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A1. Basic Hydrogeology

A1.1 Hydrogeological concepts to describe the underground

FEMAR learning/teaching material

Montag, 19. Juni 2023

Learning outcomes

After working through the material, the participant should be able to

1. **Define groundwater and underground geological structures, where groundwater occurs.**
2. **Classify the type of underground media in terms of ability to store and transmit subterranean water.**
3. **Discuss the importance of groundwater as a fresh water reserve.**
4. **Review different components of water cycle in a quantitative comparative way.**

Suggested literature:

- Freeze R. A., Cherry J. A. (1979): Groundwater, Prentice Hall.
- Todd, D. K., Mays, L. W. (2004). Groundwater hydrology. John Wiley & Sons.
- McWhorter, D. B., Sunada, D. K. (1977). Ground-water hydrology and hydraulics. Water Resources Publication.
- Fetter C. W. (1994): Applied hydrogeology, Prentice Hall.
- Domenico P. A., Schwartz F. W. (1990): Physical and chemical hydrogeology, Wiley & Sons.
- Brassington R. (1988): Field hydrogeology, Wiley & Sons.
- Heath R. C. (1983): Basic groundwater hydrology, USGS Water Supply Paper 2220.
- Price M. (1996): Introducing groundwater, Chapman and Hall.

Self-learning materials:

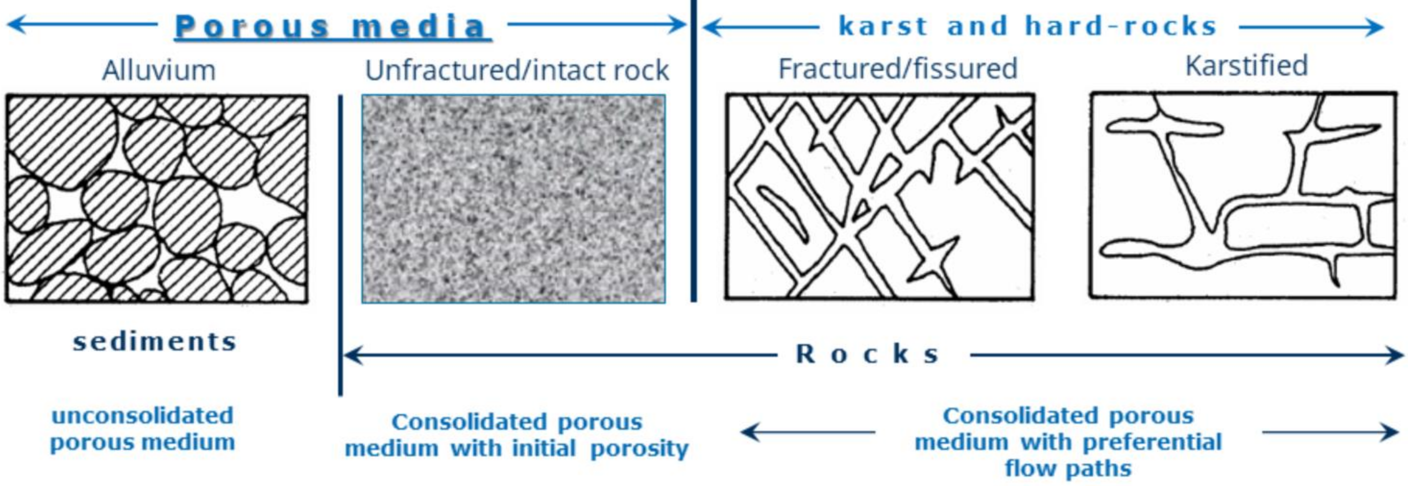
- Books available from Groundwater Project (Online Platform for Groundwater Knowledge): https://gw-project.org/books/
- Bakker, M., & Post, V. (2022). Analytical Groundwater Modeling: Theory and Applications Using Python. CRC Press.
- The Interactive Groundwater-I Book for the MHSE09 Groundwater course, (available at: https://prabhasyadav.github.io/iGW-I/intro.html).

The underlined ones are textbooks.

Types of subsurface media
(genesis classification)

Two general types:

- Porous sediments and rocks (porous media)
- Karstified and fractured rocks (karst and hard-rocks)

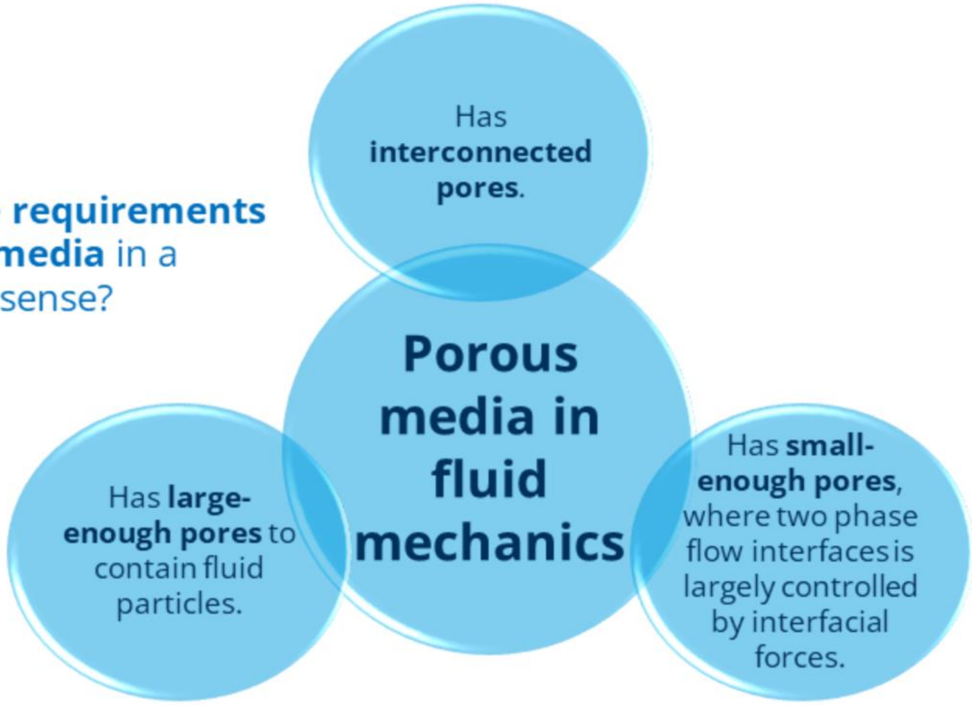


- Unconsolidated porous medium is formed due to deposition of solid particles mostly by water as the erosional force and depositional environment.
- Consolidated porous medium is comprised of rocks with preserved initial porosities, that is formed by increased pressure acting together with thermal and chemical processes (sandstone is a good example for such rocks).
- Consolidated porous medium may have preferential flow paths as secondary porosity due to diagenesis, tectonic forces (in fissured or fractured hard-rocks), and rock dissolution (in karst rocks).
- This course mainly focus on porous media!

What is porous media?

"... The term "porous" can be applied to all matters, because all matters contain some non-solid space ..." (Corey, 1994)!

So, what are **the requirements for the porous media** in a hydrogeological sense?



The term "porous" can be applied to all matters, because all matters contains some non-solid pore spaces; However, additional restrictions are placed upon a matter to be considered as porous media (Corey, 1994):

1. Non-solid space within the solid matrix is interconnected. This means that subsurface discrete fractures and caves are not a part of porous media.
2. The smallest dimension of the non-solid space must be large enough to contain fluid particles; that is, it must be large compared to the mean-free path of fluid molecules.
3. Dimensions of the non-solid space must be small enough so that when interfaces between two fluids occur within the non-solid space, the orientation of interfaces is controlled largely by interfacial forces (The interfacial force will be discussed later). This means that large subsurface fractures and caves cannot be considered as a part of porous media).

Types of subsurface media
(with regards to water storage and/or transmit)

- **Aquifer (groundwater reserve)**: can store and transmit significant (=exploitable) amounts of water
- **Aquitard**: can store and transmit water but to a much lesser extent than an (adjacent) aquifer
- **Aquiclude**: can store but cannot transmit groundwater
- **Aquifuge**: can neither store nor transmit groundwater

Hydrostratigraphy: Classification of lithostratigraphic units with regard to water-bearing characteristics.

A schematic hydrostratigraphic unit

lithostratigraphic unit			Hydrostrati-grafic nature
Symbol	Lithology	Period	
	Alluvium	Quaternary	**Aquifer**
	Marl	Neogene	**Aquitard**
	Sandstone	Paleogene	**Aquifer**
	Claystone	Upper Cretaceous	**Aquiclude**
	Karstified limestone	Lower Cretaceous	**Aquifer**
	Granitic basement	Pre-Cretaceous	**Aquifuge**

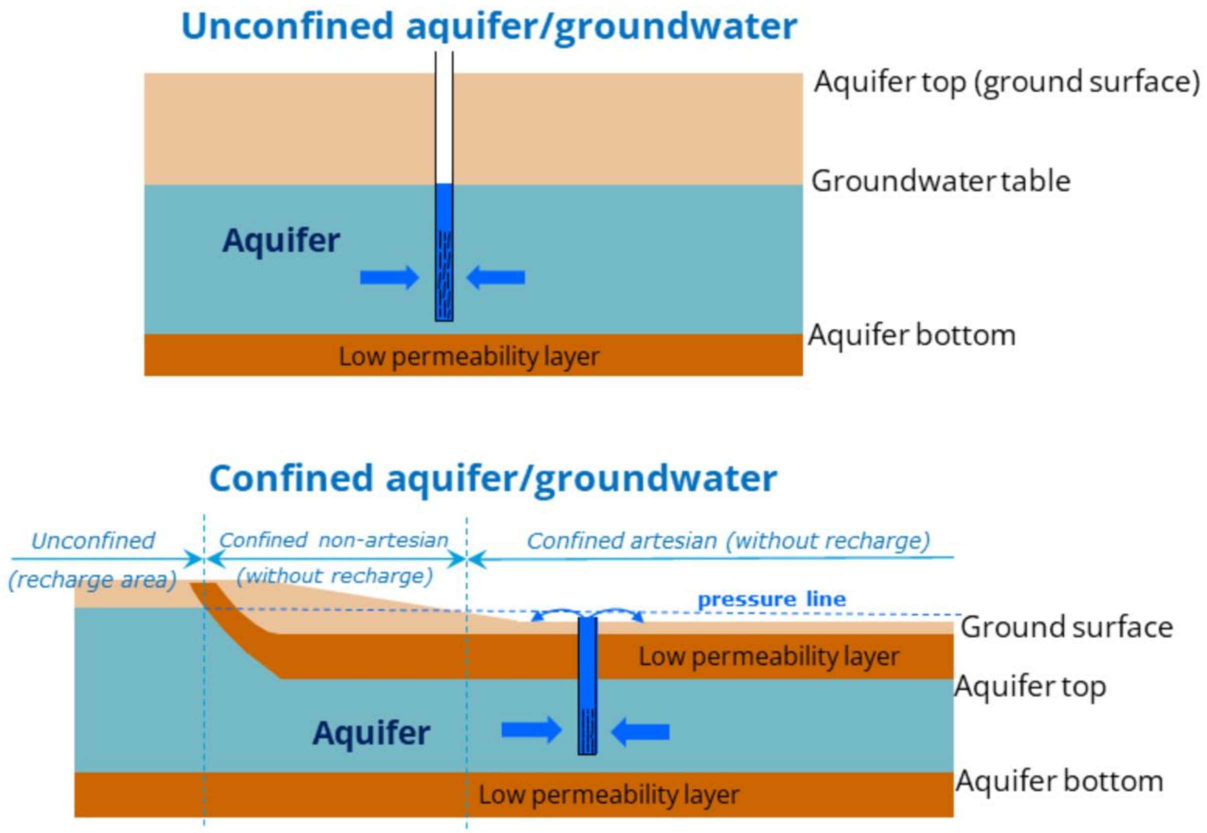
Classification of subterranean media based on the capability to store and/ or transmit groundwater under natural conditions.
Examples:

- Aquifer : alluvial and carbonate karst rocks
- Aquitard: siltstone and marl
- Aquiclude: clay and claystone (or sometimes called mudstone)
- Aquifuge: igneous rocks such as basalt and granite

Hydrostratigraphy is a subject area in stratigraphy.

The colors in the stratigraphic column should not be selected on arbitrary basis but rather should standardly reflect the geological period.
On the other hand, the pattern should define the main lithology.
In some cases some additional information about hydrogeological characteristics, such as hydraulic conductivities, thicknesses, and geological features, may be given in a hydrostratigraphic unit.

Types of aquifers



FEMAR Learning material

Topic A1: Basic Hydrogeology

A1.1 Hydrogeological concepts to describe the underground

Groundwater or an aquifer is termed <u>unconfined (phreatic)</u>, if the groundwater does not extend up to the aquifer top.

- The position of the groundwater table is therefore changed during water injection or extraction (“free“ groundwater table).
- Water in a borehole drilled in a confined aquifer rises up to the groundwater table.
- The low permeability layer can be an aquitard or aquiclude or aquifuge.

Groundwater or an aquifer is termed <u>confined</u>, if the aquifer contains groundwater throughout its entire thickness.

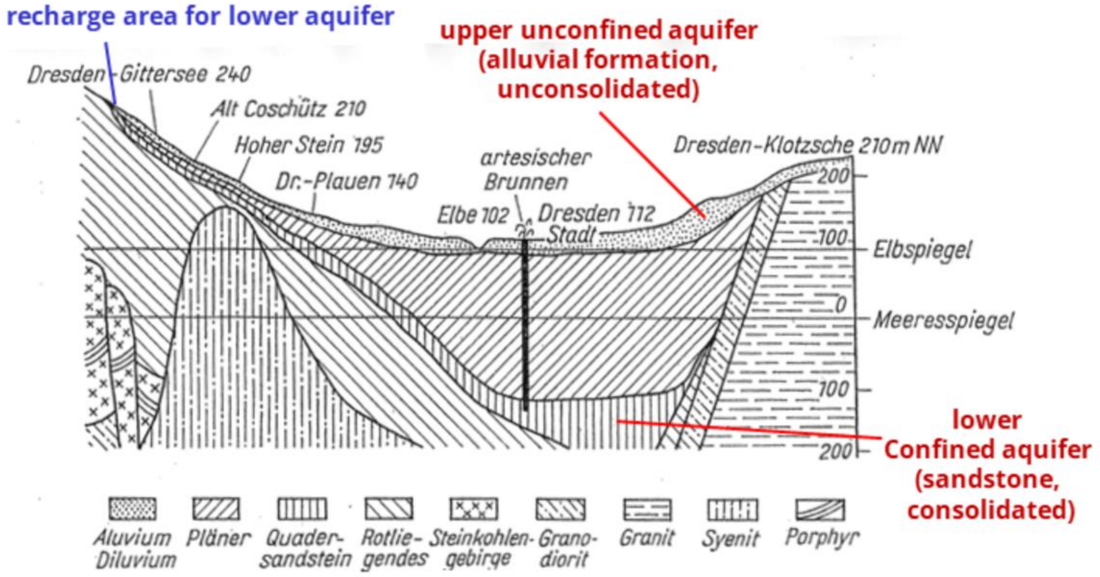
- The pore space remains completely water filled during water injection or (moderate) extraction.
- This requires a low permeable cover layer. In addition, the groundwater recharge area must be located at higher altitude than the aquifer top.
- The elevation of the groundwater table in the recharge area defines the position of the confined aquifer‘s <u>pressure line</u>.
- Water in a borehole rises up to the pressure line (neglecting friction losses), i.e. higher than the elevation of the aquifer top.

<u>Artesian groundwater</u> is confined groundwater with the pressure line above ground surface.

- Water in a borehole rises up to the ground surface and then forms a fountain.
- Artesian springs and Artesian wells are based on this principle.

Example of a multilayer aquifer system

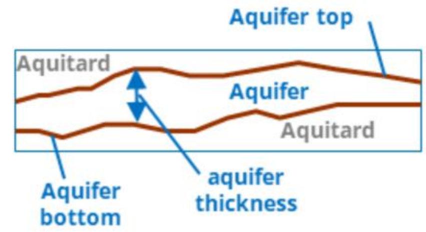
Subsurface Underneath Dresden



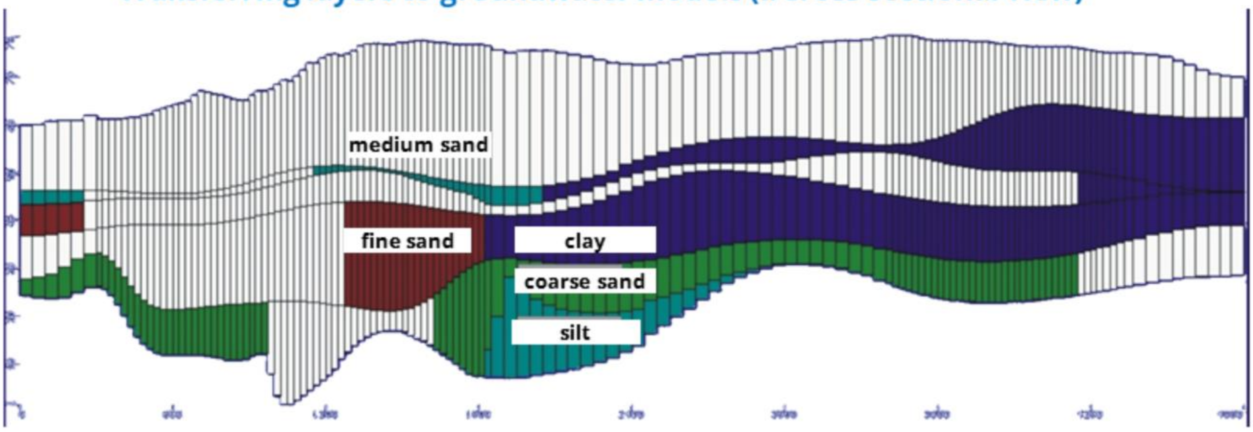
Aquifers can be multilayered, esp. in case their constituents are of sedimentary origin (both consolidated and unconsolidated).

Defining aquifer geometry
(top, bottom, and thickness)

- Aquifers usually appear/call as *permeable layers*.
- The upper aquifer boundary is called *aquifer top*.
- the lower boundary is called *aquifer bottom*.
- The vertical distance between aquifer top and aquifer bottom is called aquifer thickness.



Transferring layers to groundwater models (a cross sectional view)

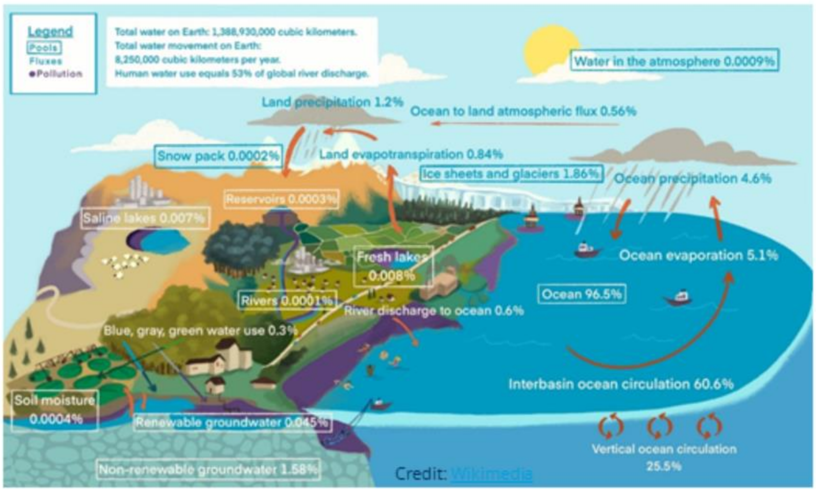


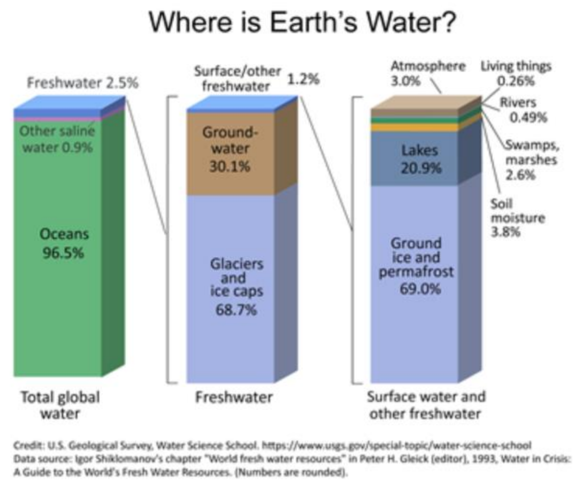
- The term „layer“ is used because the lateral extent is rather large as compared to their vertical extent (maybe 10 – 100 km vs. 10 – 100 m).
- Upper and lower aquifer boundaries do not have to be horizontal and the thickness may be spatially variable.

Groundwater as a Part of the Global Water Cycle

- Available water reserves on Earth:

- The total volume of water: ~1,358,710,150 km³ ($\approx 10^{18}$ m³)
- The total volume of fresh-water: ~38,000,000 km³ ($\approx 10^{16}$ m³)



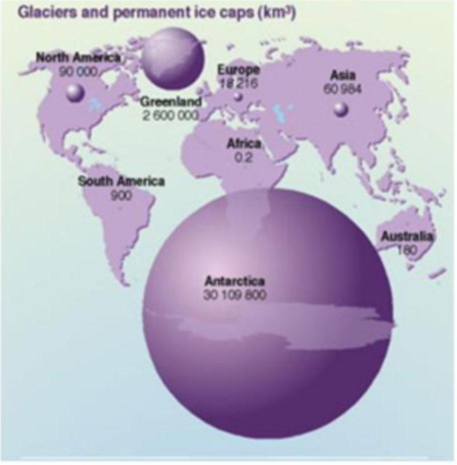


- Most of the water reserves are saline.
- Groundwater is the most important fresh-water reserve in ice-free parts of our planet.
- Cf. percentages for different parts of the water cycle

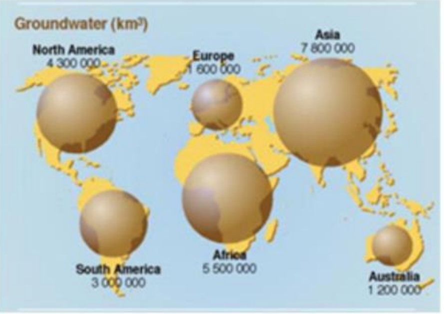
Groundwater as a Part of the Global Water Cycle

- Available water reserves on Earth:

➢Spatial distribution of different water resources



Credit: UNEP



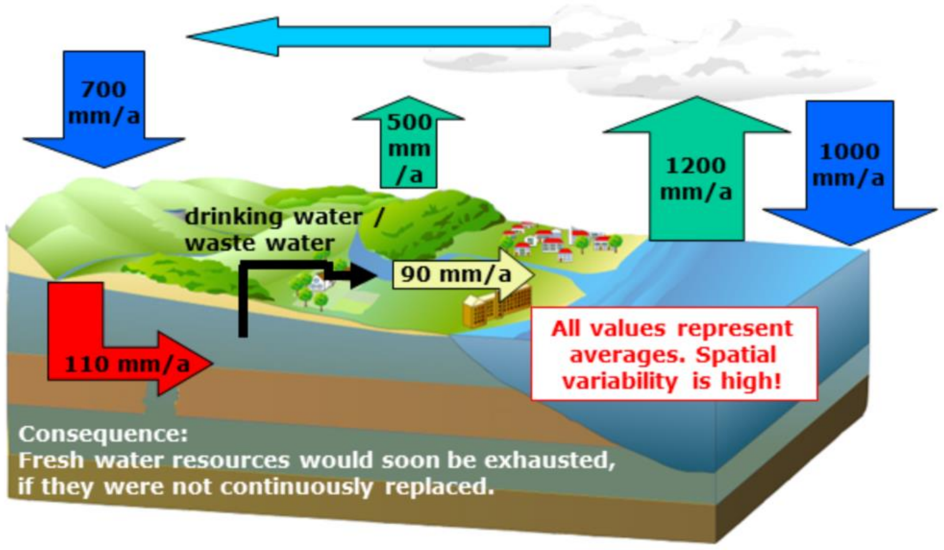
includes saline groundwater!

- Global distribution of fresh solid water (ice), fresh surface water, and groundwater.
- Cf. values for different parts of the world.

Groundwater as a Part of the Global Water Cycle

- Dynamic water reserve variations:

57,700 km³ of water is dynamically participating in the cycle each year.



- Dynamic variability of water resources at different part of water cycle is depicted.
- Cf. values for different parts of the water cycle

The Water Balance (budget)

Goal: to quantify the dynamic variability within the whole or a part of the water cycle

General equation:

inflow = outflow + change in storage

Hydrological water balance:

$$P = ET + R + \Delta S$$

Precipitation [L or L³]

Evapotranspiration [L or L³]

Runoff [L or L³]

Change in storage [L or L³]

ΔS can be
negative (water depletion),
zero (steady state), or
positive (water accumulation)

Inflows and outflow and change in storage may be expressed as volume or height.

Cases of change in storage:

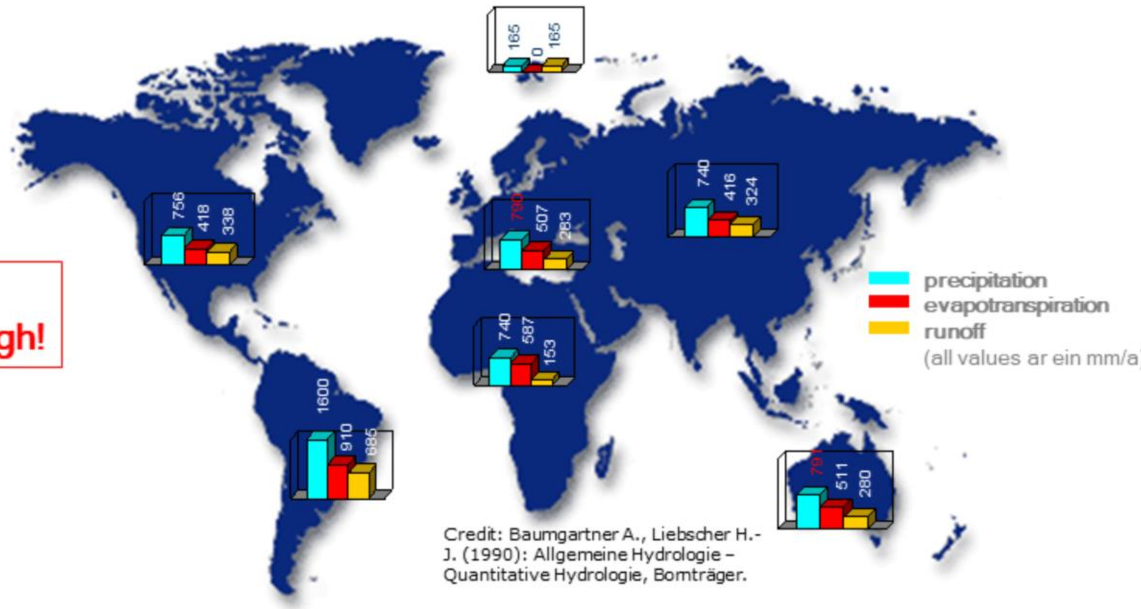
- Positive $\Delta S > 0$: Water volume is increasing with time in the investigation area.
- Neqative $\Delta S < 0$: Water volume is decreasing with time in the investigation area.
- No-change in storage $\Delta S = 0$: Water volume does not change with time in the investigation area (steady-state, i.e. inflow equals outflow).

The Water Balance (budget)

Continental scale hydrological inflows/outflows

(averaged values)

Spatial variability is high!



Credit: Baumgartner A., Liebscher H.-J. (1990): Allgemeine Hydrologie – Quantitative Hydrologie, Bornträger.

- Note that values corresponding to water resources are expressed as volumes, percentages of a total, or heights (to give an impression relative to the precipitation, likewise this map).