Basic Concepts of Groundwater Hydrology

Objectives

1. Review important terminology and concepts, so everyone has sufficient background to absorb course materials.

2. Highlight the topics that are relevant to SW-GW interaction.
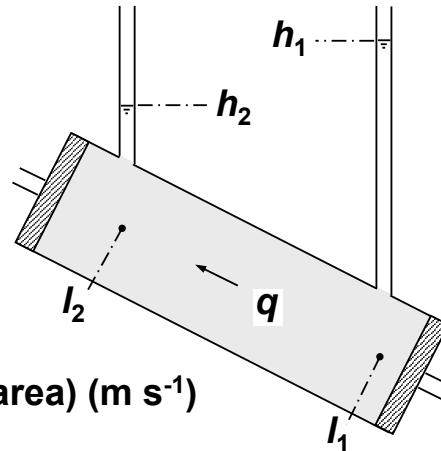
Darcy's Law

$dh = h_2 - h_1$ hydraulic head

$dl = l_2 - l_1$

$$q = -K \frac{dh}{dl}$$

q: specific discharge (= flow rate / area) (m s^{-1})
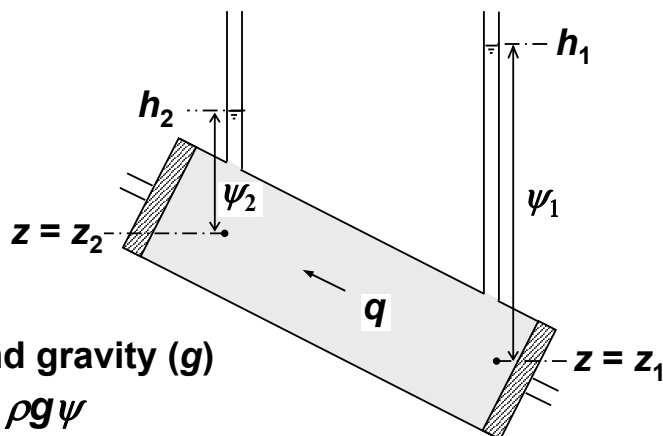
K: hydraulic conductivity (m s^{-1})

1

Hydraulic head has two parts.

$h_1 = z_1 + \psi_1$

$h_2 = z_2 + \psi_2$
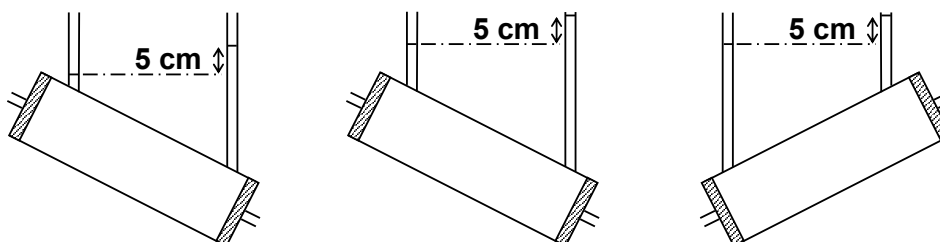
elevation   pressure head

Multiplying h by density (ρ) and gravity (g)

$\rho g h = \rho g z + \rho g \psi$

$= \rho g z + P$

hydraulic potential   gravitational potential + pressure (J m^{-3})

5 cm

5 cm

5 cm

All tubes have the same flow rate – flow is driven by the hydraulic gradient, not by the absolute values of the head.

2

Hydraulic conductivity depends on material and fluid properties.

$$K \;=\; k \;\times\; (\rho g\,/\,\mu)$$

permeability (m^2)   ↑   ⌐ dynamic viscosity (N m^{-2} s)

specific weight (N m^{-3})

Permeability depends on the characteristic pore size (d_c).

$$k \;=\; C \times d_c^2$$

C: empirical coefficient dependent on porosity, pore geometry, connectivity, etc.

For "clean sands", one may estimate *k* from the grain diameter (d_{10}) of smallest portion (10 %) of sand and $C \cong 8 \times 10^{-4}$.

Example: Medium sand, $d_{10} = 0.25$ mm

Fine sand, $d_{10} = 0.13$ mm

Reference: Fetter (2001. *Applied Hydrogeology*, p. 86).

3

Viscosity of water is strongly dependent on temperature.

$$\mu \cong 0.89 \times 10^{-3} \text{ N } m^{-2} \text{ s at 25 }^oC, \quad 1.5 \times 10^{-3} \text{ N } m^{-2} \text{ s at 5 }^oC.$$

Example: Calculate *K* of the medium sand at 25 ^{o}C and 5 ^{o}C.

What are some implications on SW-GW interaction?

$\rightarrow$ **Temperature effects on streambed seepage**
Constantz (1998. *Water Resour. Res.*, 34: 1609-1615)

Other transient factors affecting streambed *K*?

- **Episodic or continual sediment erosion/deposition**

- **Change in porosity due to change in pressure gradient**
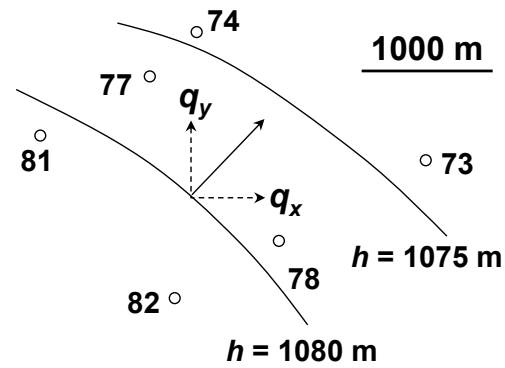
- **Variability associated with biological processes**

Rosenberry et al. (2021. *Hydrol. Process.*, 35: e14226)   4

Darcy's Law in a confined aquifer

piezometric surface

aquifer

1000 m

○74

77 ○ q_y

○81

○73

q_x

○78 h = 1075 m

82 ○

h = 1080 m
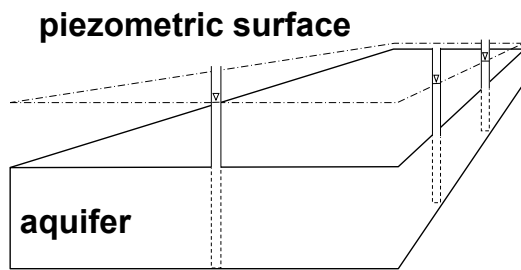
$$q_x = -K\frac{\partial h}{\partial x} \quad q_y = -K\frac{\partial h}{\partial y}$$
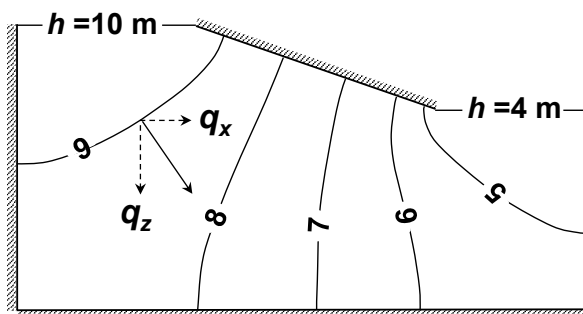
Contour lines of *h* are called 'equipotentials'. Flow vectors are normal to equipotentials in homogeneous, isotropic aquifers.

Suppose that the aquifer consists of the medium sand and temperature is 5 ºC.

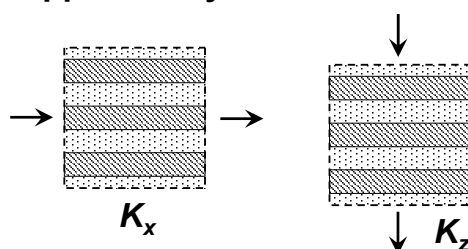Magnitude of the flow vector $\vec{q} = (q_x, q_y)$?

5

Darcy's Law in a vertical cross section

h =10 m

h =4 m

9

q_x

q_z

8

7

6

5

$$q_x = -K\frac{\partial h}{\partial x} \quad q_z = -K\frac{\partial h}{\partial z}$$

Layering and anisotropy of *K*

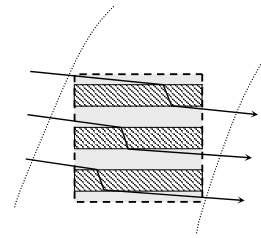Suppose a layered sediment: sand ▦   and clay ▨

K_x

K_z

$$q_x = -K_x\frac{\partial h}{\partial x} \quad q_z = -K_z\frac{\partial h}{\partial z}$$

Hydraulic conductivity is dependent on direction: anisotropy.

6

Flow lines may not be normal to hydraulic head contour lines in anisotropic materials.
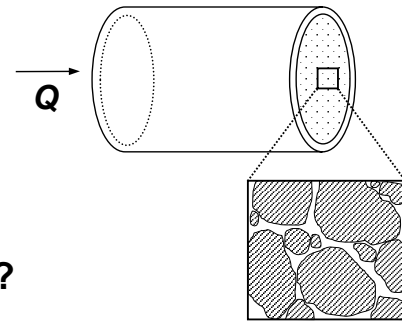
Are layered sediments common near lakes and rivers?

Specific discharge and average linear velocity

Suppose Q (m^3 s^{-1}) of water is flowing through a sand column with an area A (m^2).
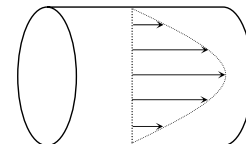
Specific discharge q (m s^{-1}) = ?

Is this equal to the average flow velocity (v)?
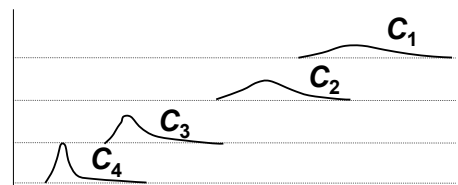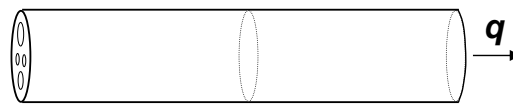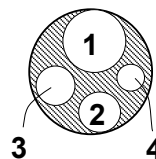
porosity = n_p

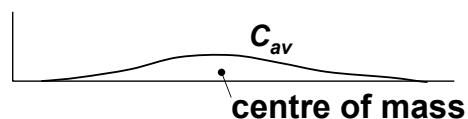**Actual flow velocity varies within a pore 'tube'.**

   Why?

Flow velocity also varies among different-size pores.

   Why?

Suppose that solute molecules are instantaneously released from the left end. The middle graph shows theoretical concentration 'profiles' at some time after the release.

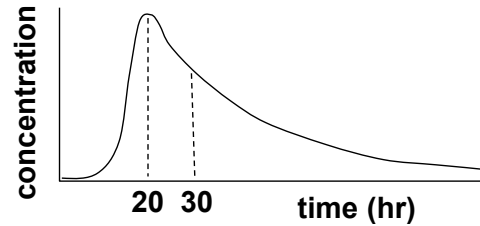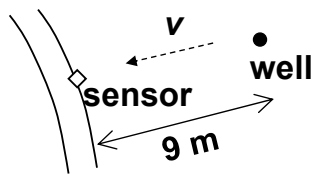C_1

C_2

C_3

C_4

C_{av}

centre of mass

What we can 'measure' by sampling the column is the bottom profile, showing the average concentration of all pores. The centre of solute mass travel at the linear average velocity (v).

The spreading is called 'dispersion'.

Understanding of dispersion is important for the interpretation of tracer test data used in SW-GW interaction studies.
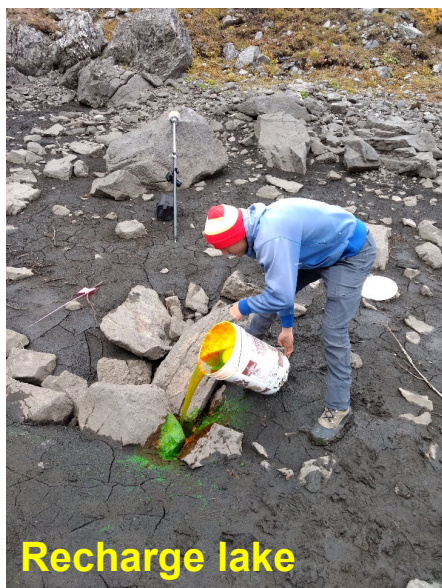

Suppose a 'conservative' tracer was released from a well located 9-m upslope from a stream. Average linear velocity (v) ?

Hydraulic gradient between the well and the stream is 0.02. Horizontal hydraulic conductivity (K)?

Fluorescein (a.k.a. Uranine) Tracer Test
Fortress Ski Area, Kananaskis, AB
Groundwater flow through coarse moraine

~150m

Recharge lake

Headwater spring

Travel time = 230 min, v = 0.011 m s⁻¹.
→ K of moraine ~ 0.1 m s⁻¹

He and Hayashi (2023, *Hydrol. Process.*, in press)