FACH HOCHSCHULE LÜBECK

Hydrology Groundwater

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Content

Objectives

To learn about ...

- types of aquifers
- groundwater hydrology terms
- measurement of water levels
- calculation of groundwater flow and storage

Basics to understand groundwater flow and storage

- Physical background
- Hydrological Relevance
- Application

Groundwater
Relevance

Groundwater is the largest store in the hydrological cycle. It compensates for seasonal variations and provides mid-term and long-term safety for drinking water supply. Aquifers clean water and remove or attenuate/reduce the concentration of bacteria, organic pollutants and even some metals due to natural attenuation and degradation.

- drinking water supply (safe and secure)
- management of water resources under changing climate
- managed aquifer recharge

Groundwater also plays an important role in runoff storm generation. Management of groundwater along coasts and in semi-arid and arid regions is key for water security.

Terminology

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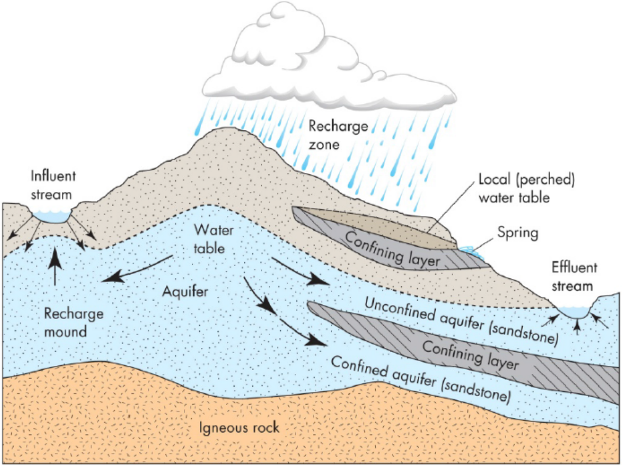
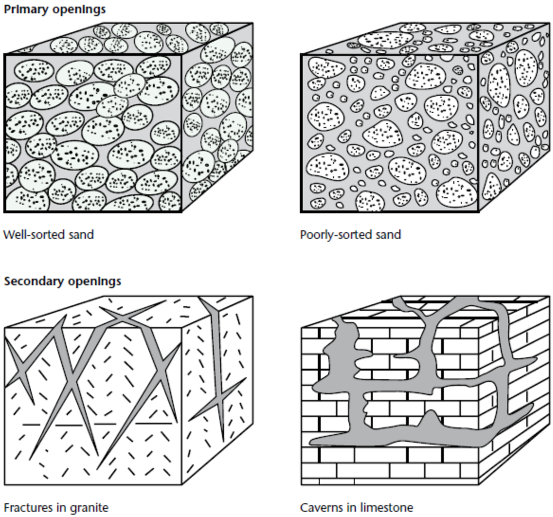


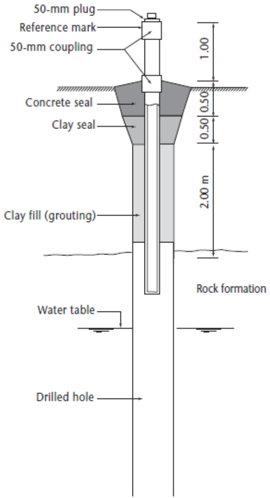
USGS, 2012

Physical background

Porosity

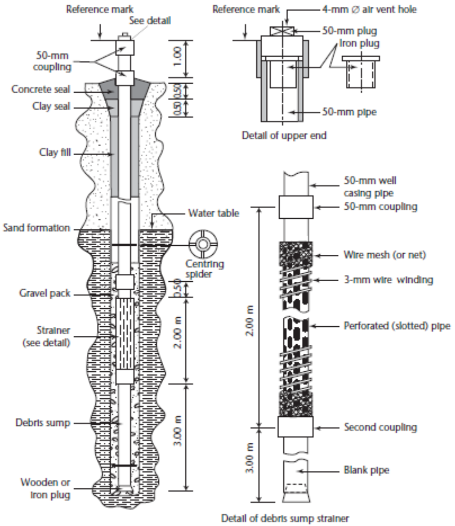

Primary openings
Well-sorted sand
Poorly-sorted sand
Secondary openings
Fractures in granite
Caverns in limestone

Water Level Observation

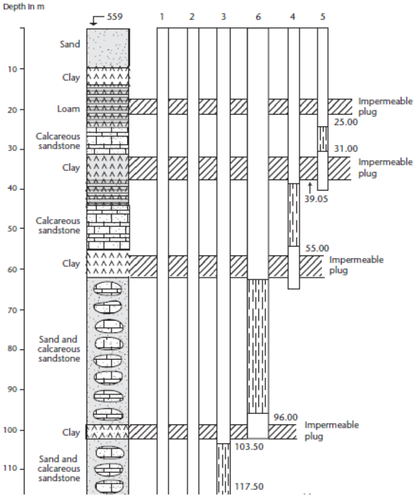


WMO, 2008

Construction of a Borehole



Multi-Level Boreholes



WMO 2008

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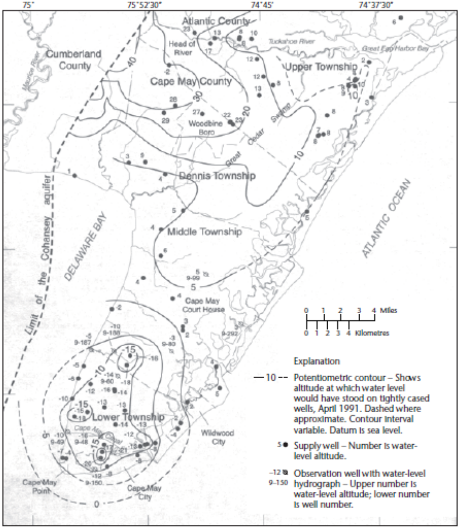
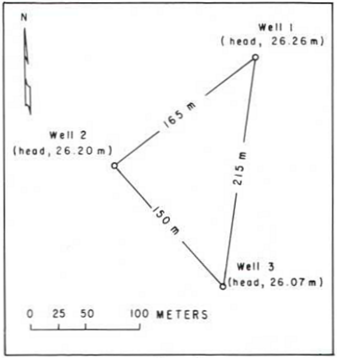
Map of Observation Data

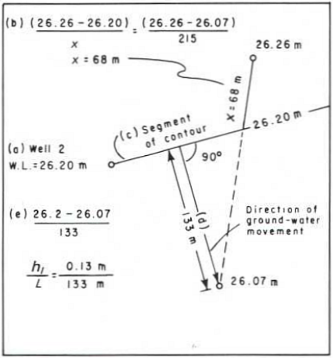


Based on United States Geological Survey digital data, 1:100 000, 1983. Universal Transverse Mercator Projection, Zone 18.

WMO, 2008

Hydrologic Triangle





Heath, 2008

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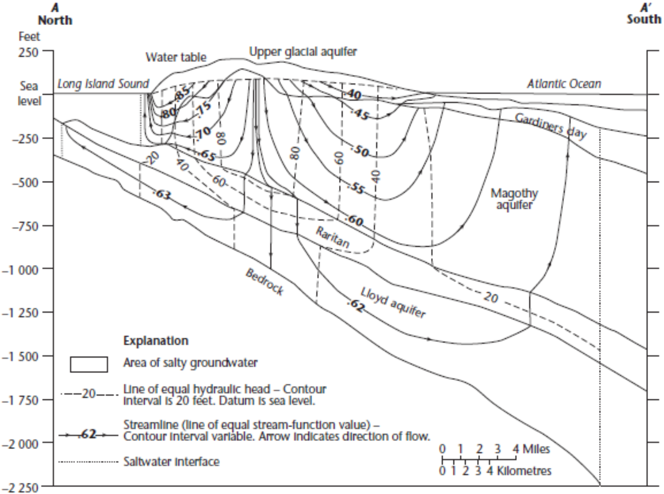
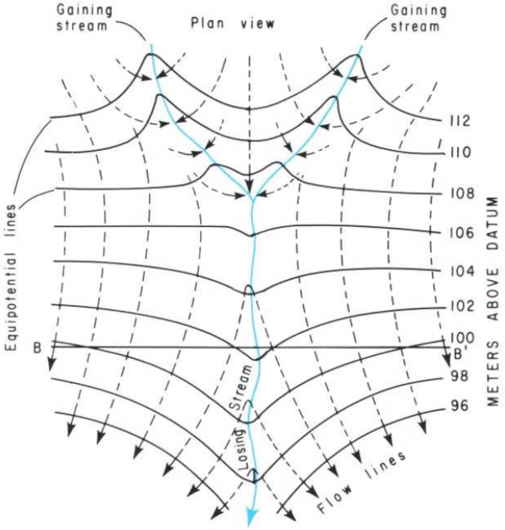
Cross-section with Observation Data



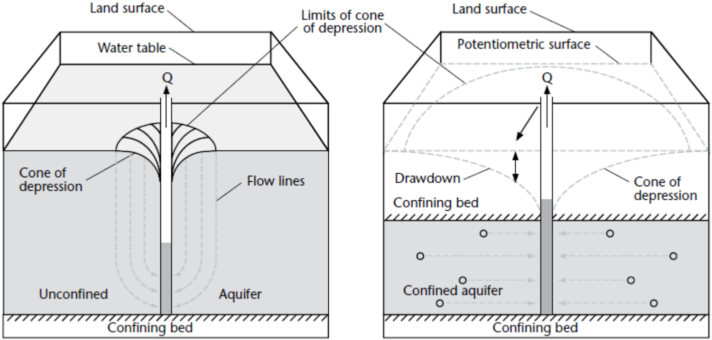
WMO, 2008

Interpretation of Contours



Heath, 2008

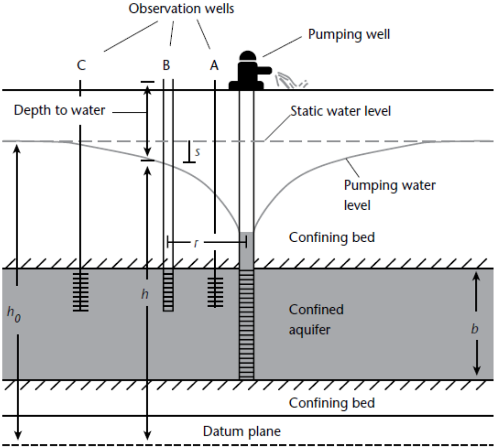
Pumping and Storage



Drawdown from a pumped well in (left) an unconfined aquifer and (right) in a confined aquifer (Heath, 1983)

WMO, 2008

Pumping and Storage



WMO, 2008

Parameters

The main physical properties of aquifer to be quantified are as follows:

- Porosity (P). Porosity is the ratio of void volume to the bulk volume (grains plus void space). Primary porosity refers to porosity developed during the formation of the rock. Secondary porosity refers to fractures, joints and solution cavities. Effective porosity is the volume of pores that is available for transport of water, divided by the bulk volume. Porosity is expressed as percentage.

- Hydraulic conductivity (K). The hydraulic conductivity is the ease through which water is able to move through interconnected pore space or fractures. The hydraulic conductivity depends both on the rock properties as well on water properties (fresh, saline). Hydraulic conductivity is expressed in metres/day.

- Transmissivity (T). Transmissivity is product of average hydraulic conductivity and saturated thickness of the aquifer. Transmissivity is expressed in m^2/day.

- Storativity (S). Storativity or storage coefficient is the volume of water released or stored in a column of the aquifer with a unit cross-sectional area (1 m^2) at a lowering or rise of head respectively of a unit distance (1 m). It applies to confined and semi-confined aquifers. Storativity is dimensionless.

- Specific yield (S_y) is the ratio of volume that a formation would yield by gravity to its own volume, under unconfined conditions. It represents very closely the effective porosity.

WMO, 2008

Porosity

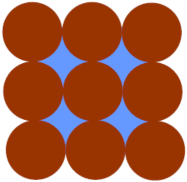
Rock description	*Range of porosity (n) in percentage*	*Range of hydraulic conductivity (K) in m/d*
Gravel	0.2 – 0.4	10^2–10^3
Sand	0.2 – 0.5	1–10^2
Silt	0.3 – 0.5	10^{-1}–1
Clay	0.3 – 0.7	10^{-8}–10^{-2}
Fractured basalt	0.05 – 0.5	0–10^3
Karst limestone	0.05 – 0.5	10^{-2}–1
Limestone, dolomite	0.0 – 0.2	10^{-2}
Shale	0.0 – 0.2	10^{-7}
Fractured crystalline rocks	0.0 – 0.1	0–10^2
Dense crystalline rocks	0.0 – 00.5	$<10^{-5}$

Source: Fetter, 2000

WMO, 2008

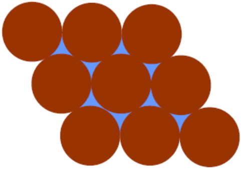
Packing Density

cubic packing (loosest possible packing)



porosity = n = 47.64%

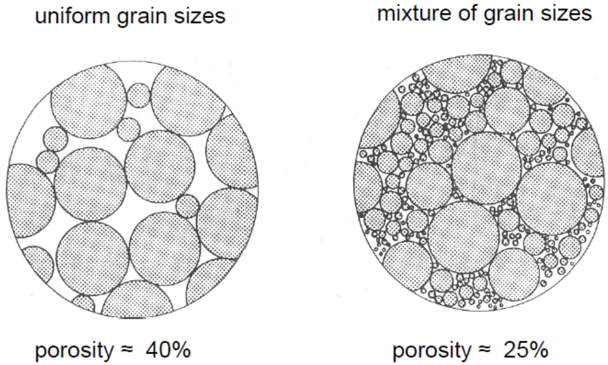
rhombohedron packing (tightest possible packing)



porosity = 25.95%

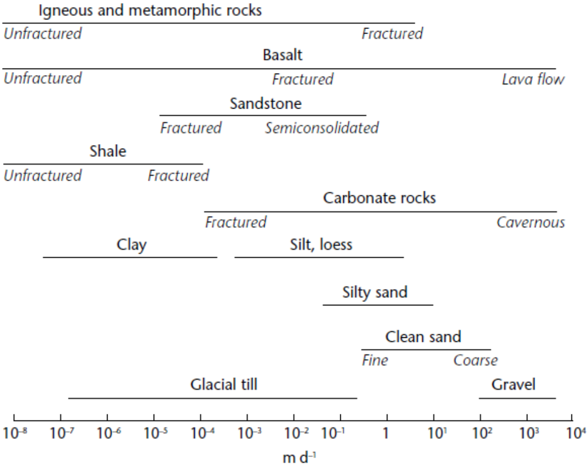
USGS, 2012

Grain Size Distribution



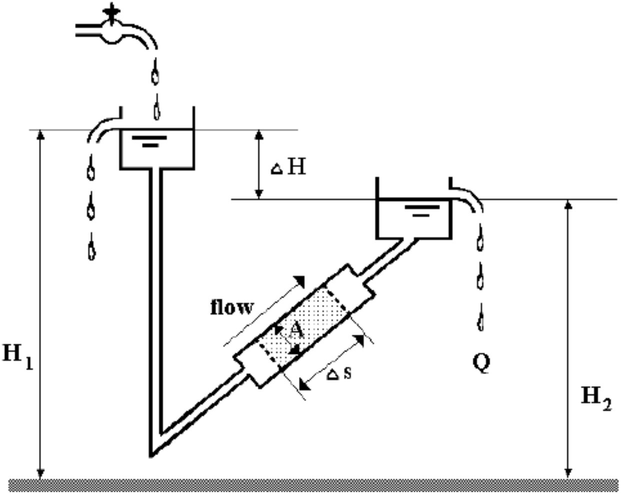
USGS, 2012

Hydraulic Conductivity



WMO, 2008

Darcy Experiment



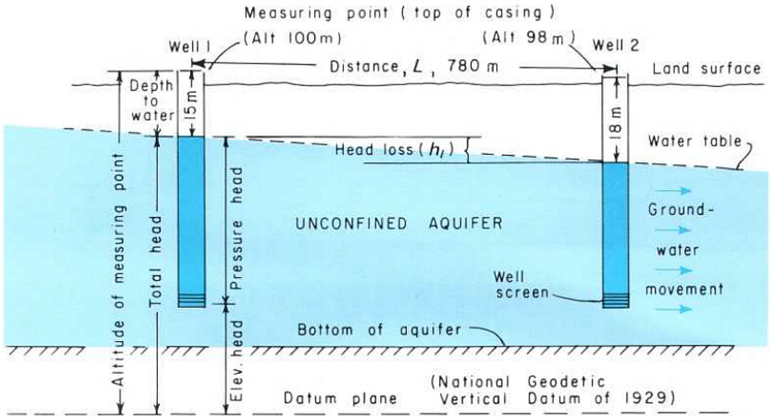
Savenje, 1992

Darcy's Law

$$
\begin{aligned}
v_f &= -k_f * dh/dx \, [m/s] \\
Q_a &= v_f * A \, [m^3/s]
\end{aligned}
$$

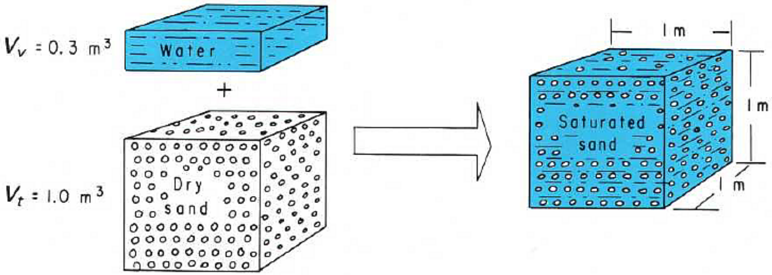
v_f	hydraulic conductivity $[m/s]$
dh	change in water level $[m]$
dx	along distance x $[m]$
dh/dx	gradient
Q	flux, discharge $[m^3/s]$
A	area of aquifer cross-section $[m^2]$

Flow Lines



Heath, 2008

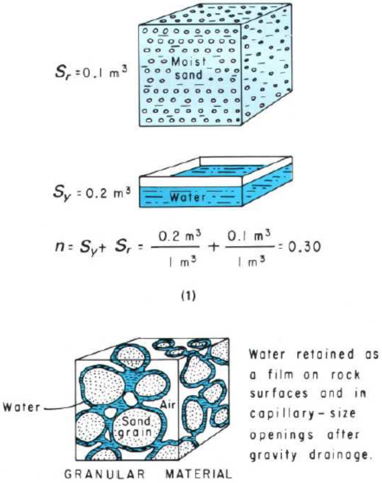
Porosity



$$\text{Porosity } (n) = \frac{\text{Volume of voids } (V_v)}{\text{Total volume } (V_t)} = \frac{0.3 \text{ m}^3}{1.0 \text{ m}^3} = 0.30$$

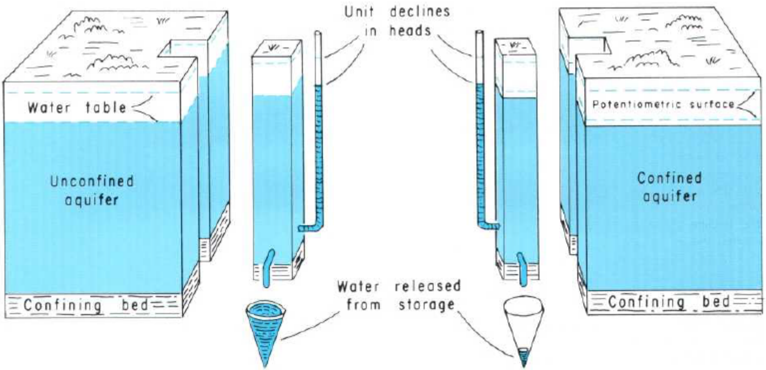
Heath, 2008

Groundwater Yield



Heath, 2008

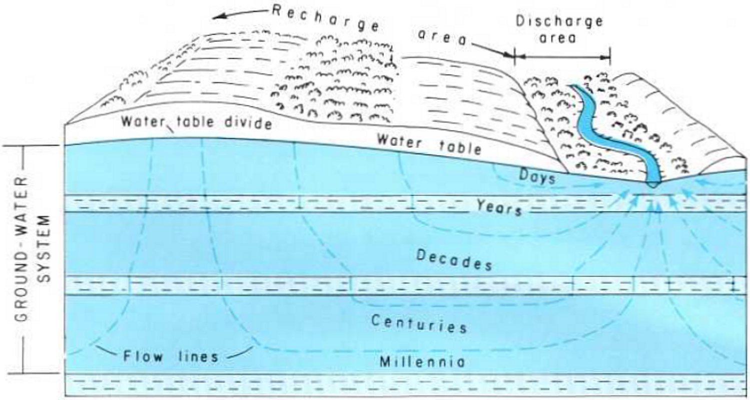
Specific Yield and Storativity



Heath, 2008

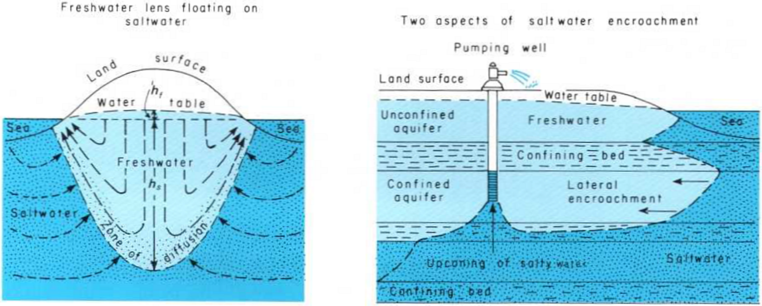
Groundwater Flow Lines

Flow Paths



Heath, 2008

Seawater Intrusion



Heath, 2008

Summary ...

- Monitoring
- Contour Line Interpretation
- Modeling