Groundwater

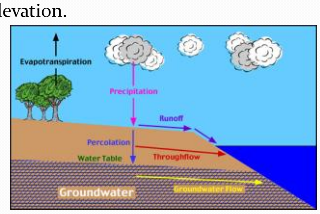
GG22A: GEOSPHERE & HYDROSPHERE
Hydrology

Definitions

- *Groundwater*
  - Subsurface water in soil or rock that is fully saturated.
- *Aquifer*
  - Contains enough saturated material to yield significant quantities of water and has a high water-bearing capacity.
- *Aquitards*
  - Less permeable materials that transmit water at lower rates and have low water-bearing capacities.
- *Aquicludes*
  - Impermeable rocks with no water-bearing capacity.

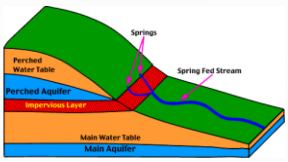
Groundwater

- The top of groundwater zone is the **water table**.
- ~22% of terrestrial fresh water is stored as groundwater.
- Groundwater tends to flow by way of gravity to the point of lowest elevation.



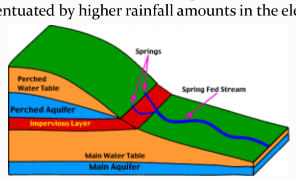
Unconfined groundwater

- Upper limit of unconfined groundwater is defined by the water table (the level where pore water pressure = atmospheric pressure).
  - The water table is a subdued version of surface topography. The relief of the water table also depends on the texture and permeability of the material.



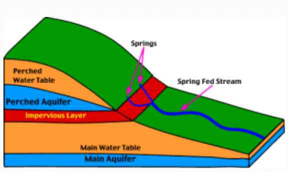
Unconfined groundwater

- In open-textured rock, the water table may be more or less horizontal.
- In fine-textured rock, groundwater movement will be slower:
  - height of the water table will be built up under the elevated relief areas, accentuated by higher rainfall amounts in the elevated areas.



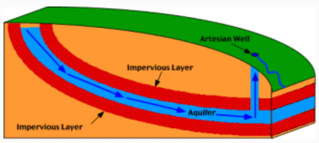
Perched groundwater

- Occurs where an elevated body of water (at some height above the main groundwater body) is situated above an underlying impermeable or semi-permeable bed which is not continuous over a large area.



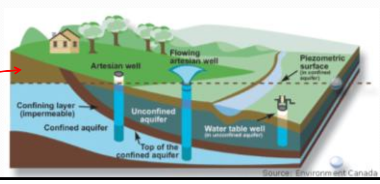
Confined groundwater

- Upper boundary of the water body is formed by an overlying less permeable bed.
- Confined groundwater is generally under greater hydraulic pressure than the free flow of unconfined groundwater.



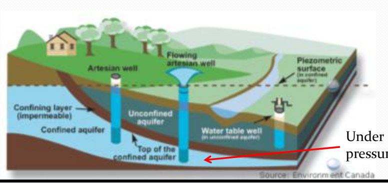
Confined groundwater

- Most confined aquifers have an unconfined area for recharge to occur.
- The confining beds rarely form a complete barrier to water flow.



Confined groundwater

- Water in the confined aquifer is under pressure
  - releasing the pressure locally will cause the water to rise to a the level of the hydrostatic head.
  - This imaginary level is called the ***potentiometric surface***.



Aquifer properties

- *Porosity*
  - percentage of total volume of rock represented by voids
- *Permeability / hydraulic conductivity*
  - ability of water to move through aquifer
- *Specific retention*
  - amount of water that can be held against gravity (= field capacity)
- *Specific yield*
  - amount of "available" water
  - = porosity - specific retention

Groundwater storage

- Amount of storage depends on the material forming the aquifer, especially its porosity which determines how much water it can hold.
  - Soils tend to have a higher porosity than most rocks.

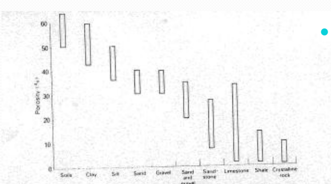
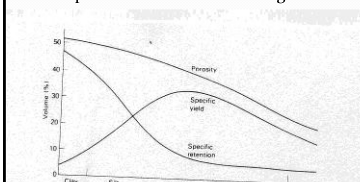


Figure 6.3 *Typical ranges in measured porosity for various materials (compiled from data from various sources).*

- But not all water is available.
  - This also depends on how the pores are connected, or its permeability.

Groundwater storage

- Porosity, specific yield and specific retention control the ability of an aquifer to store and retain water.
  - Specific Yield: volume of freely draining water.
  - Specific Retention: remaining water held by tension.

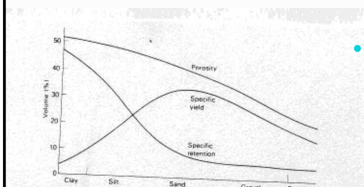


igure 6.4 *The relation between porosity, specific retention and specific yield for different types of nconsolidated material, showing typical values which may differ significantly from values at a articular site (from an original diagram by Eckis, 1934).*

With increased coarseness, both porosity and specific retention decline.

Groundwater storage

- Silt and Clay have a relatively high porosity, but the available water is small.
- Gravel and Boulders have lower porosity, but also lower retention, so higher yield.



igure 6.4 The relation between porosity, specific retention and specific yield for different types of nconsolidated material, showing typical values which may differ significantly from values at a rticular site (from an original diagram by Eckis, 1934).

- The amount of water present also depends on storage changes:
  - Inflows and outflows; the groundwater balance.

Groundwater balance

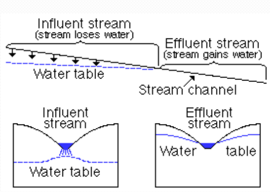
- The groundwater balance can be expressed as:

$$\Delta S = Q_r - Q_d$$

where: ΔS = change in groundwater storage
Q_r = Recharge
Q_d = Discharge

Groundwater balance

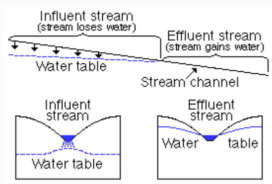
- Recharge: 4 components.



1. Infiltration at the ground surface.
2. Seepage from surface water bodies into the groundwater (influent seepage).
3. Groundwater inflow from adjacent aquitards and aquifers.
4. Artificial recharge by irrigation, leaking pipes etc.

Groundwater balance

- Discharge: 4 components.



1. Evaporation, especially where the water table is close to the surface.
2. Natural discharge by springs and effluent seepage into surface water bodies.
3. Groundwater leakage and outflow into adjacent aquifers.
4. Artificial abstraction.

Groundwater balance

- Effluent seepage is a major type of groundwater discharge, sustaining the base flow, or fair-weather flow of rivers.

Changes in groundwater storage

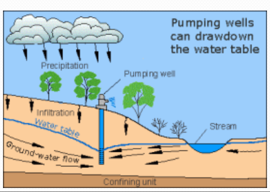
- The Coefficient of Storage of an aquifer is the volume of water that is taken into storage or released
  - per unit area of aquifer
  - per unit change of head.

Changes in groundwater storage

- Unconfined Aquifers:
  - Related to variations in water table level, which rises with recharge and falls with discharge.
  - Water table fluctuations follow a rhythmic seasonal pattern.
  - Longer-term variations may also occur related to rainfall patterns.
  - Artificial abstraction can also change storage.

Changes in groundwater storage

- If the rate of artificial abstraction is higher than the rate of recharge, the water table can become lower
  - "cone of depression" around the well
  - excessive pumping can lead to wells no longer supply water.



Changes in groundwater storage

- Confined Aquifers:
  - changes are affected by compression and elastic rebound of the aquifer.
  - In a confined aquifer, there are:
    - inter-granular pressures (due to weight of overlying deposits)
      - Effective stress
    - hydrostatic pressures (due to the pore-water).
      - Neutral stress
  - Inter-granular pressures + hydrostatic pressures = total stress.

Changes in groundwater storage

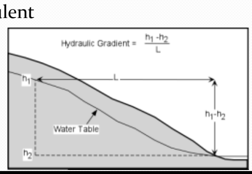
- Confined aquifers:
  - On pumping of water:
    - inter-granular pressure increases
    - hydrostatic pressure decreases
    - no reduction in total stress.
    - but an increase in the load carried by the grains (due to a reduction in pore-water pressure)
  - leads to **compression**.

Changes in groundwater storage

- Confined aquifer compression:
  - If pumping stops:
    - Grains will rebound elastically to their original position with recharge.
  - If pumping continues:
    - Excess discharge over recharge leads to increasing inter-granular pressure and compression, which may cause **subsidence**.

Groundwater flow

- Groundwater flows in proportion to the hydraulic gradient (i.e. the difference in water table height or potentiometric surface)
  - This may be very different to the surface topography
  - Most groundwater flow is laminar – i.e. "smooth" or non-turbulent



Groundwater flow

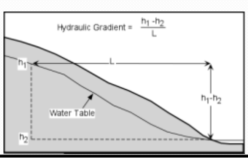
- If flow is through small pores:
  - Darcy's Law applies and the hydraulic conductivity is fundamentally important.
- If flow is through fissures:
  - Darcy's Law does not apply, and movement is controlled by fissure connectivity.
- Rates of flow are slow and concentrated where the voids are larger and better connected.
  - Direction and speed of flow can be calculated from the hydraulic gradient and hydraulic conductivity of the water-bearing material (Darcy Equation).

Groundwater flow

- Darcy's Equation:

$$q = -K \frac{\partial h}{\partial l}$$

q = specific discharge
K = Hydraulic Conductivity
$\partial h / \partial l$ = Hydraulic Gradient
h = Hydraulic pressure head
l = Length



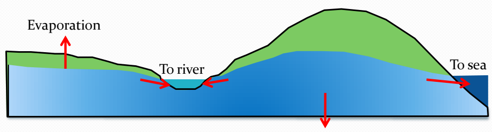
Groundwater flow

- Factors affecting hydraulic conductivity:

1. Character of the Material: geometry of the pores and distribution of the grain sizes. Surface roughness of the particles. Structural patterns (faults, joints, folds).
2. Groundwater as a Fluid: density and viscosity. Temperature and salinity.

	porosity %	specific yield %	hydraulic conductivity m day^{-1}
clay	35-60	1-5	10^{-7} to 10^{-3}
sand	30-50	10-30	0.01 to 1000
gravel	25-40	20-30	100 to 10000
chalk	5-30	1	1000 to 5500
sandstone	5-30	5-20	10^{-5} to 0.01

Where does groundwater go?



Groundwater contamination

- Sources:
  - Sewers and septic tanks
  - Waste dumps (both industrial and residential)
  - Gasoline Tanks (like occur beneath all service stations)
  - Biological waste products
    - Can be removed from the groundwater by natural processes if the aquifer has interconnections between pores that are smaller than the microbes. For example a sandy aquifer may act as a filter for biological contaminants.
  - Agricultural pollutants such as fertilizers and pesticides.
  - Salt water contamination - results from excessive discharge of fresh groundwater in coastal areas.

Saltwater intrusion