Groundwater hydraulics 1
Introduction

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Dept. Landscape Water Conservation

Conditions for credit

A) Presence at lecture and exercises (2 lectures + 2 exercises missing allowed)

B) Midterm calculation and theory test (1 calculation + 3 questions) 10 point max (counts in exam)

C) Essay/presentation of groundwater situation at your area

D) 4 analytical homeworks submission

E) Submission of a project in Groundwater Vistas (Modflow) for credit before exam

Requirements for the exam

Lectures posted on the webserver of Dept.143:
http://storm.fsv.cvut.cz/ Teaching

Exam is taken without notes, calculators, cell phones computers etc. Pre-printed questions are given

Exam is written – max of 2hrs, consist of 6 questions (10 points each) and 2 calculations – (15 points each) of total 100 max. One midterm test 10 points max.

Classification ECTS	**A**	**B**	**C**	**D**	**E**	**F**
Points/percentage	100-90	89-80	79-70	69-60	59-50	< 50
Relative to old system	*1,0*	*1,5*	*2*	*2,5*	*3*	*4*

Themes of the course

1. Classification of aquifers
2. Fundamental principles of water flow in saturated porous media
3. Darcy’s equation
4. Dupuit assumptions
5. Unconfined flow in aquifer, well hydraulics
6. Unsteady flow in aquifers
7. Numerical modelling of steady and unsteady groundwater flow

Themes of the lectures 1-4

1. **Introduction:** Presentation of practical applications of the groundwater flow – protection of the water resources, remediation of the subsurface environment, groundwater flow under the water structures, influence of the groundwater flow on the subsurface constructions

2. **Importance of the ground water,** types of the subsurface water, classification of aquifers, Macroscopic approach, water flow theory – hydraulic head, measurements, Components of the ground water balance calculation

3. **Darcy´s law, limitations of the Darcy´s law**
   Parameters of the saturated porous media, homogeneity, anisotropy
   Example of the physical groundwater model

4. **Mathematical description (3D) of the ground water flow**
   – continuum equation, general formulation of the Darcy´s law
   Initial and boundary conditions
   Specific storativity

Themes of the lectures 5-8

5. Simplifying conditions of the ground water flow solution

Dupuit assumptions – planar groundwater flow, aquifer storativity

Non-steady planar groundwater flow equation in confined and unconfined aquifers

6. Dupuit assumptions applications examples for steady state groundwater flow – dam seepage, flow in confined aquifer with variable transmissivity, flow in confined aquifer with overflow, flow in the unconfined aquifer and with overflow

7. Radial flow - wells

Continuum equation for the axisymetric groundwater flow

Practical applications - wells

8. Groundwater flow in confined aquifer with overflow

Solution of the set of well, imaginary wells method

Themes of the lectures 9-12

9. Unsteady planar flow – Boussinesque equation

Application of the Boussinesque equation for the planar flow

10. Unsteady axisymmetric groundwater flow

Pump and slug tests

Saturated hydraulic conductivity identification methods

11. Numerical modelling of groundwater flow – general approach

Principle of finite difference and finite element methods

MODFLOW model basics – 3D groundwater unsteady flow application

12. Groudwater modeling – hands on

Input data, initial, boundary conditions, outputs

Topics of the labs (exercises)

Introduction of the course

Porous medium parameters – porosity, number of porosity, saturated hydraulic conductivity

Darcy's law – experiment, hydraulic head, average and pore velocity

Confined aquifer groundwater flow

Hydraulic approach, vertical wall dam seepage, Dupuit assumptions

Trapezoidal dam seepage

Flow of soil block with vertical infiltration

Well network groundwater flow, flow near to the boundary

Introduction to the numerical modelling – software presentation

Testing task – group solution Modflow, several tasks similar to analytical tasks

Individual task of groundwater flow Modflow (3 lectures)

Groundwater hydraulics

Science and engineering about presence and movement of water in the **fully and permanently** saturated subsurface of the Earth mantle.

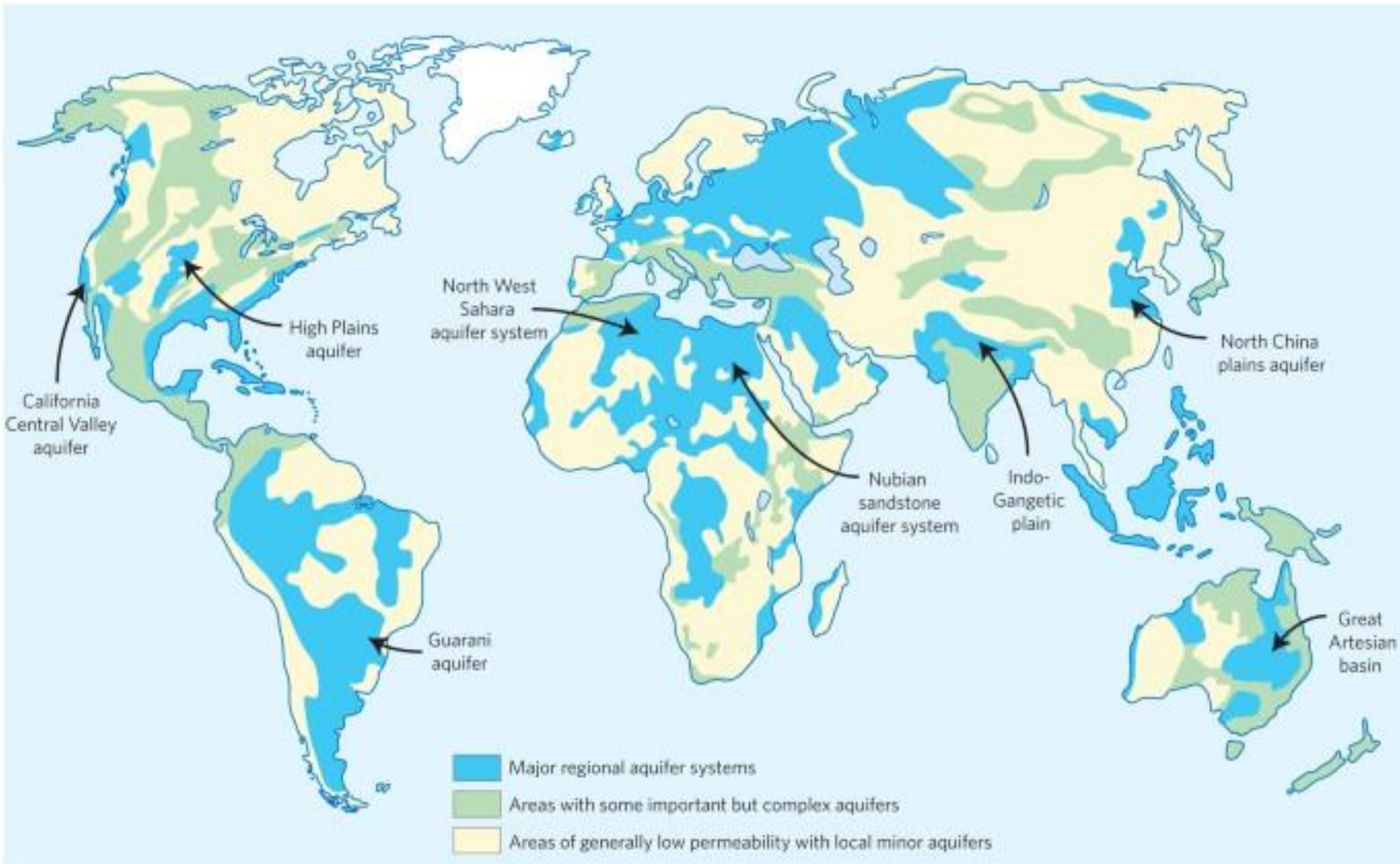
Close links to Hydrogeology, Hydrology, Soil Science and Soil Physics, Earth Mechanics, Foundation of Hydrostructures (Dams, Weirs, River Locks…), Surface Hydraulics, Subsurface Structures (Tunnels…), Agricultural Sciences (Erosion, Drainage, Irrigation), Contamination Hydro(geo)logy, Ecology, Remediation of Polluted sites, Landfills, Housing Structures (e.g. Netherlands)…

Global water balance on Earth

Parameter	Area $(km^2)*10^6$	Volume $(km^3)*10^6$	Volume (%)	Eqv. Height as globe cover (m)	Typical residence time
Oceans and seas	361	1370	94	2500	~4000 years
Lakes and reservoirs	1.55	0.13	< 0.01	0.25	~10 years
Wetlands	< 0.1	< 0.01	< 0.01	0.007	1-10 years
Rivers	< 0.1	< 0.01	< 0.01	0.003	~2 weeks
Soil water	130	0.07	< 0.01	0.13	2 weeks – 1 year
Groundwater	130	60	4	120	2 weeks - 10000 yrs
Glaciers	17.8	30	2	60	10-1000 years
Atmospheric water	504	0.01	< 0.01	0.025	~10 days
Biospheric water	< 0.1	< 0.01	< 0.01	0.001	~1 week

Groundwater (excl. glaciers) forms 90-99% of terrestrial water

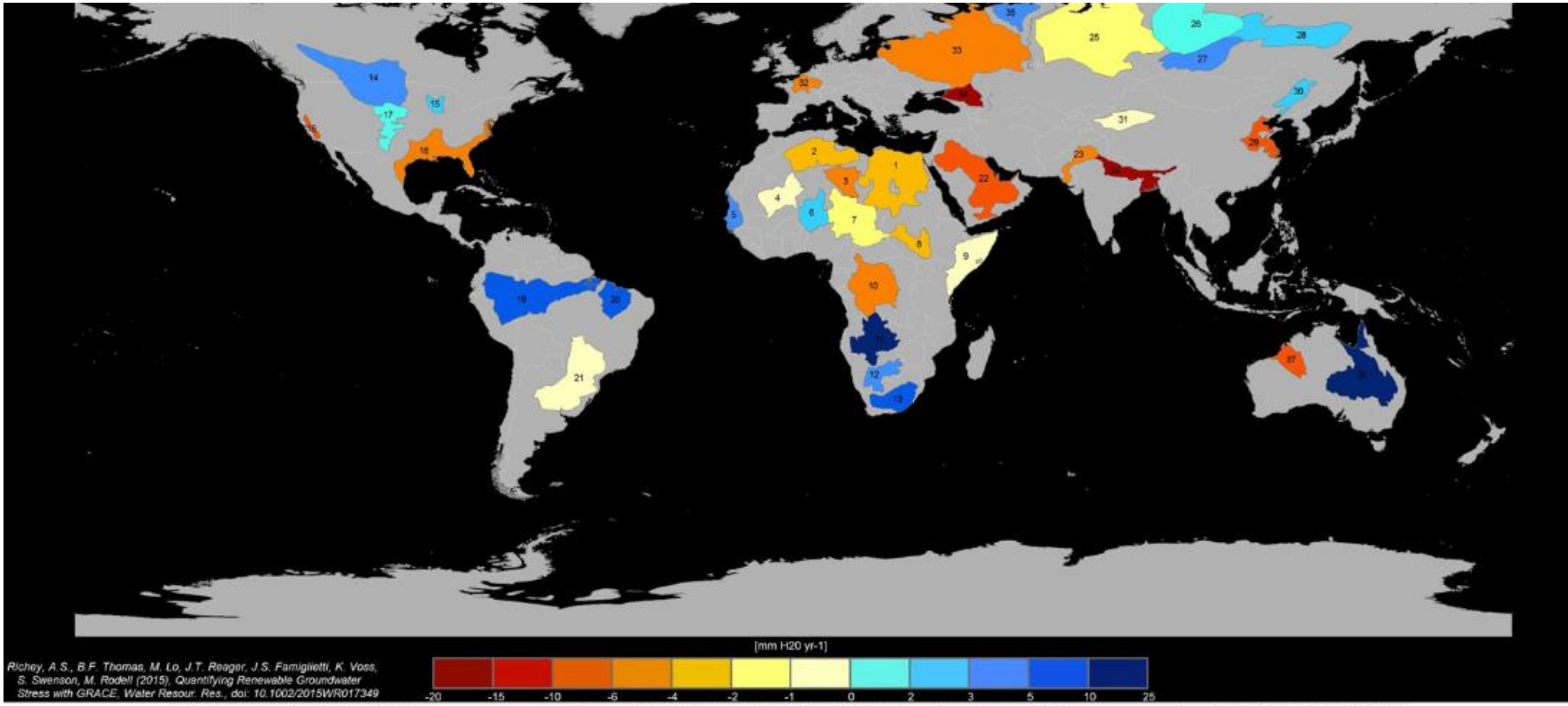
Major groundwater (aquifers) on Earth



2.5 billion people depend on groundwater
used for almost 50% of drinking water worldwide,
one of the primary sources of water used for irrigation.

https://groundwateru.org/groundwater/

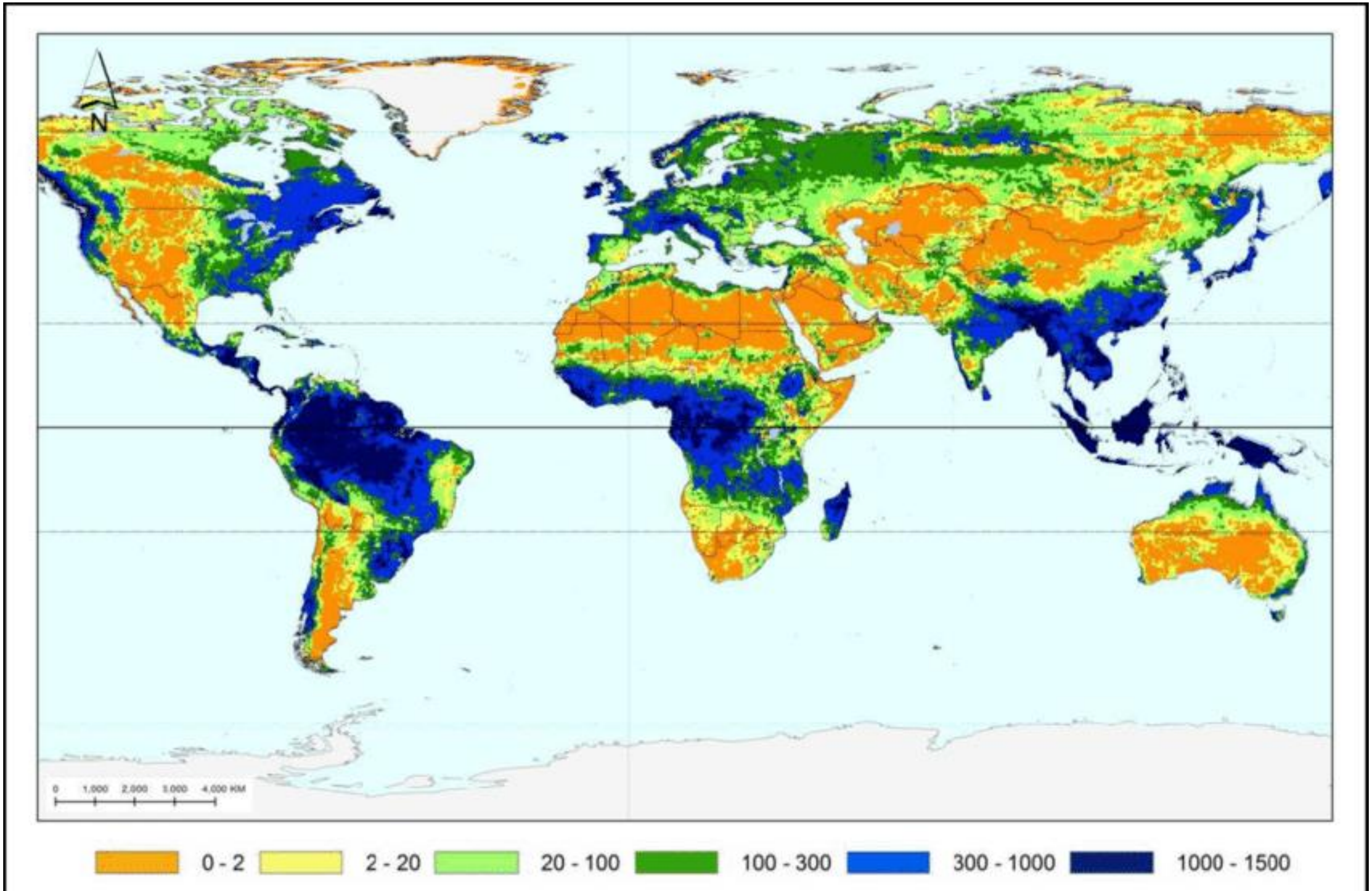
Long term groundwater gains and losses (mm/y)



1 Nubian Aquifer System (NAS)
2 Northwestern Sahara Aquifer System (NWSAS)
3 Murzuk-Djado Basin
4 Taoudeni-Tanezrouft Basin
5 Senegalo-Mauritanian Basin
6 Iullemeden-Irhazer Aquifer System
7 Lake Chad Basin
8 Sudd Basin (Umm Ruwaba Aquifer)
9 Ogaden-Juba Basin
10 Congo Basin
11 Upper Kalahari-Cuvelai-Upper Zambezi Basin
12 Lower Kalahari-Stampriet Basin
13 Karoo Basin
14 Northern Great Plains Aquifer
15 Cambro-Ordovician Aquifer System
16 Californian Central Valley Aquifer System
17 Ogallala Aquifer (High Plains)
18 Atlantic and Gulf Coastal Plains Aquifer
19 Amazon Basin
20 Maranhao Basin
21 Guarani Aquifer System
22 Arabian Aquifer System
23 Indus Basin
24 Ganges-Brahmaputra Basin
25 West Siberian Basin
26 Tunguss Basin
27 Angara-Lena Basin
28 Yakut Basin
29 North China Aquifer System
30 Song-Liao Basin
31 Tarim Basin
32 Paris Basin
33 Russian Platform Basins
34 North Caucasus Basin
35 Pechora Basin
36 Great Artesian Basin
37 Canning Basin

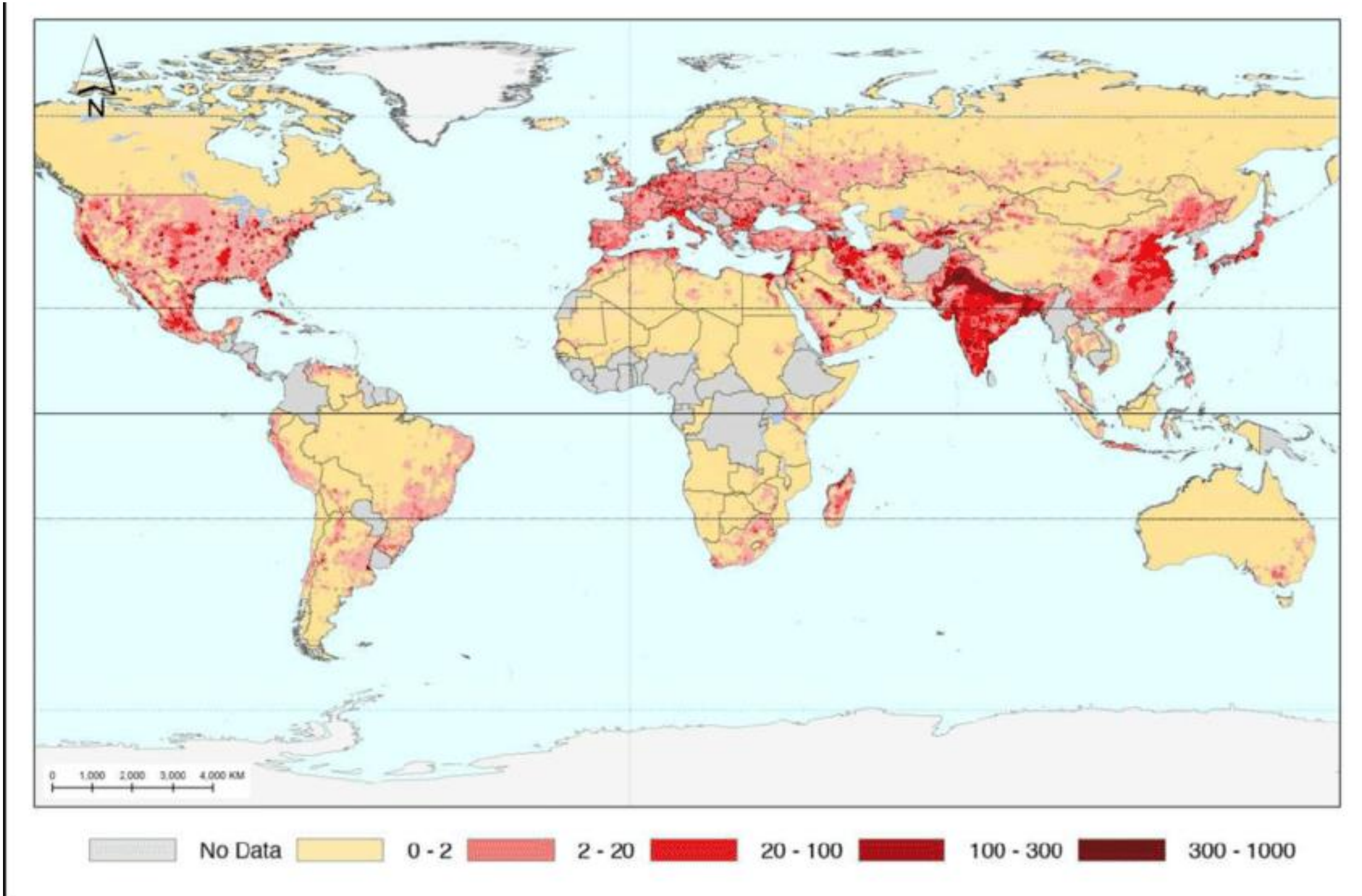
https://gracefo.jpl.nasa.gov/resources/48/map-of-groundwater-storage-trends-for-earths-37-largest-aquifers/

Simulated groundwater recharge (mm/year)



https://doi.org/10.1029/2010GL044571

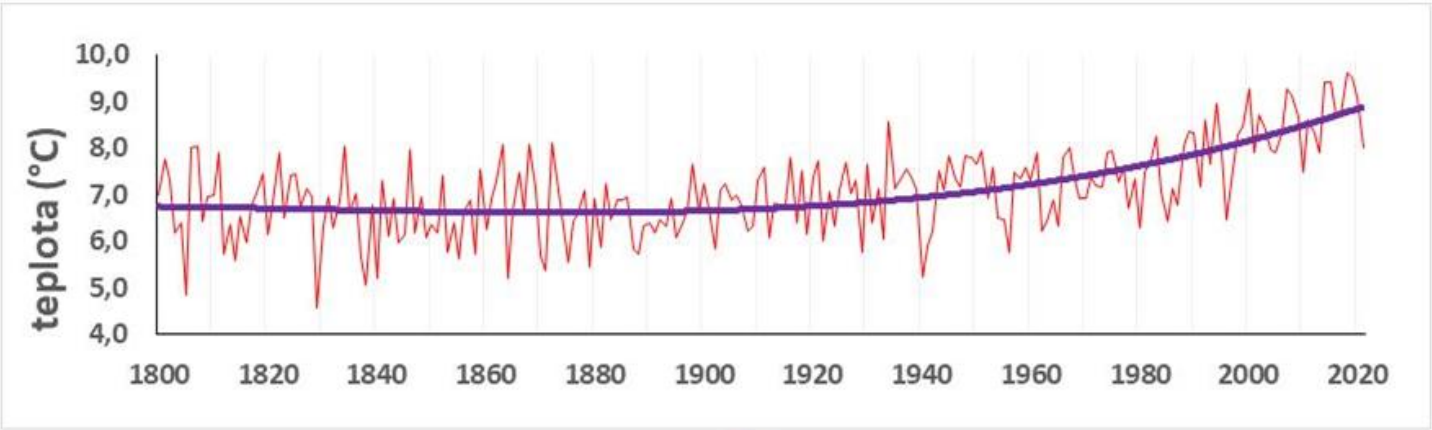
Intensity of groundwater extraction (mm/year)



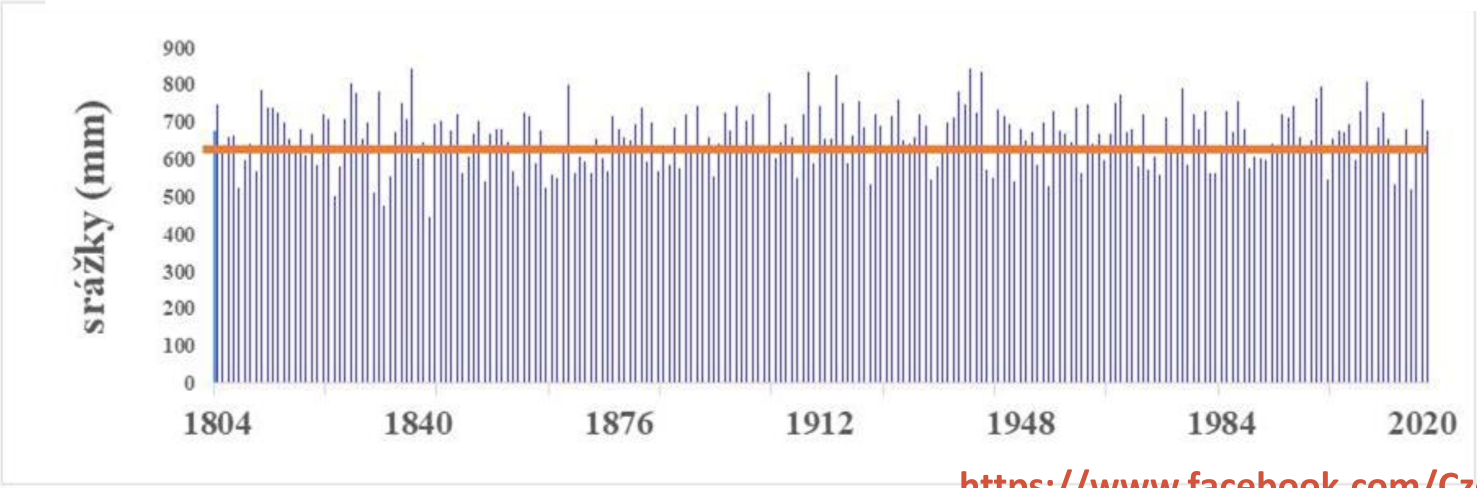
https://doi.org/10.1029/2010GL044571

Climate in CZ in last 200 years

Average temperature in CZ (1800-2021)

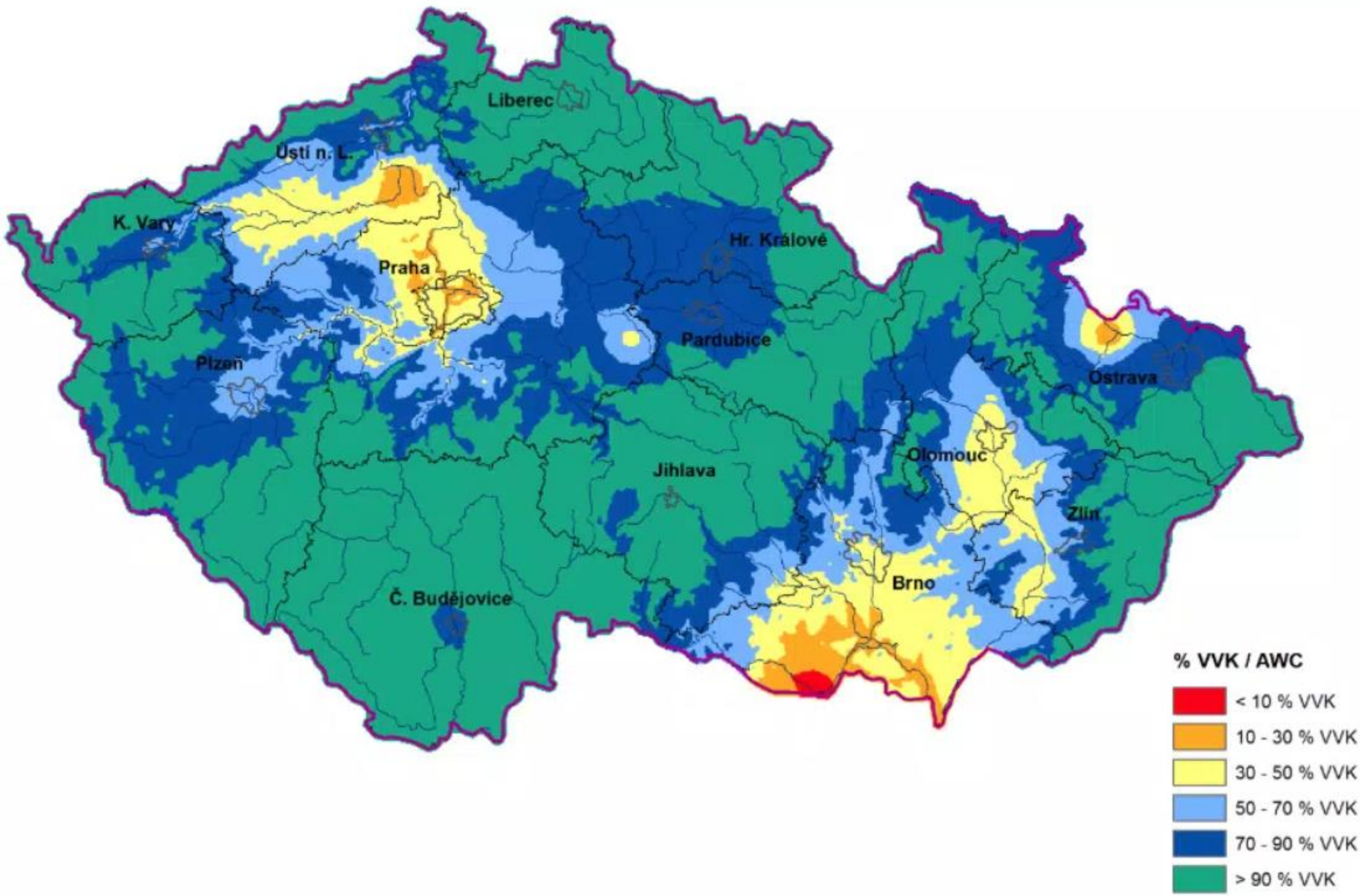


Average precipitation in CZ (1804-2021)



https://www.facebook.com/CzechGlobe

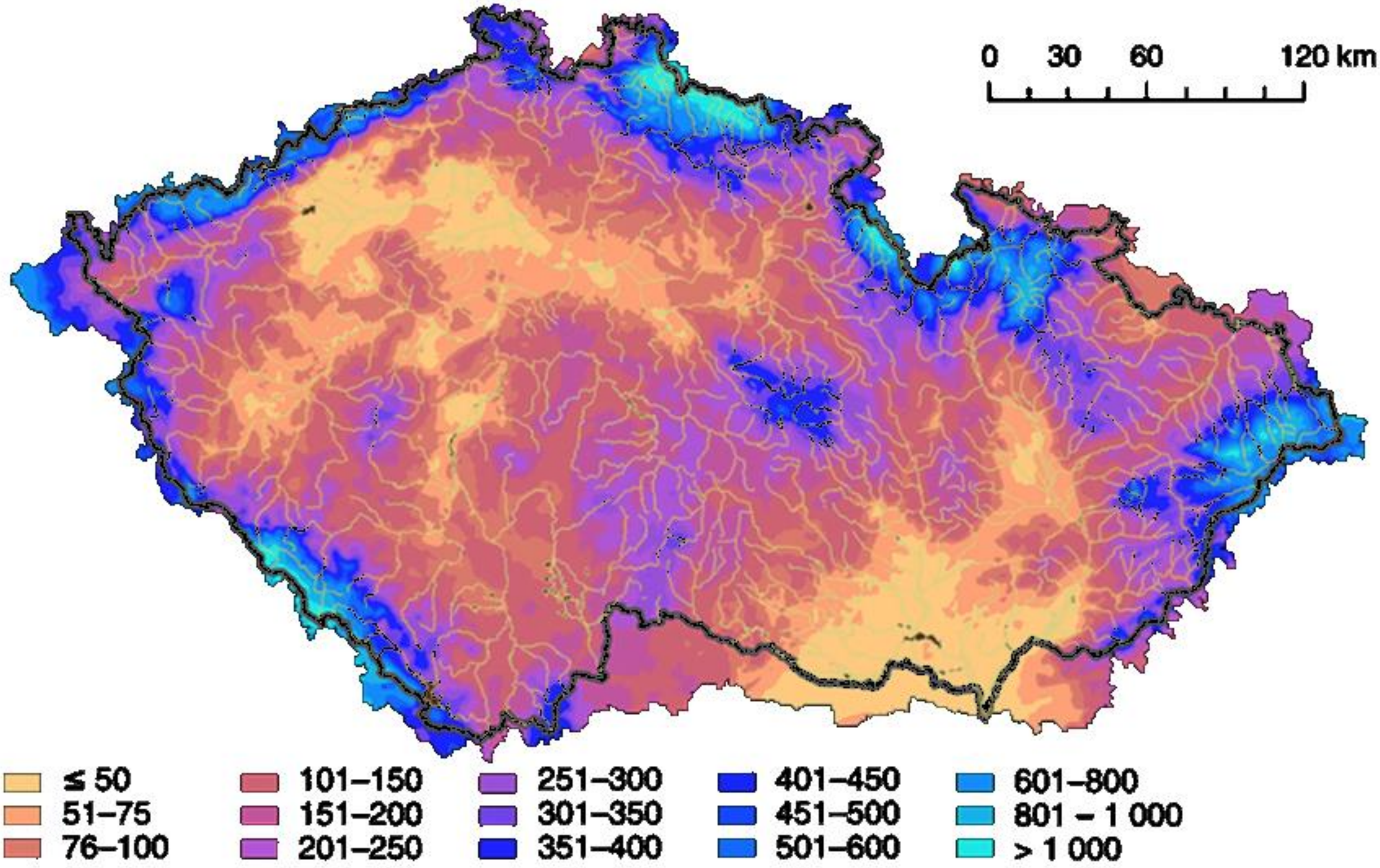
Available soil water 2.4.2019 (0-20 cm)



https://www.intersucho.cz

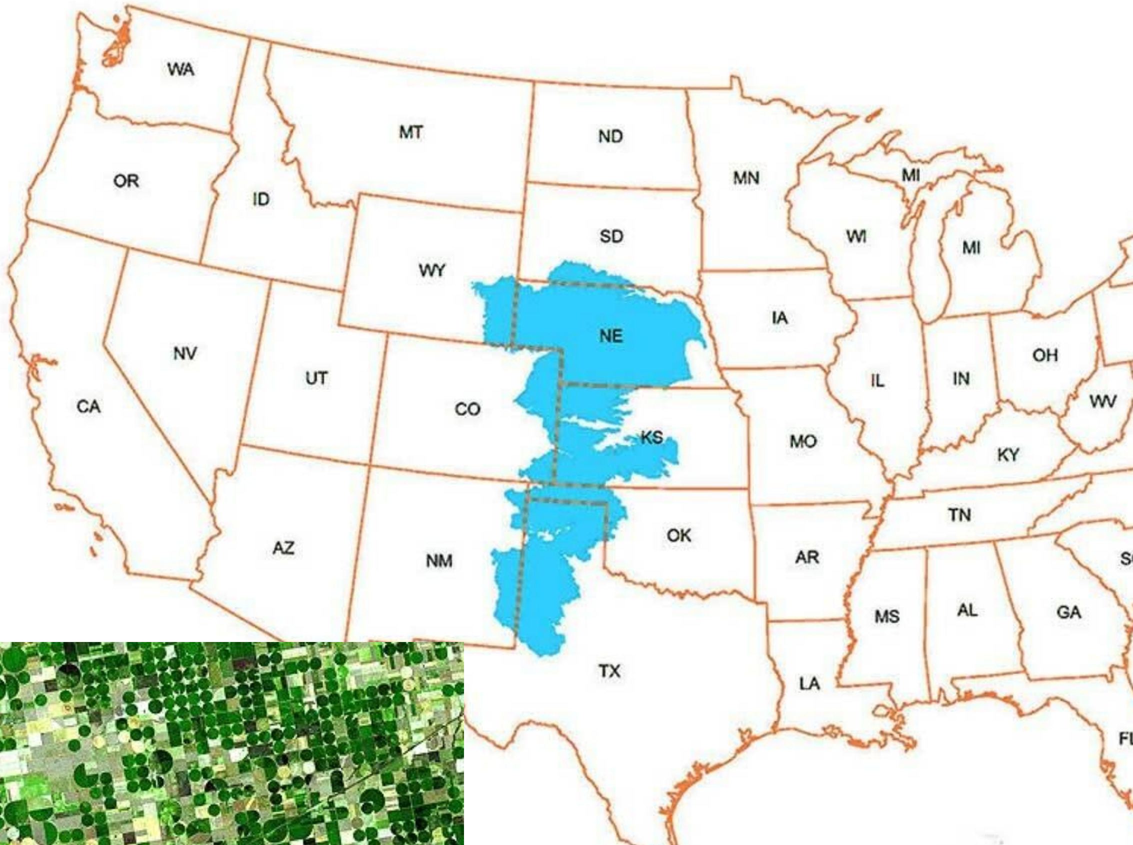
Available Water content

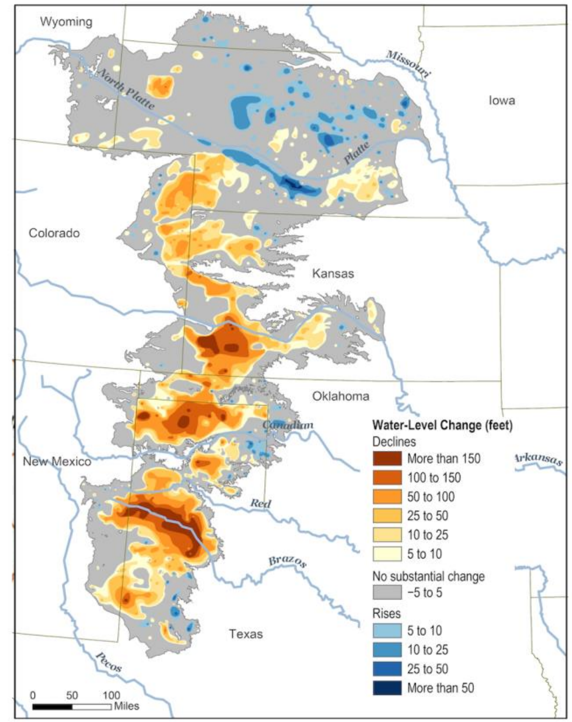
Runoff eqvivalent 1981–2010



ŠERCL, Petr; KUKLA, Pavel. Základní hydrologické údaje za referenční období 1981–2010. Vodohospodářské technicko-ekonomické informace, 2016,58. 1: 49. / barevně invertováno

Ogallala aquifer, biggest in USA – intensive exploatation for irrigation needs

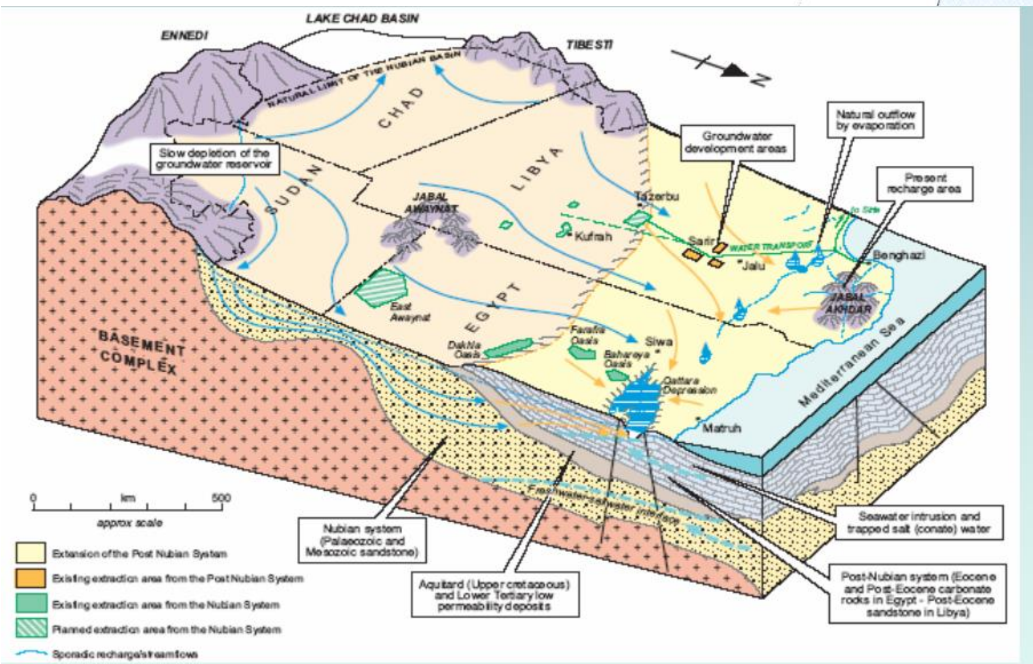


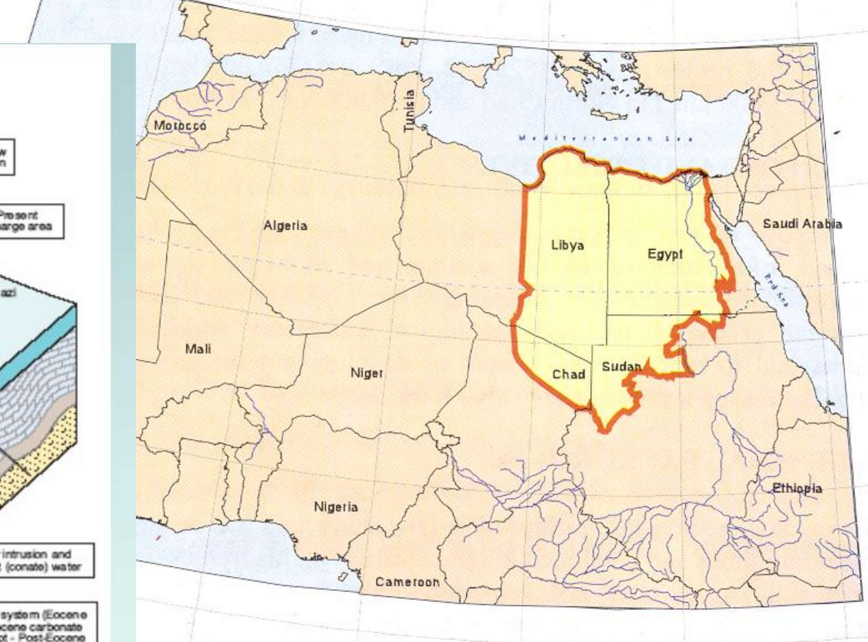


USGS
science for a changing world

[Video]

Nubian fossile aquifer in Saharan Africa (globally biggest fossile - does not recharge) [source]

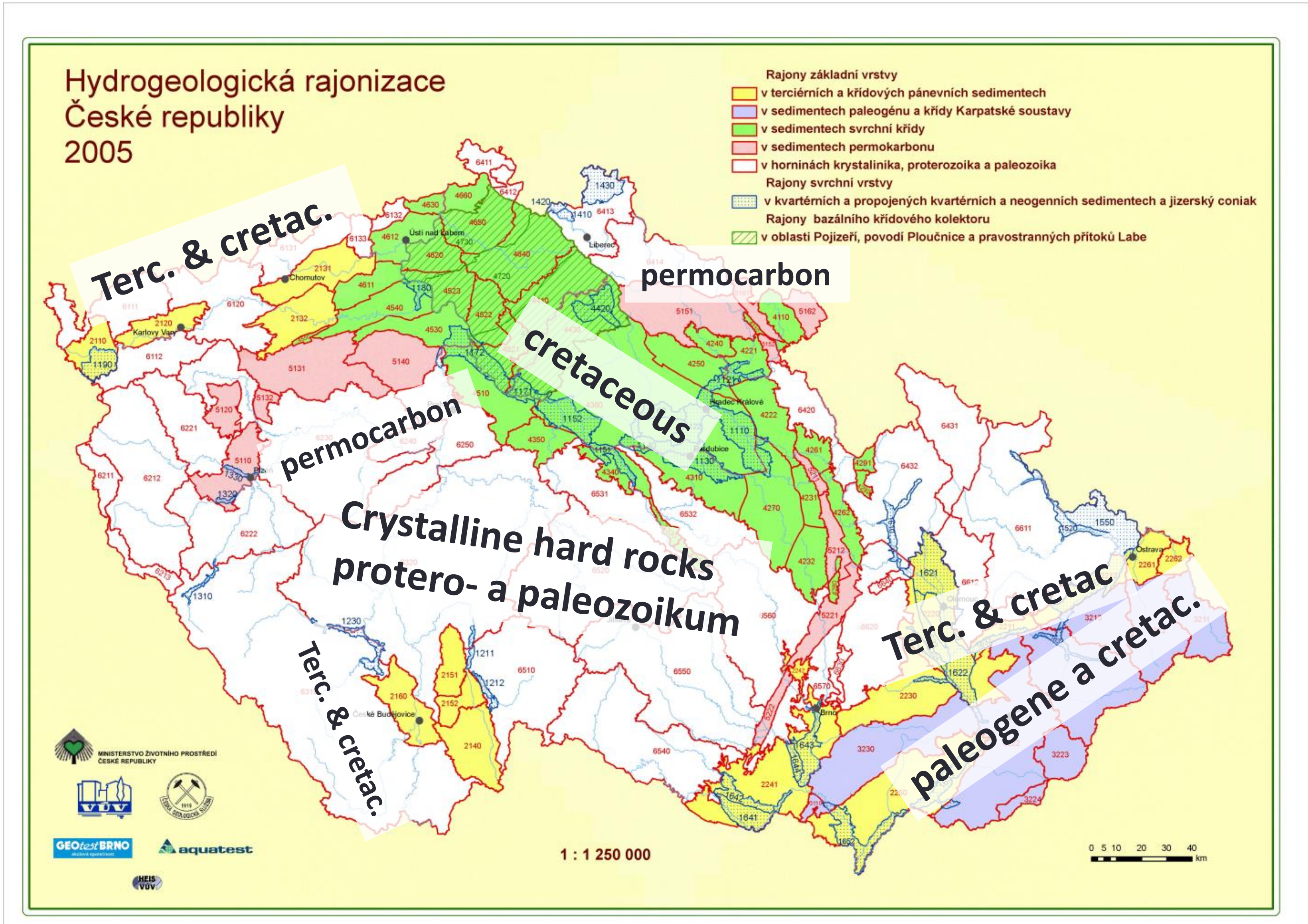




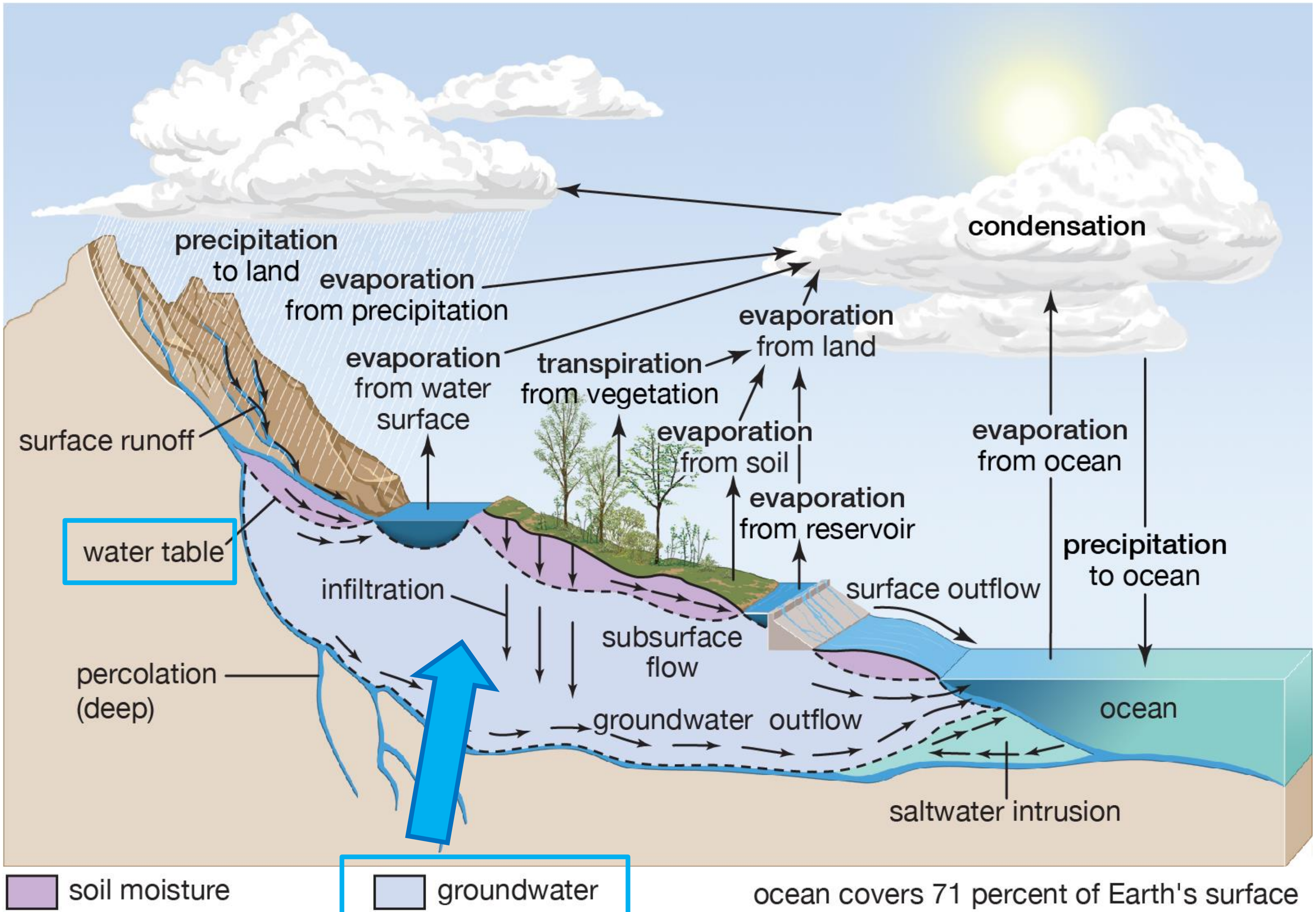
https://www.nsasja.org/domain_en.php

The Great Man-made River Project (GMRP)

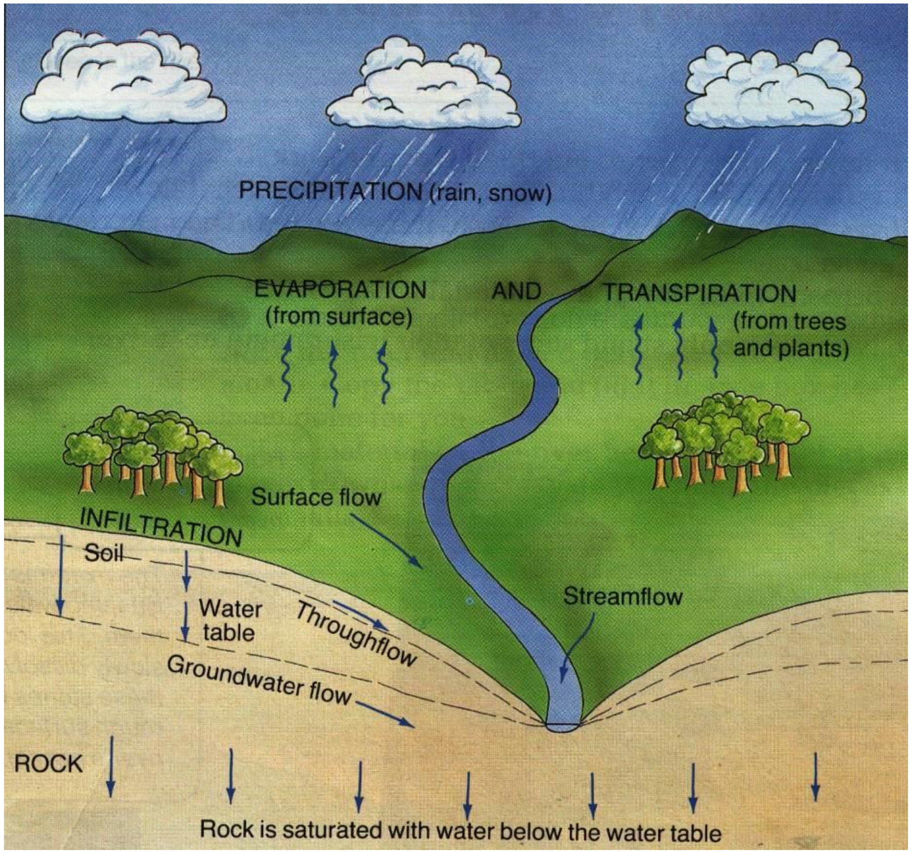
Hydrogeological structures CZ



Terrestrial hydrological cycle



Groundwater in hydrological cycle



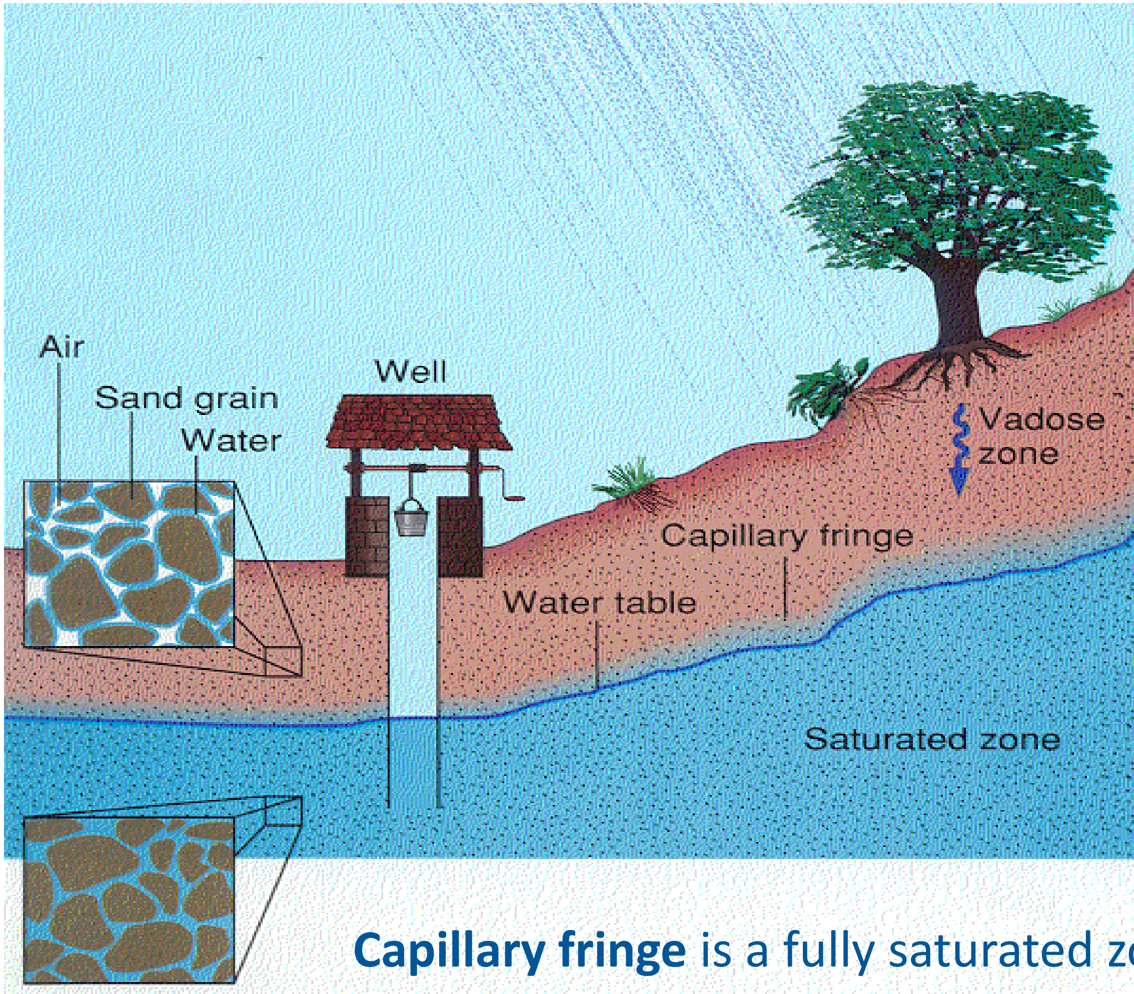
source: http://atschool.eduweb.co.uk/nelthorp/room8/intra/geograph/tests/watercyclec.htm

Soil above the water table is partially saturated, saturation is time variable (**unsaturated/vadose zone**) – can be also fully saturated for limited time

Saturated zone
rock, soil under the water table is **FULLY** saturated (groundwater)

- Global storage of water in soil and rock environment is approx. 10x higher than storage of water in lakes, reservoirs and rivers
- Soil cover balances extremes of the discharge, flooding, erosion effect
- Storage of the water for plants

Groundwater in hydrological cycle

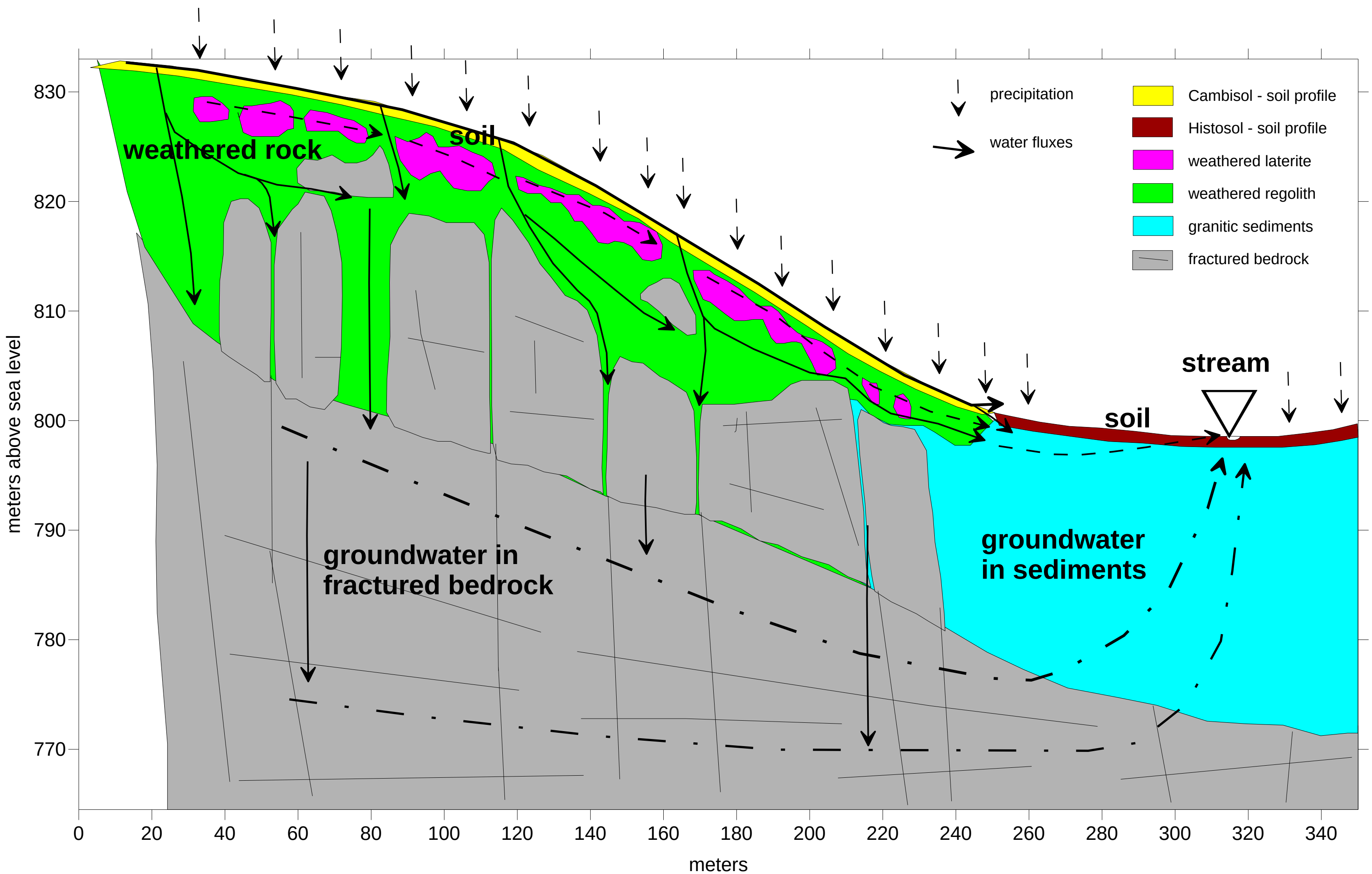


Soil above the water table: solids – water - air **(unsaturated/vadose zone**) – can be also fully saturated for limited time

Saturated zone
rock, soil under the water table is **FULLY** saturated (groundwater) **solids and water ONLY**

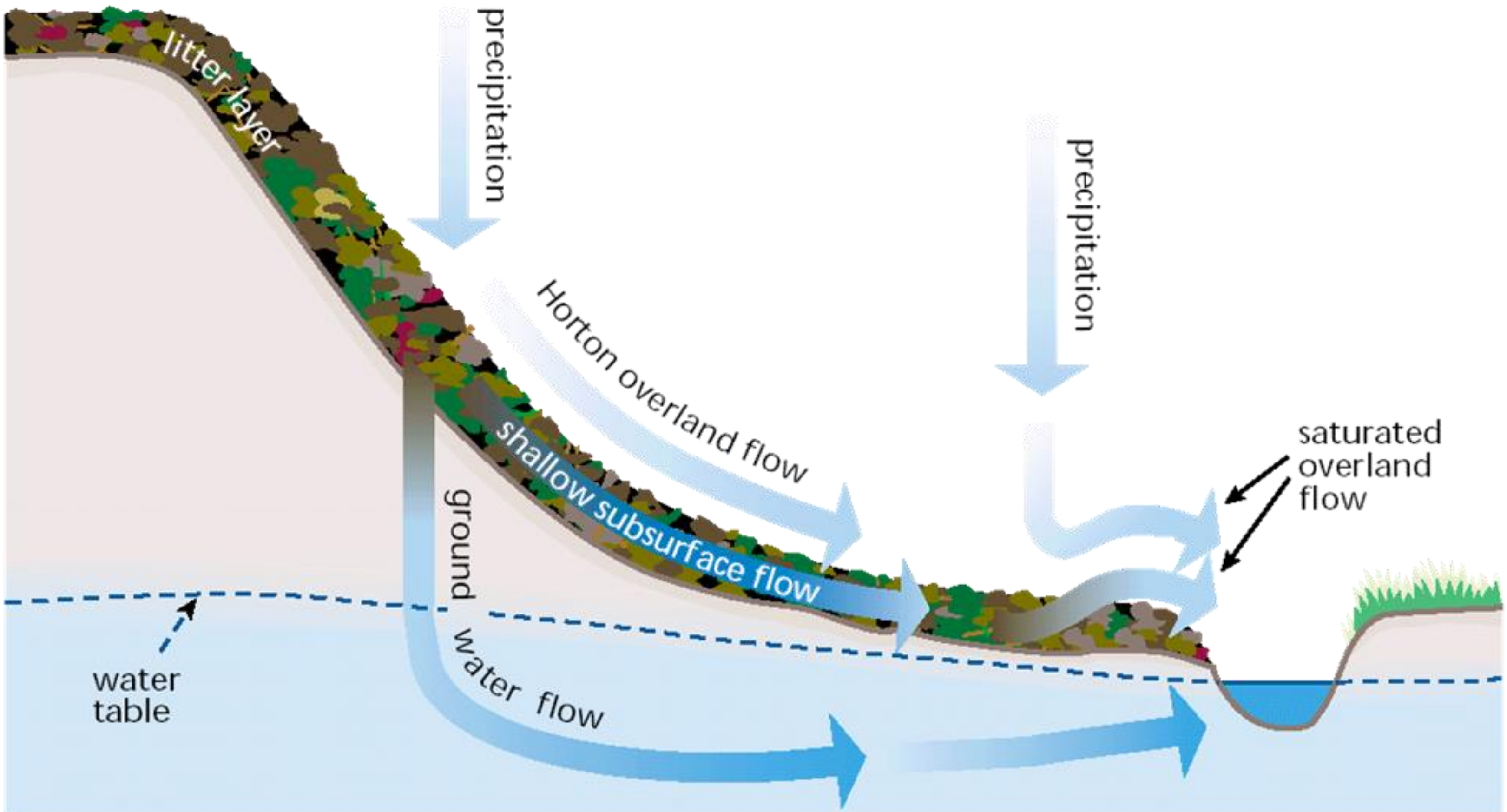
Capillary fringe is a fully saturated zone above the groundwater where water fully saturates all pores thanks to capillary forces greater in absolute than capillary pressure relevant for the biggest pore (see definition of *air entry value* in soil physics)

Water pathways in landscape

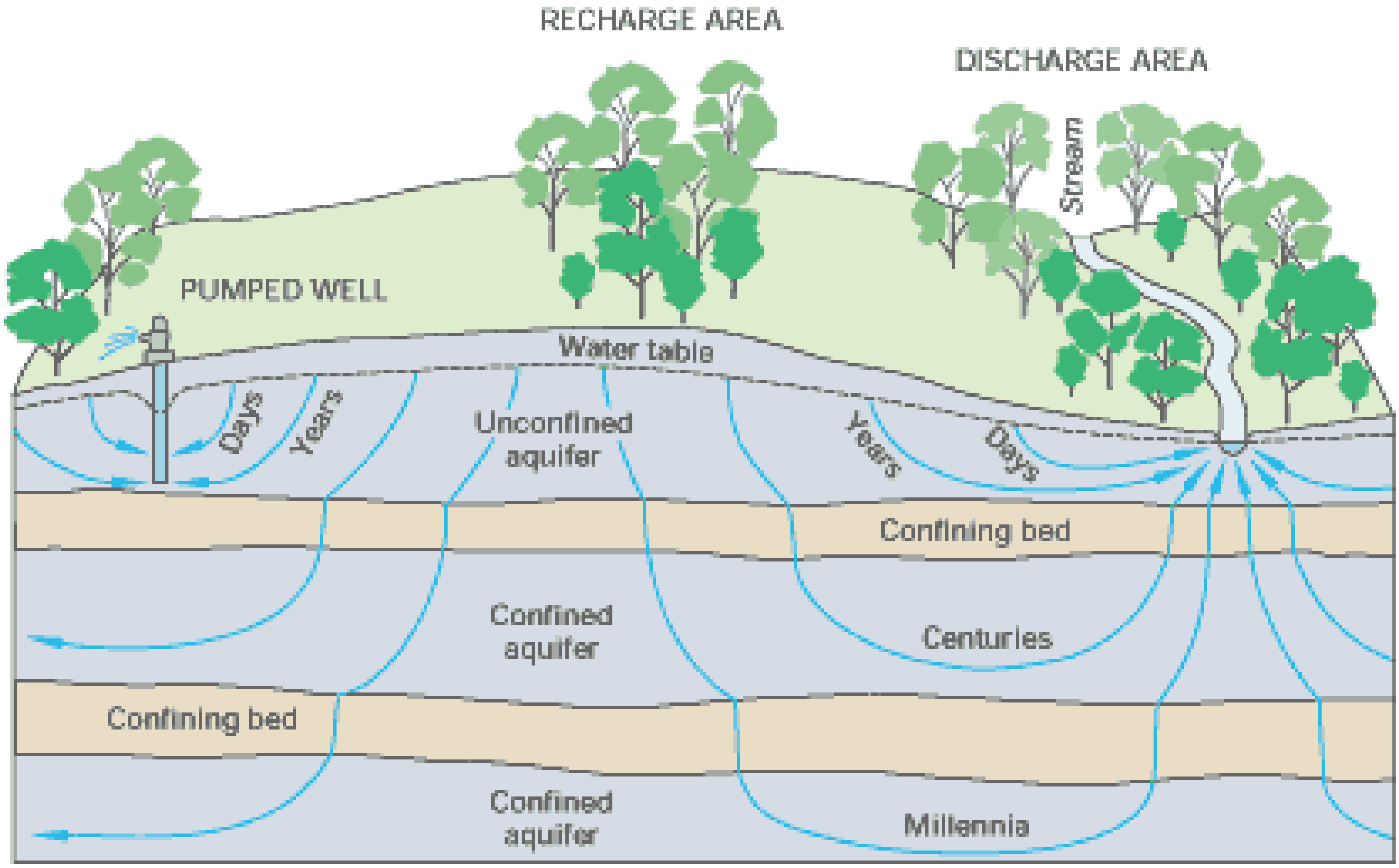


Jizera Mts. research, CZ, Martin Sanda

Water pathways in landscape



Residence time of groundwater



Charles Flowerday, USGS

Geothermal groundwater

Fly Geyser Nevada