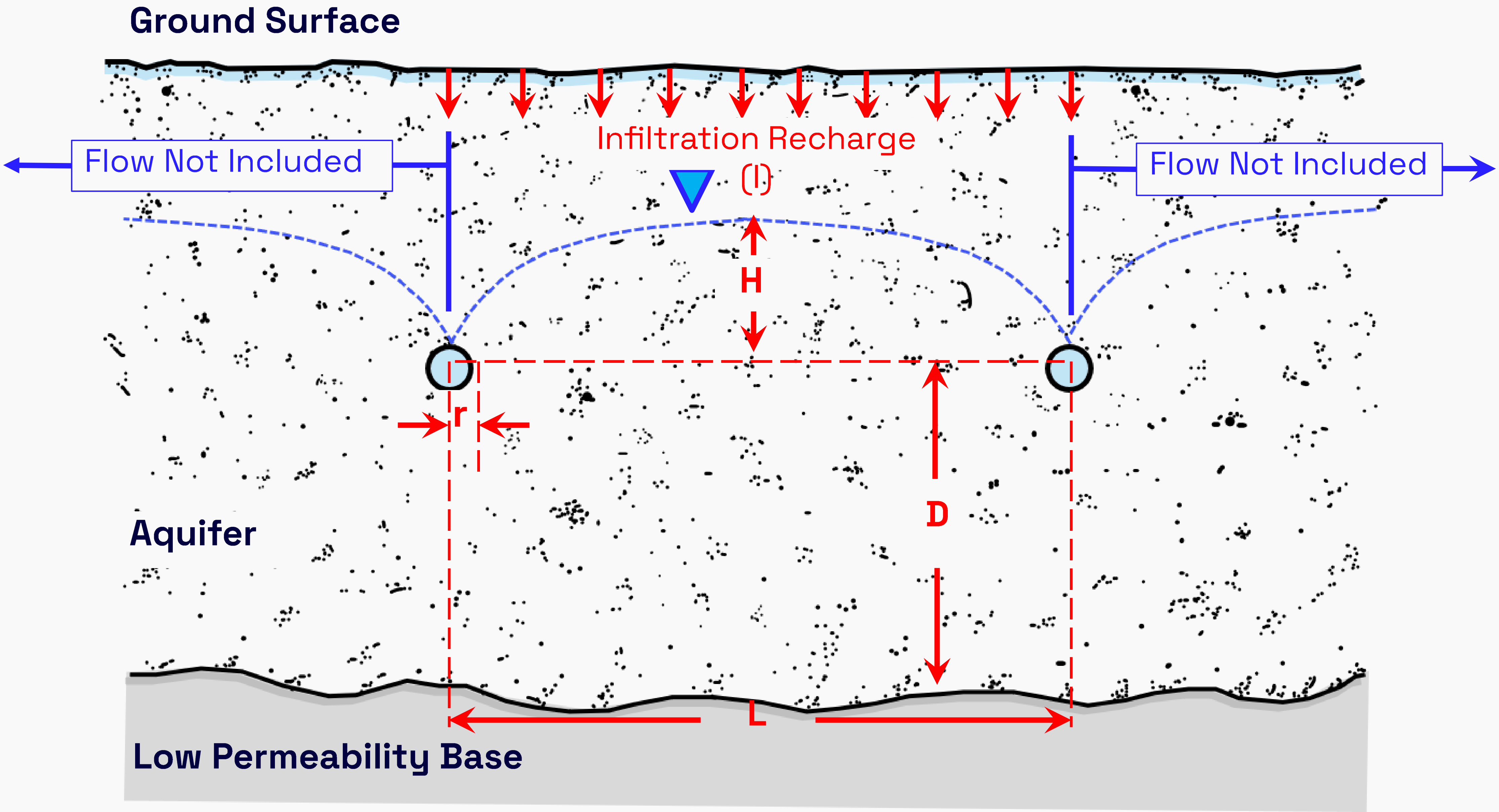
2D Drainage: Spacing Equation



Hooghoudt Equation:

$$L = \sqrt{\frac{4KH}{I}(2d_e + H)}$$

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Equations & Variables

Drain spacing: $(L) = \sqrt{\frac{4KH}{I}(2d_e + H)}$

Equivalent depth: $d_e = \frac{D}{1+\frac{D}{L}\left(2.55\ ln\left(\frac{D}{r}\right)-c\right)}$ for $\frac{D}{L} \leq 0.31$

$d_e = \frac{L}{2.55\ ln\left(\frac{L}{r}\right)-1.15}$ for $\frac{D}{L} > 0.31$

Where $c = 3.55 - 1.6\frac{D}{L} + 2\left(\frac{D}{L}\right)^2$

Symbol	Units	Description
L	L	Drain spacing
H	L	Maximum height of the water table above the drains
D	L	Depth from the drain centreline to impermeable layer
d_e	L	Equivalent depth* below the drain
I	L/T	Infiltration rate
K	L/T	Hydraulic conductivity of aquifer
r	L	Drain radius
c	-	Dimensionless correction factor used to calculate d_e

* Equivalent depth, d_e ,replaces the actual depth to the impermeable layer so the equation can account for converging flow and added head loss near the drain.

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When to use

Use the Hooghoudt equation for first-pass drain spacing estimates where groundwater is mainly supplied by distributed infiltration from above.

It is most useful for flat or gently sloping sites with parallel drains, a shallow water table, and a reasonably defined impermeable layer below the drains.

Typical Applications

Typical applications include agricultural tile drainage, wet fields, wetland drainage, underdrains below broad infiltration areas, and engineered containment areas where drainage is needed above or inside low-permeability liners, such as landfill cells or tailings cells.

Limits & Assumptions

- Main water source should be infiltration from above.
- Does not account for lateral groundwater flow from outside the drain field.
- Best suited where external lateral flow is small compared to vertical (or is cut off).
- Assumes long, parallel drains with similar depth and spacing.
- Assumes steady recharge and a defined impermeable layer below the drains.

About the Equation

The Hooghoudt equation is solved iteratively because the drain spacing, L, depends on the equivalent depth, d_e ,and d_e also depends on L.

A practical way to solve it is to start with an estimated drain spacing, calculate d_e ,then update L. Repeat until the calculated spacing changes very little between iterations.

This is easy to do in a spreadsheet.

Worked Example

A proposed road crosses a small marshy area. Parallel subsurface drains will be installed to reduce pore pressures to improve the soil strength and reduce road maintenance requirements.

Assume the following parameters:

I = 0.005 m/d
K = 1.0 m/d
H = 0.4 m
D = 2.6 m
r = 0.05 m

Note: Your main design parameters are the drains depth to impermeable base (D), the maximum allowable water level above drains (H), and the distance between the drains (L). You'll need to prescribe two of those main design parameters and solve for the third. This example solves for the spacing between drains (L).

Worked Example

Step 1: Make an initial guess at L. and then calculate the value of D/L.

Initial guess: **L = 100m**

D/L = 2.6/100 = **0.026**

Step 2: Calculate the equivalent well depth (de) based on the D/L value from Step 1:

[EQ1] $$d_e = \frac{D}{1+\frac{D}{L}\left(2.55\, ln\left(\frac{D}{r}\right)-c\right)} \quad \text{for } \frac{D}{L} \leq 0.31$$

OR

[EQ2] $$d_e = \frac{L}{2.55\, ln\left(\frac{L}{r}\right)-1.15} \quad \text{for } \frac{D}{L} > 0.31$$

Since our initial guess for D/L = 0.026 we use equation 1 above. Note that equation 1 also uses the correction factor c.

$$c = 3.55 - 1.6\frac{D}{L} + 2\left(\frac{D}{L}\right)^2 = 3.55 - 1.6\frac{2.6}{100} + 2\left(\frac{2.6}{100}\right)^2 = 3.5$$

$$d_e = \frac{2.6}{1+\frac{2.6}{100}\left(2.55\ln\left(\frac{2.6}{100}\right) - 3.5\right)} = 2.2 \quad \text{for } \frac{D}{L} \leq 0.31$$

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Worked Example:

Step 3: Calculate the well spacing (L)

$$\mathbf{L} = \sqrt{\frac{4(1)(0.4)}{0.005}(2(\mathbf{2.2}) + 0.4)} = \mathbf{39}\boldsymbol{m}$$

Step 4: Return to Step 1 and use L = 39 and reiterate until the solution converges

The converged solution for these inputs variables will be approximately L – 35m.

Comparison to numerical solutions

Comparison to 2D Sectional Models

Two steady-state 2D sectional models were created to match the conditions assumed by the Hooghoudt equation.

The input values were: I = 0.001 m/d; H = 0.4m; D =10.6m; r = 0.05m and K = 1m/d

Calculated drain spacing

- Hooghoudt: **141 m**
- MODFLOW 2D: **141 m**
- Anaqsim 2D: **141 m**

For this simple steady-state setup, the analytical and numerical results matched closely.

Comparison to 3D Numerical Models

Three-dimensional models were also created in MODFLOW and Anaqsim to test the effect of lateral flow entering the drainage area.

These models represented a wetland drainage case with high infiltration from above, while also allowing some lateral inflow from the model boundaries.

The following input values were used: I = 0.02 m/d; H = 2.3m; D = 6m; r = 0.05m; and K =1m/d.

Calculated drain spacing

- Hooghoudt: **67 m**
- MODFLOW 3D: **50 m**
- Anaqsim 3D: **50 m**

Comparison to numerical solutions (Continued)

In this case, Hooghoudt overestimated the drain spacing (i.e.. too few drains) needed to drain the area.

The comparison showed that the Hooghoudt result became closer to the numerical models when infiltration from above made up a larger share of the total water entering the drainage area.

As lateral inflow becomes more important, the Hooghoudt equation becomes less reliable for estimating drain spacing.