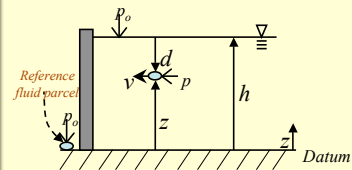


Groundwater Flow

• Today

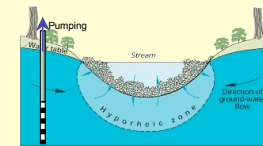
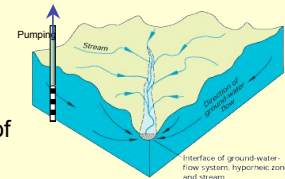
- What causes groundwater flow?
- Mechanical Energy
- Fluid Potential, Φ
 - Energy per unit mass
- Hydraulic Head, h
 - Energy per unit weight
 - Composed of
 - » Pressure head
 - » Elevation head



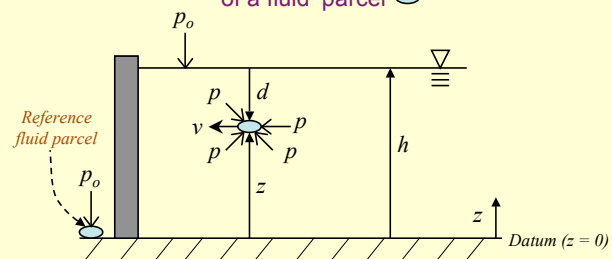
Groundwater Balance

$$\begin{aligned} \text{Change in storage (compressibility + porosity)} \\ = \text{Recharge} - \text{Pumping} - \text{GW} \\ \text{Discharge} - \text{ET}_{\text{GW}} \pm \text{Underflow} \end{aligned}$$

What is the ultimate cause of fluid movement?



Components of Fluid Potential, Φ of a fluid 'parcel' \circ



What makes groundwater flow?

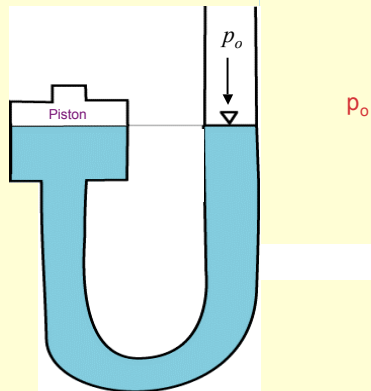
Answer:

What forms of energy does water have?

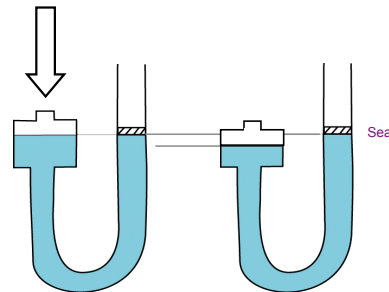
What is the formula for gravitational potential energy?



Why does the water rise?

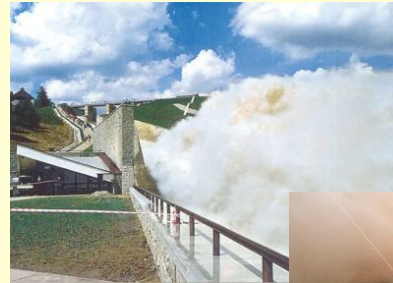


Elastic Energy



Elastic Energy

$$EE = m \int_{p_0}^p \frac{dp}{\rho}$$

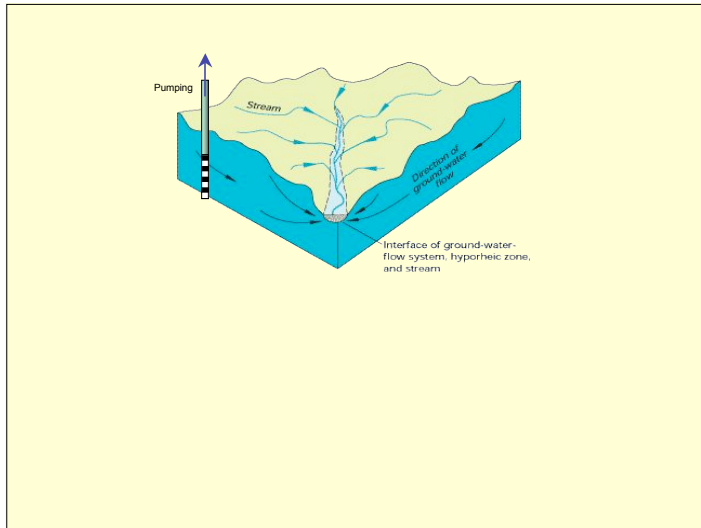


Why is the water spraying up into the air?



What is kinetic energy equal to?

What drives flow is the sum of these types of energy, called the “**fluid potential**”. The fluid potential is defined as the “**total mechanical energy per unit mass of water**”.



Review: What kinds of mechanical energy can a fluid (parcel) have?

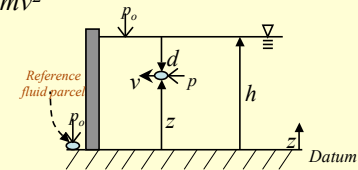
- Potential Energy
 - gravitational
 - reflects the work to lift mass from elevation $z = 0$, the datum, to elevation z :

$$PE = mgz$$

- Kinetic Energy
 - energy required to accelerate fluid from rest to observed velocity, v

$$KE = \frac{1}{2} mv^2$$

- Elastic Energy
 - compressional
 - work done in raising fluid pressure from reference pressure, p_o , to pressure, p



Fluid Potential

•So, the components of Φ
[total mechanical energy per unit mass] are:

$$\Phi = .$$

$$\Phi =$$

$$\Phi =$$

Fluid Potential

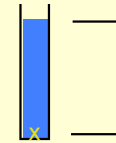
$$\Phi = gz + \frac{p - p_o}{\rho} + \frac{1}{2} v^2$$

Fluid Potential

What are the units of fluid potential?

Hydraulic Head

How does it work?

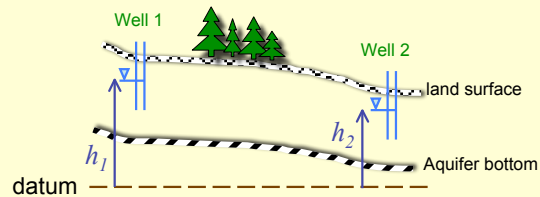


———— datum

Hydraulic Head

Therefore, h , the hydraulic head, is directly related to the fluid potential.

Water flows from areas of higher head to lower head.



$h_1 > h_2$, so water will flow from Well 1 toward Well 2

Hydraulic Head

Recall that our conclusion that h is representative of Φ is based on three major assumptions:

- Velocity is negligible
- Density is essentially constant
- g is constant

Finally, from earlier diagrams, recall that the dimensions of h are $[L]$, e.g., meters.

-this dimensional convenience is one reason we work with head if we can.

Components of Hydraulic Head

$$\Phi = gz + \frac{p - p_o}{\rho} = gh$$

$$h = \frac{\Phi}{g} = z + \frac{p}{\rho g} - \frac{p_o}{\rho g}$$

Components of Hydraulic Head

$$h = z + \frac{p}{\gamma} = h_z + h_p = h_z + \psi$$

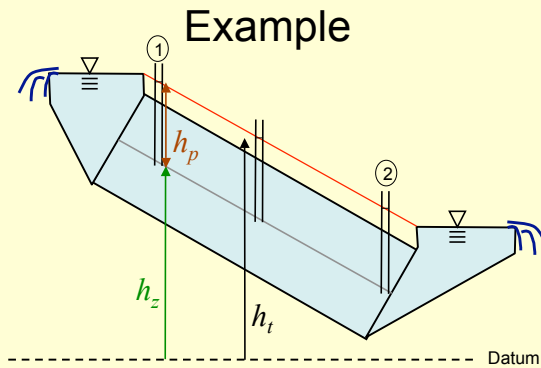
= elevation head + pressure head

SI Units of Hydraulic Head

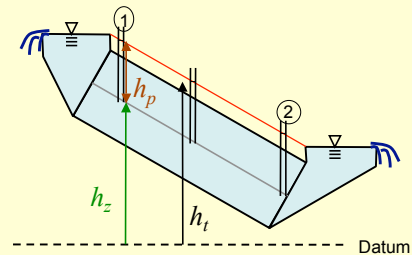
$$p = \frac{N}{m^2} = \frac{kg \cdot m}{s^2 \cdot m^2} =$$

$$\gamma = \rho g = \frac{kg}{m^3} \cdot \frac{m}{s^2} =$$

$$\frac{p}{\gamma} = \frac{kg}{s^2 \cdot m} \div \frac{kg}{s^2 \cdot m^2} =$$

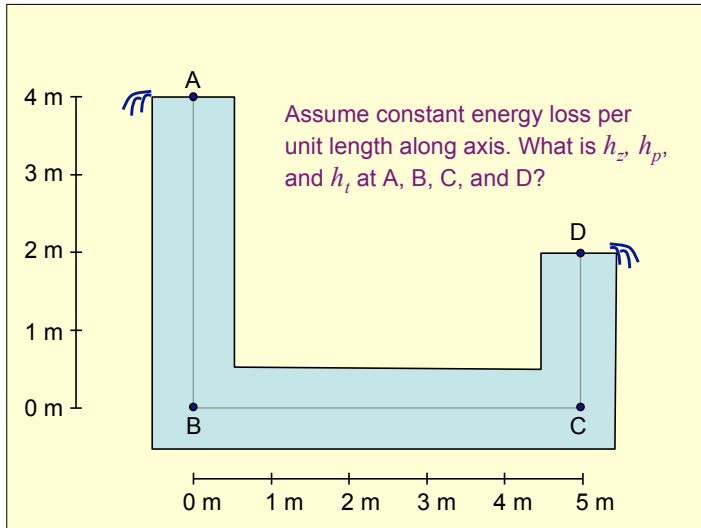


- Note:
- constant head tanks at end
 - pressure head (constant)
 - elevation head (decreasing to right)
 - total head (decreasing to right)



Interpolate between the piezometers to get continuous head lines:





Groundwater Flow

- Review
 - Groundwater flow is in response to gradients of mechanical energy
 - Three types
 - Potential
 - Kinetic
 - Kinetic energy is usually not important in groundwater
 - Elastic (compressional)
 - Fluid Potential, Φ
 - Energy per unit mass
 - Hydraulic Head, h
 - Energy per unit weight
 - Composed of
 - » Pressure head
 - » Elevation head
- Next Time
 - Darcy's Law
 - Hydraulic Conductivity
 - Specific Discharge

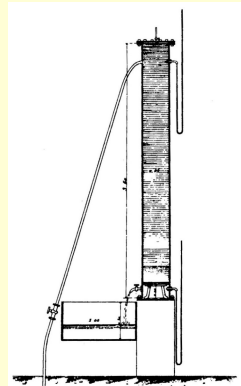
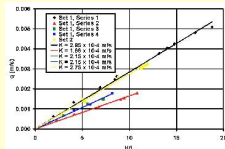
<http://biosystems.okstate.edu/darcy/index.htm>

Next time: Darcy's Law

Henry Darcy, a French hydraulic engineer interested in purifying water supplies using sand filters, conducted experiments to determine the flow rate of water through the filters.



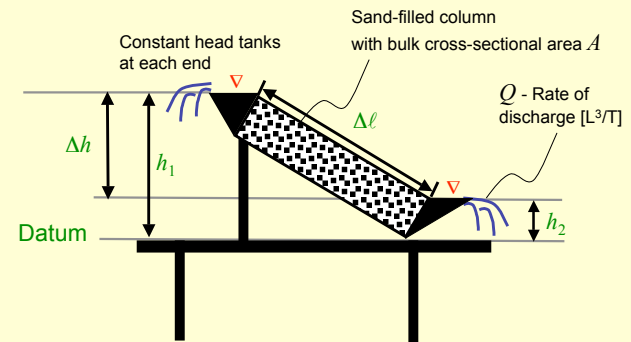
Published in 1856, his conclusions have served as the basis for all modern analysis of ground water flow



Freeze, R. Allen. "Henry Darcy and the Fountains of Dijon." *Ground Water* 32, no.1(1994): 23-30.

Next time: Darcy's Law

Cartoon of a Darcy experiment:



What controls the discharge, Q ?