Groundwater Hydrology

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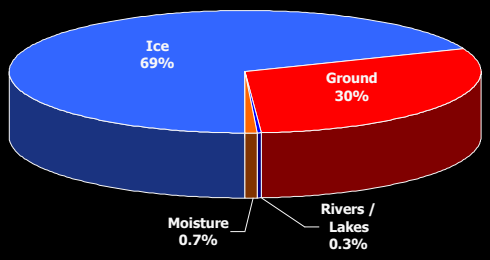
Why study groundwater?

- Important source of fresh water
- Large portion of the Earth's fresh water as groundwater
- Important to know the renewal time
  - Residence time ~5000 a
- Self-sustaining use important (slowly renewable source)

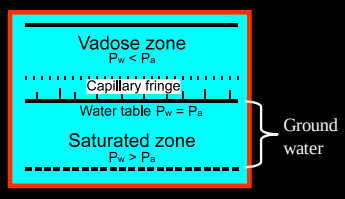
Fresh water on Earth



What is groundwater?

- If a hole is dug the water that flows freely into the hole is groundwater.
  - Since the air in the hole is at atmospheric pressure, the pressure in the groundwater must be higher if it is to flow freely into the hole.
- The zone between ground surface and the top of the groundwater is called the *vadose zone* (unsaturated zone).
  - Water there is held to the soil particles by capillary forces.

Water beneath land surface



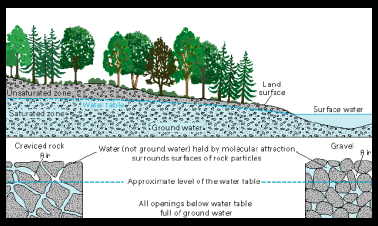
Aquifers / Veitar

- Groundwater-bearing formations sufficiently permeable to transmit and yield water in usable quantities are called aquifers.
- Two types of aquifers: (1) unconfined and (2) confined.

Source of Groundwater

- Atmospheric precipitation is the main source of fresh groundwater.
- The water may have *infiltrated* directly into the ground where it landed, or been *collected* via *surface runoff* and then seeped into the ground.

Groundwater system
Grunnvatnskerfi



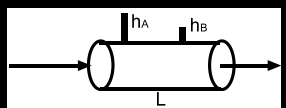
Vatn streymir úr hlíðum

Vatnafræði
GROUNDWATER FLOW

Darcy

Pipe flow – Darcy's law

- Demonstration of Darcy's law
- Pipe filled with sand
- Water applied under pressure at A
- Discharges at B



Darcy's law

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

- q – specific discharge, [L T^{-1}]
- Q – discharge, [L^3 T^{-1}]
- A – cross sectional area, [L^2]
- dh/dl – hydraulic gradient
- K – hydraulic conductivity [L T^{-1}]

Hydraulic conductivity

- Also referred to as the **Coefficient of permeability**
- Intrinsic permeability, $K_i = C\,d^2$
  - C – shape factor
  - d – grain size (diameter)
- Hydraulic conductivity then, $K = K_i * \gamma/\mu$, where $\gamma = \rho\, g$ and μ is dynamic viscosity.

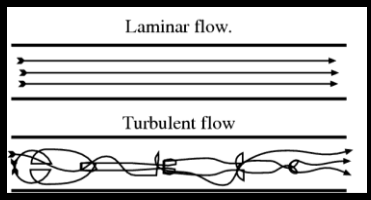
Velocity of the water

- v sometimes called Darcy velocity $v = \frac{Q}{A}$
- Note that is the average velocity through the cross section, not the water velocity
- Average velocity of the water itself $v_x = \frac{Q}{n_e A}$

Applicability of Darcy's law

- Only for laminar flow, not turbulent
- Reynolds number used to determine whether flow laminar or turbulent

Laminar & Turbulent flow



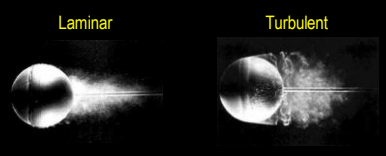
Reynolds number

$$\mathrm{Re} = \frac{\rho q d}{\mu}$$

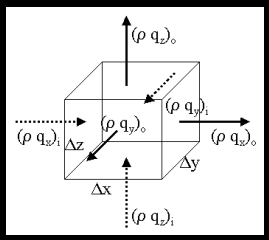
- Where
  - ρ is density
  - q is discharge velocity
  - d diameter of discharge passageway
  - μ is the viscosity

Characteristic Numbers

- If *Re* smaller than ~2200 the fluid flow is laminar, if higher then the flow is turbulent.



Control Volume



Vatnafræði
AQUIFERS

Types

What are Aquifers?

- Groundwater-bearing formations sufficiently permeable to transmit and yield water in usable quantities are called aquifers.
  - Most common are unconsolidated sands and gravels.
- Two types of aquifers: (1) unconfined and (2) confined.

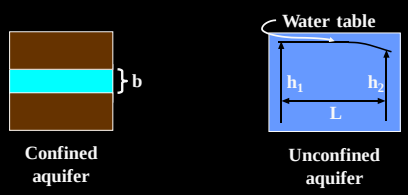
Unconfined aquifers

- Are under-ground lakes in porous materials
- Top of the unconfined aquifer is the **water table**
  - Also called phreatic surface, after the Greek word phrear, ``well"
- That is the plane where groundwater pressures are equal to atmospheric pressure.

Confined Aquifer

- A layer of water-bearing material that is sandwiched between two layers of much less pervious material
- The pressure condition is characterized by the *potentiometric surface*, which is the surface obtained by connecting equilibrium water levels in tubes, or piezometers, penetrating the confined aquifer

Aquifer types



Potentiometric (Piezometric) Surface

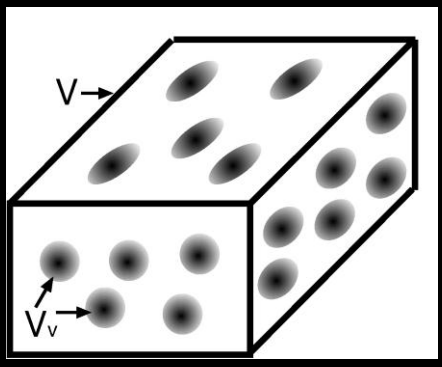
- If it is above the upper confining layer, the static water level in a well will be above the aquifer.
- Such a well is called an *artesian* well, named after wells bored in Artois (N-France) in the eighteenth century.

Gropa / Porosity

- Hlutfall holrýmis á móti heildarrúmáli
  - The percentage that is void of material,

$$n = \frac{V_v}{V} \times 100$$

- Þar sem V_v er holrýmið, V heildarrúmmálið og n gropan
  - Where V_v is the void space, V the total volume, and n porosity



Calculating *n*

- $V_v = V - V_s$,
  - where v – void, s – solid
- $V_s = m_s/\rho_s$,
  - where ρ – density, m_s – dry weight

Porosity of materials

- Well rounded and sorted sediments have porosity of 26% – 48%
- If well sorted, then porosity depends only on the packing (not grain size)

Packing

Cubic packing of spheres

n = 47.65%

Rhombohedral packing of spheres

n = 25.95%

Porosity – mixed grain sizes

- If a mixture of grain sizes, then porosity will be lower
  - Small grains fill in the void space
- Porosity of sedimentary rocks 1 – 30%
- Plutonic rock ~2% (+2 – 5% if fractured)
- Weathering can increase to 30 – 60%

Effective porosity, n_e

- Measured by drying the sample at 105°C
- Then submerged in known volume of water
- What goes into sample is a measure of the effective void space

Conductivity

- If the voids are poorly interconnected, the rock cannot convey water from one void to another.

Hydraulic conductivity

- Also referred to as the

  Coefficient of permeability

- Intrinsic permeability, $K_i = C\,d^2$
  - C – shape factor
  - d – grain size (diameter)

Estimating water content

- **Specific yield, S_y**
  - Ratio of volume of water drained by gravity to total volume
- **Specific retention, S_r**
  - Ratio of volume of water a rock can retain to total volume
- If two rocks have equal porosity, but different grain size, more water will be retained in the fine grained rock, why?
  - Surface tension

Specific yield and retention

- The sum of those is,

$$n = S_y + S_r$$

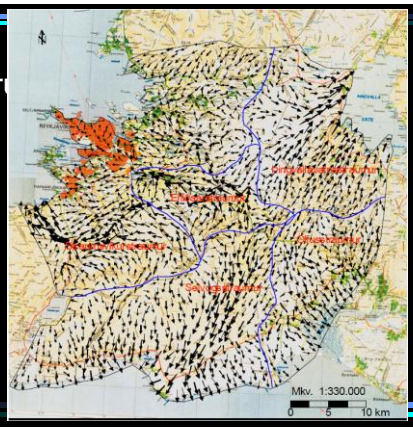
→ porosity

Aquifer transmissivity

$$T = b\,K$$

- T – transmissivity [$L^2\ T^{-1}$]
- b – thickness of saturated layer [L]
- K – hydraulic conductivity [$L\ T^{-1}$]

Gr



Water withdrawal

- Common to withdraw groundwater but too fast or extensive withdrawal (mining) can lead to:
  - Cone of depression
  - Wells can go "dry"
  - Lower water table
    - Serious consequences for vegetation
  - Increased concentration of chemicals in water
  - Saltwater intrusion
  - Subsidence

Saltwater intrusion

- Saltwater flowing inland into aquifers
- Sea water has higher density than freshwater - and thus the pressure under saltwater is higher than with freshwater
- The withdrawal of freshwater and this pressure difference triggers a flow from the saltwater column to the freshwater column

Subsidence

- Drained soil compacts
- Water table falls, peat exposed to oxygen
- Decomposes
- Subsidence