | 46·9 | 55·0 | 63·7 |
| 300 | 4·2 | 7·0 | 10·5 | 14·7 | 19·6 | 25·2 | 31·5 | 38·5 | 46·2 | 54·6 | 63·7 | 73·5 |
| 350 | 4·9 | 8·4 | 12·6 | 17·2 | 23·2 | 30·2 | 37·8 | 46·3 | 53·8 | 62·5 | 71·5 | 81·0 |
| 400 | 5·6 | 10·0 | 14·4 | 19·4 | 25·6 | 33·6 | 42·2 | 51·0 | 60·0 | 69·3 | 79·5 | 90·0 |
| 450 | 6·3 | 10·5 | 15·5 | 21·5 | 28·5 | 36·5 | 45·5 | 55·5 | 65·5 | 76·0 | 86·5 | 97·5 |
| 500 | 7·0 | 11·0 | 17·0 | 23·5 | 31·0 | 40·5 | 51·0 | 62·0 | 73·0 | 84·0 | 95·0 | 106·5 |

From Dept. of Conservation and Extension, Government of Rhodesia, Dept. In-Service Manual.

***Cook's Method Contd.***

This gives the runoff for a 10 yr return period. For other return periods, other than 10 years, the conversion factor is:

| **Return Period (yrs):** | 2 | 5 | 10 | 25 | 50 |
|---|---|---|---|---|---|
| **Conversion factor:** | 0.90 | 0.95 | 1.00 | 1.25 | 1.50 |

Another factor to be considered is the shape of the catchment.

Table 3.5 gives the runoff for a catchment, which is roughly square or round. For other catchment shapes, the following conversion factors should be used:

Square or round catchment (1)

Long & narrow (0.8)

Broad & short (1.25)

## Surface Drainage Channels

The drainage channels are normally designed using the Manning formula. The required capacity of a drainage channel is calculated from the summation of the inflowing streams.

The bed level of an open drain collecting flow from field pipe drains should be such as to allow free fall from the pipe drain outlets under maximum flow conditions, with an allowance for siltation and weed growth. 300 mm is a reasonable general figure.

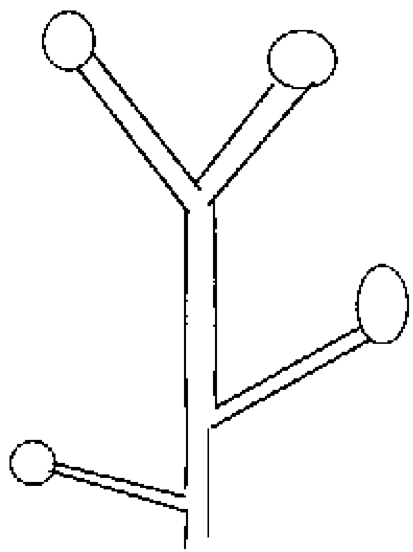
## Surface Ditch Arrangements

The ditch arrangement can be random, parallel or cross- slope.

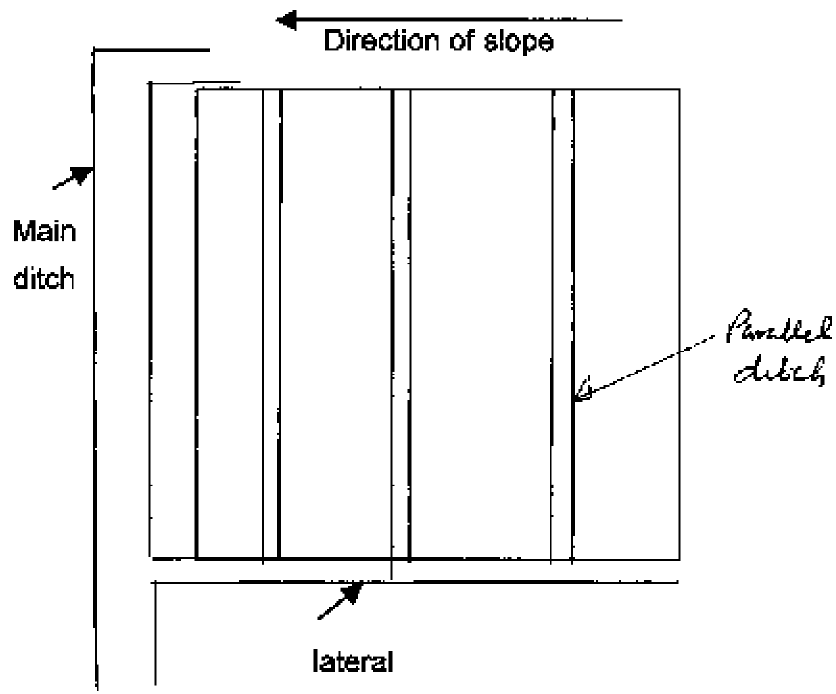
***Random ditch system***: Used where only scattered wet lands require drainage.

***Parallel ditch system***: Used in flat topography. Ditches are parallel and perpendicular to the slope. Laterals, which run in the direction of the flow, collect water from ditches.

# Surface Ditch Arrangements



Random ditch system




Parallel ditch system.

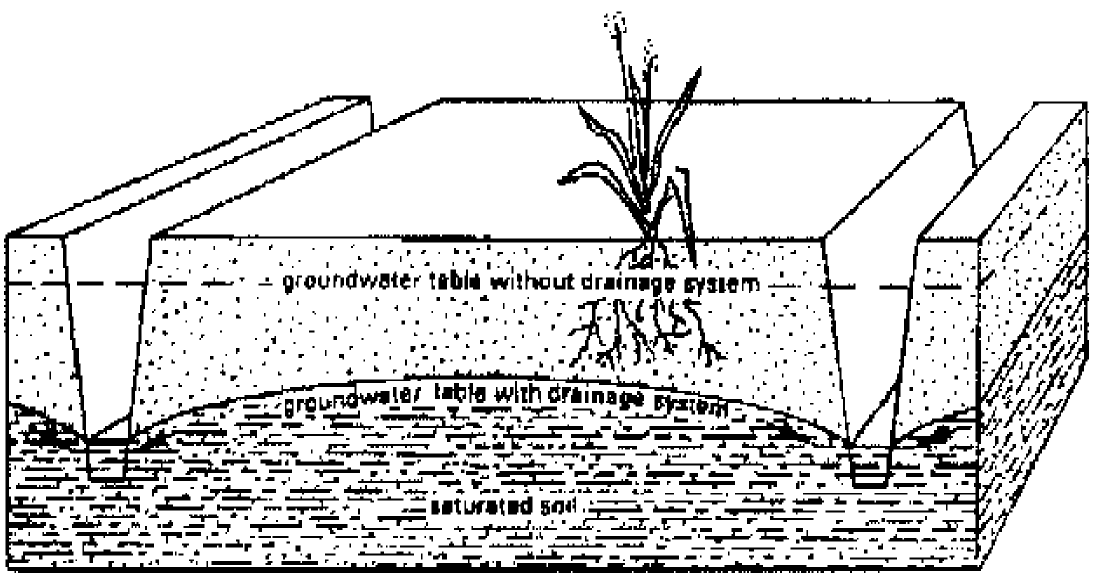
# DESIGN OF SUB-SURFACE DRAINAGE SYSTEMS

**Sub-surface drainage** is the removal of excess groundwater below the soil surface.

It aims at increasing the rate at which water will drain from the soil, and so lowering the water table, thus increasing the depth of drier soil above the water table.

Sub-surface drainage can be done by open ditches or buried drains.

Fig. 99. Control of the groundwater table by means of deep open drains



**Sub-Surface Drainage Using Ditches**

Ditches have lower initial cost than buried drains;

There is ease of inspection and ditches are applicable in some organic soils where drains are unsuitable.

Ditches, however, reduce the land available for cropping and require more maintenance that drains due to weed growth and erosion.

## Sub-Surface Drainage Using Buried Drains

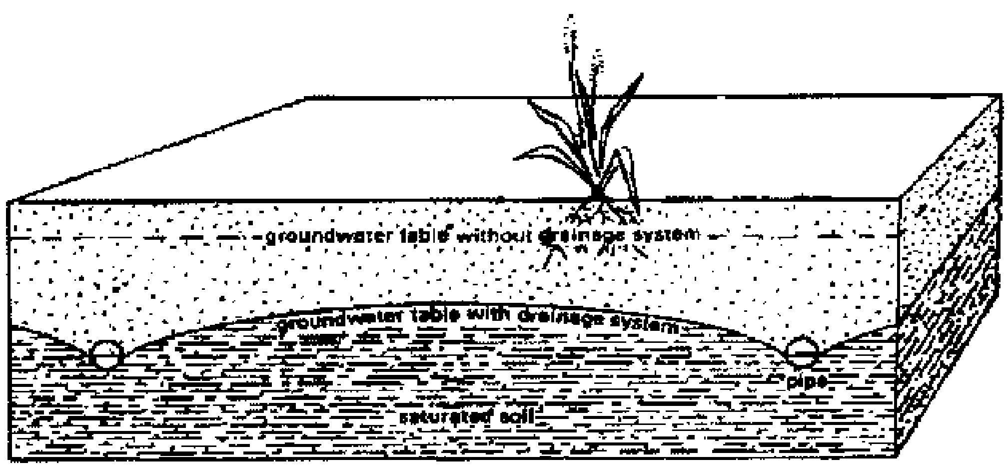
Buried drains refer to any type of buried conduits having open joints or perforations, which collect and convey drainage water.

They can be fabricated from clay, concrete, corrugated plastic tubes or any other suitable material.

The drains can be arranged in a parallel, herringbone, double main or random fashion.

Drain pipes are made of clay, concrete or plastic.

They are usually placed in trenches by machines.

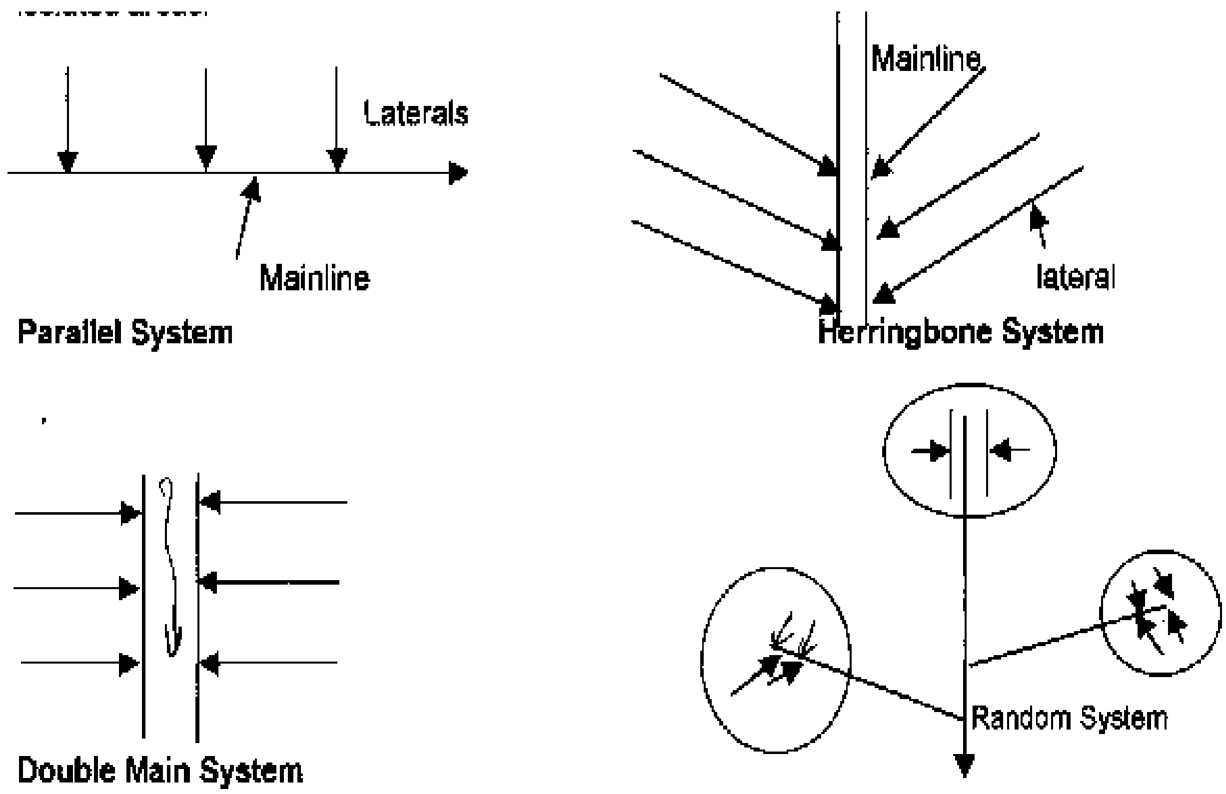


In clay and concrete pipes (usually 30 m long and 5-10 cm in diameter) drainage water enters the pipes through the joints (see Figure).

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

# Buried Drains

# Arrangements of Sub-Surface Drains



## Sub-Surface Drainage Designs

The Major Considerations in Sub-surface Drainage Design Include:

1. Drainage Coefficient;
2. Drain Depth and Spacing;
3. Drain Diameters and Gradient;
4. Drainage Filters.

## 1. Drainage Coefficient

This is the rate of water removal by a drain to obtain the desired protection of crops from excess surface or sub-surface water and can be expressed in mm/day, m/day etc.

Drainage is different in Rain-Fed Areas and Irrigated Areas.

This is chosen from experience depending on rainfall. The following are guidelines.

**Table 4.1 : Drainage Coefficient for Rain-Fed Areas***

| **Mean Annual Rainfall (MAR)** *(mm/yr)* | **Drainage coefficient (mm/day)** *Ministry of Agric.* | *Hudson* |
|---|---|---|
| 2000 | 25 | 20 |
| 1950 | 25 | 19.5 |
| 1500 | 19 | 15 |
| 1000 | 13 | 10 |
| 875 | 10 | 10 |
| < 875 | 7.5 | 10 |

……………………………………………………………………………

*From Ministry of Agric., U.K (1967) & Hudson (1975)

## Other Methods For Obtaining Drainage Coefficient in Rain-Fed Areas

**A.** Hudson suggests:

MAR > 1000 mm, drainage coefficient is MAR/1000 mm/day

MAR < 1000 mm, drainage coefficient is 10 mm/day.

**B. From rainfall records:** determine peak rainfall with a certain probability depending on the value of crops or grounds to be protected e.g. 5 day rainfall for 1: 2 return period.

**C. Divide the rainfall** of the heaviest rainfall month by the days of the month e.g. if in an area, the heaviest rainfall month is August with 249 mm.

i.e. Drainage discharge = 249/31 = 8.03 mm/day.

Use this method as a last resort.

**Drainage Coefficient in Irrigated Areas**

In irrigated areas, water enters the groundwater from:

- Deep percolation,
- Leaching requirement,
- Seepage or Conveyance losses from watercourses and canals, and
- Rainfall for some parts of the world.

**Example**

In the design of an irrigation system, the following properties exist:

- Soil field capacity = 28% by weight,
- Permanent wilting point = 17% by weight;
- Bulk density = 1.36 $g/cm^3$ ;
- Root zone depth = 1m = 1000 mm;
- Peak ET = 5 mm/day;
- Irrigation efficiency = 60%,
- Water conveyance efficiency = 80%,
- Water lost in canals contributing to seepage = 50%;
- Rainfall for january = 69 mm and
- Evapotranspiration = 100 mm;
- Salinity of irrigation water is 0.80 m mhos/cm while that acceptable is 4 mmhos/cm.

➢ Compute the drainage coefficient.

**Solution:**

Readily available moisture (RAM) = ½ (FC - PWP)

= 1/2(28 - 17)

= 5.5%.

In depth,

RAM = 0.055 x 1.36 x 1000 mm

= 74.8 mm = Net irrigation

Shortest irrigation interval = RAM/peak ET

= 74.8/5 = 15 days

With irrigation efficiency of 60 %,

GIR = 74.8/0.6 = 124.7 mm.

This is per irrigation.

**(a) Water losses** = GIR - Net irrigation

= 124.7 - 74.8

= 49.9 mm

Assuming 70% is deep percolation while 30% is wasted on the soil surface (Standard assumption),

Deep percolation = 0.7 x 49.9

= 34.91 mm

**(b)Seepage**

$$\text{Conveyance Efficiency} = \frac{\text{Water delivered to farm}}{\text{Water delivered at dam}}$$

$$= 0.8$$

Water delivered to farm = GIR = 124.7 mm

i.e. Water released at dam = 124.7/0.8 = 155.9 mm

Excess water or water lost in canal = 155.9 - 124.7

= 31.2 mm

Since half of the water is seepage (given), the rest will be evaporation during conveyance

Seepage = 1/2 x 31.2 mm

= 15.6 mm

## (c) Leaching Required

**Note:** In surface irrigation systems, deep percolation is much higher than leaching requirement so only the former is used in computation.

**(d) Rainfall** = 69 mm in the month;

in 15 days it will be 34.5 mm

It is assumed that excess water going down the soil as a result of deep percolation can be used for leaching. In sprinkler system, leaching requirement may be greater than deep percolation and can be used instead.

Neglecting Leaching Requirement,

Total water input into drains

= Deep percolation +Seepage +Rainfall

= 34.91 + 15.6 + 34.5

= 85.01 mm

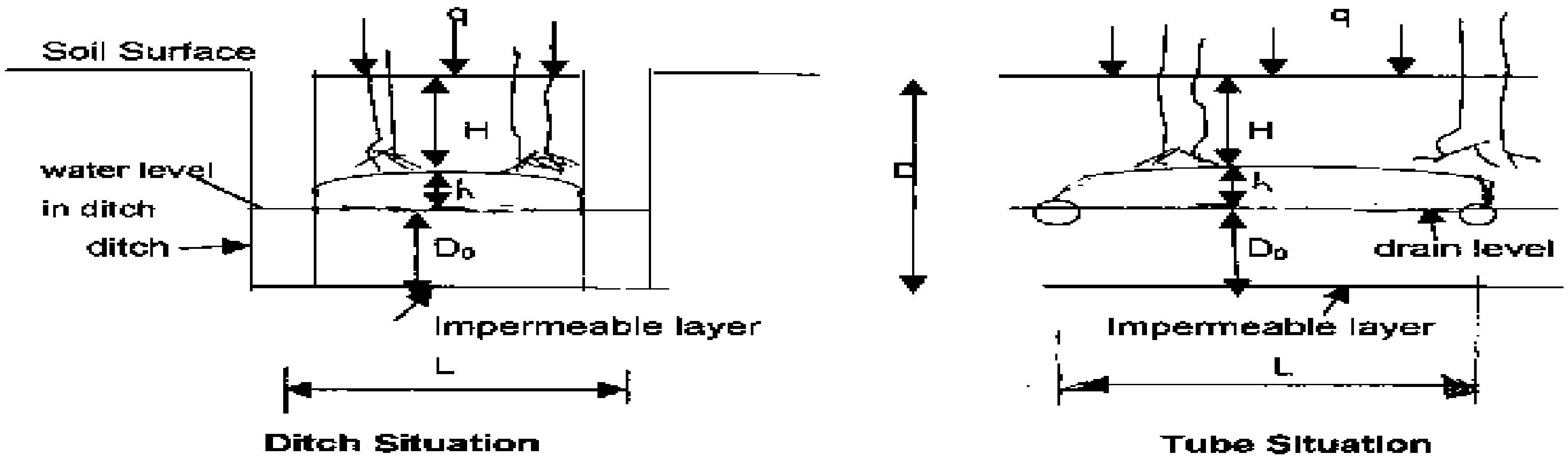
This is per 15 days, since irrigation interval is 15 days

Hence,

Drainage coefficient = 85.01/15 = 5.67

**= 6 mm/day.**

# 2. Drain Depth and Spacing




L = drain spacing;

h = mid drain water table height (m) above drain level;

Do = depth of aquifer from drain level to impermeable layer(m);

Q = water input rate(m/day) = specific discharge  or drainage coefficient;

K = hydraulic conductivity(m/day);

H = depth to water table.

## **Design Water table depth (H)**:

This is the minimum depth below the surface at which the water table should be controlled and is determined by farming needs especially crop tolerance to water.

Typically, it varies from 0.5 to 1.5 m.

# Design Depth of Drain

The deeper a drain is put, the larger the spacing and the more economical the design becomes.

Drain depth, however, is constrained by soil and machinery limitations.

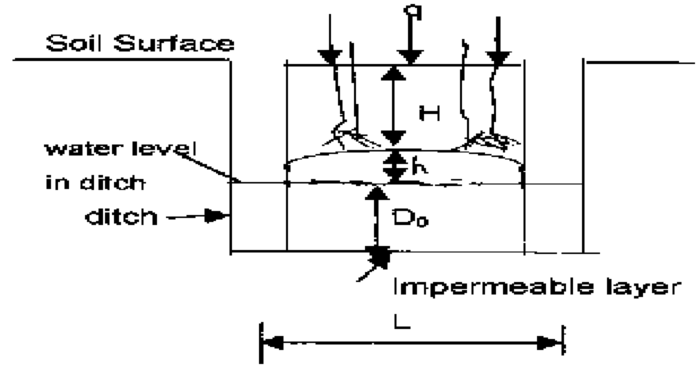
**Table : Typical Drain Depths(D)**

| Soil Type | Drain Depth (m) |
|---|---|
| Sand | 0.6 |
| Sandy loam | 0.8 - 1.0 |
| Silt loam | 0.8 - 1.8 |
| Clay loam | 0.6 - 0.8 |
| Peat | 1.2 - 1.5 |

# Drain Spacing (L)

This is normally determined using the Hooghoudt equation. It states that for ditches reaching the impermeable layer:

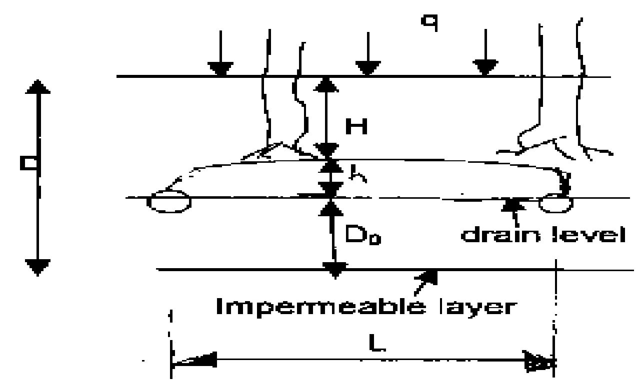
$$L^2 = \frac{8KD_o h}{q} + \frac{4Kh}{q}$$



Ditch Situation

For tube drains which do not reach the impermeable layer, the equation can be modified as:

$$L = \frac{8Kdh}{q} + \frac{4Kh^2}{q}$$



Tube Situation

Where

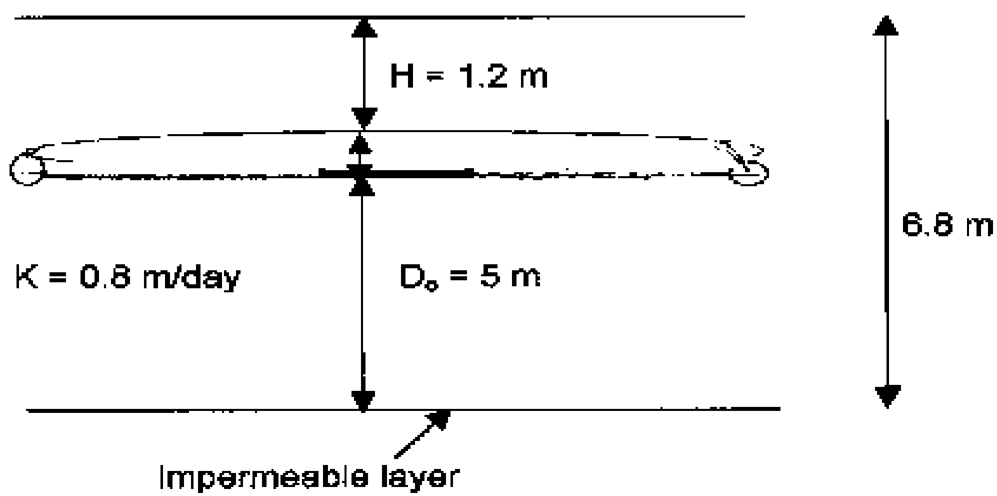
d = Houghoudt equivalent

The equation for tube drains can be solved using trial and error method or the graphical method.

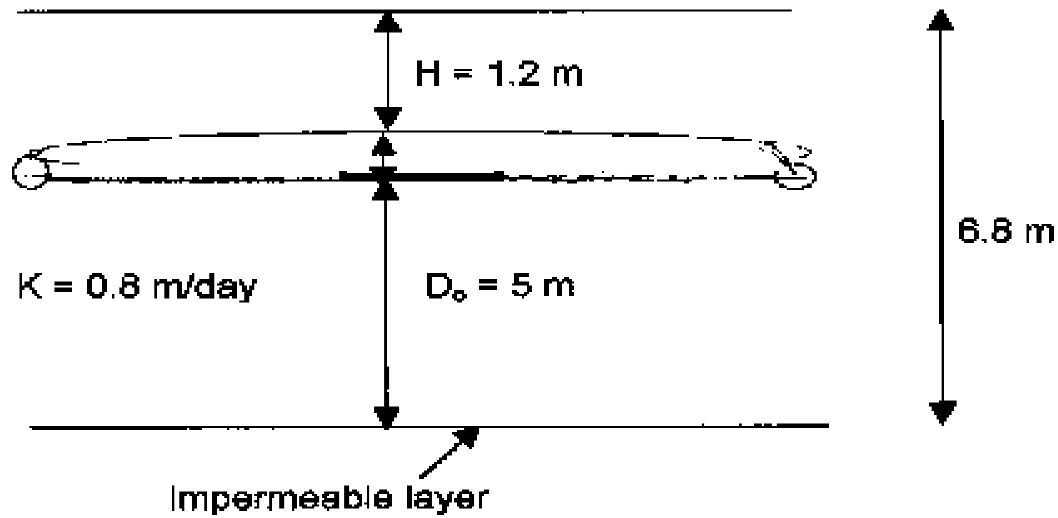
# Example

For the drainage design of an irrigated area, drain pipes with a radius of 0.1 m are used. They are placed at a depth of 1.8 m below the soil surface. A relatively impermeable soil layer was found at a depth of 6.8 m below the surface. From auger hole tests, the hydraulic conductivity above this layer was estimated as 0.8 m/day. The average irrigation losses, which recharge the groundwater, are 40 mm per 20 days so the average discharge of the drain system amounts to 2 mm/day.

Estimate the drain spacing, if the depth of the water table is 1.2 m.



**Solution:**




Analytical solution

$$L^2 = \frac{8Kdh}{q} + \frac{4Kh^2}{q} = \frac{8 \times 0.8 \times d \times 0.6}{0.002} + \frac{4 \times 0.8 \times 0.6^2}{0.002}$$

$$= 1920\ d\ + 578 ----------(1)$$

**Trial One:** Assume L = 75 m

for L = 75 m and Do = 5 m, from Hooghout table, d = 3.49 m

From eq. (1), $L^2 = (1920 \times 3.49) + 576 = 7276.8$; L = 85.3 m

Comment: The chosen L is small since 75 < 85.3 m

**Trial Two:** Assume L = 100 m,

for L = 100 m and Do = 5 m, from table, d = 3.78 m

From (1), $L^2 = (1920 \times 3.78) + 576 = 7833.6$; L = 88.51m

Comment: Since 88.51 < 100, try a smaller L;

L should be between 75 and 100 m.

**Table. Values of Equivalent depth of Houghoudt for $r_o$ = 0.1 m, D and L in m**

| L → | 5 m | 7.5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| D | | | | | | | | | | | |
| 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 |

**Table. Values of Equivalent depth of Houghoudt for $r_o$ = 0.1 m, D and L in m**

| L → | 50 | 75 | 80 | 85 | 90 | 100 | 150 | 200 | 250 |
|---|---|---|---|---|---|---|---|---|---|
| D | | | | | | | | | |
| 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 |

# Table. Values of Equivalent depth of Houghoudt for $r_o$ = 0.1 m, D and L in m

| L → | 5 m | 7.5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| D | | | | | | | | | | | |
| 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 → | 50 | 75 | 80 | 85 | 90 | 100 | 150 | 200 | 250 |
|---|---|---|---|---|---|---|---|---|---|
| D | | | | | | | | | |
| 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 |

**Trial Three:** Assume L = 90 m,

d = 3.49 + 15/25(3.78 - 3.49) = 3.66 m

$L^2$ = (1920 x 3.66) + 576 = 7603.2 m ; L = 87 m

Comment: Since 87 < 90, try a smaller L;

L should be between 75 and 90.

**Trial Four:** Assume L = 87 m,

d = 3.49 + 12/25(3.78 - 3.49) = 3.63 m

$L^2$ = (1920 x 3.63) + 576 = 7545.6; L = 86.87 m

Comment: The difference between the assumed and calculated L is <1, so : Drain Spacing = 87 m.

## Graphical Solution

Calculate $\dfrac{4Kh^2}{q}$ and $\dfrac{8Kh}{q}$

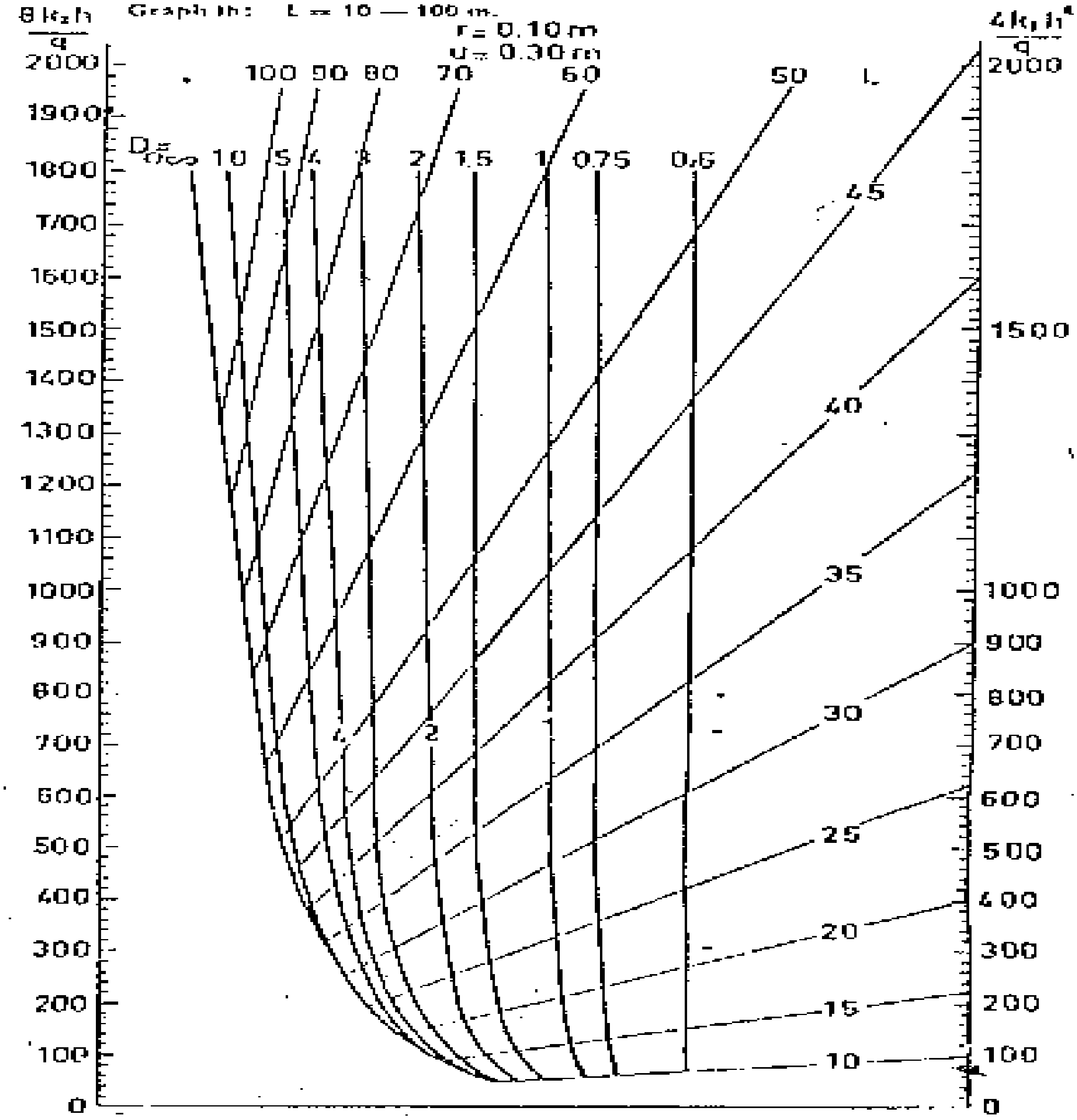
$$\frac{4Kh^2}{q} = \frac{4\times0.8\times0.6^2}{0.002} = 576$$

$$\frac{8Kh}{q} = \frac{8\times0.8\times0.6}{0.002} = 1920$$

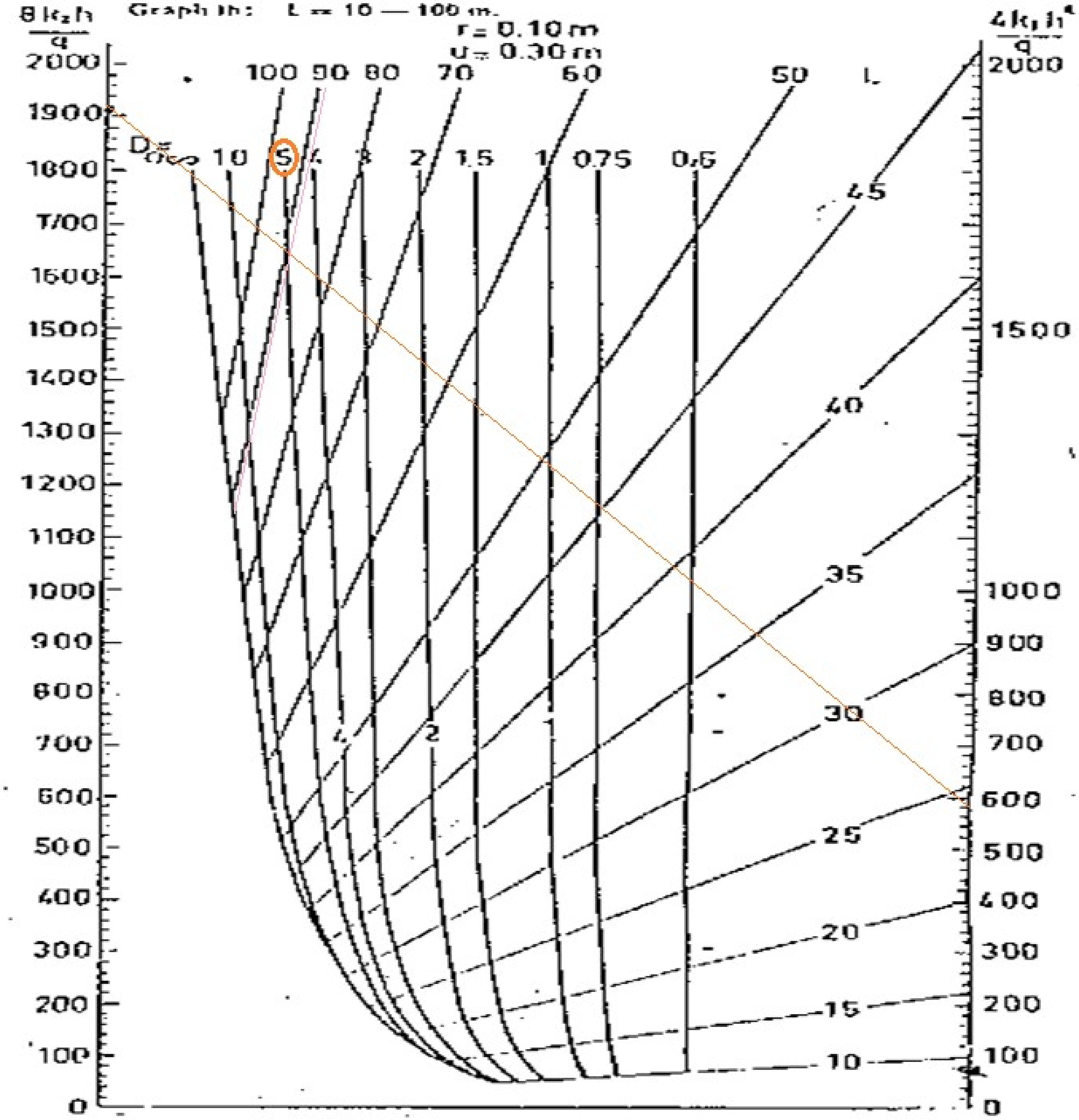
Locate the two points on graph given and join.

For a value of Do = 5 m; produce downwards to meet the line.
Read off the spacing on the diagram

**L = 87 m**



8 k₂ h / q
Graph Ih: L = 10 — 100 m.
r = 0.10 m
u = 0.30 m
4 k₁ h / q
100 90 80 70 60 50 L
D = ∞ 10 5 4 3 2 1.5 1 0.75 0.6
45 40 35 30 25 20 15 10
2000 1900 1800 1700 1600 1500 1400 1300 1200 1100 1000 900 800 700 600 500 400 300 200 100 0
2000 1500 1000 900 800 700 600 500 400 300 200 100 0



Graph Ih: L = 10 — 100 m.
r = 0.10 m
u = 0.30 m
100 90 80 70 60 50 L
10 5 4 3 2 1.5 1 0.75 0.5
45
40
35
30
25
20
15
10
2000 1900 1800 1700 1600 1500 1400 1300 1200 1100 1000 900 800 700 600 500 400 300 200 100 0
2000 1500 1000 900 800 700 600 500 400 300 200 100 0

# 3. Drain Diameters and Gradients

There are two approaches to design:

**(a) Transport approach:**

- Assumes that pipes are flowing full from top to end of field.
- Assumes uniform flow.
- Widely used in United States, Canada and Germany.
- Used to design collector drains.

**(b) Drainage approach:**

- Assumes that water enters the pipe all down the length as it is perforated.
- This is more realistic.
- Widely used in United Kingdom, Holland and Denmark.
- This is used to design lateral drainage pipes.

# Parameters Required to use Solution Graphs

**(a) Types of pipes:** Pipes can be smooth or rough:

Clay tiles and smooth plastic pipes are smooth; while

Corrugated plastic pipes are rough.

**(b) Drainable area:** The area drained by one lateral. It is equal to the maximum length of a lateral multiplied by drain spacing.

The whole area drained by the laterals discharging into a collector represents the drainable area of the collector.

**c)Specific discharge:** Earlier defined. Same as drainage coefficient.

**d) Silt safety factors:** Used to account for the silting of pipes with time by making the pipes bigger. 60, 75 and 100 % pipe capacity factors are indicated. This means allowing 40, 25 and 0% respectively for silting.

**e) Average hydraulic gradient(%):** It is normally the soil slope.

## Example:

The drainage design of a field is:

drain spacing = 30 m,

length of drain lines = 200 m,

slope = 0.10%,

specific discharge = 10 mm/day.

Estimate drain diameter. Assume 60% silt factor and clay tiles.

**Solution**:

Area to be drained by one lateral = 30m x 200m = 6000 $m^2$ = 0.6 ha

Slope = average hydraulic gradient = 0.10% ;

q = 10 mm/day

Using chart for smooth drains,

nearest diameter = **70 mm inside diameter.**

## 4. Drainage Filters

Filters for tile drains are permeable materials e.g. gravel placed around the drains for the purpose of improving the flow conditions in the area immediately surrounding the drains as well as for improving bedding conditions.

Filters provide a high hydraulic conductivity around the drains which stabilizes the soil around and prevent small particles from entering the lateral drains since they are perforated.

**Soils that Need Filters**

a) Uniform soils will cause problems while non-uniform ones are widely distributed stabilize themselves.

b) Clays have high cohesion so cannot be easily moved so require no filters.

c) Big particles like gravel can hardly be moved due to their weight.

* Fine soils are the soils that will actually need filters especially if they are uniform.

**Drainage Filters Continued**

a) Filters are needed to be gravel with same uniformity with the soil to be protected.

b) D15 Filter < 5 D85 Soil ; D15 Filter < 20 D15 Soil ; D50 Filter < 25 D50 Soil.

These are the filtration criteria.

To give adequate hydraulic conductivity,

D85 Filter > 5 D15 Soil.

These criteria are difficult to achieve and should serve as guidelines.

## Laying Plastic Pipes:

A Trench is excavated, the pipe is laid in the trench, permeable fill is added, and then the trench is filled. This is for smooth-walled rigid plastic pipes or tile drains.

A Flexible Corrugated Pipe can be laid by machines, which lay the pipes without excavating an open trench (trench less machines).

## TYPES OF FIELD DRAINAGE

The different field drainage methods can be classified as:

1. Horizontal drainage
    - i. Surface drainage
    - ii. Sub-surface drainage
        - a. Tile/Mole drains
        - b. Interceptor drains
2. Vertical drainage i.e. Tube wells

# VERTICAL DRAINAGE (DRAINAGE TUBEWELLS)

The areas where there is sweet water, the pumped water is directly utilized for irrigation.

In case of saline sub-soil water and availability of fresh surface water, the drainage water can be used for irrigation after mixing with appropriate ratio.

Drainage tube wells have larger pumping capacity.

In the Indus basin most of the drainage wells are having the 0.08 cumecs capacity.

In the Indus basin even 0.17 cumecs wells have been found economically viable.

Drainage tube wells are installed in groups in such a way that cone of depression of individual wells overlap each other sufficiently.

**The Conditions Required for Vertical Drainage**

If the following conditions are present, then vertical drainage is preferred over the surface or sub-surface methods:

a. An aquifer of adequate transmissivity;

b. Adequate vertical permeability between the root zone and the water table;

c. Extremely flat land, natural/surface drains are non existent;

d. Highly developed land where other forms of drainage may become expensive or not possible; and

e. Pumped drainage water can be utilized for irrigation purposes; etc.

***Example:***

Design a drainage tube well with following data:

Designed discharge, Q = 0.1 cumecs;

Depth of static water level (SWL) from ground level = 3 m;

Assume, drawdown (DD) due to daily pumping = 6 m.

***Solution:***

**a. Type of pump**

As pump is of bigger capacity (0.1 cumecs) and water has to be pumped from deeper depths, use turbine pump.

**b. Housing pipe**

***i. Diameter:*** Use 20 cm diameter pipe

***ii. Length:***

Static water level (SWL) = 3 m

Draw down (DD) = 6 m

Pumped water level (PWL) = SWL + DD = 3 + 6 = 9 m

Add 3 m to PWL to allow the errors in estimate of drawdown.

Therefore, Length of Housing pipe = 9 + 3 = 12 m

**c. Screen (Strainer)**

***i. Screen Type:*** Use fibre glass screen.

***ii. Screen Diameter, d:*** The diameter of screen should be same as for Housing pipe, i.e. d = 20 cm.

***iii. Screen Length, L:***

$$L = Q/q$$

Assume

V = 0.03 m/sec; Open area, P = 10%

Surface area per m length = $\pi d \times 100$

$= \pi \times 20 \times 100$

$= 6280\ cm^2$

Open area, $P = 10\% = 628\ cm^2 = 628 \times 10^{-4}\ m^2$

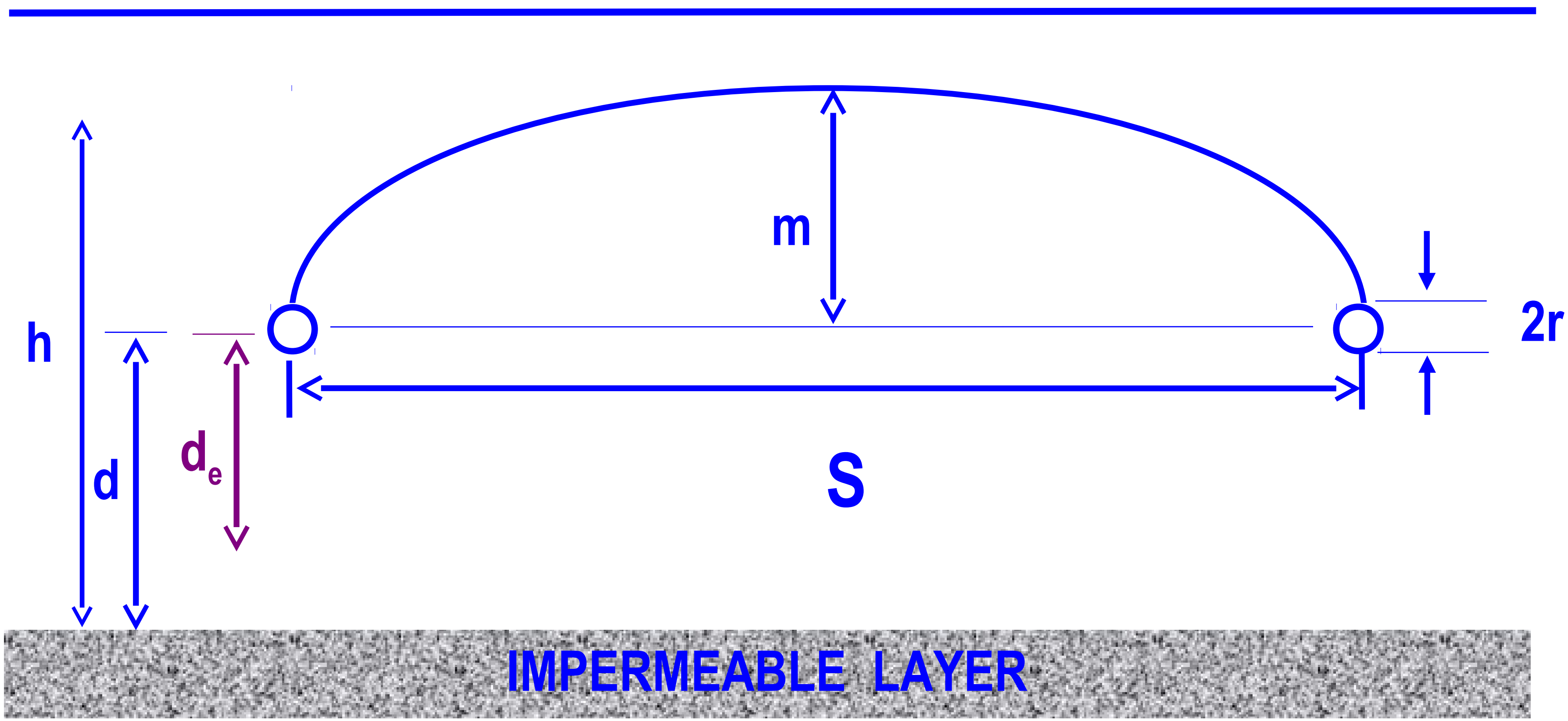
Flow through perforated area, $q = V \times P = 0.03 \times 628 \times 10^{-4}$

$= 0.0019$ cumecs

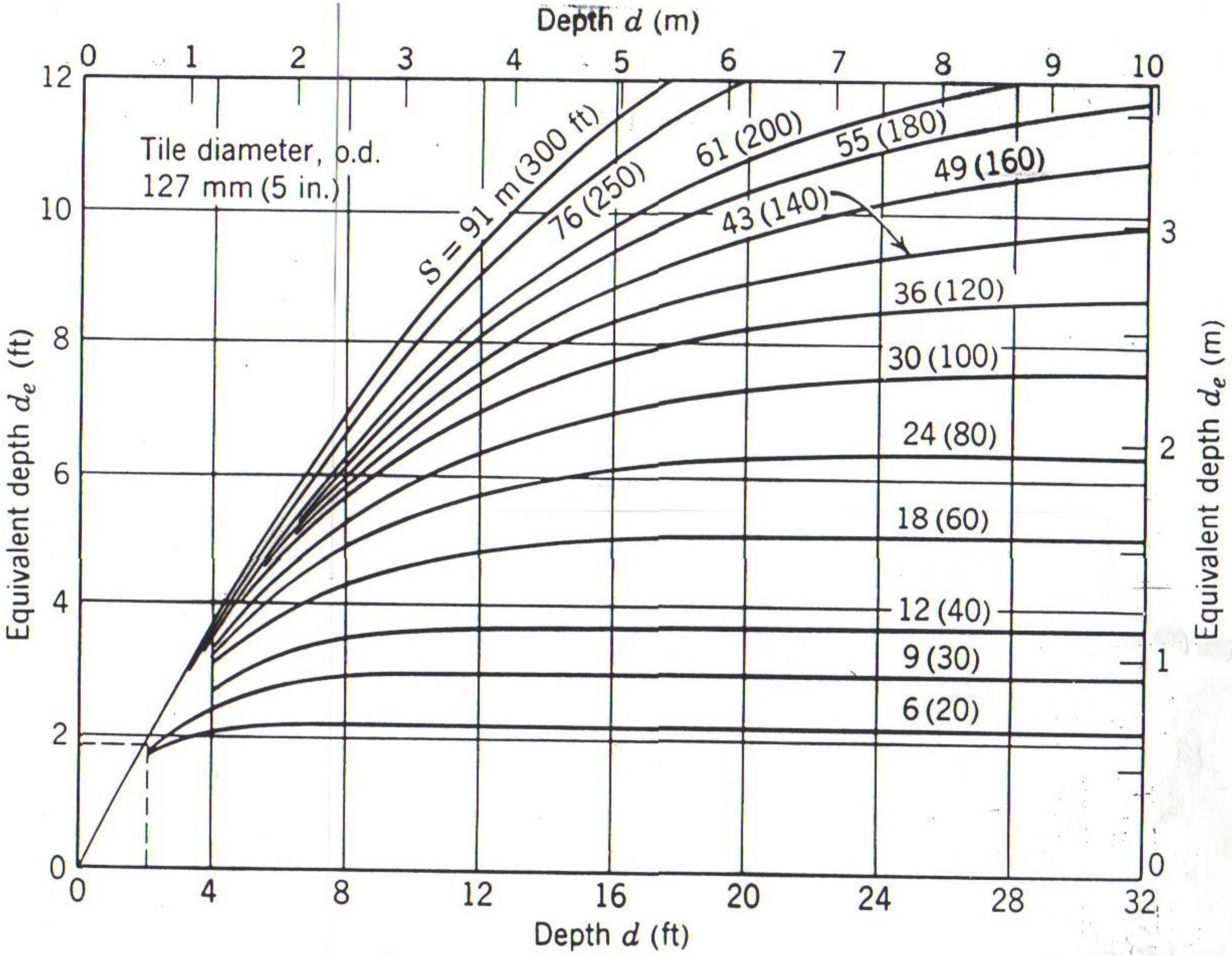
Now, $L = Q/q = 0.1/0.0019 = 53.08\ m$

Provide screen of length 55 m.

# Hooghoudt Equation




$$q = \frac{4Km(m + 2d_e)}{S^2}$$


Depth $d$ (m)
0
1
2
3
4
5
6
7
8
9
10
Tile diameter, o.d.
127 mm (5 in.)
S = 91 m (300 ft)
76 (250)
61 (200)
55 (180)
49 (160)
43 (140)
36 (120)
30 (100)
24 (80)
18 (60)
12 (40)
9 (30)
6 (20)
Equivalent depth $d_e$ (ft)
12
10
8
6
4
2
0
Equivalent depth $d_e$ (m)
3
2
1
0
0
4
8
12
16
20
24
28
32
Depth $d$ (ft)