## Chapter 4

# Subsurface Drainage

## 4-1 Definitions:

### 4-1-1 Water Table:

It is the highest level of subsurface water in the soil. The pressure at the water table is equal to the atmospheric pressure.

### 4-1-2 Water Logging:

It is the case when the water table arises close to the ground surface causing damage for the cultivated crops. That may be due to the increase of irrigation water, or the seepage from irrigation canals, or the upward movement of ground water under piezometric pressure in absence of drainage systems.

### 4-1-3 Subsurface Drain:

It is a pipe that is laid and buried at a sufficient depth from the ground surface. For direct drainage, the wall of the subsurface drain contains small holes to permit entering the water from the soil to the pipe. For the transporting subsurface drain, the wall of the pipe is solid of course.

### 4-1-4 Hydraulic Conductivity ( k ):

It is the velocity of water through the soil voids per unit hydraulic gradient.

$$k = \frac{v}{i} = \frac{q}{a\,i} \qquad \& \qquad \text{Dimensions: } [k] = \frac{L}{T}$$

Where, v: the velocity.

q: the discharge.

a: the cross sectional area.

### 4-1-5 Hydraulic Gradient ( i ):

It is the rate of loss of the hydraulic head along the distance.

### 4-1-6 Hydraulic Head ( h ):

It is the height of water above the drain level. It represents the energy causing water flow into the drain. The drain level is the center line of subsurface drains or is the water level in the field drains.

### 4-1-7 Porosity ( n ):

It is the percentage ratio of the volume of the voids of soil to the total volume of the soil formation.

### 4-1-8 Drainable (Effective) Porosity ( f ):

It is the percentage ratio of the volume of the water free to be drained to the total volume of the soil formation.

## 4-2 Planning of the Subsurface Drainage Network:

The subsurface drainage network consists of two types of pipes, the laterals and the collectors, as shown in figure (4-1).

The laterals, with equal spacing, take the water from the soil and deliver it to the collector drains. The collectors deliver the water to an open drain.

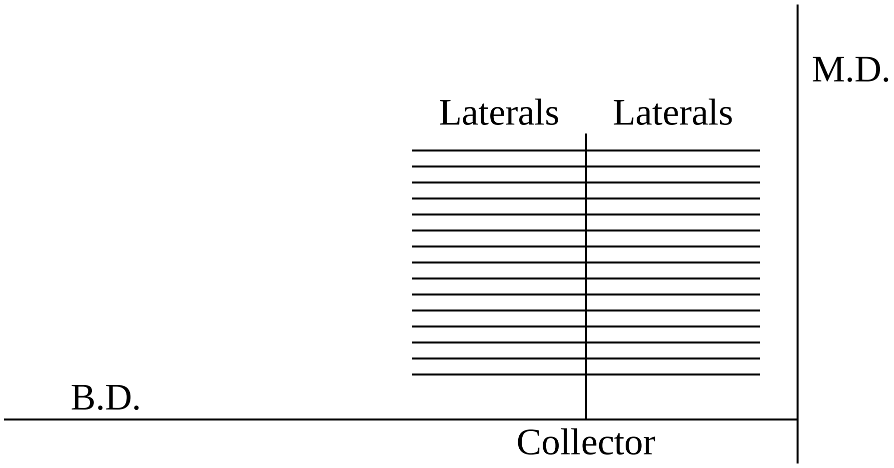



**Figure (4-1): Planning of the Subsurface Drainage Network.**

### 4-2-1 The Laterals:

It is preferred as possible that the laterals are laid between clear borders (mesqas, roads, --- etc.). Laterals are laid at the both sides of the collector with right angles. Laterals have a length of 200 - 250 m., a slope of 10 - 20 cm. / 100 m., and a constant diameter . The depth of laterals is 1.20 - 1.50 m. below the ground surface. Spacing between laterals is 30 - 70 m.

PVC corrugated pipes are commonly used for laterals. Water enters this type of pipes through small holes existed in the corrugation valis. So, water enters uniformly along the length of the PVC pipes.

Another type of pipes for laterals is cement pipes with lengths of 30 cm. The cement pipes are laid in series with longitudinal spacing of 1 - 2 mm. to permit entering of the water. The friction loss is small due to the smooth inner surface of the cement pipes.

### 4-2-2 The Collectors:

It is preferred as possible that the collectors are laid parallel to clear borders (mesqas, roads, --- etc.) avoiding intersections (with buildings, trees, ---- etc.). Collectors are aligned in general from the canals to the open drains according to the slopes of the ground surface. The length of collectors has not to exceed 2 km., otherwise open drains have to be established.

Slope of collectors is 2 - 10 cm. / 100 m. according to the diameter, as shown in table (4-1). The diameters of collectors can increase in the direction to the outfall due to the increase of the discharge. The common used diameters are 15, 20, 25, 30, 35, and 40 cm.

| Diameter (cm.) | Slope (cm./100m.) |
|---|---|
| 15 | 6 - 10 |
| 20 | 4 - 6 |
| 25 | 3 - 4 |
| 30 - 45 | 3 |
| 50 - 60 | 2 - 3 |

**Table (4-1): Slopes of Collectors.**

The depth of collectors has to be minimized as possible in order to reduce the cut requirements and also to achieve free clearance of about 25 cm. at the outfall of collectors into the open drains. However, the depth of the outfall of the collector has not to exceed 2.5 m. below the average level of the ground surface.

Spacing between collectors is 400 - 500 m. Cement pipes are commonly used for collectors with lengths of 75 m.

It has to be noted that collectors can be divided into two zones: dewatering and transporting zones. The dewatering zone has variable discharges from the laterals, while the transporting zone has a constant discharge. Also, the diameter of collector is variable in the dewatering zone, while it is constant in the transporting zone.

### 4-2-3 Manholes:

Manholes are used for maintenance purposes with maximum spacing of 180 m. and common diameters of 75 - 100 cm. They are used at the connections between the laterals and the collectors, at the locations of changing the diameters of collectors, and at the outfalls of the collectors.

### 4-2-4 Filters:

Filters are used generally for the laterals. Gravel filter is used for soil with clay ratio < 40 %, where it is laid with 5 cm. thickness below and above the laterals. Artificial fibers are used recently to form filters around the pipes of laterals. This process is executed in the factory of pipes.

## 4-3 Design of the Subsurface Drainage Network:

### 4-3-1 The Laterals:

Spacing between laterals depends on the soil properties, required water table level after drainage, and the drainage factor. The drainage factor depends on the irrigation efficiency (consequently the quantity of water losses) and the seepage water (from irrigation canals or irrigated lands or the ground aquifer).

For calculating the spacing between laterals, the drainage factor is taken 1 mm./day in general. In case of rice, the drainage factor may be considered 2 mm./day.

There are two cases for calculating the spacing between laterals; the steady state flow and the unsteady state flow.

***(A) Steady State Flow:-***

The case of steady state flow assumes that the rates of both supplied and drained water do not change with time, as shown in figure (4-2).

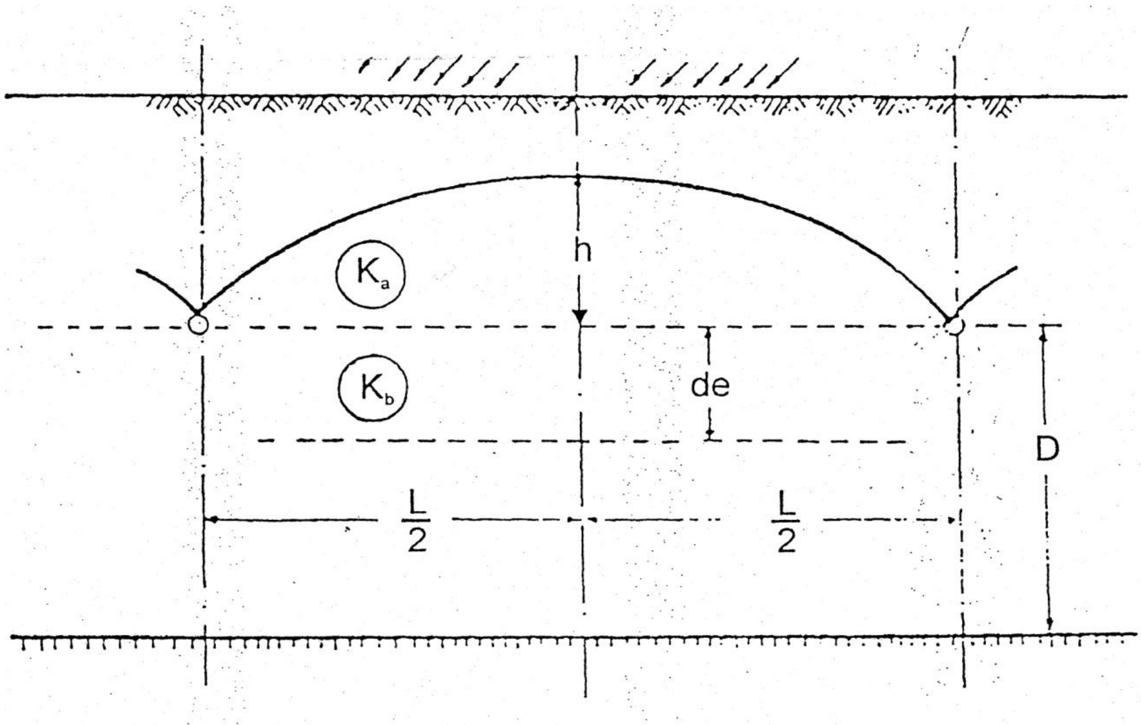



**Figure (4-2): Steady State Flow for Laterals.**

The common formula used to determine the spacing between laterals is Hooghoudt equation:

$$L^2 = \frac{4\, k_a\, h^2 + 8\, k_b\, d_e\, h}{q}$$

Where, L: Spacing between laterals (m.).

$k_a$: Hydraulic conductivity for soil above laterals level (m./day).

h: Hydraulic head = height of water table above laterals level at the middle distance between two laterals (m.).

q: Drainage factor (m./day).

$k_b$: Hydraulic conductivity for soil below laterals level (m./day).

$d_e$: The equivalent depth to the impermeable layer below laterals level (m.).

It has to be noted that the hydraulic conductivity is constant above and below laterals level ($k_a = k_b = k$ ) in case of homogeneous soil.

The equivalent depth ($d_e$ ) depends on the conversion of the flow lines of water approaching the laterals. This conversion depends on the real depth of the impermeable layer below laterals level (D), radius of laterals (r), and the spacing between laterals (L). However, the value of $d_e$ is determined either from table (4-2) or using Moody equation:

If $0 < (D/L) < 0.31$,
then

$$d_e = \frac{D}{1 + [ D/L ] [ 2.55 \ln (D/r) - 3.5 ]}$$

If $(D/L) > 0.31$,
then

$$d_e = \frac{L}{2.55 [ \ln (L/r) - 1.15 ]}$$

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

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

**Table (4-2): Values of ($d_e$) for Laterals of 20 cm Diameter.**

***(B) Unsteady State Flow:-***

The case of unsteady state flow takes into consideration the time necessary to reduce the water table level from its maximum value to the required value. As shown in figure (4-3), water table level increases to its maximum value directly after water supply to the soil. Water table level decreases to its required value due to the subsurface drainage process.

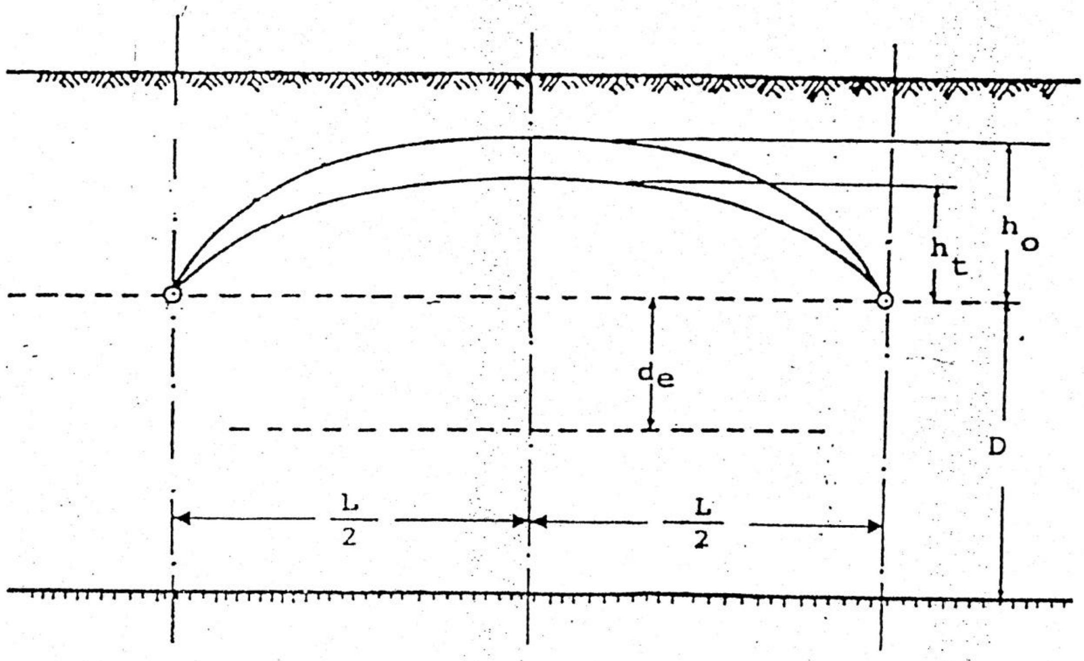



**Figure (4-3): Unsteady State Flow for Laterals.**

The common formula to determine the spacing between laterals is Glover - Dumm equation:

$$L^2 = \frac{(\pi^2 / f)(k\, d_e\, t)}{\ln[1.16\,(h_o / h)]}$$

Where, L: Spacing between laterals (m.).

$\pi = 3.14$

f: Drainable (effective ) porosity ( % ).

k: Hydraulic conductivity for soil (m./day).

$d_e$: The equivalent depth to the impermeable layer below laterals level (m.).

t: Time necessary to reduce water table level from $h_o$ to h (day).

$h_o$: Maximum height of water table above laterals level at the middle distance between two laterals (m.).

h: Required height of water table above laterals level at the middle distance between two laterals (m.).

## 4-3-2 The Collectors:

The common formula to design the diameters of collectors is Wessiling equation:

$$\mathbf{Q = q\,B\,l = 89\,\eta\,d^{2.714}\,i^{0.572}}$$

Where, Q: Total discharge of the collector ($m.^3$/sec.).

q: Drainage factor for collectors (m./sec.).

B: Width of the area served by the collector (m.).

l: Length of collector (m.).

$\eta$: Factor of safety for sedimentation ( % ).

d: Diameter of collector (m.).

i: Slope of collector (m./m.).

For calculating the capacity of collectors, the drainage factor is 2 - 4 mm./day (2 mm./day for middle Egypt and south of Delta, 3 mm./day for middle of Delta, and 4 mm./day for north of Delta affected by piezometric pressures causing upward movement for the ground water).

The length of collector is determined according to its diameters. The obtained value ( l ) from Wessiling equation has to be reduced by a factor of safety ( p ) for using different diameters. So, the actual length ( $l_{act}$ ) is:

$$\mathbf{l_{act} = p \times l}$$

<u>Where,</u> p = 0.80 if only 2 diameters are used.

p = 0.70 if 3 or more diameters are used.

The factor of safety for sedimentation ( $\eta$ ) is considered because the capacity of collectors is decreased with time due to the sedimentation of some materials into the pipes (soil particles, chemical materials, --- etc.). However, $\eta = 0.75$ for $d \geq 0.15$ m.

As mentioned before (item 4-2-2), sometimes a transporting zone of collector may be needed. In order to design the transporting zone, the equation will be:

$$\mathbf{Q = q\, B\, l = 50\, \eta\, d^{2.714}\, i^{0.572}}$$

<u>where,</u> l = the length of the dewatering zone of collector (m.).

**Example:**

An area of 400 m. x 700 m. is in need of a subsurface drainage system. The area is located along an open drain which is parallel to the short side. The rates of irrigation water, surface runoff, deep seepage, and the crop requirements are 0.005, 0.001, 0.001, and 0.002 m./day respectively.

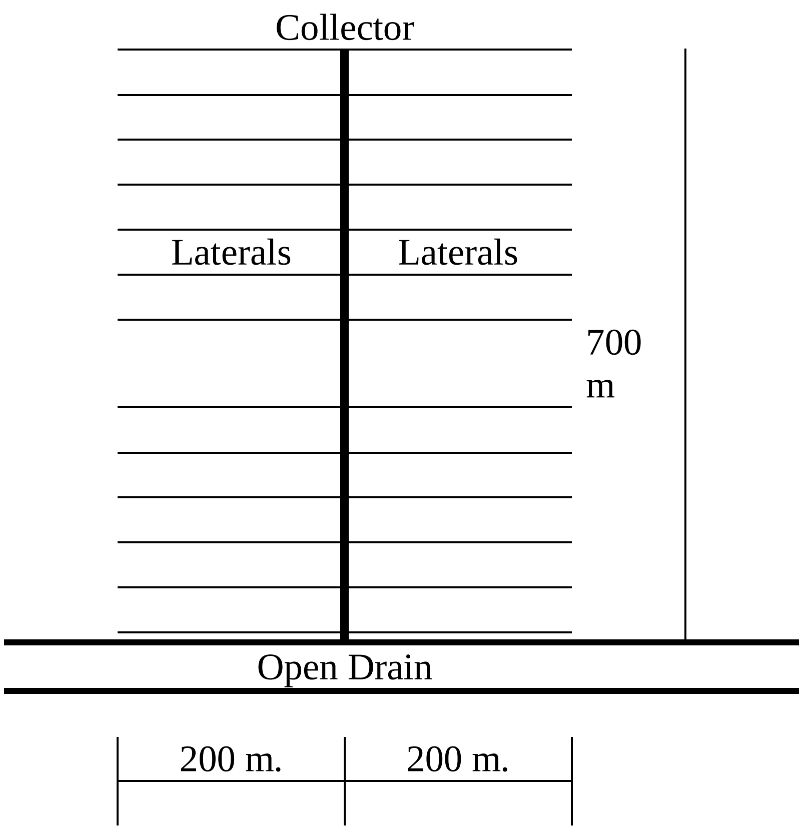
The hydraulic conductivity of the soil is 1 m./day. The depths of laterals (10 cm. diameter) and the impermeable layer are 1.2 m. and 3.7 m. below the ground surface. The water table level is required to be 1 m. below the ground surface. For collectors, the drainage factor is 4 mm./day and the average slope is 6 cm./100 m.

1- Draw a planning for the subsurface drainage system ?

2- Design the laterals and the collectors ?

**Solution:**

**1- The Planning:**



The subsurface drainage system is composed of one collector (700 m. long) and laterals (each of 200 m. long) on its both sides. The collector discharges its water into the open drain.

## 2- The Design:

1- The Laterals:

*To get the drainage factor (q):*

Input = Output

Irrigation water = Surface runoff + Deep seepage + Crop requirements + q

0.005 = 0.001 + 0.001 + 0.002 + q

q = 0.001 m./day

*To get spacing between laterals:*

For steady state flow, Hooghoudt equation:

$$L^2 = \frac{4\,k_a\,h^2 + 8\,k_b\,d_e\,h}{q}$$

$k_a = k_b$ = 1 m./day & h = 0.2 m. & D = 2.5 m.

$$L^2 = \frac{[\,4 \times 1 \times (0.2)^2\,] + [\,8 \times 1 \times d_e \times 0.2\,]}{0.001}$$

$$\therefore L^2 = 1600\,d_e + 160$$

| $L_{assumed}$ | $d_e$ | $L_{calculated}$ |
|---|---|---|
| 30 | 1.79 | 55 |
| 50 | 2.02 | 58.2 |
| 60 | 2.06 | 58.8 |
| 58 | 2.05 | 58.65 |

$\therefore L = 58$ m.

Number of laterals = 700 / 58 = 12.07 ≅ 12

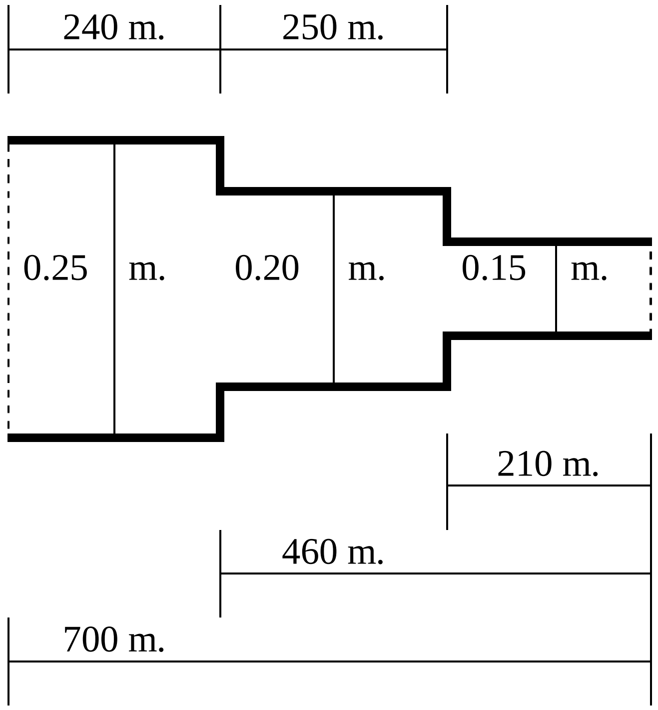
2- The Collector:

$$Q = q\,B\,l = 89\,\eta\,d^{2.714}\,i^{0.572}$$

$$\frac{4}{1000 \times 24 \times 60 \times 60} \times 400 \times l = 89 \times 0.75 \times d^{2.714} \times [6/(100 \times 100)]^{0.572}$$

$$\therefore l = 51754.43\,d^{2.714}$$

| **d** | **0.15** | **0.20** | **0.25** | **0.30** |
|---|---|---|---|---|
| **l** | 300.5 | 656.1 | 1202.1 | ----- |
| **$l_{act}$ , (p=0.7)** | 210 | 460 | 700 | ----- |



**Exercise:**

For the area given in the last example:-

1- Design the laterals and the collector, where the depth to the impermeable layer is great ?

2- Design the laterals and the collector, where the open drain is located at the same direction but it is 300 m. far from the area ?

3- Compare the results of the three cases ?

4- Give your comment concerning the three cases ?