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Irrigation and Drainage

Lecture No: 46 Subsurface Drainage Design

Dr. DAMODHARA RAO MAILAPALLI

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Drainage Design Principles

The Design of a Subsurface Drainage system Requires Developing Criteria that:

- ✓ Specify the operation of the system and the physical configuration that fulfill the drainage objective(s).
- ✓ Consider irrigation and drainage systems as an integrated water management system.
- ✓ Minimize deep percolation losses through improved irrigation water management (source control)
- ✓ Characterized by establishing the water-table depth at the mid-point between laterals and the drainage coefficient (that specifies the maximum volume, expressed as depth of water to be removed in a 24-h period)
- ✓ Specify option regarding reuse of drainage water for irrigation or stimulation of in situ use by crop through control of water table.

Drainage Design Steps

Investigating- soil profile, geo-hydrologic and groundwater quality

↓

Measuring - quality of proposed irrigation water

↓

Estimating - Sources of drainage water other than irrigation

↓

Reviewing and analyzing - climatic data of the area

↓

Selecting - appropriate crop(s)/cropping pattern

Contd..

Drainage Design Steps

Selecting - appropriate crop(s)/cropping pattern

Measuring- hydraulic conductivity of the root zone soil

Estimating - drainage coefficient

Optimizing – drain depth placement and lateral drain spacing

- Drain depth is specified and the spacing is calculated based on the recharge schedule and the mid-point water-table depth criteria.
- Drain depth is varied to calculate a range of depths and spacing, and economic analysis is performed for each case.

Contd..

Drainage Design Steps

Determining - lateral pipe size and main pipe size

↓

Designing - drain envelop material

↓

Designing - the drainage disposal system or reuse of drainage water

↓

Design the pump size to pump the maximum drainage discharge from the field

Note

✓ The USBR (United States Bureau of reclamation) recommends installation of drains at a depth of 2.4 m, if possible, to provide a balance between the system cost and spacing.

Estimation of Drainage Requirement or Drainage Coefficient

For estimation of drainage requirement (or drainage intensity, or drainage coefficient), following steps may be followed:

- ✓ Collect long-term rainfall and other weather data for the project area
- ✓ Calculate daily average rainfall, evaporation, and evapotranspiration rate for the target crop season
- ✓ Perform water-balance
- ✓ Under natural rainfall condition, water balance can be expressed as

$$P = ET + R + D$$

or

$$D = P - ET - R$$

Where, P = rainfall rate (mm/d); ET = evapotranspiration rate (mm/d); R = surface runoff amount, mm/d

D = deep percolation or subsurface drainage amount (mm/d)

- ✓ The “D” value will indicate the drainage coefficient or drainage requirement.

Drain Spacing

Depth and Spacing

- ✓ Depth and spacing should be such that the water table midway between the drains remains below the root-zone
- ✓ Deeper the drains, wider the spacing and less is the number of drains (Economical)
- ✓ Depth & spacing of sub-surface drains (pipe drain) depend on
  - o Hydraulic conductivity of soil
  - o Kind of crop
  - o Outlet condition
  - o Agronomic practices

Drain Spacing

Relationship among Drain properties - soil characteristics – depth of water table and the corresponding discharge derived under

- ✓ Steady-state condition
- ✓ Unsteady-state condition

Steady state:

Rate of Recharge to ground water (GW) = Rate of discharge through pipe drain

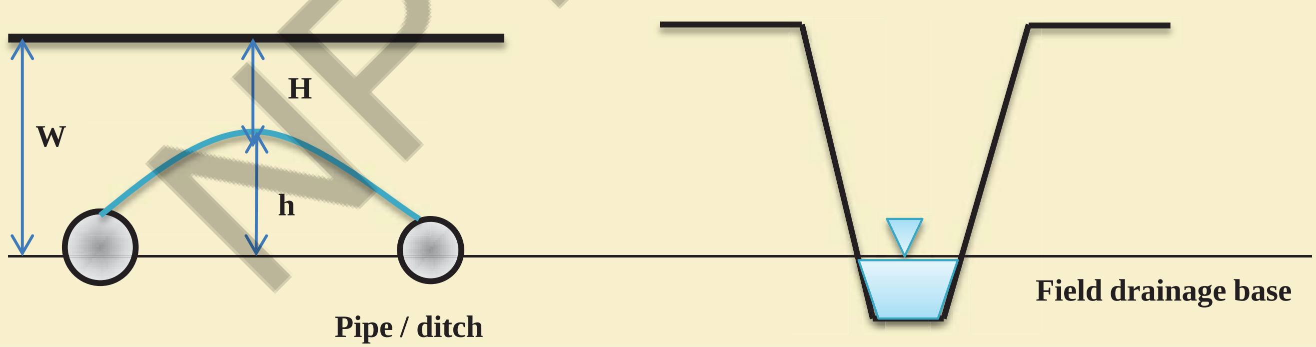
Hydraulic head (Height of water table between the drains) remains constant (h=constant)

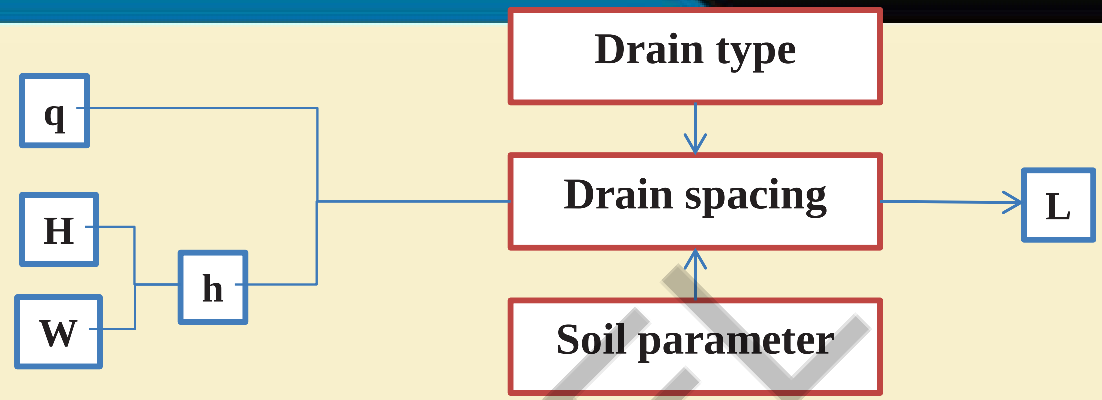
Unsteady state:

Rate of Recharge varies with time. Flow of GW towards drains is not steady

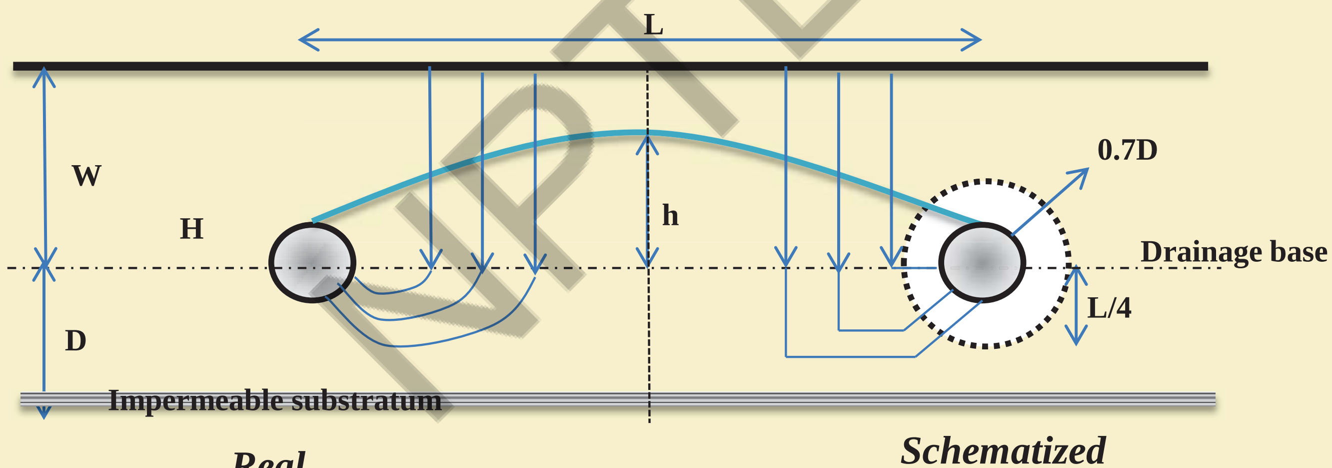
Drain Spacing

- ✓ **Steady state formula**
  - o Steady constant flow occurs through the soil to the drain
  - o Discharge equals to recharge
  - o 'h' constant
- ✓ **Unsteady state formula**
  - o All the parameters vary





procedure for determination of drain spacing for parallel pipe drainage



Typical pipe drainage flow pattern

Hooghoudt formula (Steady state)

Hooghoudt's formula is based on Dupuit-Forcheimer assumptions. The assumptions of Hooghoudt's formula can be summarized as follows:

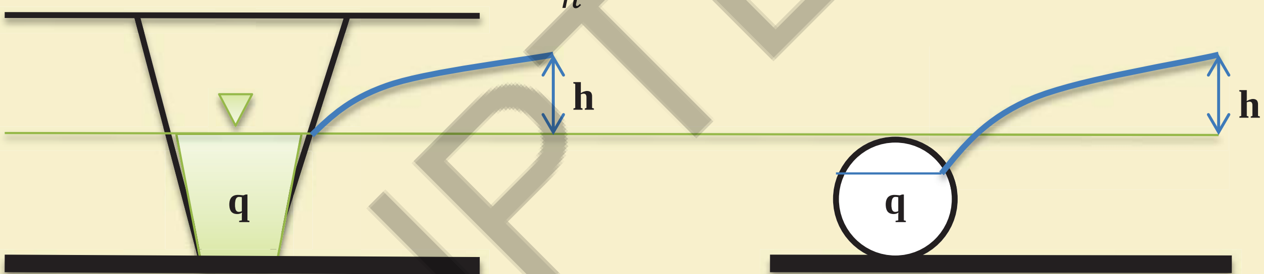
- ✓ The soil is homogeneous and isotropic
- ✓ Darcy's law is valid for flow of water through soil into the drain
- ✓ An impermeable layer underlies the drain
- ✓ The hydraulic gradient at any point in the flow regime is equal to the slope of water-table above the point
- ✓ The diameter of the drain is small compared to saturated thickness below the drain
- ✓ The drains have no entrance resistance
- ✓ The flow through drain is half-full

Hooghoudt formula (steady-state)

- ✓ Only head loss due to horizontal (h_h) and radial flow (h_r) to the pipes are considered
- ✓ Losses due to vertical flow is usually insignificant

$$h = h_h + h_r$$

$$h = q\frac{{L_h}^2}{8KD_h} + \frac{qL}{\pi K}\ln\frac{aD_r}{u}$$



Hooghoudt conceived that a Parallel open ditch system with the ditches reaching to the impermeable substratum could generate the same q for the same water table head h as an identically spaced pipe drain system by reducing depth **D** to the impermeable stratum.

Equivalent flow (horizontal):

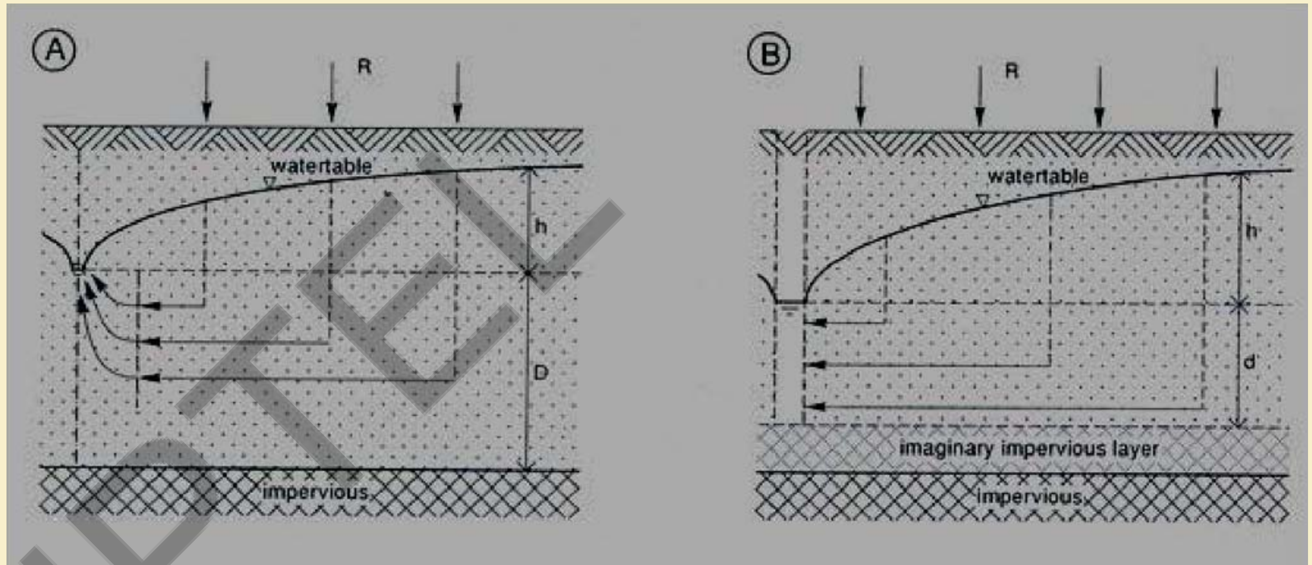
h = h_h^*(equivalent) = $q\,\frac{L_h^{\,2}}{8KD_h^{\,*}}$

Since d < D, $h_h^* > h_h$, $D_h^* \approx d + h/2$

$$h = q\,\frac{L^2}{8K(d + h/2)}$$

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

The horizontal flow takes place partly below the drainage base (average thickness = d) and partly above the drainage base (thickness of this zone = h/2)



Transformation underlying the Hooghoudt formula

- ✓ If both zones have different K,

$$q = \frac{8K_2dh}{L^2} + \frac{4K_1h^2}{L^2}$$

Where, K_1 = upper zone hydraulic conductivity; K_2 = lower zone hydraulic conductivity

'd' is determined as,

$$d = \frac{D}{\frac{8D}{\pi L}\ln\frac{D}{u}+1} \qquad \text{for } D > L/4$$

$$d = \frac{\pi D}{8\ln\frac{L}{u}} \qquad \text{for } D < L/4$$

Where **u** is the wet entry perimeter of the drain

✓ Hooghoudt equation

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

Horizontal flow above drain level $$q = \frac{4Kh^2}{L^2}$$ (Rothe equation)

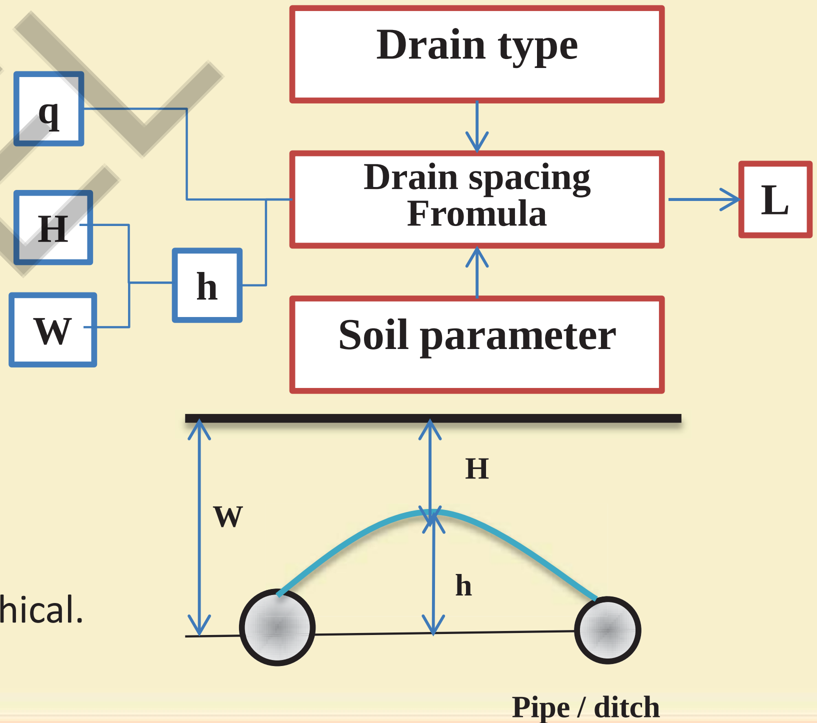
Horizontal flow below drain level $$q = \frac{8Kdh}{L^2}$$

For two layer soil profile $$q = \frac{8K_2dh}{L^2} + \frac{4K_1h^2}{L^2}$$

Use of Hooghoudt Formula

Procedure for determining drain spacing

- ✓ Formulation of basic design criteria (q and H)
- ✓ Establishment of field drainage base W; and h=W-H
- ✓ Establishment of soil parameters K and D
- ✓ Selection of drain type (pipe or ditch) and determination of ‘u’
- ✓ Determine drain spacing by Hooghoudt formula



The solution of Hooghoudt formula is either trial and error or graphical.

Trial and Error Solution

- ✓ Since L depends on d; d depends on L, Hooghoudt equation is an implicit equation.
- ✓ Assume a value of L and determine d from the equation

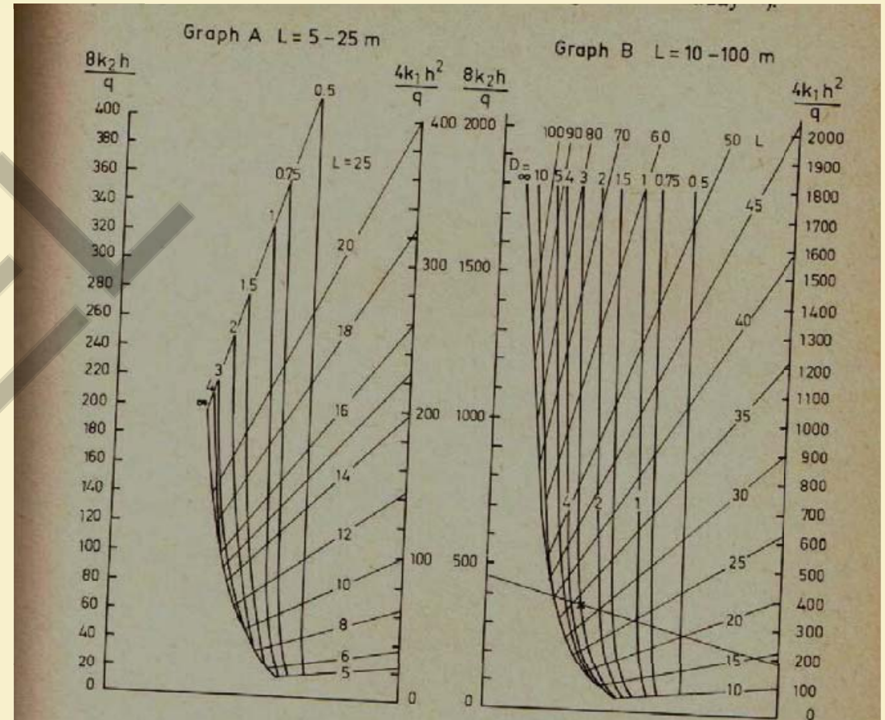
$$d = \frac{D}{\frac{8D}{\pi L}\ln\frac{D}{u}+1} \qquad \text{for } D > L/4$$

$$d = \frac{\pi L}{8\ln\frac{L}{u}} \qquad \text{for } D < L/4$$

- ✓ Solve the Hooghoudt formula for L and compare the value with the assumed value of L
- ✓ Modify the value of 'L' and repeat the steps until the calculated and assumed values are equal.

Graphical Solution

1. Find $\frac{8K_2h}{q}$ & $\frac{4K_1h^2}{q}$
2. Draw a line connecting these two values
3. Mark the point where the line crosses the 'D' value
4. Find L value corresponding to this (i.e. parallel to other 'L' lines)



For pipe drains with $r_o = 0{\cdot}04–0{\cdot}10$ m, $u = 0{\cdot}30$ m*

FIGURE 7.8 *Nomograph for the solution of the Hooghoudt drain spacing formula* (VAN BEERS 1965)

Thank You!!

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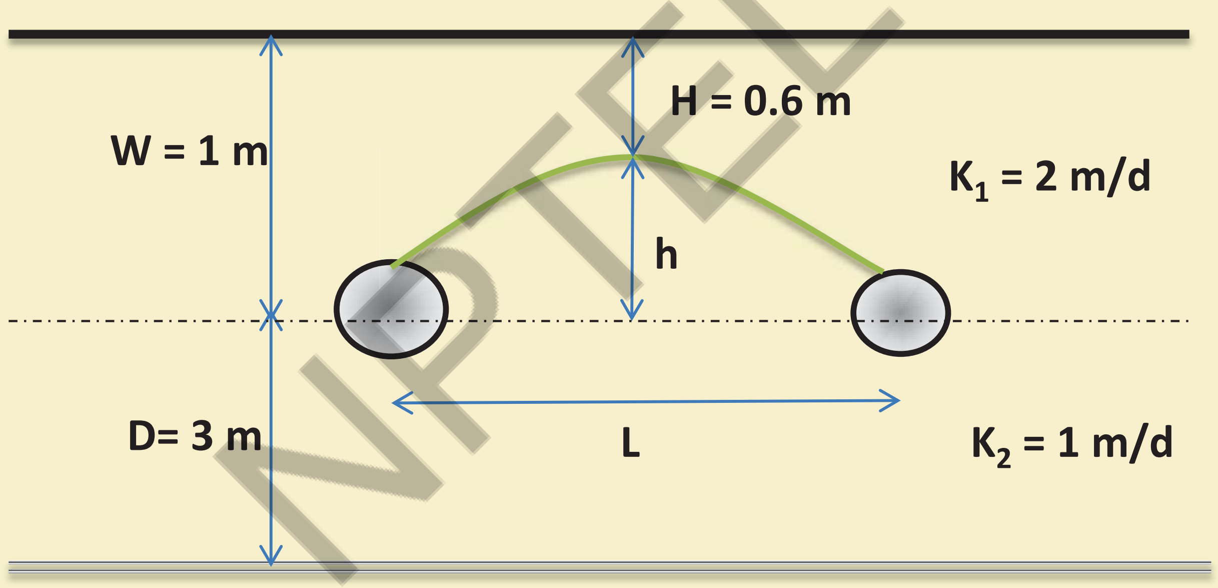
Exercise 47.1:

Determine the required drain spacing for the basic design criteria q = 7 mm/d, H= 0.6 m, pipe with OD = 0.2 m and u = 0.3 m



Trial and Error solution:

For first trial L = 40 m, with D = 3.0 m and u = 0.3m

$$q = \frac{8K_2dh}{L^2} + \frac{4K_1h^2}{L^2}$$

$$d = \frac{D}{\frac{8D}{\pi L}\ln\frac{D}{u}+1} \quad \text{for D > L/4}$$

$$d = \frac{\pi D}{8\ \ln\frac{L}{u}} \quad \text{for D < L/4}$$

$$d = \frac{\pi D}{8\ \ln\frac{L}{u}}$$

$$= \frac{\pi\times 40}{8\ \ln\frac{40}{0.3}}$$

= 2.15 m

$$L^2 = \frac{4K_1h^2}{q} + \frac{8dK_2h}{q}$$

$$= \frac{4\times 2\times 0.4^2}{0.007} + \frac{8\times 1\times 2.15\times 0.4}{0.007}$$

= 34 m

For second trial L = 32 m,

$$d = \frac{\pi D}{8\ \ln\frac{L}{u}}$$

$$= \frac{\pi \times 34}{8\ \ln\frac{34}{0.3}}$$

= 2 m

$$q = \frac{8K_2dh}{L^2} + \frac{4K_1h^2}{L^2}$$

$$d = \frac{D}{\frac{8D}{\pi L}\ln\frac{D}{u}+1}$$ for D > L/4

$$d = \frac{\pi D}{8\ \ln\frac{L}{u}}$$ for D < L/4

$$L^2 = \frac{4K_1h^2}{q} + \frac{8dK_2h}{q}$$

$$= \frac{4\times2\times0.4^2}{0.007} + \frac{8\times1\times2\times0.4}{0.007}$$

= 33 m

Final solution = 33 m

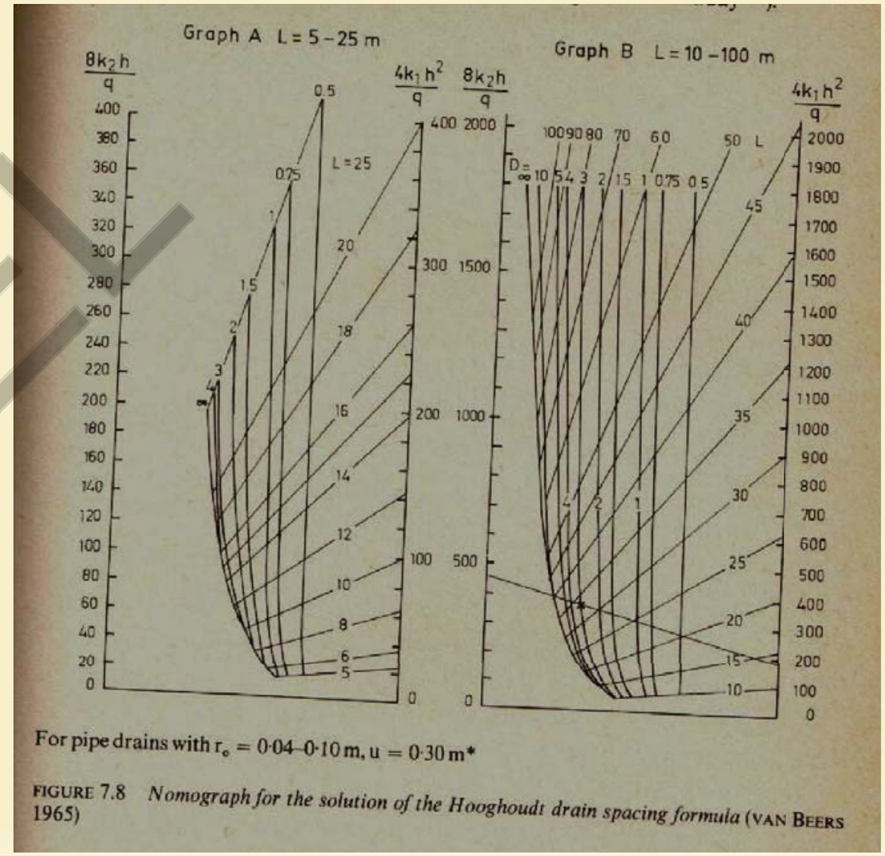
Graphical solution:

Find, $\frac{8K_2h}{q} = \frac{8\times1\times0.4}{0.007}$ = *457*

& $\frac{4K_1h^2}{q} = \frac{4\times2\times0.4^2}{0.007}$ = 183

Connect 183 and 457 points in the graph.

When the connecting line intersects with **D = 3 m, read L = 33 m**



Notes on Hooghoudt Formula

1. The spacing 'L' increases when
   - ✓ *K* increases
   - ✓ *q* decreases
   - ✓ *D* increases (less influence when L is small)
   - ✓ *h* increases (increase of W or decrease of H)

$$q = \frac{8K_2dh}{L^2} + \frac{4K_1h^2}{L^2}$$

$$d = \frac{D}{\frac{8D}{\pi L}\ln\frac{D}{u}+1} \quad \text{for } D > L/4$$

$$d = \frac{\pi D}{8\ln\frac{L}{u}} \quad \text{for } D < L/4$$

2. **Simple Hooghoudt formula**: When the drainage flow above the drainage base is neglected

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

(useful when h is smaller or the stratum below the base is more favorable to drain)

3. Where a significant vertical flow is to be expected and relevant flow zone has a very low hydraulic conductivity (h-h_v), instead of h, should be used in the Hooghoudt equation

Limitations of Hooghoudt Equation

- ✓ The Hooghoudt's equation assumes an elliptical water table, which occurs below the soil surface.

- ✓ Due to excess precipitation, water table may rise to the soil surface, and ponded water remains on the surface for relatively long periods.

- ✓ For such conditions, the application of Hooghoudt's equation based on the D–F assumptions will not hold.

- ✓ The streamlines will be concentrated near the drains with most of water entering the soil surface in that vicinity.

Estimation of Equivalent Depth

- ✓ **Hooghoudt's (1940)** equation for equivalent depth (d_e)

$$d_e = \frac{\pi L}{8 \ln \frac{L}{\pi r_0}}$$

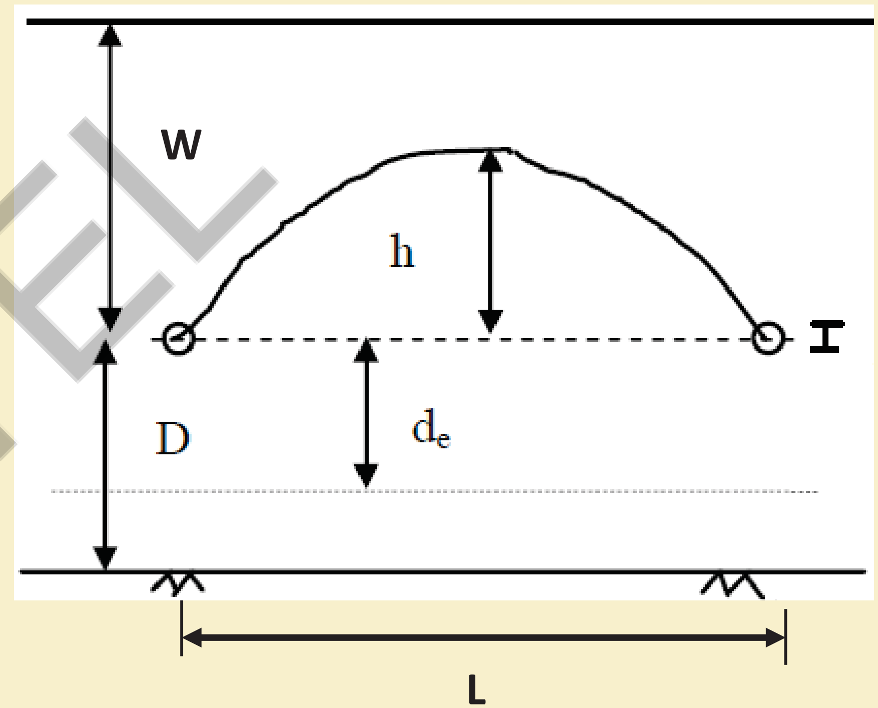
- ✓ **Van Beers** equation for equivalent depth (d_e) is (ILRI, 1973):

$$d_e = \frac{D_s}{1 + \frac{8D}{\pi L} \times \frac{8Ds}{\pi^2 r_0}}$$

- ✓ **Moody** (1966) equation for equivalent depth (d_e) is

$$d_e = \frac{D}{1 + \left(\frac{D}{L}\right)\left[\frac{8}{\pi} \ln \frac{D}{r_0} - 3.4\right]}, \qquad 0 < \frac{D}{L} \leq 0.3$$

$$d_e = \frac{L}{\frac{8}{\pi}[\ln \frac{L}{r_0} - 1.15]}, \qquad \frac{D}{L} > 0.3$$



Where, r_0 is the radius of drain; D is the drain depth; Ds is the thickness of the aquifer below drain level

Donnan's Formula

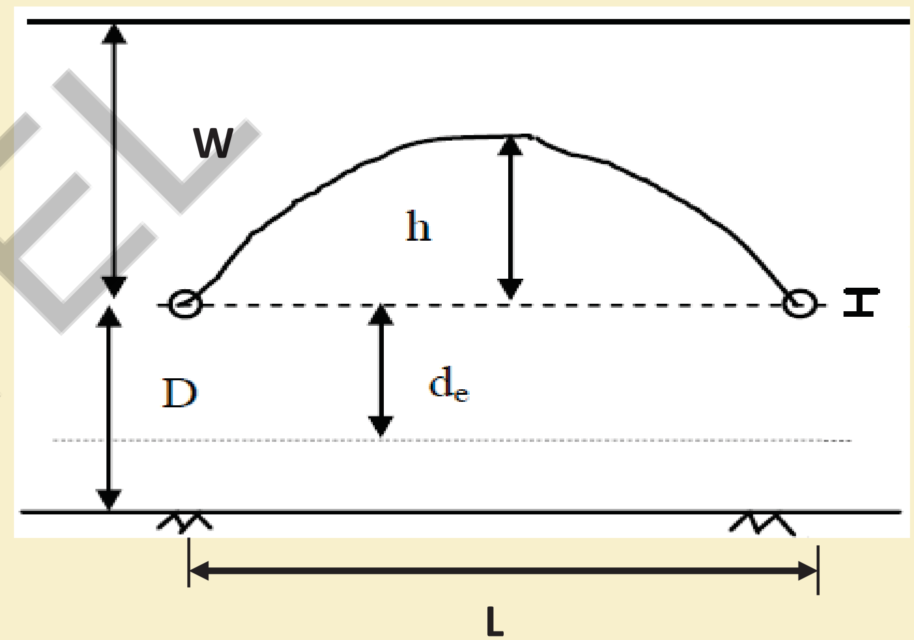
- ✓ **Donnan** proposed the following formula for parallel drain spacing:

$$L^2 = \frac{4k}{q}[(D + h)^2 - D^2]$$

Solving for algebraic functions, the above equation reduces to

$$L^2 = \frac{4kh^2}{q} + \frac{8kDh}{q}$$

which is similar to Hooghoudt's equation.



Ernst Equation

- ✓ It is applicable for two - layered soil profile having different K values
- ✓ Position of the drain level may be above or below the interface of the two layers
- ✓ it considers radial flow
- ✓ $K_t < K_b$

Application of Hooghoudt Equation

- ✓ It is applicable for homogeneous soil and for two - layered soil profile having different K values
- ✓ Drain level coincides with the interface of the two layers
- ✓ It does not allow radial flow towards the drain
- ✓ $K_t > K_b$

Ernst Equation

Total hydraulic head required (h)= $h_v+h_h+h_r$

$$h = q\left(\frac{D_v}{K_v} + \frac{L^2}{8\sum(KD)_h} + \frac{L}{\pi K_r}\ln\frac{aD_r}{u}\right)$$

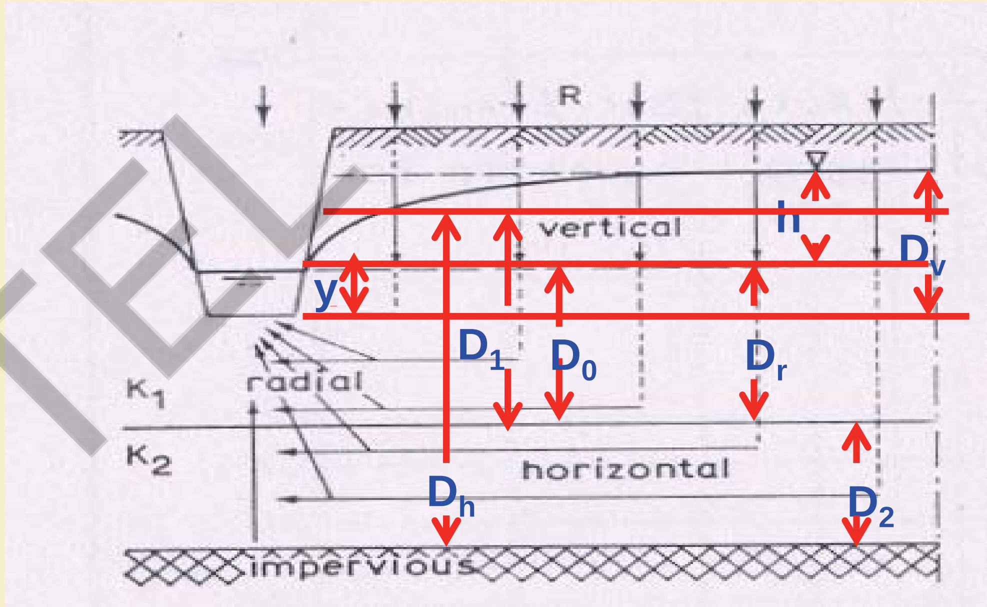
Where, D_o or (D_o+D_2) & $D_r \le L/4$

D_v = thickness of the layer through which vertical flow occurs;

= y+h for open ditch; = 'h' for pipe drain

D_h= average thickness of the layer through which horizontal flow takes place

D_r = thickness of the layer through which radial flow takes place



Where,

D_1 = avg. thickness of the top layer below the water table with permeability K_t

D_2= thickness of the bottom layer with permeability K_b

D_0 = thickness below drain level up to the interface of both the layers/impermeable layer in which the drains are located.

a = geometry factor of radial resistance

u =wetted perimeter of the drain

About 'u'

✓ pipe drains run half full. So,

$$u = \frac{2\pi r_0}{2} = \pi r_0$$

- ✓ For open ditch with trapezoidal cross section,

$$u = b + 2y\sqrt{Z^2 + 1}$$

- ✓ Pipe drains in trench,

$$u = b + 2r_0$$

- ✓ Pipe drains surrounded by envelope,

$$u = b + 2(2r_0 + m)$$

Where,

b = bottom width,

y = depth of water in the drain,

z = side slope of the drain

m =height of envelope over the pipe

b = width of the trench

About 'a'

It is a function of soil profile and position of the drain

Drain in the bottom layer, a = 1 , since radial flow is restricted to this layer

If drain is in the top layer, value of 'a' depends on the ratio of K_b and K_t

If $\frac{K_b}{K_t} < 0.1$; Bottom layer is considered impervious. So, soil profile becomes one layer and 'a' = 1

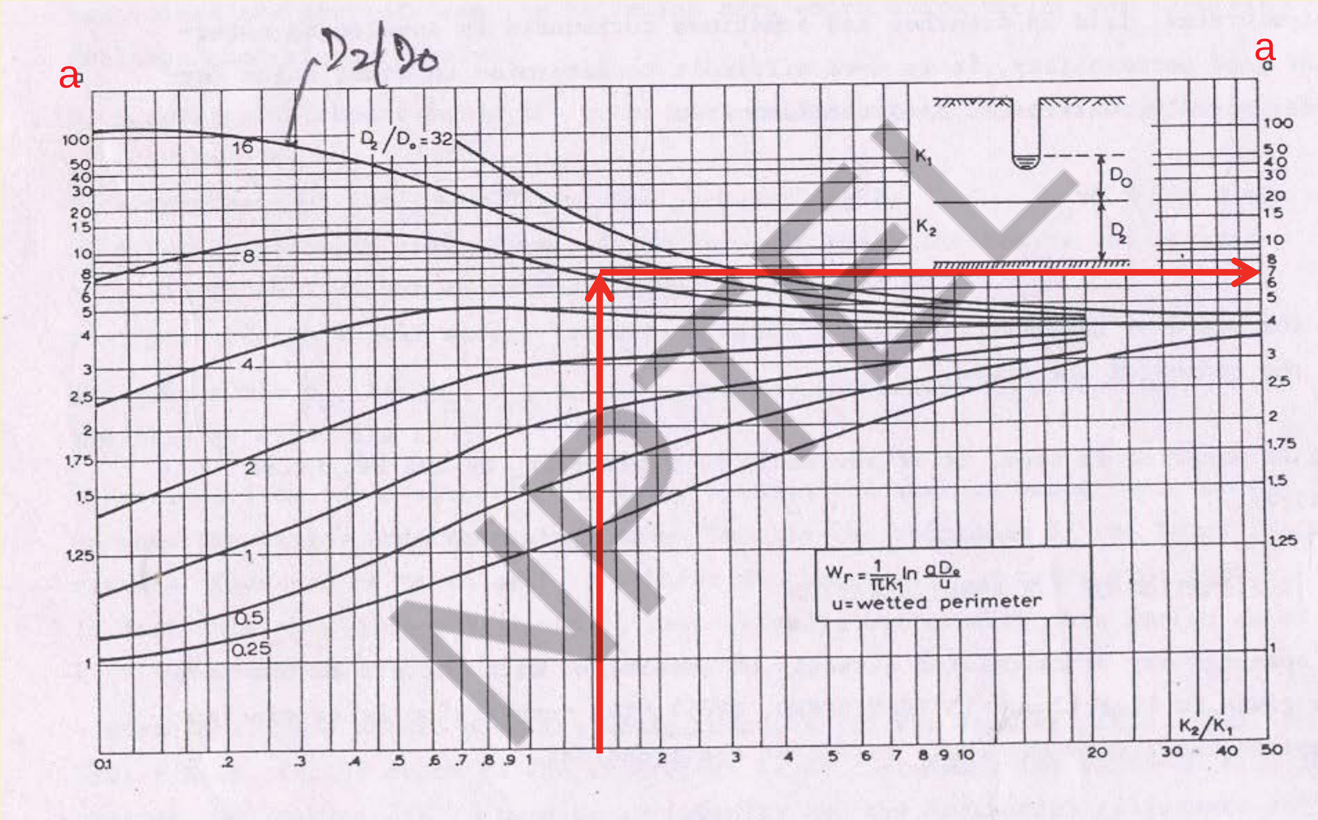
$0.1 < \frac{K_b}{K_t} < 50$ 'a' value is decided based on $\frac{K_b}{K_t}$ and $\frac{D_b}{D_t}$ values by **relaxation method** and **Nomographs**

$\frac{K_b}{K_t} > 50$ then, a = 4

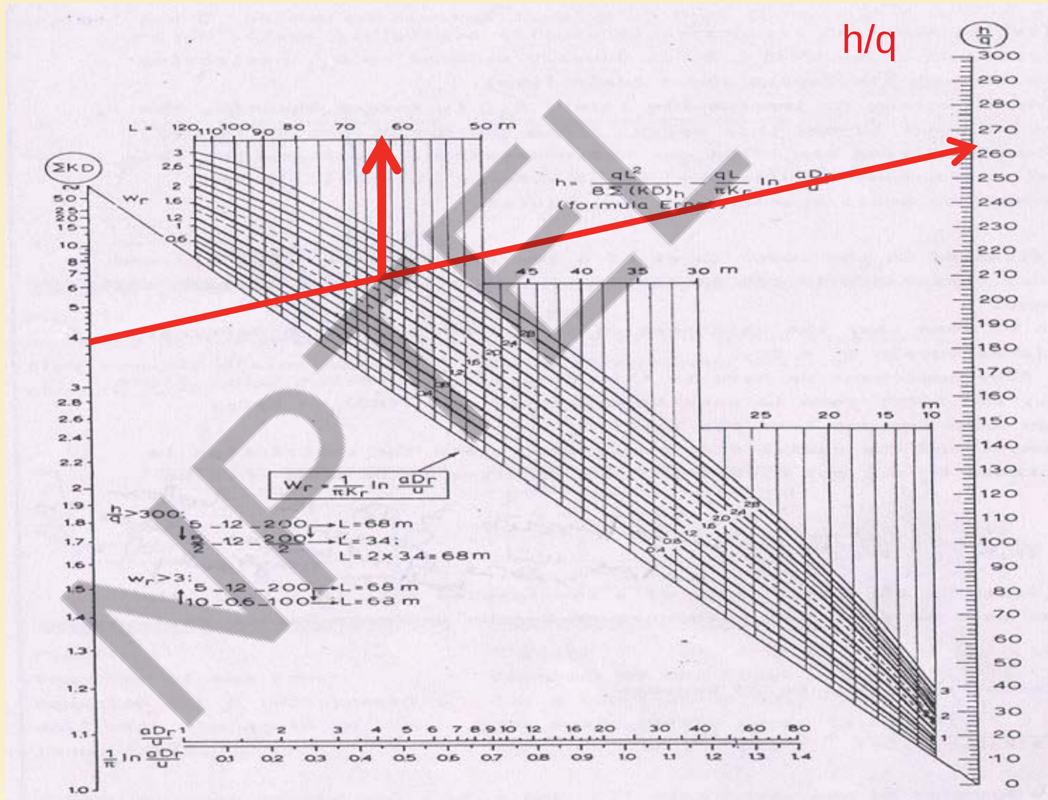
Geometry factor by Relaxation method

$\frac{K_b}{K_t}$	$\frac{D_b}{D_t}$						
	1	2	3	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
4 →		3.4		4.45			
5	2.8	3.5		4.4	4.8	5.0	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

Nomograph for determination of geometry factor



Determination of 'L' from nomograph with Ernst Equation when Do < L/4



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Irrigation and Drainage

Lecture No: 48 Sub-Surface Drainage Design

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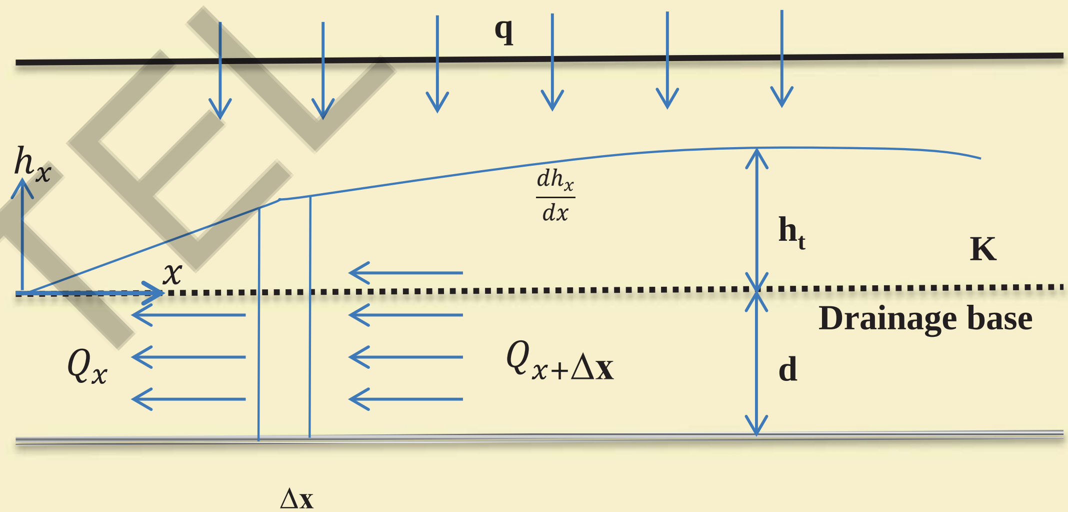
Falling Water Table – Glover-Dumm equation

- ✓ The **Glover-Dumm Equation** is used to describe a falling water table after its sudden rise due to an instantaneous recharge.
- ✓ This is a typical situation in irrigated areas where the shallow water table often rises sharply during the application of irrigation water and then recedes more slowly.
- ✓ When **h<d<<L**, the flow to the drains is essentially horizontal and it follows that

$$Q_x = KD_h \frac{\delta h_x}{\delta x} \qquad (1)$$



Horizontal drainage flow to ditches

Water balance for element Δx below the water table

$$(Q_{x+\Delta x} - Q_x) + q.\Delta x = \frac{\delta h_x}{\delta t}\Delta x.\ \mu$$

$$\frac{(Q_{x+\Delta x} - Q_x)}{\Delta x} + q = \frac{\delta h_x}{\delta t}\mu$$

$$\lim_{\Delta x \to 0} : \frac{\delta Q_x}{\delta x} + q = \frac{\delta h_x}{\delta t}\ \mu \qquad (2)$$

Combining (1) and (2),

$$\frac{\delta (K D_h \frac{\delta h_x}{\delta x})}{\delta x} + q = \frac{\delta h_x}{\delta t}\ \mu$$

$$\frac{\delta h_x}{\delta t} = \frac{K D_h}{\mu}\frac{\delta^2 h_x}{\delta x^2} + \frac{q}{\mu} \qquad (3)$$

Eqn. (3) is called Boussinesq equation which describes the water table under unsteady recharge.

Integrating eq. 3 for no recharge q=0 and the boundary conditions:

Initial condition: $h(x,0) = h_0$

Boundary condition: $h(0,t) = 0$; $h(L,t) = 0$

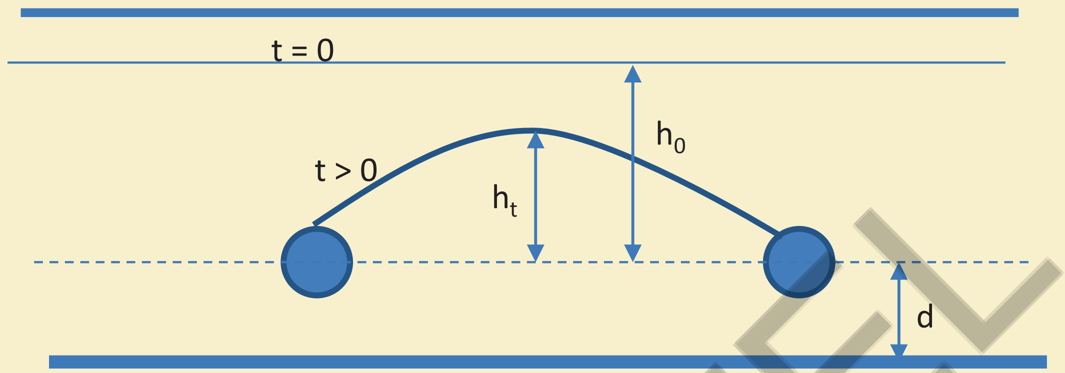
This yields the Glover-Dumm equation

According to Glover-Dumm, the mid spacing water table head h_t at time t relates to the head h_0 (at t=0) as:

$$\frac{h_t}{h_0} = 1.16e^{-\alpha t}; \qquad \alpha = \frac{\pi^2 K d}{\mu L^2} = \frac{10 K d}{\mu L^2}$$

Where,

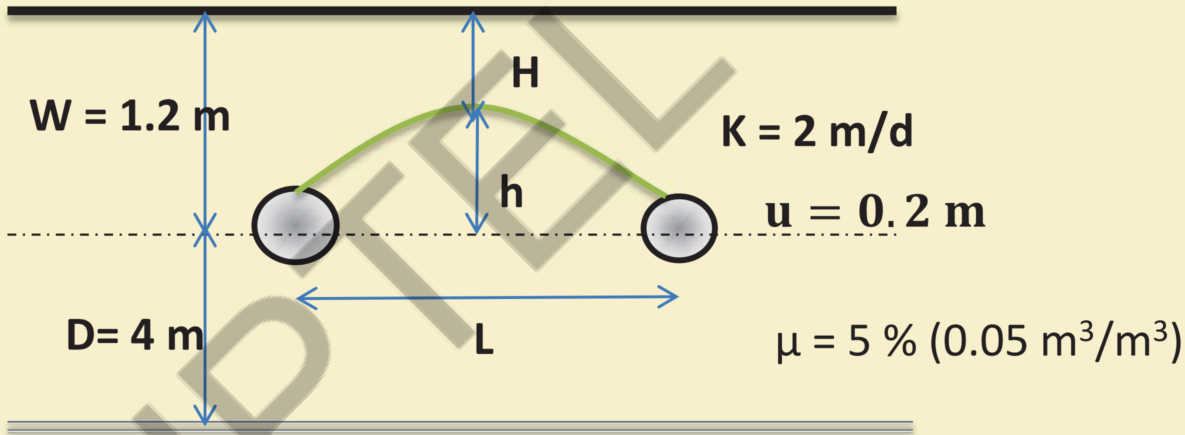
t = time, d; h_0 = initial water table head, m; h_t = water table head at t, m; α is the reaction factor (d^{-1}); μ is the drainable porosity (m^3/m^3); L = drain spacing, m; d = equivalent depth to impermeable substratum, m; K = hydraulic conductivity, m/d



- Combining the above equations, $$L^2 = \frac{10Kdt}{\mu}\left(ln\,1.16\frac{h_0}{h_t}\right)^{-1}$$
- Shape of falling water table → fourth order parabola
- **Pipe drain**: Radial distances are taken into account by replacing the depth D to the impermeable substrate by Hooghoudt equivalent depth 'd', makes the Glover-Dumm equation applicable to pipe drainage.

Exercise 48.1:

Find the drain spacing: t = 0; H_0 = 0 (water table at soil surface) and t = 4; H = 0.8 m



Solution:

$h_0 = W - H_0 = 1.2 - 0 = 1.2$ m

$h_4 = W - H_4 = 1.2 - 0.8 = 0.4$ m

- $\frac{h_4}{h_0} = \frac{0.4}{1.2} = 1.16e^{-\alpha t}$
- $0.33 = 1.16e^{-\alpha t}$; $e^{-\alpha t}$= 0.33/1.16 => $\alpha t = 1.24$

- When t = 4; α = 0.31

$$L^2 = \frac{10Kd}{\mu\alpha} = \frac{10\times 2\times d}{0.31\times 0.05} = 1290\times d$$

Since L = f(d) and d = f(L), a trial and error procedure is followed

First trial: L = 30 m, → d=2.2 m (from Hooghoudt equation)

L = (1290×2.2)$^{0.5}$= 53.3 m

Second trial: L = 60 m, → d=2.84 m

L = (1290×2.84)$^{-1}$ = 60.5 m

The solution is L = 60 m

$$q = \frac{8K_2dh}{L^2} + \frac{4K_1h^2}{L^2}$$

$$d = \frac{D}{\frac{8D}{\pi L}\ln\frac{D}{u}+1}$$ for D > L/4

$$d = \frac{\pi D}{8\ln\frac{L}{u}}$$ for D < L/4

Indirect method solution

Glover-Dumm formula and the **Hooghoudt formula** can be interrelated, enabling the non-steady basic design criteria to be translated into steady-state criteria.

- **Hooghoudt (simple) equation**:

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

- **Glover-Dumm equation**:

$$L^2 = \frac{10Kd}{\mu\alpha}$$

Dividing both the equations:

$$\frac{\frac{8Kdh}{q}}{\frac{10Kd}{\mu\alpha}} = 1 \rightarrow \frac{h}{q} = \frac{10}{8\mu\alpha}$$

For

Indirect method solution

$\frac{h}{q} = \frac{10}{8\mu\alpha}$

For $\mu = 0.05$ and $\alpha = 0.31$, $\rightarrow \frac{h}{q} = 80.65$

In Hooghoudt equation with K = 2 m/d,

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

$$L^2 = 8 \times 2 \times 80.65 \times d$$

$$= 1290 \times d$$

This is an implicit equation as L = f(d) and L = f (f (L)); which is same as the equation obtained in Ex. 47.1

Use trial and error method to find ‘L’

Fluctuating water table (de Zeeuw and Hellinga formula)

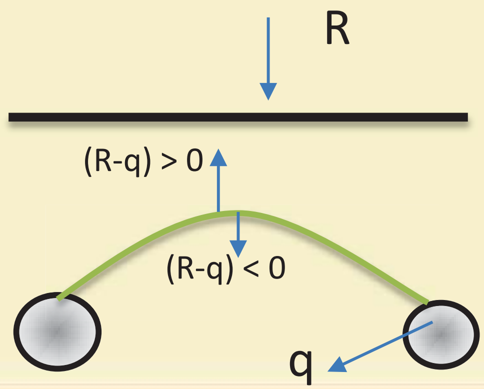
- ✓ Hooghoudt (simple) formula $L^2 = \frac{8Kdh}{q}$, maybe developed to show the non-steady response to periodic rainfall or irrigation
- ✓ In this equation, the drain discharge (q) is linearly related to the mid-spacing water table head (h_t); $q = \frac{8Kdht}{L^2}$

The variation of the drain discharge with time is thus also linearly related to the variation in time of water table head

$$\frac{dq}{dt} = \frac{8Kd}{L^2}\frac{dh}{dt} \quad (1)$$

If the groundwater body is recharged by rainfall/irrigation (R) and is completed by drain discharge (q),

Water table fall → (R-q) < 0; Water table rise → (R-q) > 0



The water table fluctuation maybe described by $\frac{dh}{dt} = \frac{(R-q)}{c\mu}$ (2)

Where, μ is the drainable porosity; C is the correction factor (0.7 to 0.9 for h at mid spacing).

During recession, the water table will not remain horizontal but fall more rapidly nearer to drains. Combining the above equations (1 and 2): take c = 0.8

$$\frac{dq}{dt} = \frac{10Kd}{\mu L^2}(R-q)$$

$$= \alpha(R-q)$$

- ✓ So the change in drain discharge $\frac{dq}{dt}$ is proportional to (R-q).
- ✓ Integrating the above equation between the limits: t = t and t = t-1; q = q_t and q = q_{t-1}.

$$\int_{q_{t-1}}^{q_t} \frac{dq}{(R-q)} = \int_{t-1}^{t} \alpha . dt$$

$$\frac{(R-q)_t}{(R-q)_{t\ -\ 1}} = e^{-\alpha\Delta t}$$

$$q_t = q_{t-1}e^{-\alpha\Delta t} + R_{\Delta t}(1 - e^{-\alpha\Delta t})$$

Since $q = \frac{8Kdh}{L^2} = 0.8\alpha\mu h\ (from\ \boldsymbol{Indirect\ solution})$

$$h_t = h_{t-1}e^{-\alpha\Delta t} + \frac{R_{\Delta t}}{0.8\alpha\mu}\ (1 - e^{-\alpha\Delta t})$$

- the above two equations maybe used to simulate drain discharge and water table depth fluctuations on the basis of weather records given the value of the reaction factor α.

Exercise 48.2:

Water table head and drain outflow calculations on the basis of de Zeeuw – Hellinga formula

For <u>Parallel pipe drainage system</u>

Given:

W = 1.2 m,

L = 40 m,

Kd = 2.5 m^2/d and

μ = 5 %

Calculations: $\alpha = \frac{10Kd}{\mu L^2} = \frac{10 \times 2.5}{0.05 \times 1600} = 0.31$; $\Delta t = 1$ day

$e^{-\alpha\Delta t} = e^{-0.31} = 0.73 \rightarrow (1-e^{-\alpha\Delta t}) = 0.27$ and $0.8\mu\alpha = 0.012$

Day	Rainfall (P), m	Evaporation (E), mm	Recharge (R), mm	Water table head (h), m	Drain outflow (q), m/d
0				0.1	0.001
1	0.005	0.001	0.004	0.16	0.002
2	0.02	0.001	0.019	0.54	0.007
3	0.01	0.002	0.008	0.57	0.007
4	0.025	0.001	0.024	0.96	0.012
5	0.005	0.002	0.003	0.77	0.01
6		0.002		0.56	[illegible]
7		0.002		0.41	0.005
8		0.002		0.3	0004
9		0.002		[illegible]	[illegible]
10		0.002		[illegible]	[illegible]

$$q_t = q_{t-1}e^{-\alpha\Delta t} + R_{\Delta t}(1 - e^{-\alpha\Delta t})$$

$$h_t = h_{t-1}e^{-\alpha\Delta t} + \frac{R_{\Delta t}}{0.8\alpha\mu}(1 - e^{-\alpha\Delta t})$$

- ✓ At the start of the rain (day 0), the water table head is 0.1 m or the mid spacing water table depth H=W-h=1.2-0.1= 1.1 m below the soil surface.
- ✓ The corresponding drain outflow

$$q = \frac{8Kdh}{L^2} = \frac{8*2.5*0.1}{1600}$$

$$= 0.001 \text{ m/d}$$

$$h_t = h_{t-1}e^{-\alpha\Delta t} + \frac{R_{\Delta t}}{0.8\alpha\mu}(1 - e^{-\alpha\Delta t})$$

For t = 1:

$$h_1 = (0.1\times0.73) + \left(\frac{0.04}{0.012}\times0.27\right) = 0.16$$

For t = 2:

$$h_2 = (0.16 \times 0.73) + \left(\frac{0.019}{0.012} \times 0.27\right) = 0.54$$

For t = 6:

$$h_6 = 0.56$$

For t = 7:

$$h_7 = 0.41\ etc$$

$$q_t = q_{t-1} e^{-\alpha \Delta t} + R_{\Delta t}(1 - e^{-\alpha \Delta t})$$

For t = 1:

$$q_1 = (0.001 \times 0.73) + (0.04 \times 0.27) = 0.002$$

For t = 2:

$$q_2 = (0.002 \times 0.73) + (0.019 \times 0.27) = 0.007$$

For t = 6:

$$q_6 = 0.007$$

For t = 7:

$$q_7 = 0.005\ etc$$

At the end of 10th day, q = 0.002 m/d. i.e. evaporation maybe expected to start

Thank You!!

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NPTEL ONLINE CERTIFICATION COURSES

NPTEL

Irrigation and Drainage

Lecture No: 49 Sub-Surface Drainage Design

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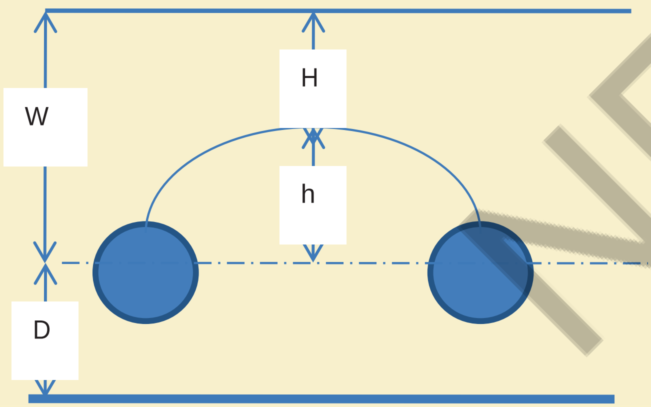
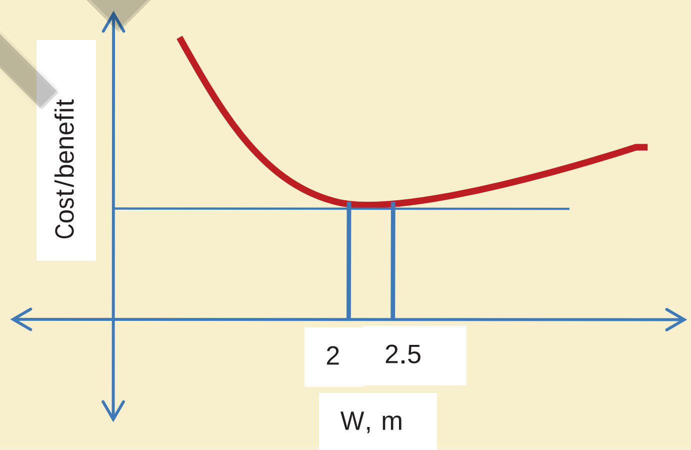
Field Drainage Base Depth

- ✓ For a given H, increasing W, increase ‘h’; wider drain spacing may be used
- ✓ Deeper drainage base could increase the cost of installation: Costly excavation
- ✓ Up to 2-2.5 m, these extra costs are normally compensated by the savings resulted from the wide spacing





Local conditions that influence drainage base depth

- ✓ **Local/regional drainage base:** The field drainage base should be higher than the local/regional drainage base.
- ✓ **Soil conditions:** Pipes should not be installed in quick sand, unconsolidated, and the layers with low hydraulic conductivity.
- ✓ **Drought risk:** A deep drainage may over drain the soil, pipe drain depth will be mostly be based on wet season situation.
- ✓ **Seepage:** a low local drainage base may constitute a sink, drawing excessive amounts of seepage water from the surroundings
- ✓ **Available machinery:** Most economical working depth is around 1-1.2m
  - o Special machines are required for beyond 1.2 m–Costly

Diameter of a Pipe Drain:

- ✓ **Hydraulic design of pipe drains (**using standard pipe flow formula**):**
  - o Discharge (Q)
  - o Hydraulic gradient(i)
  - o Pipe diameter (d)
  - o Wall roughness
- ✓ **Uniform flow:**
  - o Smooth pipe(Darcy-Weisbach): $Q = 50d^{2.71}\, i^{\,0.57}$
  - o Corrugated pipe (Chezy-Manning): $Q = 22\, d^{2.67}\, i^{\,0.50}$

  Q = discharge along the pipe, m^3/s

  d = pipe internal diameter, m

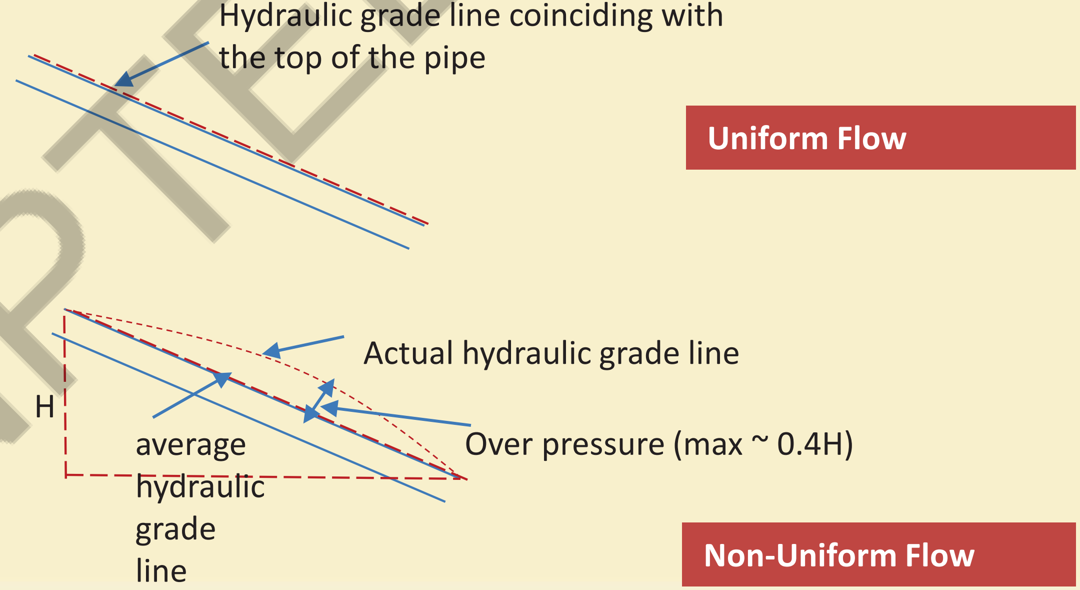
  i = hydraulic gradient ,m/m

Overdesign is practiced by increasing the discharge 1.33 (stable soils)-2 (siltation prone situations) times more to consider lifting and misalignments of the piping.

Non uniform flow:

Smooth pipe, $Q = 89\ d^{2.71}\ i^{0.57}$

Corrugated pipe, $Q = 38\ d^{2.67}\ i^{0.50}$



Example 49.1:

- Smooth concrete collector pipe
- Slope of the pipe line be 0.1%
- Receiving water from 20 ha of land drained by field drains designed for q = 5 mm/d
- An allowance to be incorporated for a subsequent 25% reduction in transfer capacity due to siltation

The discharge at the end of the line is

$$Q = \frac{q \times A}{1000 \times 3600 \times 24} \text{ m}^3/\text{s}$$

A = Drainage area, m^2 ; A= 200000 m^2; q = 5 mm/day; so, Q = 0.0116 m^3/s

Allowing for situation $Q_{design} = \frac{1}{0.75}(0.0116) = 0.0155$

$Q_{design} = 50d^{2.71}\ i^{0.57}$

d = 22 cm (inner dia)

Example 49.2:

- Parallel system of pipe drains at 35 m spacing
- Corrugated plastics drain pipe
- Line length = 200 m
- $q = 5$ mm/d
- Slope of the pipe line be 0.1%

The discharge Q at the end of the line is

$$Q = \frac{q \times A}{1000} \text{ m}^3/\text{day}$$

A = Drainage area, m^2 ; A= 200*35 = 7000 m^2; q = 5 mm/day;

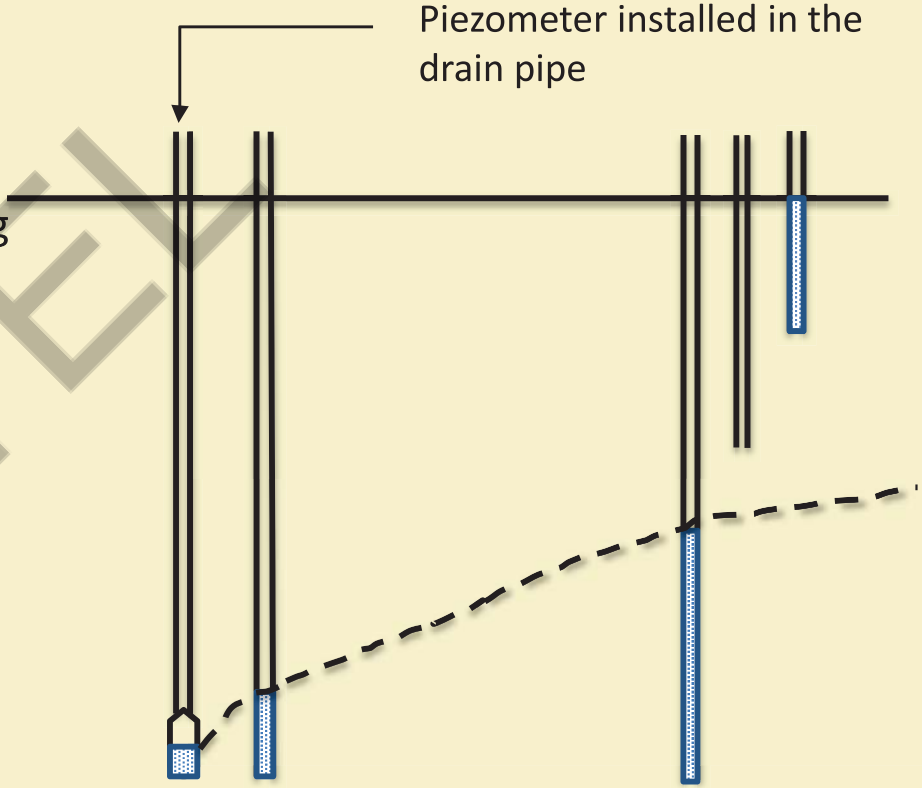
so, Q = 35 m^3/day or 0.0004 m^3/s

Taking a 50% safety to allow for situation: Q_{design}= 2 x 35 = 70 m^3/day or 0.0008 m^3/s

$Q_{design} = 38 d^{2.67}\, i^{\,0.50}$; d = 64 mm (inner dia)

Performance Checking of Pipe Systems:

✓ Check Overall functioning by
  - ✓ water table observations
  - ✓ individual drain discharges- for malfunctioning



Case : 1 Impeded infiltration or percolation

Evidence:

- ✓ Perched water table
- ✓ Water ponding on the surface

Causes :

- ✓ Hard clay pan
- ✓ Soil compaction-traffic

Performance Checking of Pipe Systems:

✓ **Case 2: High resistance in ground water flow**

Evidence:

– Slow fall in water table

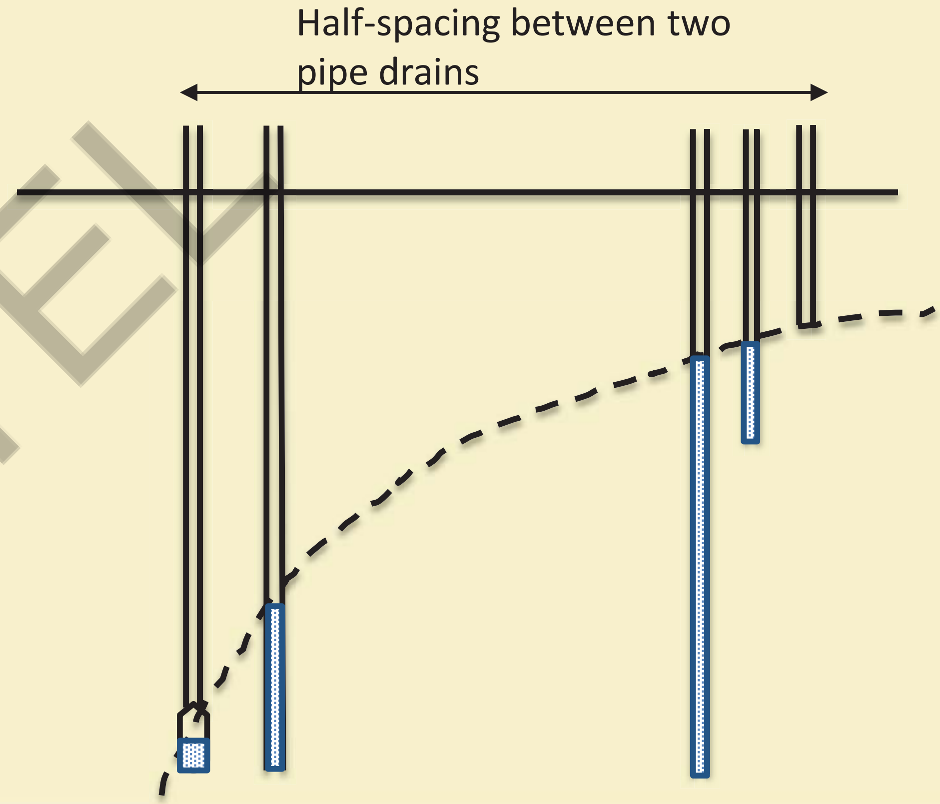
Causes :

– Under design

– Overestimation of hydraulic conductivity

– Drainage coefficient was underestimated

– Wrong drain spacing formula

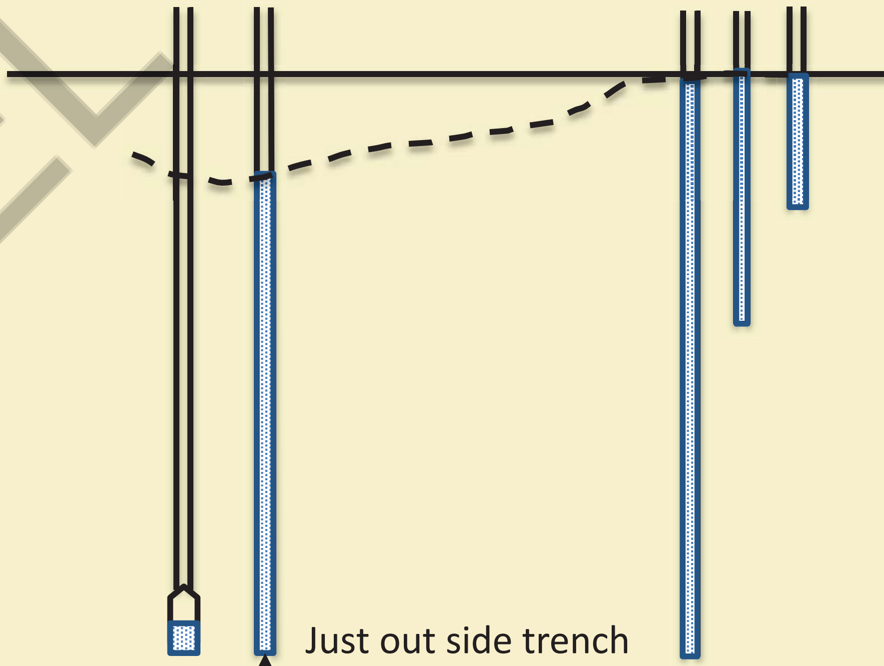


Performance Checking of Pipe Systems:

Case 3: **High entry resistance**

- Common cause of malfunctioning
- Drains have been installed in trench by unsuitable methods
- Omitting of envelops
- Clogging of pores

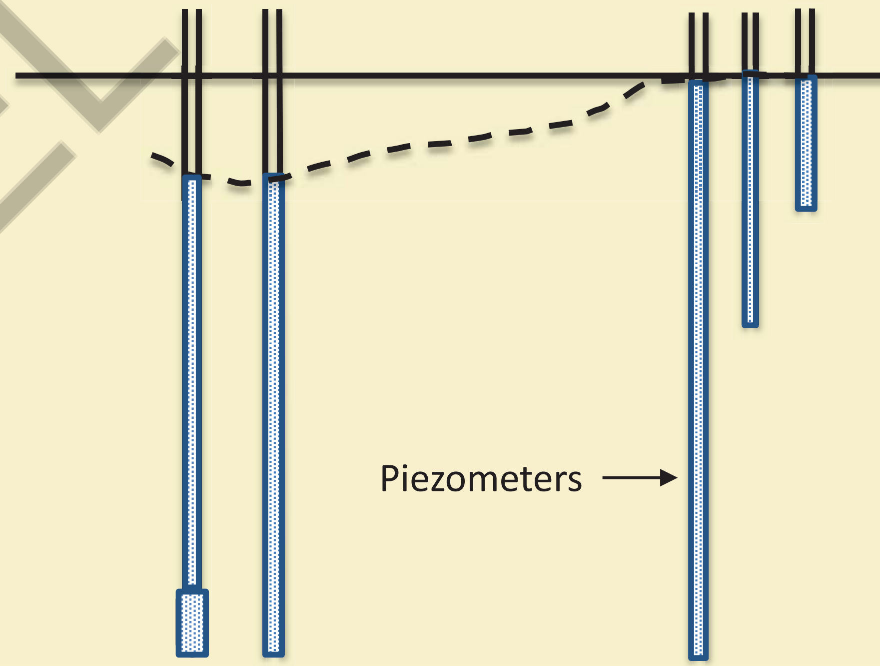
No solution – redesign the pipes



Performance Checking of Pipe Systems:

Case 4: Obstructed pipe flow

- Too high water level in the collector ditch
- Too small pipe diameter
- Misalignment of pipes
- Clogging of pipes by fines/iron compounds
- Blockage of pores by roots



Drainage Environmental Considerations

- ✓ Drainage has an impact on the environment- under scrutiny by regulators and environmentalists.
- ✓ Drainage water normally carries a high nitrate load.
- ✓ **Fogiel and Belcher (1991)** listed the following positive environmental impacts of subsurface drainage:
  - ✓ Reduced overland flow and erosion
  - ✓ Reduced sediment transport and attached phosphorous and potassium off the farm
  - ✓ Improved surface nutrient management,
  - ✓ Improved ability to monitor percolating flow
  - ✓ Reduction of nonpoint source pollution.

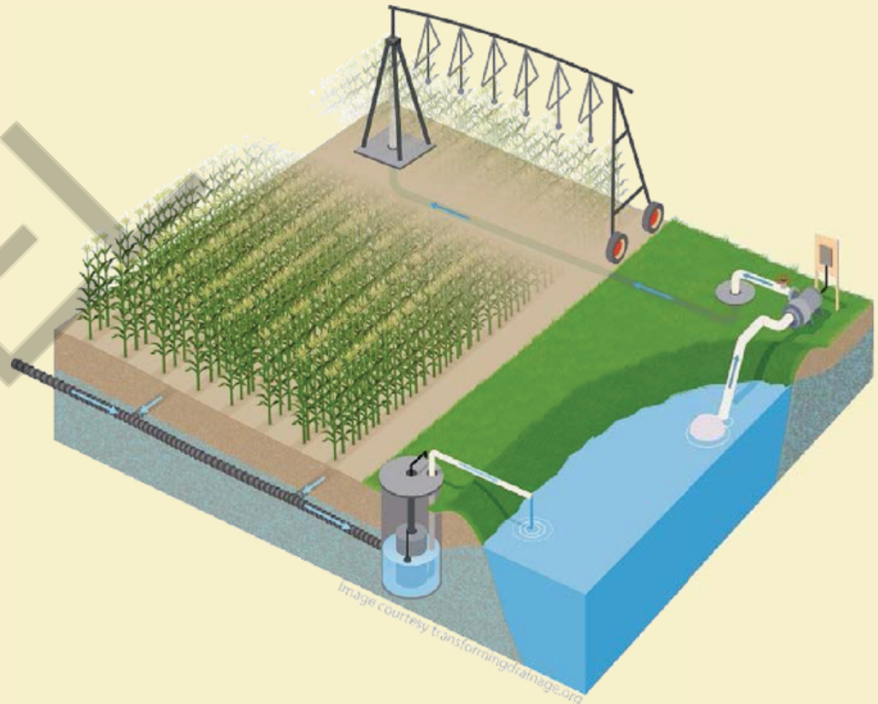
Drainage Environmental Considerations

- ✓ NRCS recommends several **techniques for the reduction** of the impact of drained water on environment.
  - ✓ Install on-farm detention ponds or wetlands that reduce nitrate concentration in drainage water before it leaves the farm,
  - ✓ Retrofit drainage systems to reduce drainage during critical periods and manage the water table
  - ✓ Implement cropping systems that reduce nitrate losses. Improve fertilizer and animal manure management and timing.

Drainage Discharge Management: Disposal and Treatment

- ✓ Options for disposal of agricultural drainage water :
  - ✓ Return the water either to natural depressions or lakes or rivers, or to salt sinks, such as ocean,
  - ✓ Return the water either to the land as part of the irrigation water supply.

- ✓ Constructing disposal basins for saline agricultural drainage waters
  - ✓ If the oceans and inland closed basins are not the options



Treatment of Drainage Water

- ✓ Treatment approaches of drainage water can be divided into three general categories:
  - Physical-
  - Chemical
  - Biological
- ✓ Some of the physical/chemical treatment
  - **Suspended Particle Removal**
    - Through sedimentation, flotation, centrifugation, and filtration.
    - Filtration further includes granular media beds, vacuum filters, belt presses, and filter presses.

Treatment of Drainage Water

- **Adsorption -** Adsorption is the process of removing soluble contaminants by attachment to a solid.
  - Removal of soluble organic compounds via adsorption onto granular activated carbon (GAC)

- **Distillation-** Distillation is a thermal process used for salt removal.
  - Heat is used to vaporize the water, leaving the salts behind

Thank You!!

Irrigation and Drainage

Lecture No: 50 Tutorial: W10

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Example W10.1:

Tile drains have to be installed in an agricultural land having soil permeability of 2.3 × 10^{-3} mm/s. An impermeable stratum exists at 3.2 m below the land surface, and it is desired to keep the water level at least 1.0 m below the land surface. The average discharge of the drainage system is 2.0 mm day^{-1}. If the tile drains are planned to be placed at 1.5 m below the land surface, the drain spacing in m (assuming the equivalent depth to be the same as the tile depth), is **(GATE 2012)**

Solution:

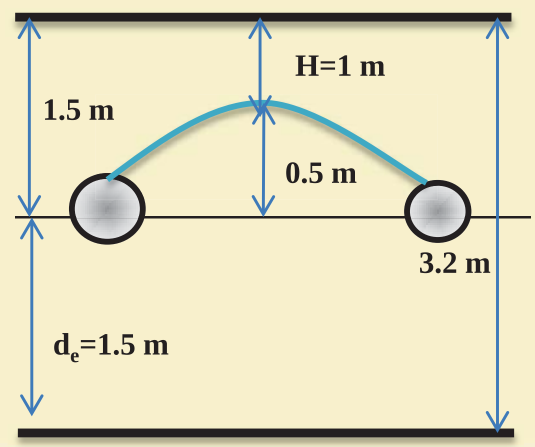
Given

Soil permeability, K = 2.3 × 10^{-3} mm/s = 198.72 mm/day

Average discharge of the drainage system, q = 2.0 mm/day

Equivalent depth d_e = d = 1.5 m

$$h = 0.5\ m.$$



We know Hooghoudt's equation

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

Substituting values in Hooghoudt's equation

$$2 = \frac{8 \times 198.72 \times 1.5 \times 0.5}{L^2} + \frac{4 \times 198.72 \times 0.5^2}{L^2}$$

$$2 = \frac{8 \times 198.72 \times 1.5 \times 0.5}{L^2} + \frac{4 \times 198.72 \times 0.5^2}{L^2}$$

$$L^2 = \frac{1192.32 + 198.72}{2} = \frac{1391.04}{2} = 695.52$$

$$\boldsymbol{L = \sqrt{695.52} = 26.37\ m\ Ans.}$$

Example W10.2:

In an irrigation command area, the irrigation interval, gross application in an irrigation and the application efficiency are 20 days, 75 mm and 60%, respectively. The soil is homogeneous with K = 0.9 m day^{-1}. The impermeable layer is at a depth of 7 m from the ground surface. The area is to be tile drain with tiles at a depth of 2 m below the ground surface. The maximum permissible steady state water table height mid-way between the drains, from the plane of the drain, is 1.2 m. using the steady state approach of Hooghoudt, assuming an equivalent depth of 4.12 m, the drain spacing in m will be **(GATE 2010)**

Solution:

Given

Irrigation interval = 20 days

Gross application in an irrigation = 75 mm

Application efficiency are = 60%,

Therefore, $q = \frac{75}{20} \times 0.6 = 2.25\,\frac{mm}{day} = 0.00225\,\frac{m}{day}$

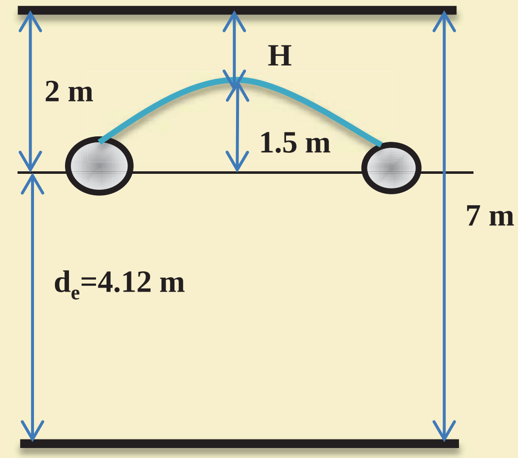
K = 0.9 m/day.

Impermeable layer depth from the ground surface = 7 m.

Tile drains depth below the ground surface= 2 m.

h = 1.2 m.

Equivalent depth d_e = d = 4.12 m



We know Hooghoudt's equation

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

Substituting values in Hooghoudt's equation

$$0.00225 = \frac{8 \times 0.9 \times 4.12 \times 1.2}{L^2} + \frac{4 \times 0.9 \times 1.2^2}{L^2}$$

$$L^2 = \frac{35.6 + 5.184}{0.00225} = \frac{40.784}{0.00225} = 18126.222$$

$$\boldsymbol{L = \sqrt{18126.222} = 134.63\ m\ (\text{Ans.})}$$

Example W10.3:

The EC of the canal water used for irrigating wheat is 1.2 mmhos/cm while it can tolerate a maximum EC of 6 mmhos/cm. the ET of wheat is 0.8 cm/day and soil hydraulic conductivity is 0.9 cm/h. the area is to be drained by the tile drain laid at a depth of 2.5 m below ground level so as to maintained water table depth at 1.5m the impervious layer is located at a depth of 4 m below the ground surface.

a. Compute the drain spacing using Hooghoudt,s equation.

b. Calculate the drainage flow rate out of a 400 ha field

c. What is the size of drain pipe laid out on a gradient of 0.001 m/m, assuring that drain is running full and Manning is 0.01? **(ARS 2009)**

Solution:

Given,

EC_{iw}= 1.2 mmhos/cm

EC_{dw}= 6 mmhos/cm

ET = 0.8 cm/day

Soil hydraulic conductivity = 0.9 cm/h.

Tile drain depth = 2.5 m

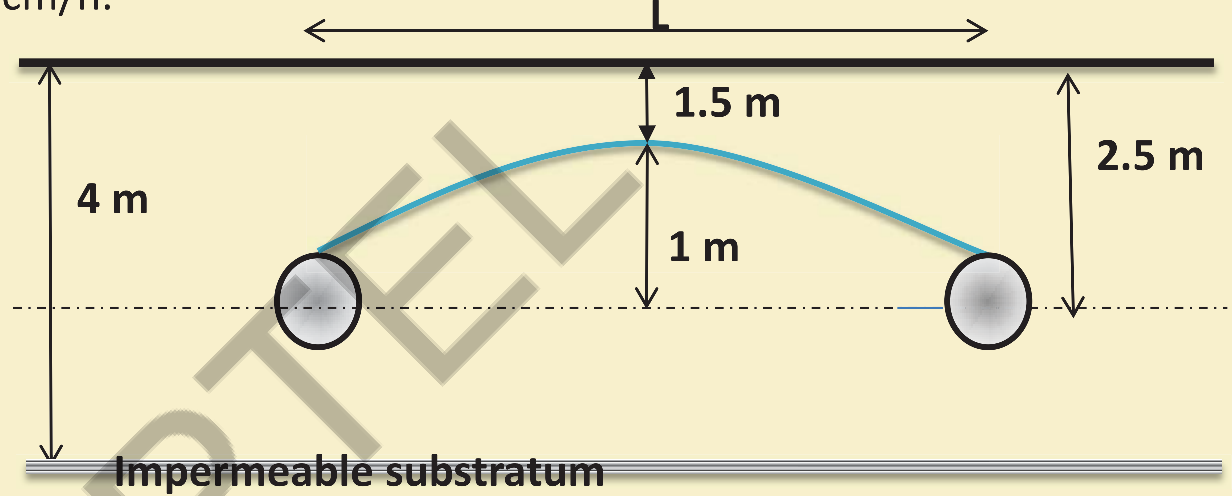
water table depth = 1.5m

impervious layer = 4 m

Area = 400 ha

Gradient = 0.001 m/m,

n = 0.01



$$LR = \frac{EC_{iw}}{EC_{dw}}$$

$$LR = \frac{1.2}{6} = 0.2$$

As we know that

$$\text{Depth of water drained} = \textit{depth of water applied} - \textit{depth of irrigation requirement}$$

$$\text{Depth of water drained} = D_i - \text{LR} \times D_i = D_i - 0.2 \times D_i = 0.8D_i$$

$$ET = 0.8D_i$$

$$0.8 = 0.8D_i$$

$$D_i = 1$$

$$LR = \frac{D_d}{D_i}$$

$$D_d = 0.2 \times 1 = 0.2$$

Drainage flow rate = 0.2 cm/day

Hooghoudt,s equation

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

$$L^2 = \frac{4 \times 0.009 \times 24 \times 1 \times 1}{0.002} + \frac{8 \times 0.009 \times 24 \times 1 \times 1.5}{0.002}$$

$$L^2 = 432 + 1296$$

$$\boldsymbol{L = 41.57}\ \textbf{m (Ans.)}$$

$$Drainage\ flow\ rate\ (Q) = q \times A$$

$$Drainage\ flow\ rate\ (Q) = \frac{0.2}{100} \times 400 \times 10000$$

$$= 8000\ \text{m}^3/\text{day}$$

$$= \boldsymbol{0.092}\ \textbf{m}^3\textbf{/s (Ans.)}$$

As we know that

$$Q = A \times V$$

$$V = \frac{1}{n} \times R^{2/3} \times S^{0.5}$$

$$Q = A \times \frac{1}{n} \times R^{2/3} \times S^{0.5}$$

$$Q = \frac{\pi}{4} \times d^2 \times \frac{1}{n} \times \left(\frac{\pi d^2}{4\pi d}\right)^{2/3} \times S^{0.5}$$

$$Q = \frac{\pi}{4^{5/3}} \times d^2 \times d^{2/3} \times \frac{1}{n} \times S^{0.5}$$

$$0.092 = 0.31 \times d^{8/3} \times \frac{1}{0.01} \times 0.001^{0.5}$$

$$0.092 = 0.98 \times d^{8/3}$$

$$d = 0.411\ m$$

$$\boldsymbol{d = 41.1}\ \textbf{cm (Ans.)}$$

Example W10.4:

The following data were obtained from an agriculture land requiring a pipe drainage system for groundwater control:

Hydraulic conductivity = 8.3 cm/h, drainable porosity = 5%, reaction factor = 0.31 per day and equivalent depth to the impermeable layer = 2.8 m

The drain spacing computed by the Glover-Dumn formula will be **(GATE 2008)**

Solution:

Given,

$$Hydraulic\ conductivity\ =\ 8.3\ cm/h = \frac{8.3}{100} \times 24 = 1.992\ \text{m/day}$$

$$Drainable\ porosity\ =\ 5\%$$

$$Reaction\ factor\ =\ 0.31\ per\ day$$

$$Equivalent\ depth\ to\ the\ impermeable\ layer\ =\ 2.8\ m$$

Glover-Dumm equation

$$L^2 = \frac{10Kd}{\mu\alpha}$$

$$L^2 = \frac{10 \times 1.992 \times 2.8}{0.05 \times 0.31}$$

$$L^2 = \frac{55.776}{0.0155}$$

$$L^2 = 3598.45$$

$$\boldsymbol{L = 59.98}$$

$$\cong \boldsymbol{60\ m}\ \textbf{(Ans.)}$$

Example W10.5:

A subsurface drainage system is installed in an agricultural area to control the water table. The design discharge rate of the drain is 2 mm/day. The depth of water table midway between the drain is 1.5 m below the soil surface. Drain pipe with a radius of 0.10 m is installed at a depth of 2 m. There is an impervious layer at a depth of 7 m below the soil surface. The hydraulic conductivity of the homogeneous soil above the impervious layer is 1m/day.

a. If the flow rate takes place only below the drain level the equivalent depth for a drain spacing of 90 m is

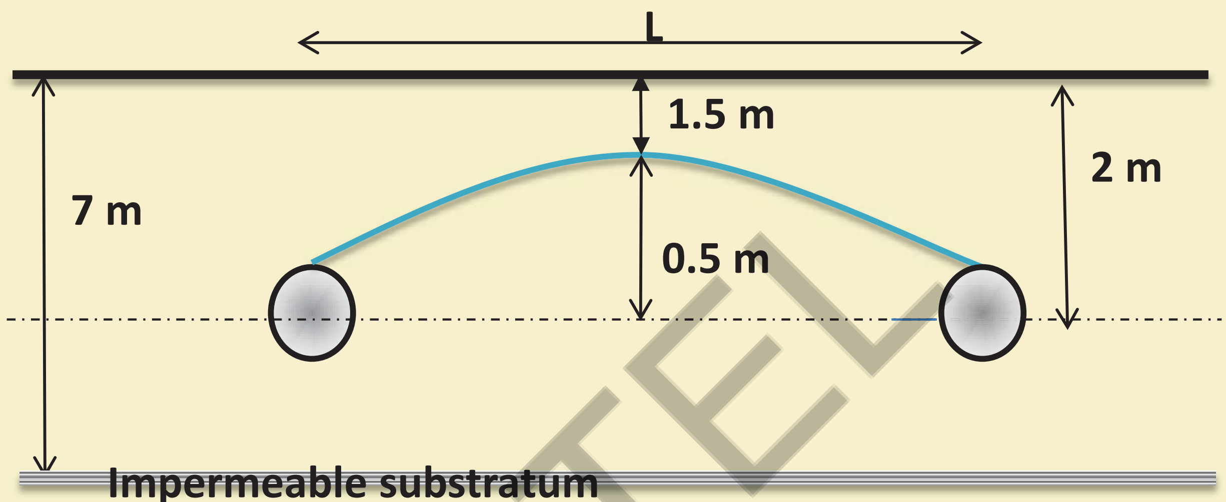
b. If the flow rate water takes place only above the drain level, the drain spacing is **(GATE 2004)**

Solution:

Given,

Discharge rate of the drain (q) = 2 mm/day=0.002 m/day

hydraulic conductivity (K) =1 m/day



As we know Hooghoudt,s equation for water below the drain level,

$$L^2 = \frac{8dKh}{q}$$

$$90^2 = \frac{8 \times d \times 1 \times 0.5}{0.002}$$

$$8100 = 2000\ d$$

As we know Hooghoudt,s equation for water below the drain level,

$$L^2 = \frac{8dKh}{q}$$

$$90^2 = \frac{8\times d\times 1\times 0.5}{0.002}$$

$$8100 = 2000\, d$$

$$\boldsymbol{d = 4.05}\ \textbf{m (Ans.)}$$

Hooghoudt,s equation for water above the drain level,

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

$$L^2 = \frac{4\times 1\times 0.5\times 0.5}{0.002}$$

$$L^2 = \frac{4 \times 1 \times 0.5 \times 0.5}{0.002}$$

$$L^2 = 500$$

$$\boldsymbol{L = 23.36}\ \textbf{m (Ans.)}$$

Thank You!!