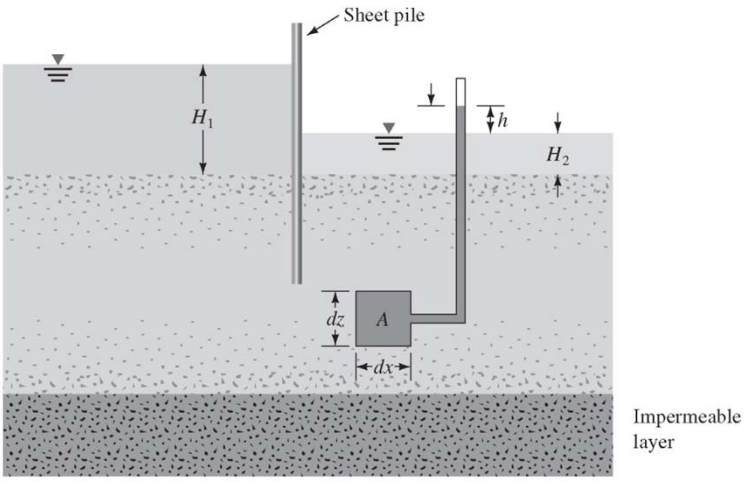
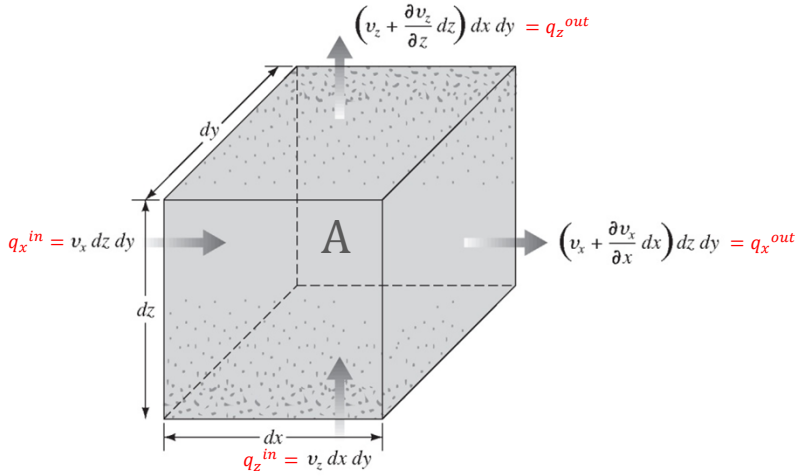
Seepage

Chapter 7

Laplace's Equation



Laplace's Equation



Laplace's Equation

No storage
No drainage

$$\frac{\partial v_x}{\partial x} + \frac{\partial v_z}{\partial z} = 0$$

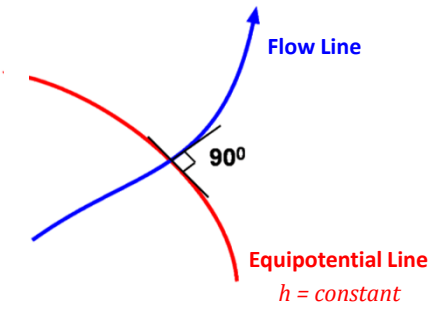
$v_x = k_x i_x = k_x\left(-\frac{\partial h}{\partial x}\right)$ ← Darcy's Law → $v_z = k_z i_z = k_z\left(-\frac{\partial h}{\partial z}\right)$

Anisotropic Soil → $k_x \frac{\partial^2 h}{\partial x^2} + k_z \frac{\partial^2 h}{\partial z^2} = 0$

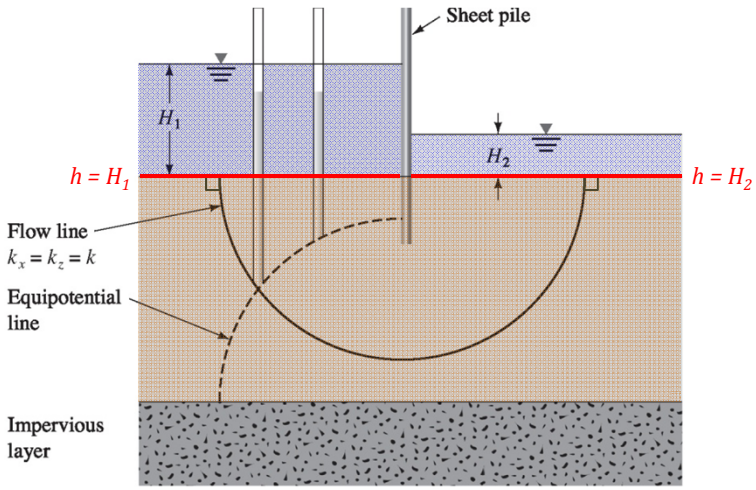
Isotropic Soil → $\frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial z^2} = 0$

Solution of Laplace's Equation

Since water can only flow due to a change in head, and equipotential lines are lines of constant head, the flow lines must be perpendicular to the equipotential lines everywhere.

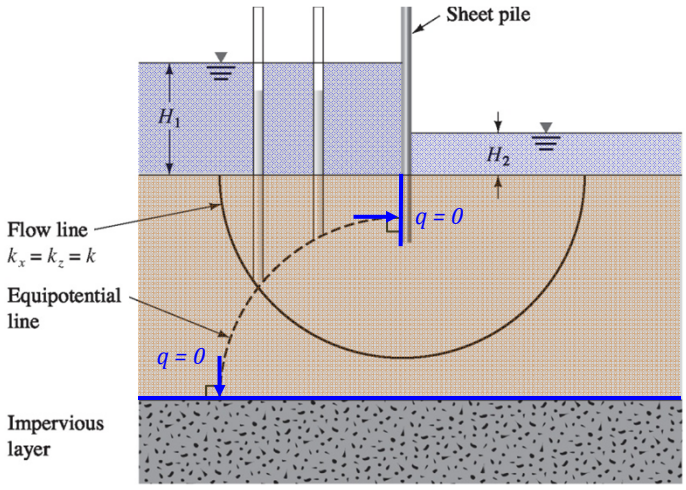


Flow Nets



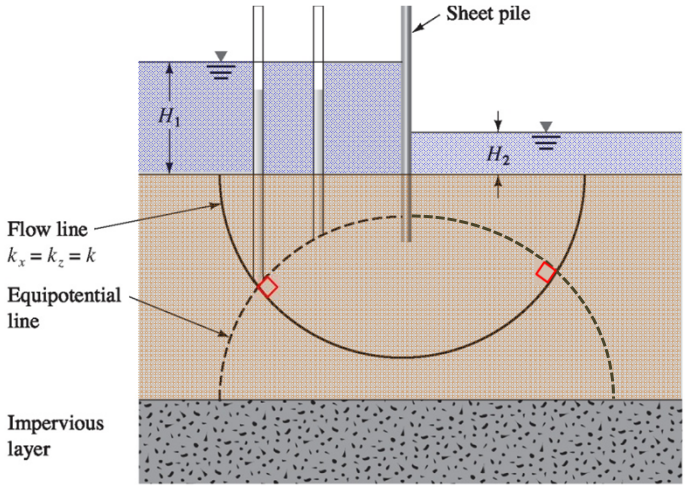
Upstream and downstream surfaces are equipotential lines

Flow Nets



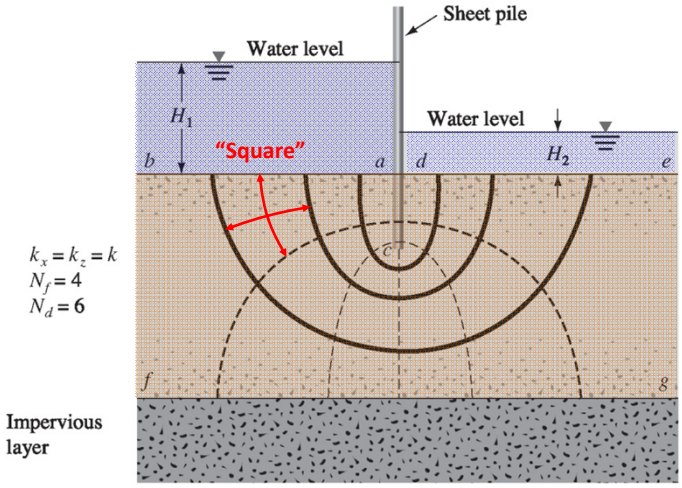
All impervious boundaries are flow lines

Flow Nets



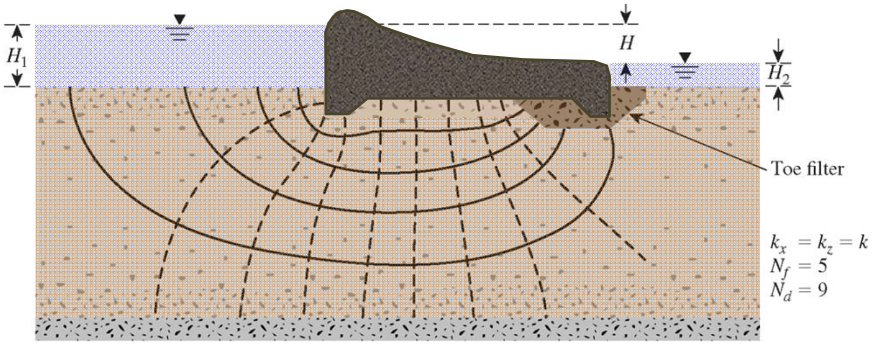
Flow lines and equipotential lines are orthogonal

Flow Nets



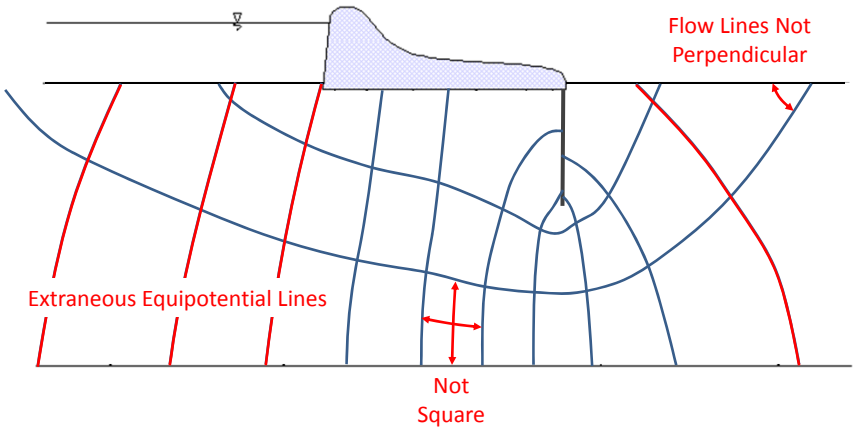
Ideally, the "cells" in the flow net should be "square"

Flow Net Example

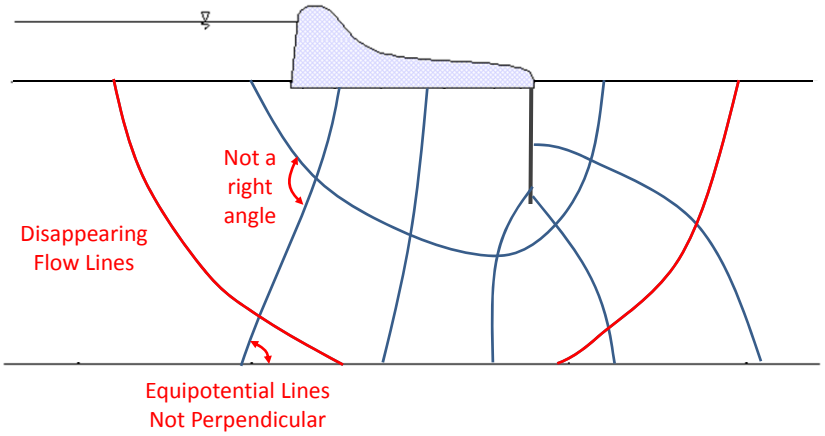


Flow lines are ⊥ to upstream ground surface
Flow lines are ⊥ to face of toe filter faces
Equipotential lines are ⊥ to impervious boundaries
Flow lines are ⊥ to equipotential lines everywhere
"Cells in the flow net are "square" everywhere

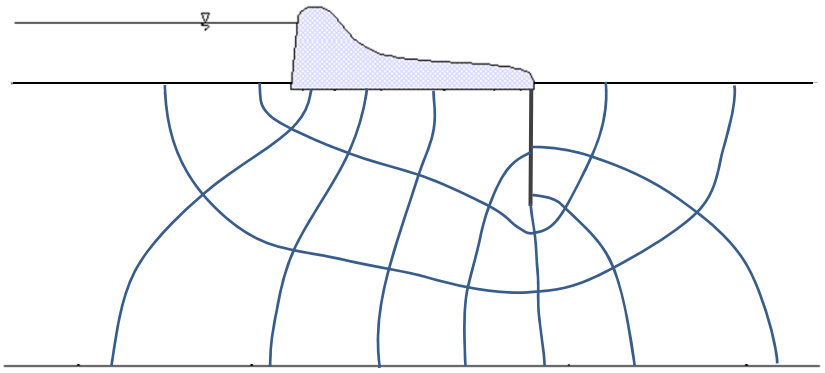
Common Flow Net Mistakes



Common Flow Net Mistakes

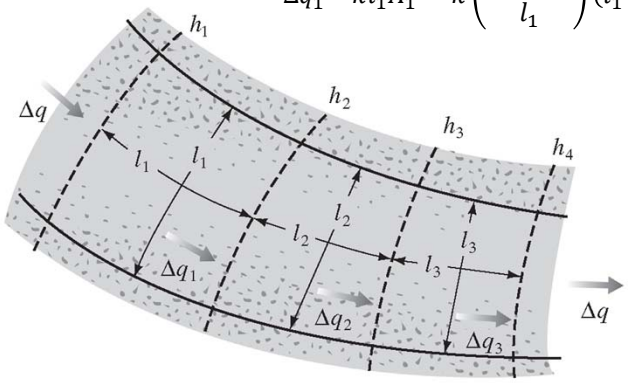


Correctly Drawn Flow Net



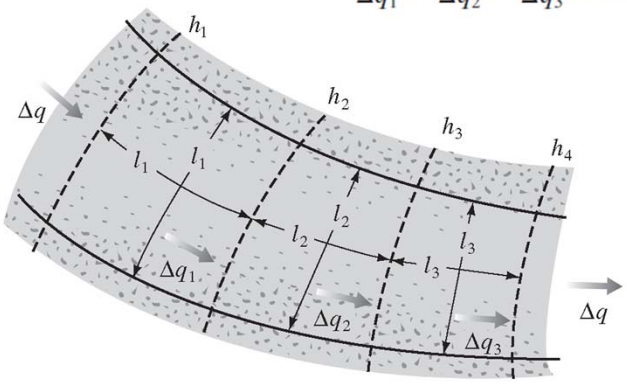
Seepage Calculations

$$\Delta q_1 = k i_1 A_1 = k\left(\frac{h_1 - h_2}{l_1}\right)(l_1 \times 1) = k(h_1 - h_2)$$



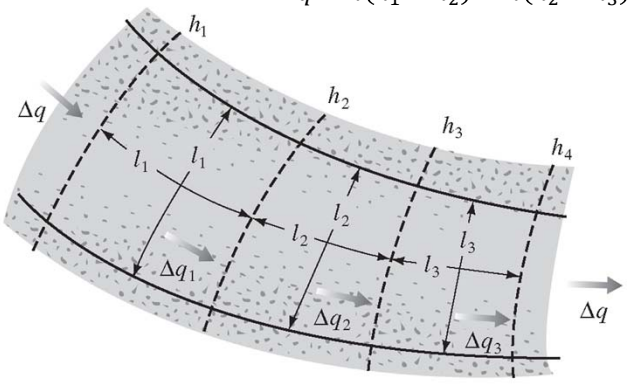
Seepage Calculations

$$\Delta q_1 = \Delta q_2 = \Delta q_3 = \cdots = \Delta q$$



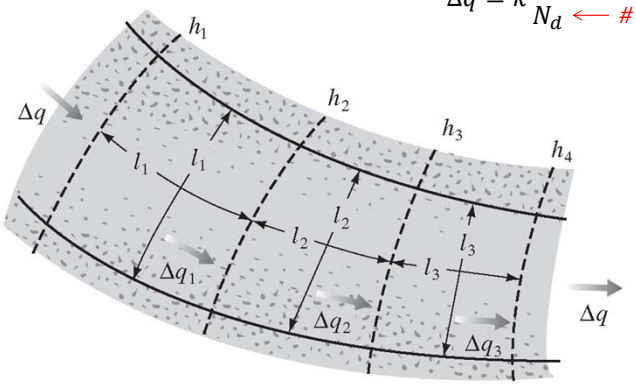
Seepage Calculations

$$\Delta q = k(h_1 - h_2) = k(h_2 - h_3) = k(h_3 - h_4) = \cdots$$



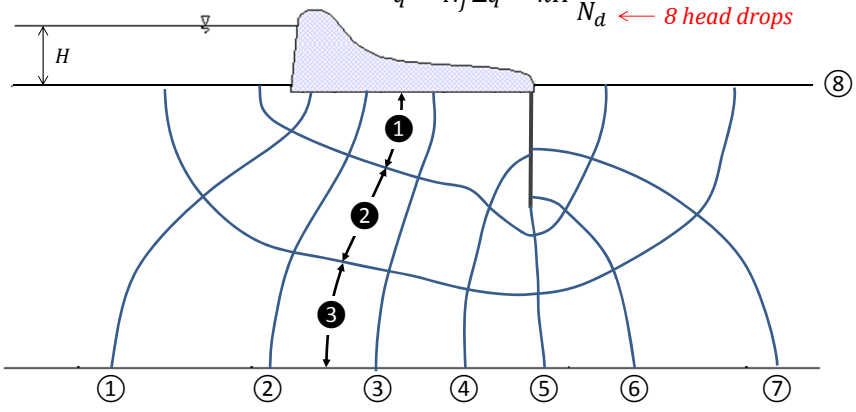
Seepage Calculations

$$\Delta q = k\frac{H}{N_d}$$ ← *Total head loss* ← *# of head drops*

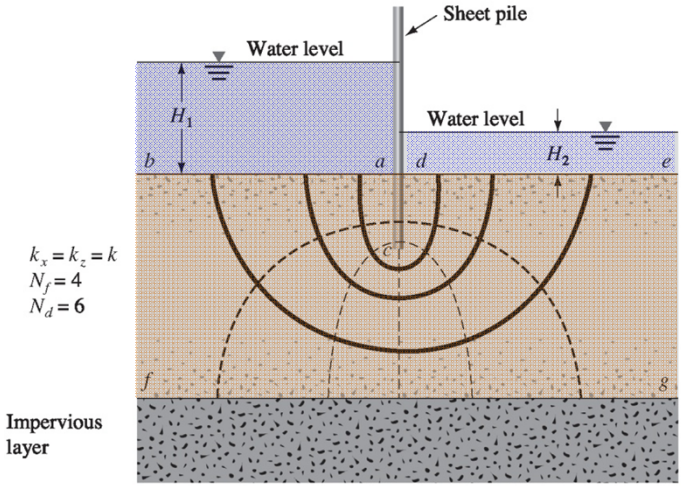


Seepage Calculations

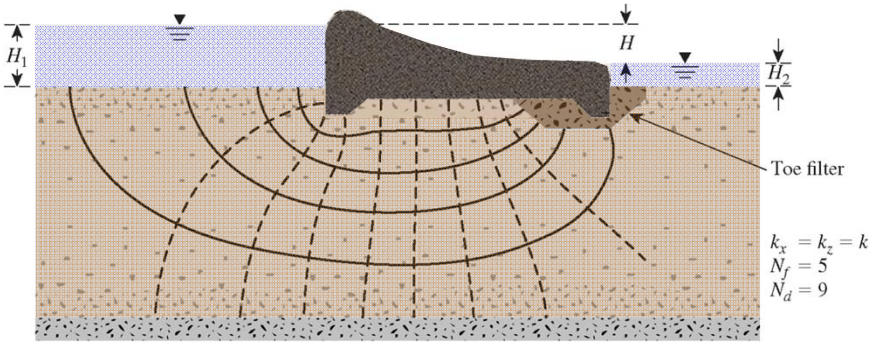
$$q = N_f \Delta q = kH\frac{N_f}{N_d}$$ ← *3 flow channels* ← *8 head drops*



Flow Nets

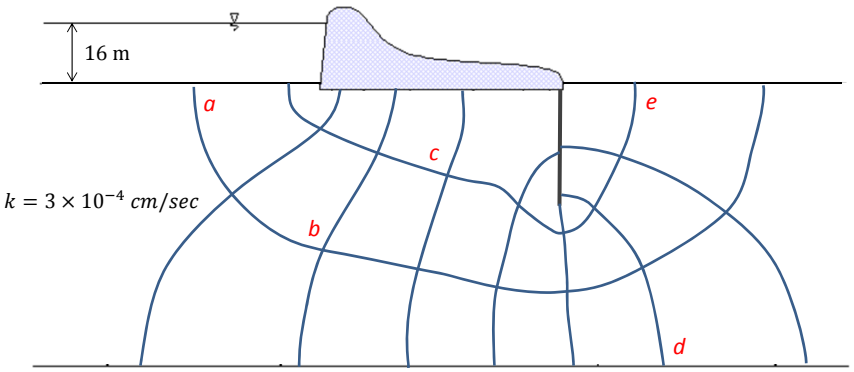


Flow Nets



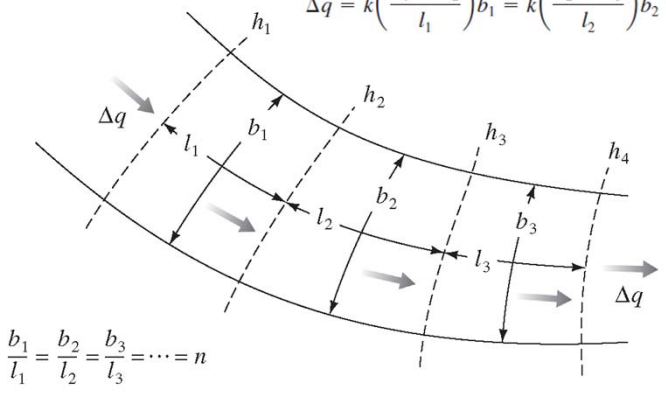
Example

1. What is the head at points *a, b, c, d* and *e*?
2. What is the seepage rate beneath the dam?



Partial Flow Channels

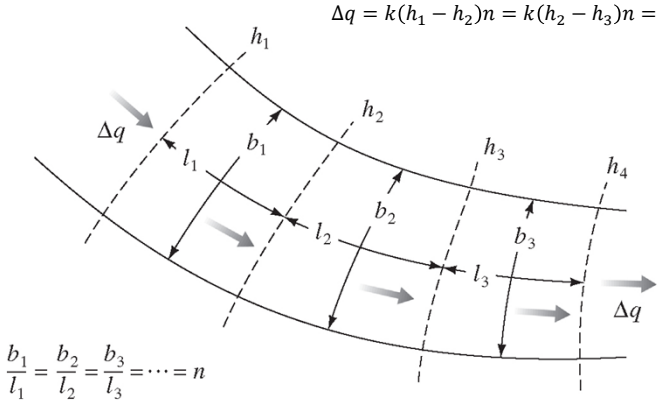
$$\Delta q = k\left(\frac{h_1 - h_2}{l_1}\right)b_1 = k\left(\frac{h_2 - h_3}{l_2}\right)b_2 = k\left(\frac{h_3 - h_4}{l_3}\right)b_3 = \cdots$$



$$\frac{b_1}{l_1} = \frac{b_2}{l_2} = \frac{b_3}{l_3} = \cdots = n$$

Partial Flow Channels

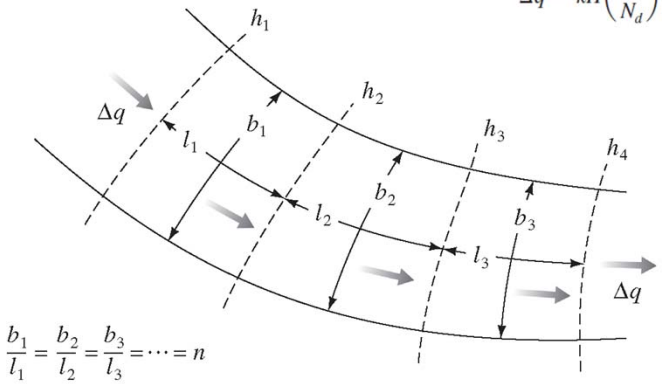
$$\Delta q = k(h_1 - h_2)n = k(h_2 - h_3)n = k(h_3 - h_4)n = \cdots$$



$$\frac{b_1}{l_1} = \frac{b_2}{l_2} = \frac{b_3}{l_3} = \cdots = n$$

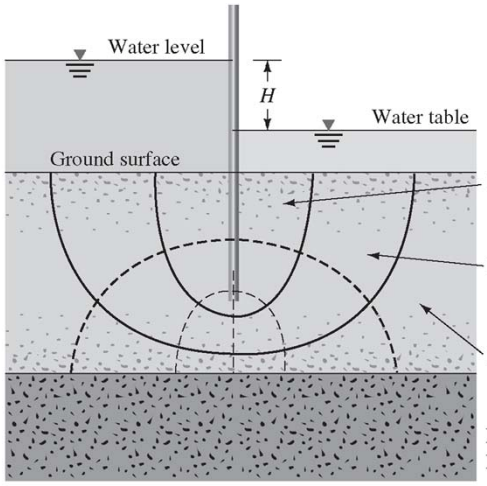
Partial Flow Channels

$$\Delta q = kH\left(\frac{n}{N_d}\right)$$



$$\frac{b_1}{l_1} = \frac{b_2}{l_2} = \frac{b_3}{l_3} = \cdots = n$$

Partial Flow Channels



$$q = k\frac{HN_f}{N_d}$$

← *2.38 flow channels*

← *6 head drops*

2.38 flow channels