Introducing groundwater physics

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Groundwater makes up more than 98% of available freshwater.
supplies 40% of drinking water in US.
supplies 70% of drinking water in China.
Aquifer: is a body of porous material that yields significant quantities of water to wells and springs.

Fundamental Laws

Darcy's law (published Henry Darcy, 1856): Describes the flow od groundwater through porous material.
q= Flux of Groundwater (m/s)
h= Potential - Water Head (m)
K= Medium Property - Hydraulic Conductivity (m/s)

q= -K delta(H)

Head: is measured in the field as the elevation to which water rises in an observation well.

1959 Hubbert shows that Darcy's law can be derived as a special case of Navier-Stokes eq.

Hydraulic conductivity (K) is a symmetric tensor, allowing anisotropy in the porous material.
depends on viscosity, density of fluid(water) and the medium properties.
Permeability (k) is a related parameter, describing the transmission properties of the medium independent of the fluid.

Groundwater Flow

Darcy's law does not hold for high velocity water flows. Breakdown occurs at a Reynolds Number between 1 and 10. Flow is still laminar, turbulent flows occur above 100.

Skipping parts on Heat Flow, and solute transport.

Governing Equations

Ground water flow can be derived by Darcy's law and a water balance equation:

$$\nabla \cdot q = -S_s \frac{\partial h}{\partial t} + W$$

Where S_s= Volume of water removed from storage per unit
h: water Head
t: time
W: sink or source of water (recharge, precipitation, pumping...)

Hydraulic Conductivity (K)

Varies over 13 orders of magnitude from 10e-14 m/s for unfractured crystaline rock to 10e-1 m/s for gravel.
Can be measured in lab.
Can be measured by pumping from one well and observing several observation wells around the pumping area. Transient mathematical model devised by Charles V. Theis.
Can also be measured by a “slug test”. A cylindrical object is dropped into the observation well to displace water. Then slug is pulled back and recovery of the water level is measured.
Hydraulic tomography: Multiple pumping stations. Multiple observation wells. Each at different depths. Slug tests at observation wells. All data is analyzed together to get something like a CT scan of the aquifer.