PLATEFORME DE CONSTRUCTIONS HYDRAULIQUES

Water Resources Engineering and Management

(CIVIL-466, A.Y. 2024-2025)

5 ETCS, Master course

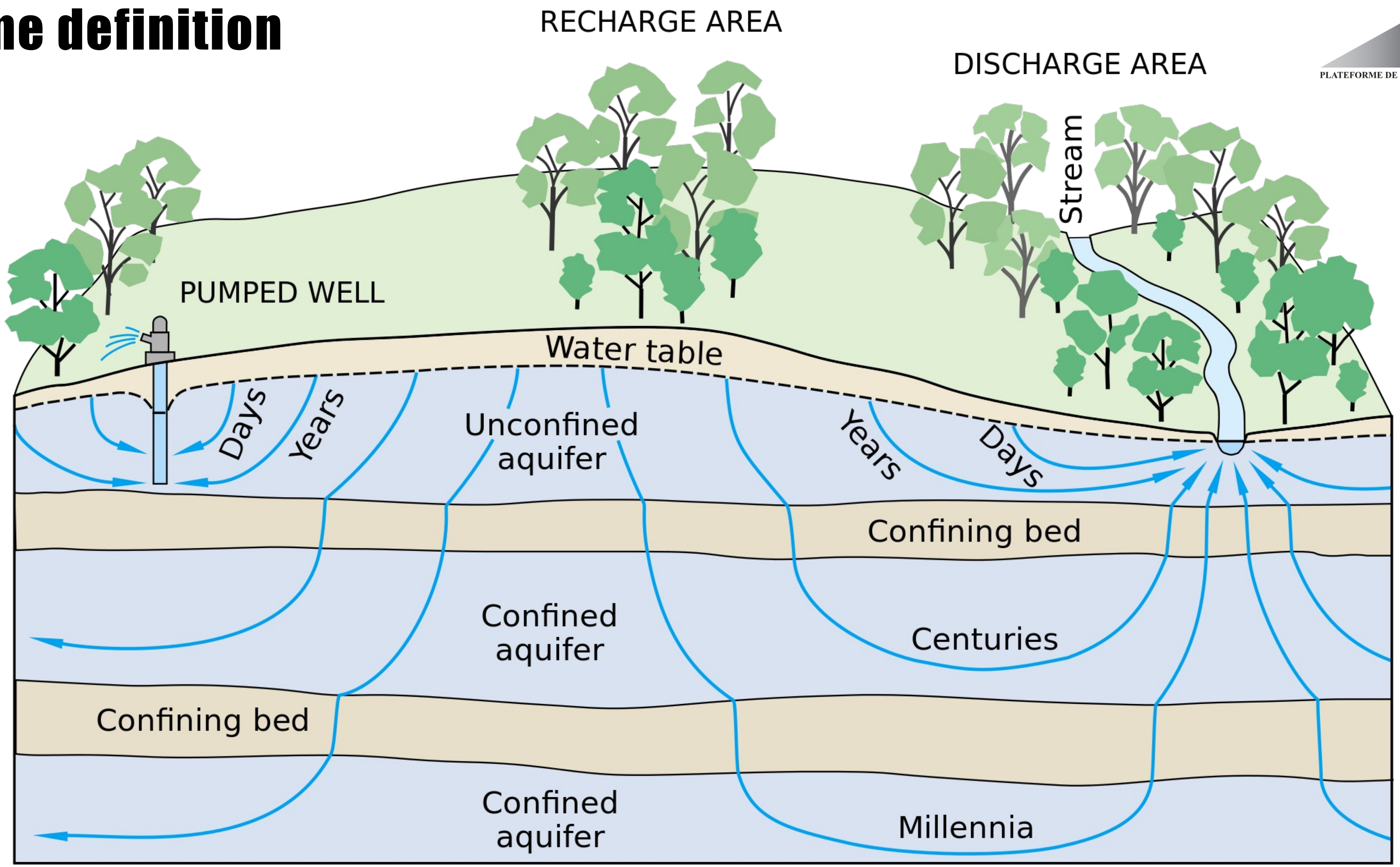
Prof. P. Perona
Platform of hydraulic constructions

Lecture 2-3: Water resources: Catchment hydrology and sub-surface water bodies

EPFL

Groundwater resources, movement, recharge and impact

Scheme definition



Why do we study groundwater?

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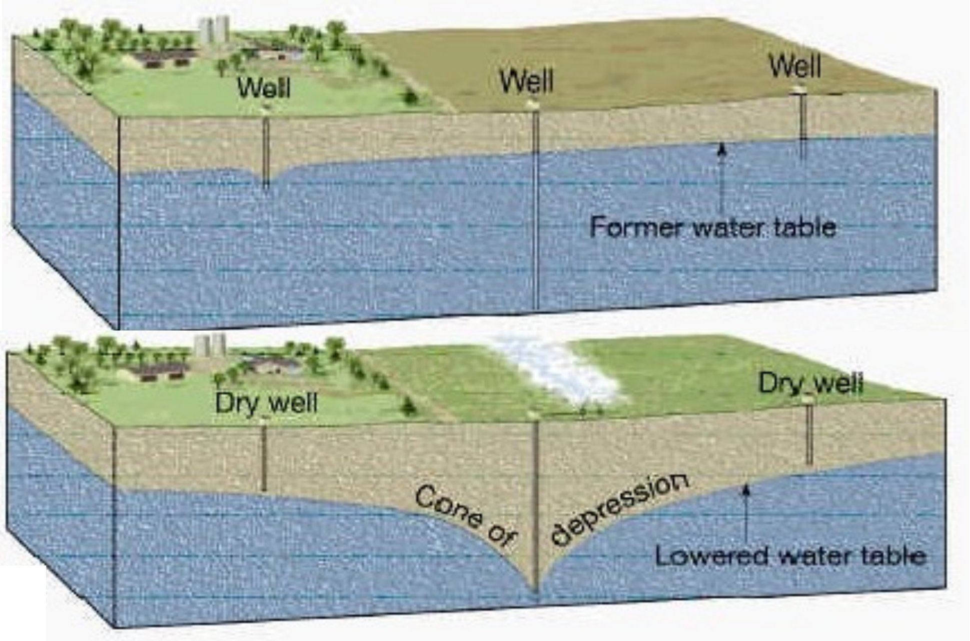
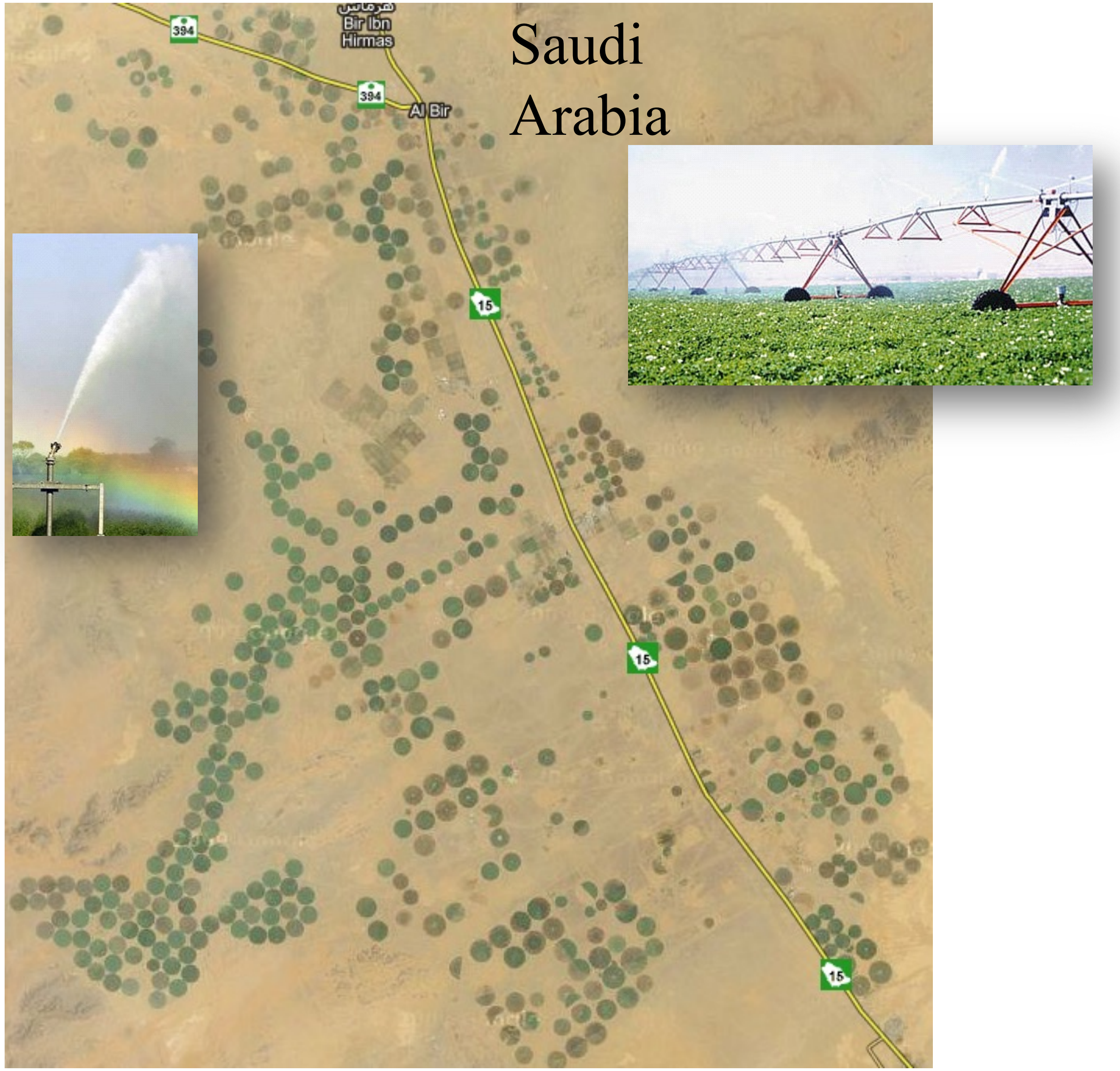
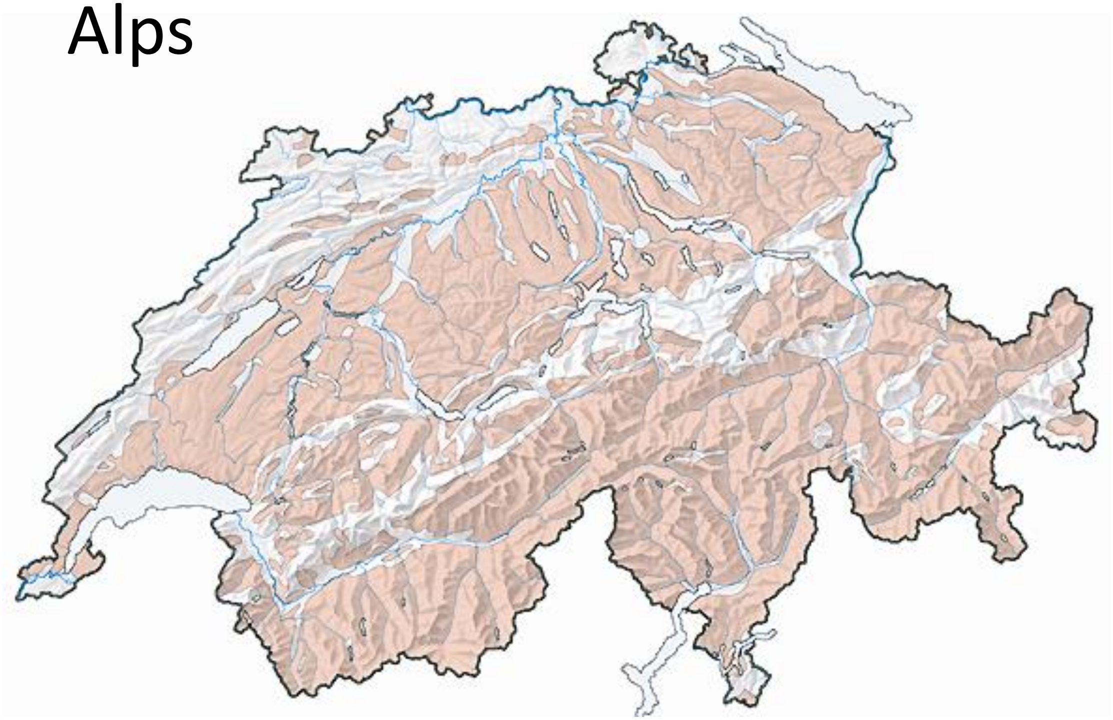
- Agricultural use
- Residential use
- Industrial use
- Drainage
- Soil processes
- Etc.

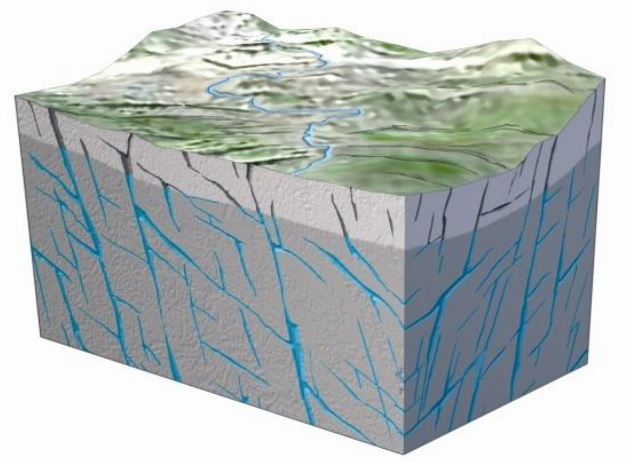




Example: Switzerland ' three types of aquifers

Consolidated, fissured aquifers in the Alps

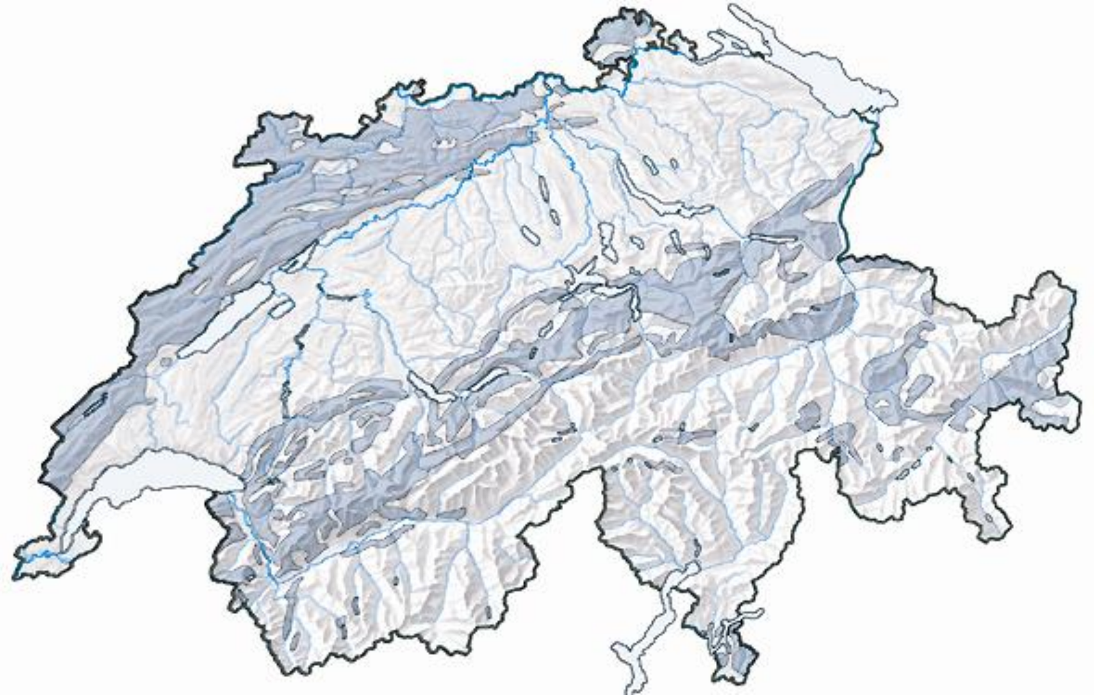


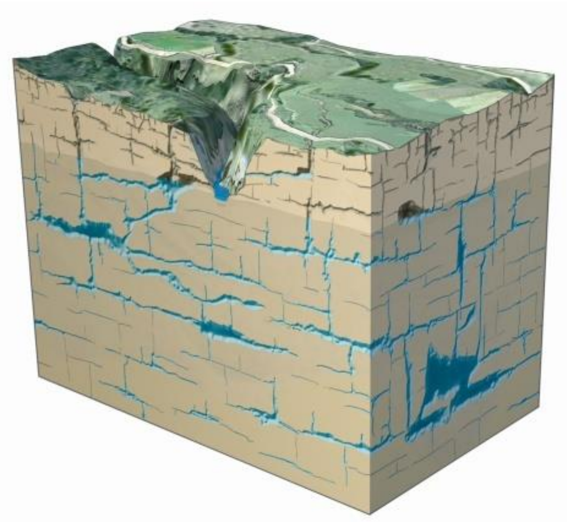


Storage capacity 20 km^3
3.7 km^3/a renewal rate

Source: FOEN

Consolidated, karstified aquifers

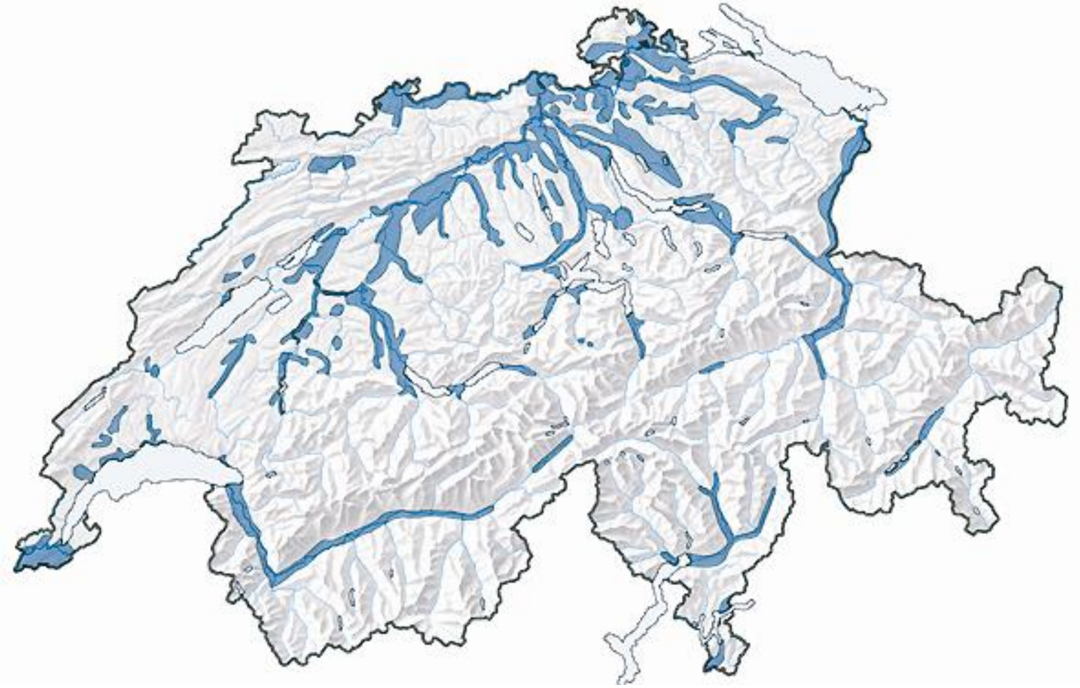


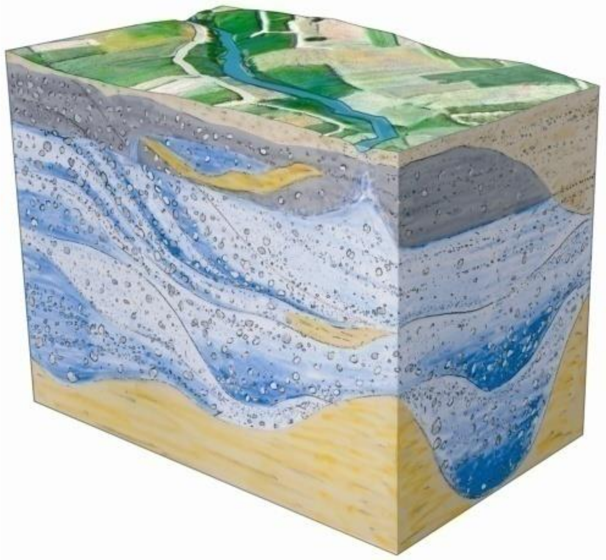


Storage 120 km^3
3.8 km^3/a renewal rate

Source: FOEN

Unconsolidated porous aquifers

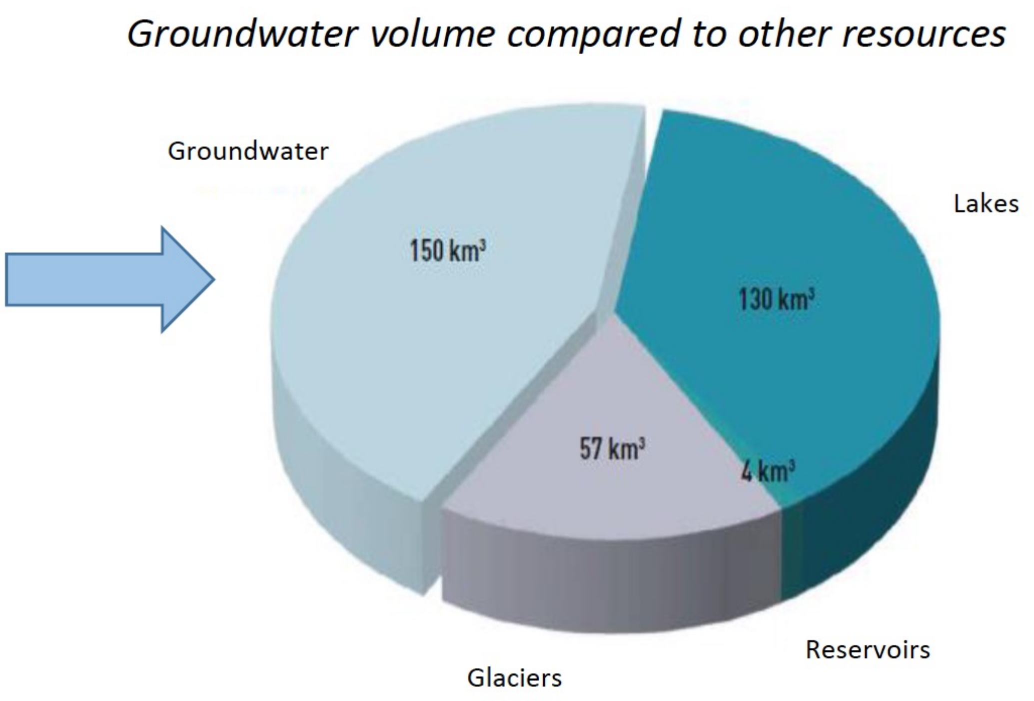


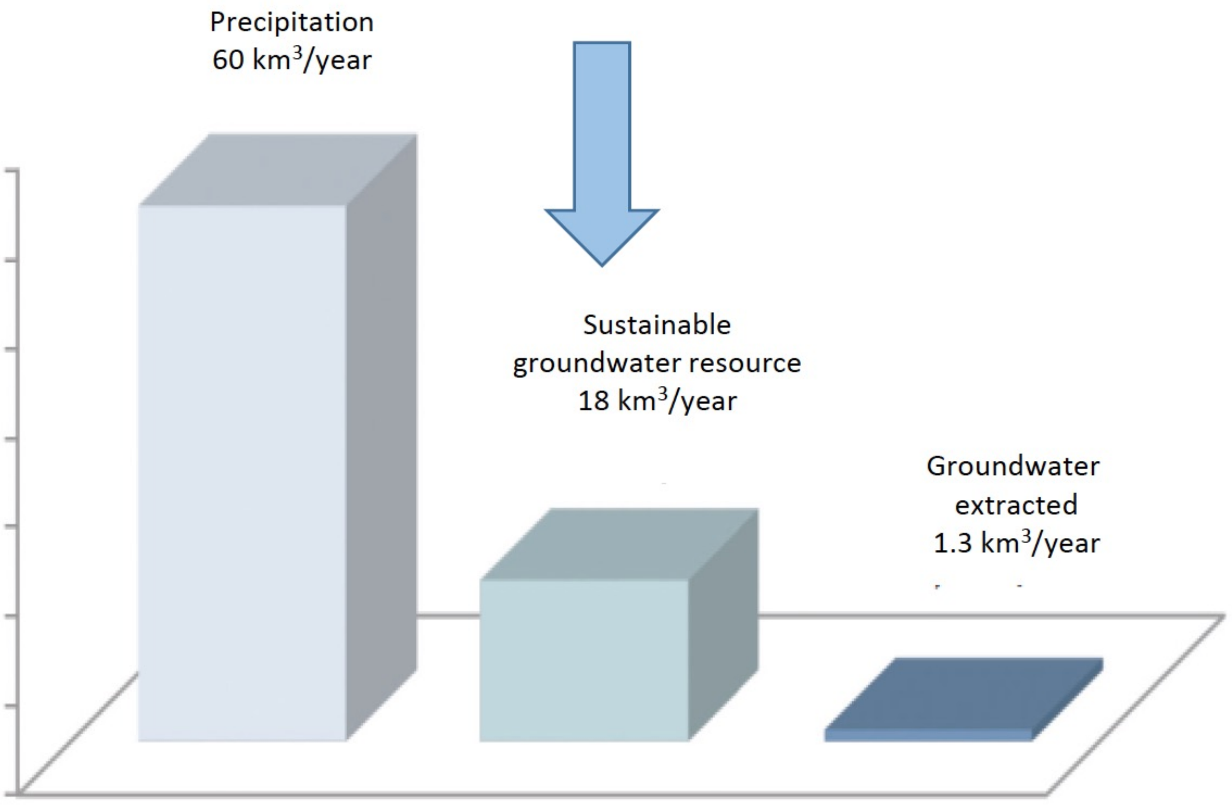


Storage 10 km^3
10.6 km^3/a renewal rate

Source: FOEN

Swiss groundwater resources: volume and renewal





Groundwater is usually of drinking water quality!

Source: FOEN

Groundwater use in Switzerland

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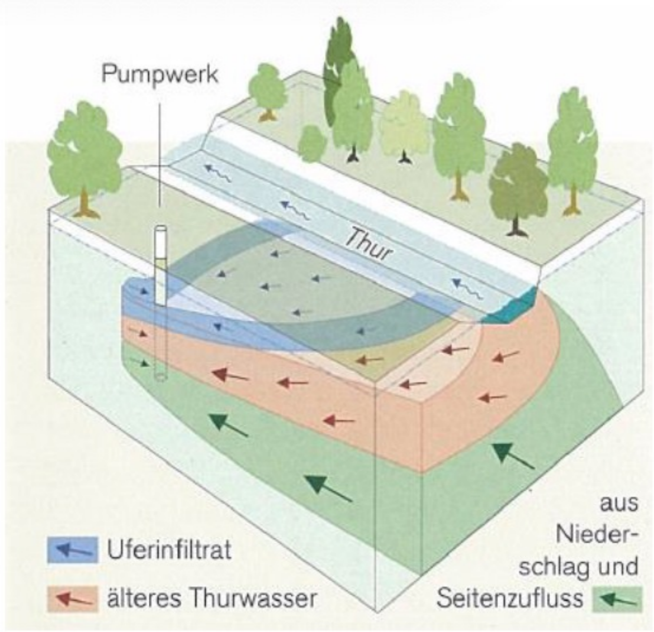
83% of the drinking water
in Switzerland is from groundwater

39% from pumping wells and
44% from spring catchments

~25% of the drinking water is bank filtrate

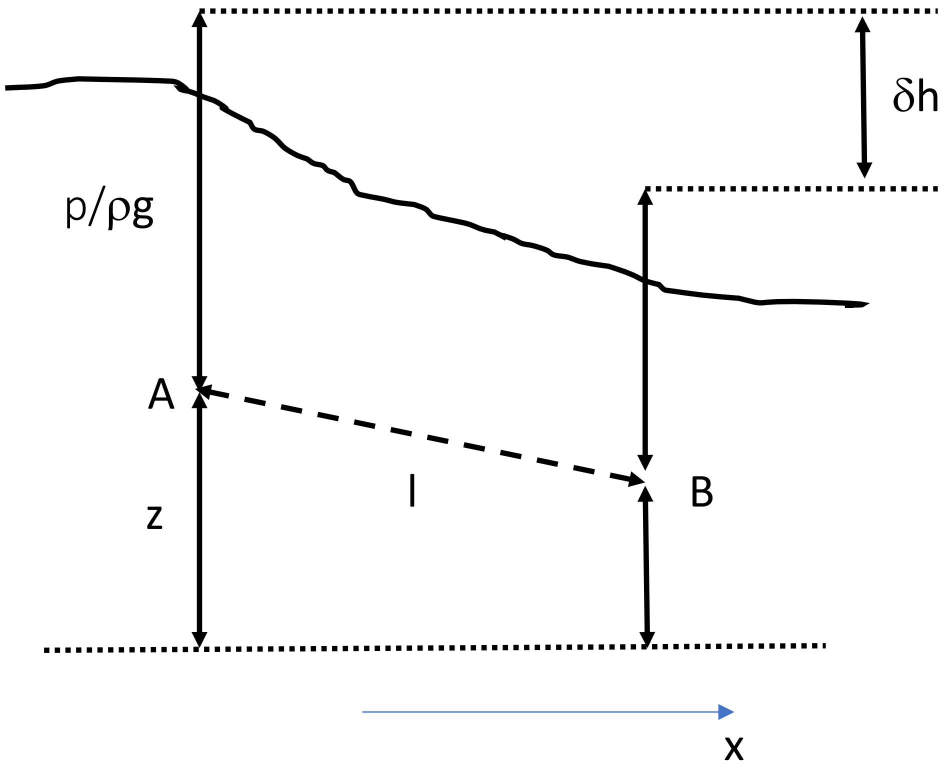
Little groundwater used
for irrigation so far
(increasing)



Source: FOEN

Water movement in (saturated) soil

Darcy's Law



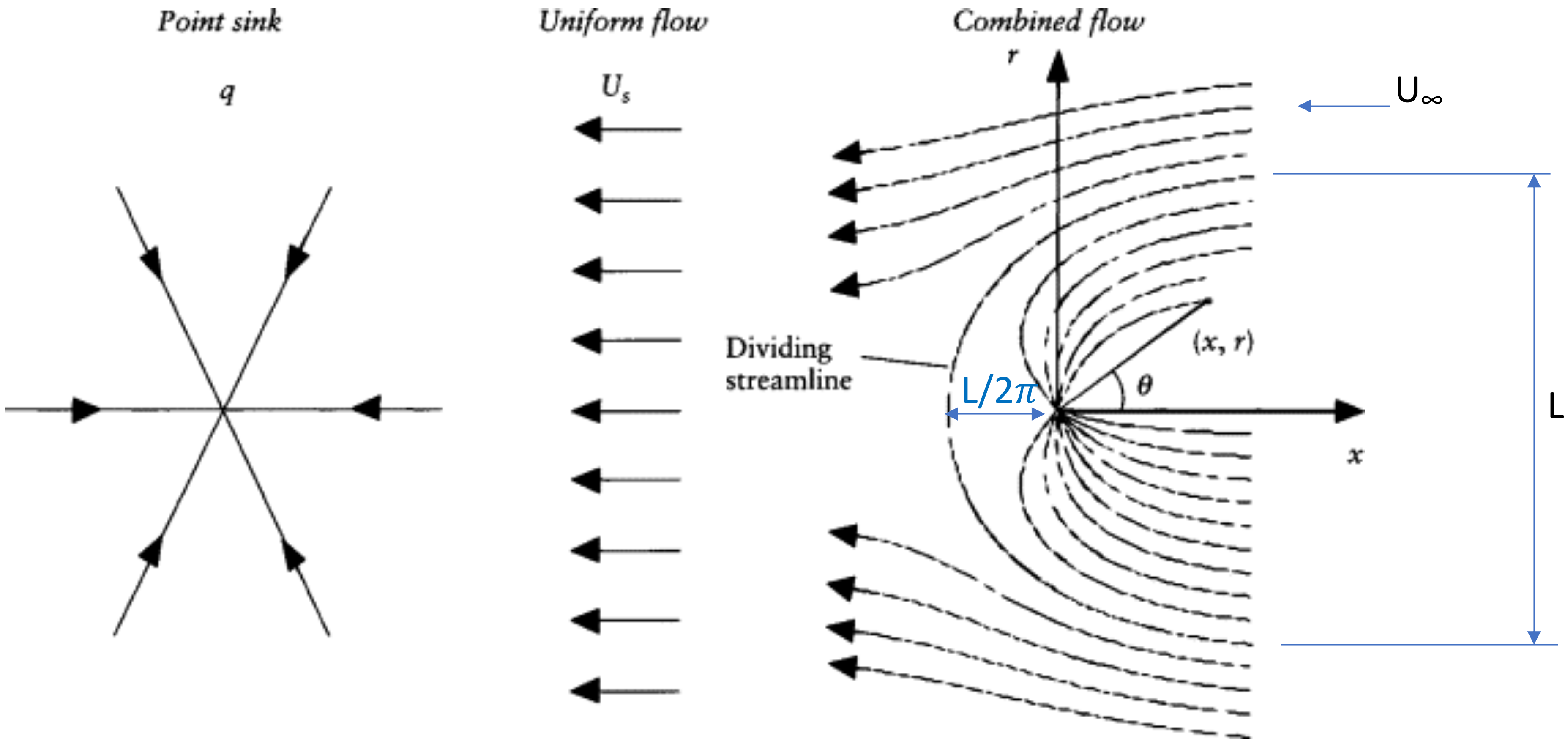
$$h = z + p/\rho g$$

$$i = -\frac{dh}{dx}$$

$$v = \frac{q}{A} = ki = -k\frac{dh}{dx}$$

k [L/T] is the saturated hydraulic conductivity coefficient (or permeability coefficient)

2D potential well



Interception zone

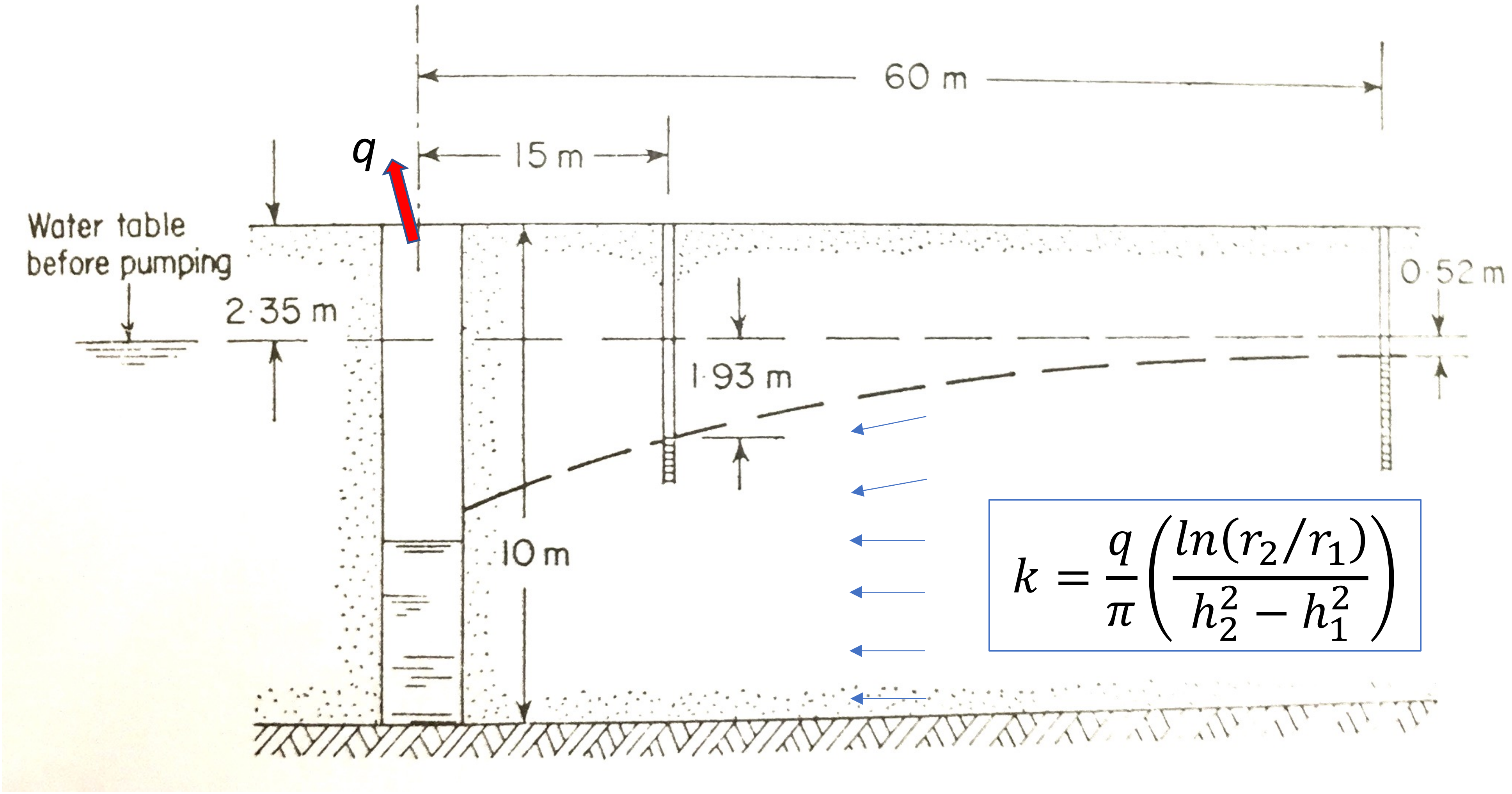
Sink flowrate (pumping)
$Q = U_\infty L D$

D is the aquifer thickness

Factors affecting *k*

- Density and viscosity of soil water (in turn affected by temperature)
- Turbulence of flow if any (e.g. in karst aquifers with large fissures)
- Soil porosity
- Shape and arrangement of soil particles (and hence origin and stress history due to erosion, construction etc)
- Degree of saturation
- Thickness of layers of water adsorbed to surface of particles
- Permeability to soil relationship status!

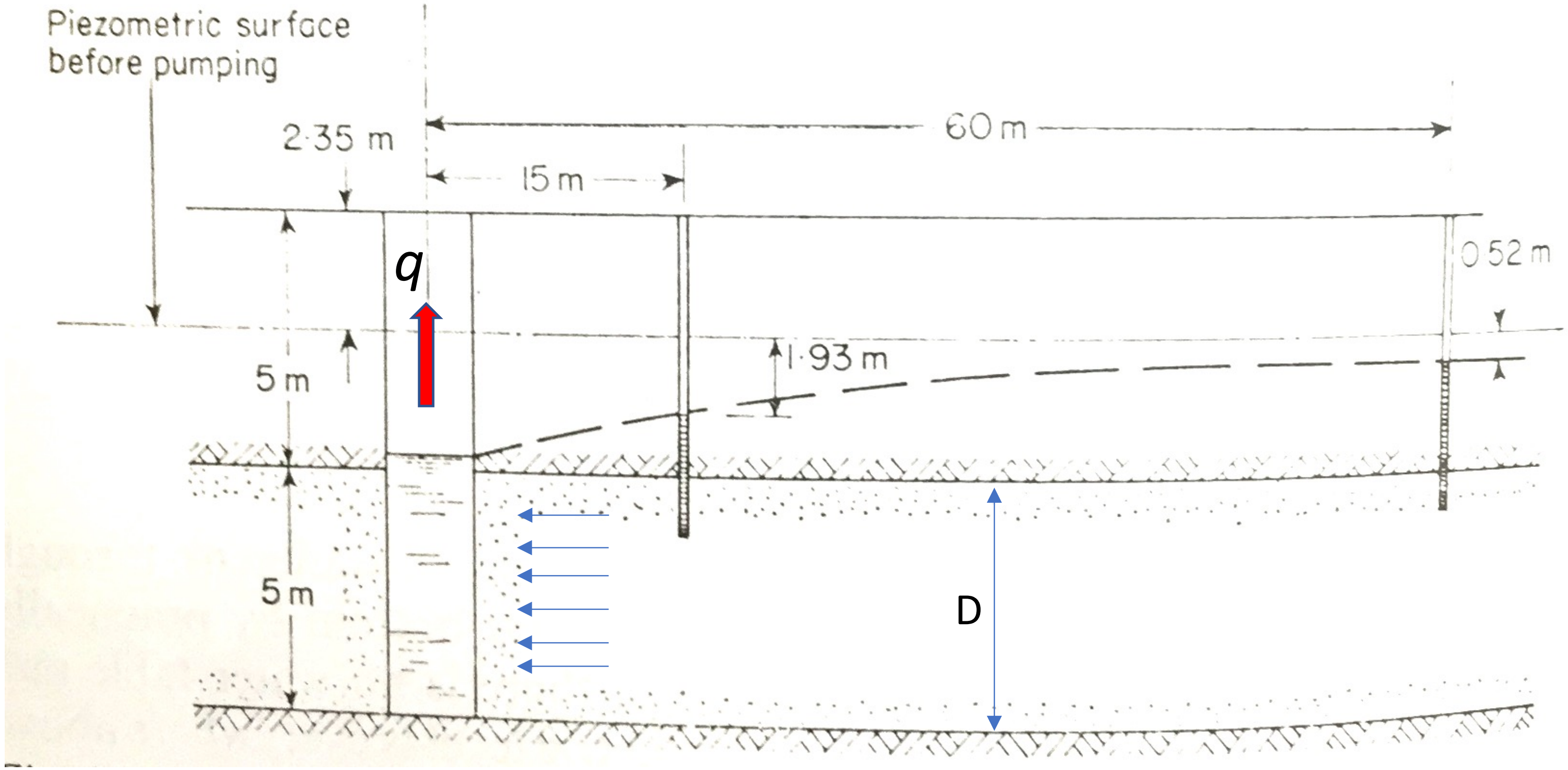
Example 1: unconfined aquifer (phreatic)



$$k = \frac{q}{\pi}\left(\frac{ln(r_2/r_1)}{h_2^2 - h_1^2}\right)$$

Example 2: confined aquifer (artesian)

- Top 5 m impermeable
- No water table
- No free surface
- Pressure causes water in observation holes to rise above the aquifer
- Water can only flow through aquifer depth D (< h)



$$q = Aki = 2\pi r D k \frac{dh}{dr} \Leftrightarrow k = \frac{q}{2\pi D}\left(\frac{ln(r_2/r_1)}{h_2 - h_1}\right)$$

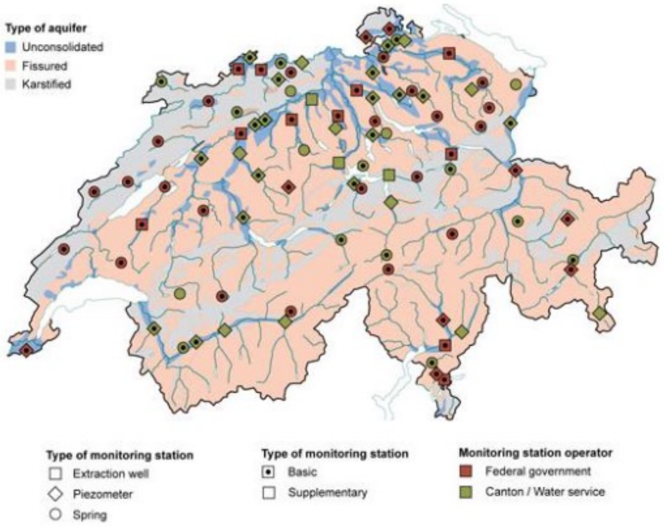
Note the difference with the phreatic one!

Legal basis of groundwater management

Swiss Federal Water Protection Act (WPA 1991) and amendments

Protection of quantity
Goal: No appreciable change in groundwater levels and springflows
Means: Licensing of concessions, monitoring of pumping, fees...

About 100 stations



Protection of quality
Goal: Drinking water quality
Means: Protection zones, enforcement of standards, rules on handling of hazardous substances...

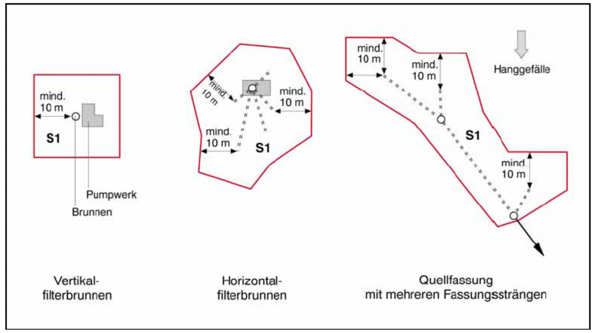
About 60 federal stations

Requirement for monitoring of both quantity and quality
Goal: Prewarning, guiding of management, verification of efficiency of measures taken
Means: observations networks, e.g. NAQUA...

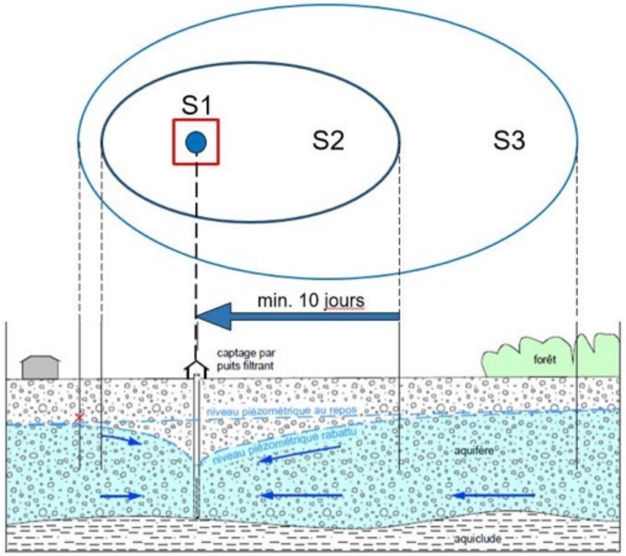
Type d'aquifère	Roches meubles	Karstique / Fissuré		
		faiblement hétérogène	fortement hétérogène	
Zones de protection des eaux souterraines	S1	S1	S1	Prescriptions
	S2	S2	S2	
			Sh	
	S3	S3	Sm	

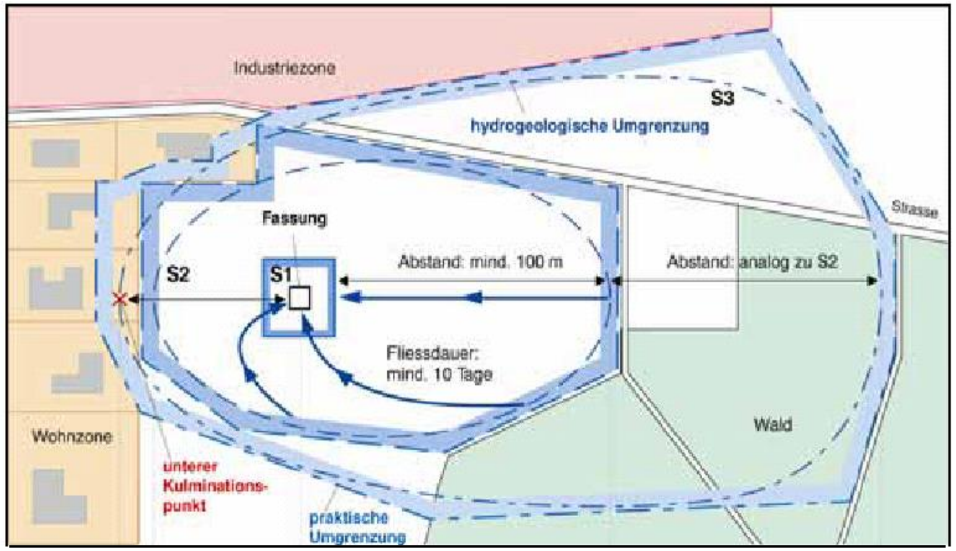
Licensing and fees for permits (temporary) and concessions (long-term: 10 to 80 years)

Groundwater abstraction: protection zones



S1 immediate vicinity of well

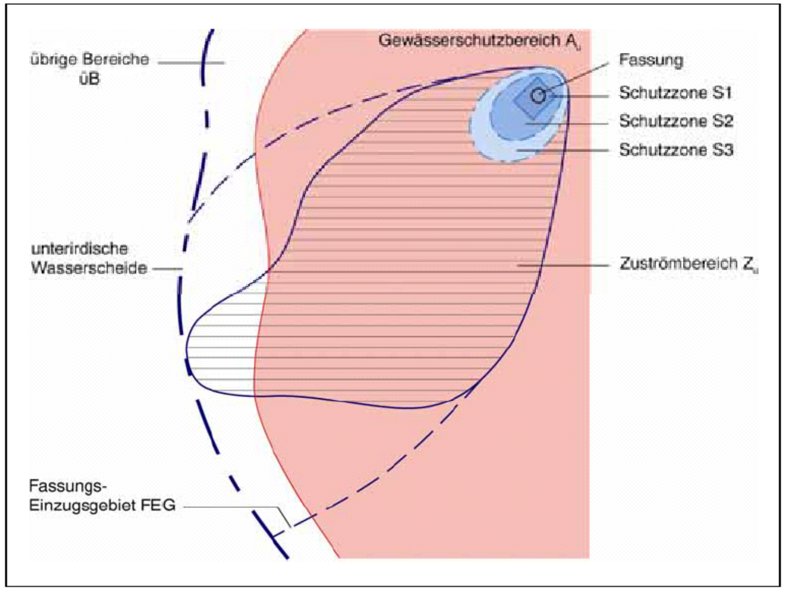




S2 10-day zone, protection against bacteria
S3 twice as large as S2, warning perimeter

Legal base of groundwater management

Swiss Federal Water Protection Act (WPA 1991) and amendments



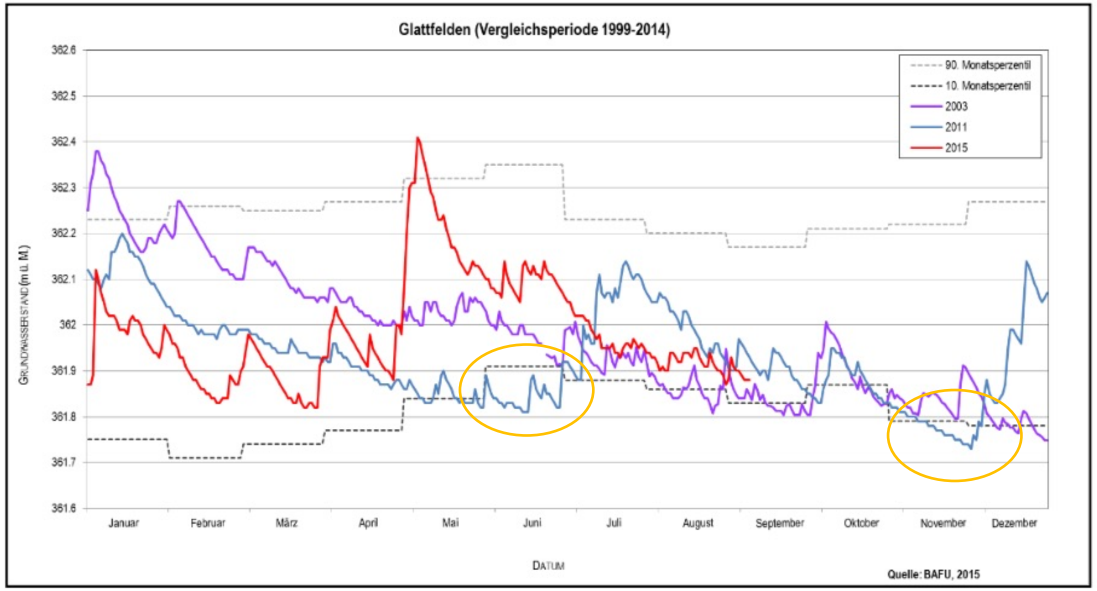
«Inflow zone» (90% of catchment), protection against persistent pollutants

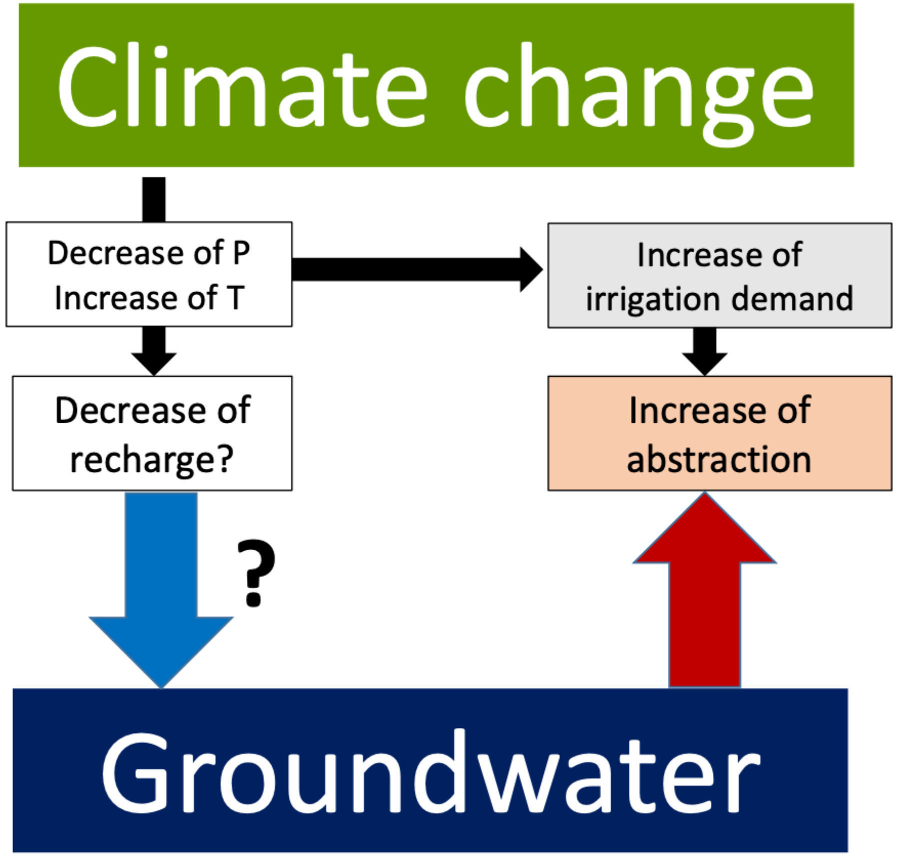
https://www.bafu.admin.ch/bafu/fr/home/themes/eaux/info-specialistes/mesures-pour-la-protection-des-eaux/protection-des-eaux-souterraines/eaux-souterraines-utilisees-comme-eau-potable.html

Courtesy of W. Kinzelbach, ETH Zurich

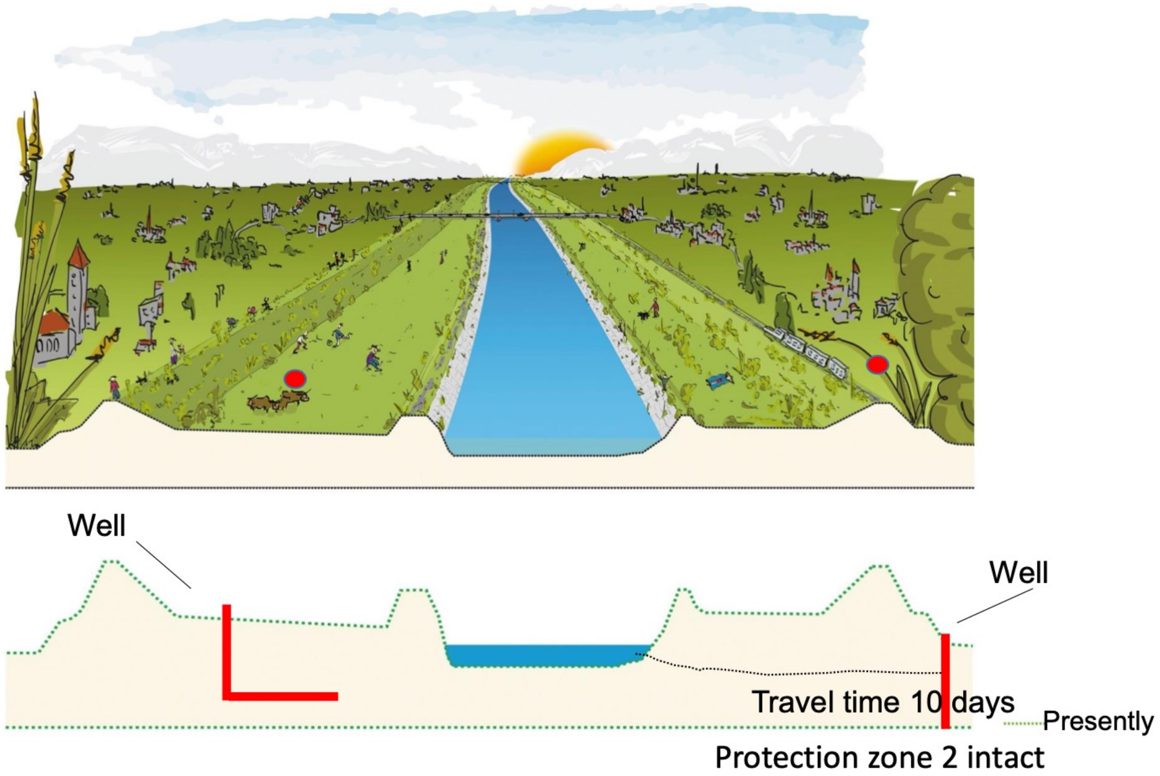
New groundwater problems

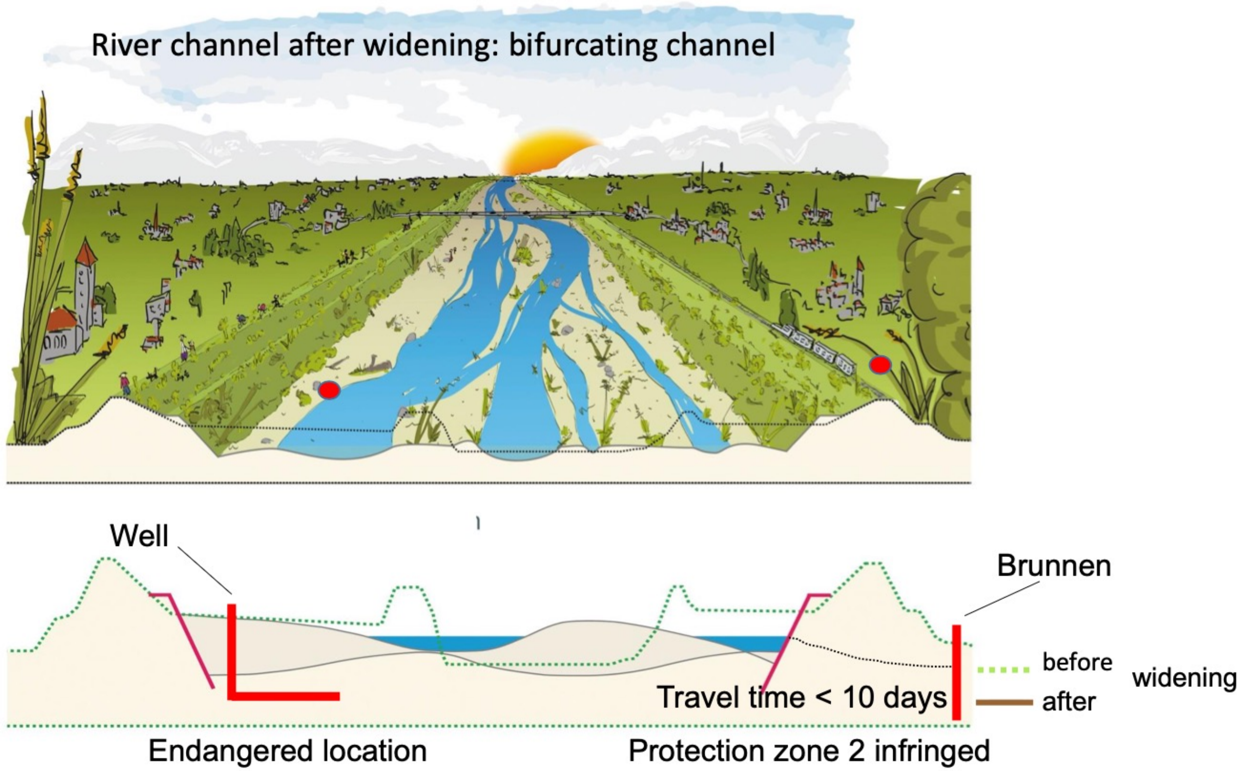
- Impact of climate change
- Drinking water aspects of river renaturalization
- New contaminants
- Use of groundwater as heat source





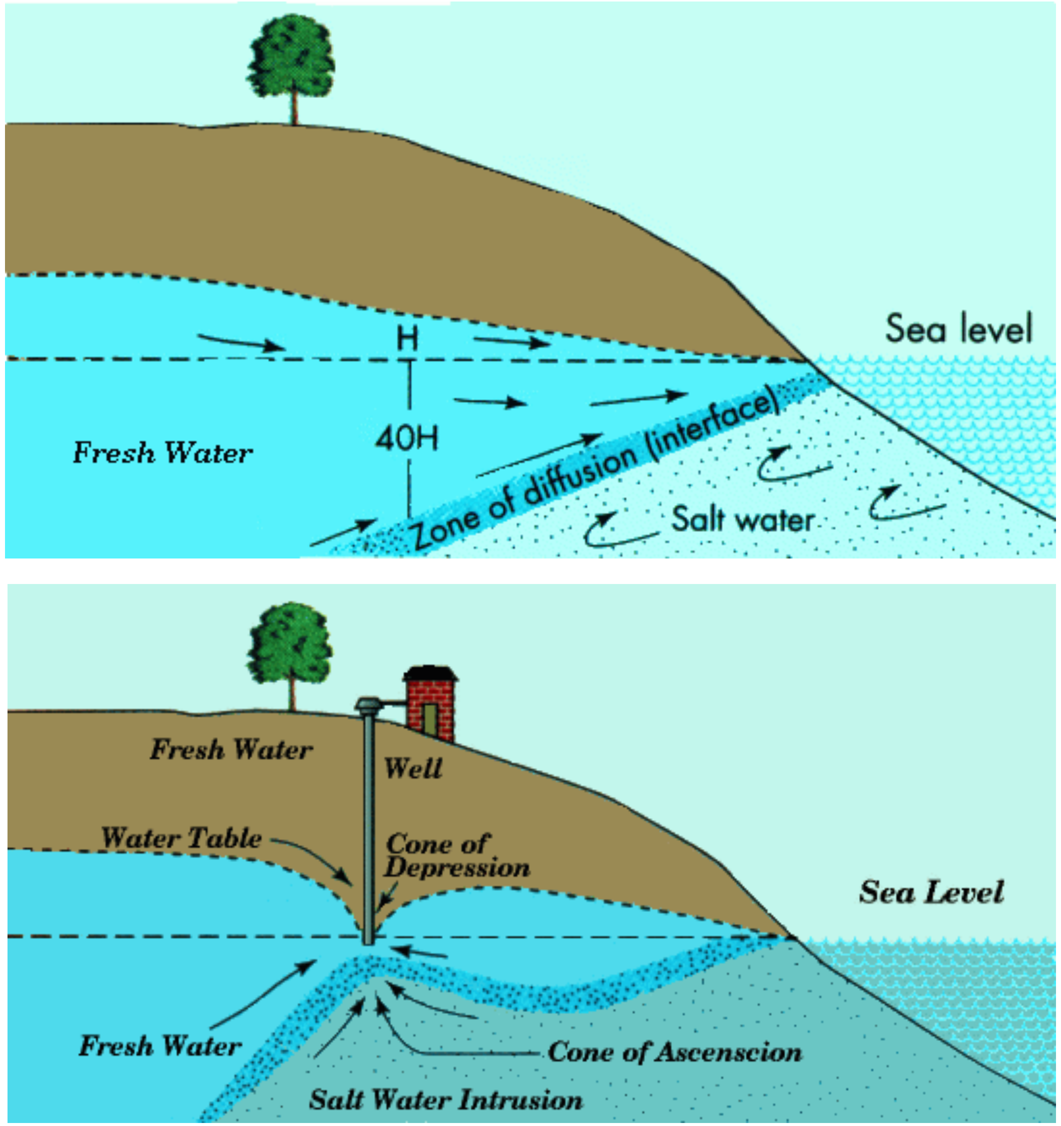
Concerns for drinking water wells (bank filtration) after river restoration

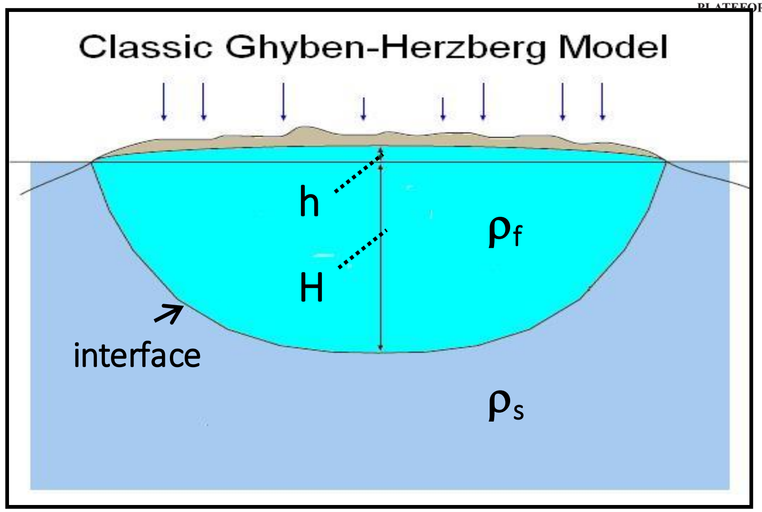




Remember the Thur restoration project (video)

Groundwater abstraction: salt water intrusion





$(H + h)\,\rho_f = H\,\rho_s$

$\rho_f = 1\ g/cm^3$

$\rho_s = 1.025\ g/cm^3$

➔ $H = (\rho_f / (\rho_s - \rho_f))\, h = 40\, h$

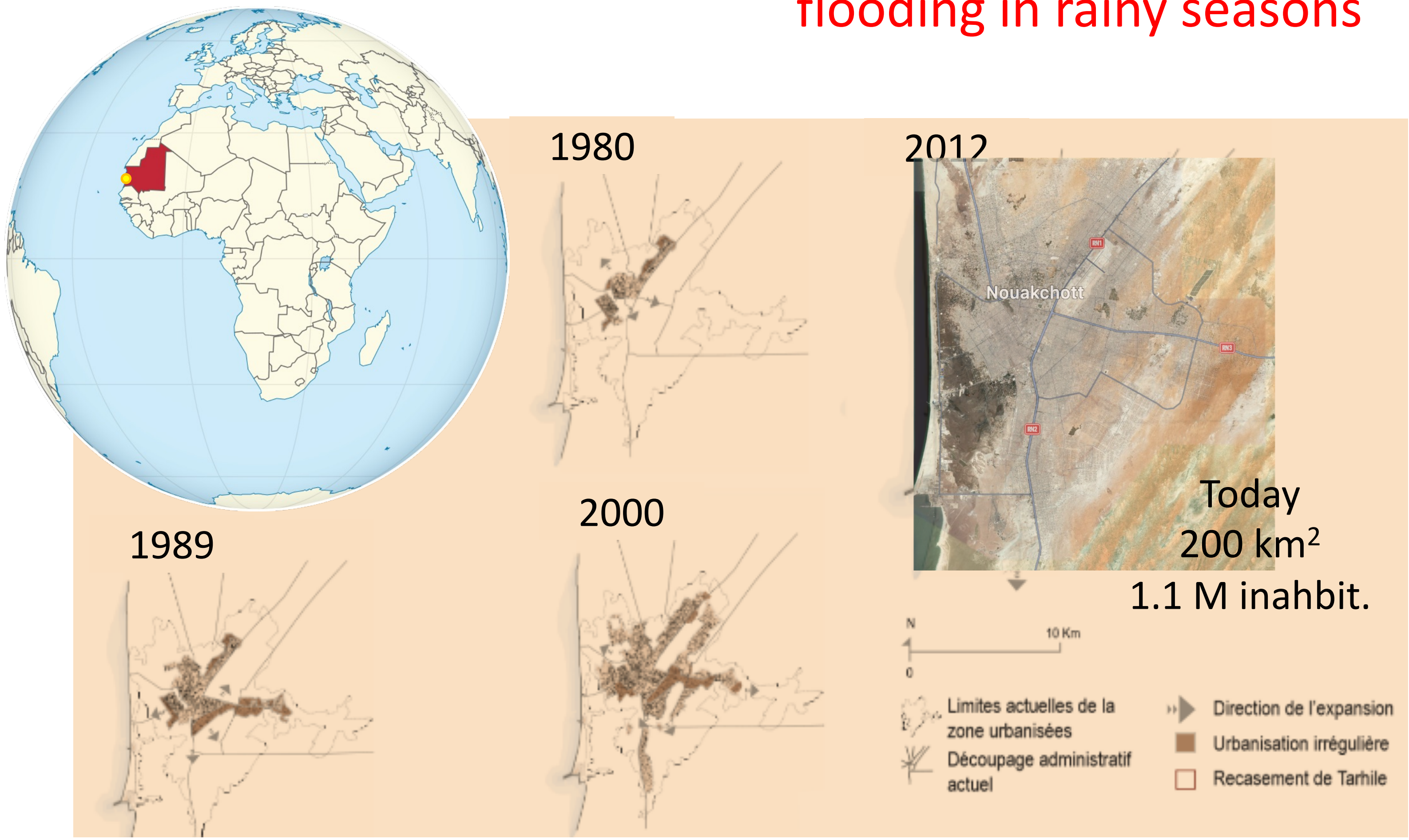
A deepening of the freshwater level in the acquifer induces a 40-times larger rise of the salt water boundary!!

Example: flooding due to GW rise (saturation- excess process)

Issues with water management can also arise because of groundwater, e.g. Mauritania

Nouakchott, in ODA Mauritania, suffers from flooding in rainy seasons

- Massive urban growth -> reduced infiltration
- Several districts below sea level
- Intense water supply, no sewer network -> high groundwater levels (+1 m in 20yrs)
- Heavy precipitation -> urban flooding (more frequent)
- Left 2000 people homeless in 2013 and Cholera outbreak
- Climate change will affect Nouakchott in the upcoming years
- Reduction in rainfall of 10%; More intense rainfall
- Sea level rise – 0.8 m



INUNDATION RISK MAP (2015)

https://www.epfl.ch/schools/enac/eira/

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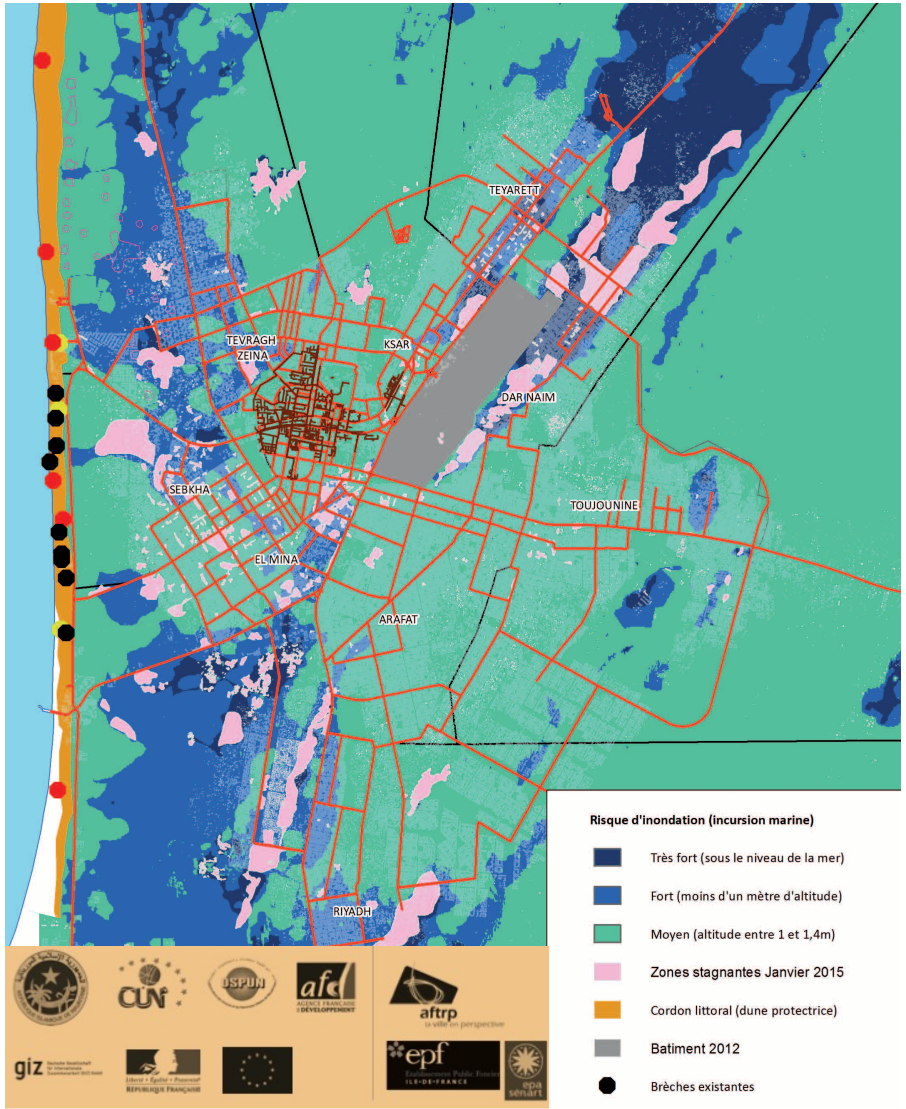

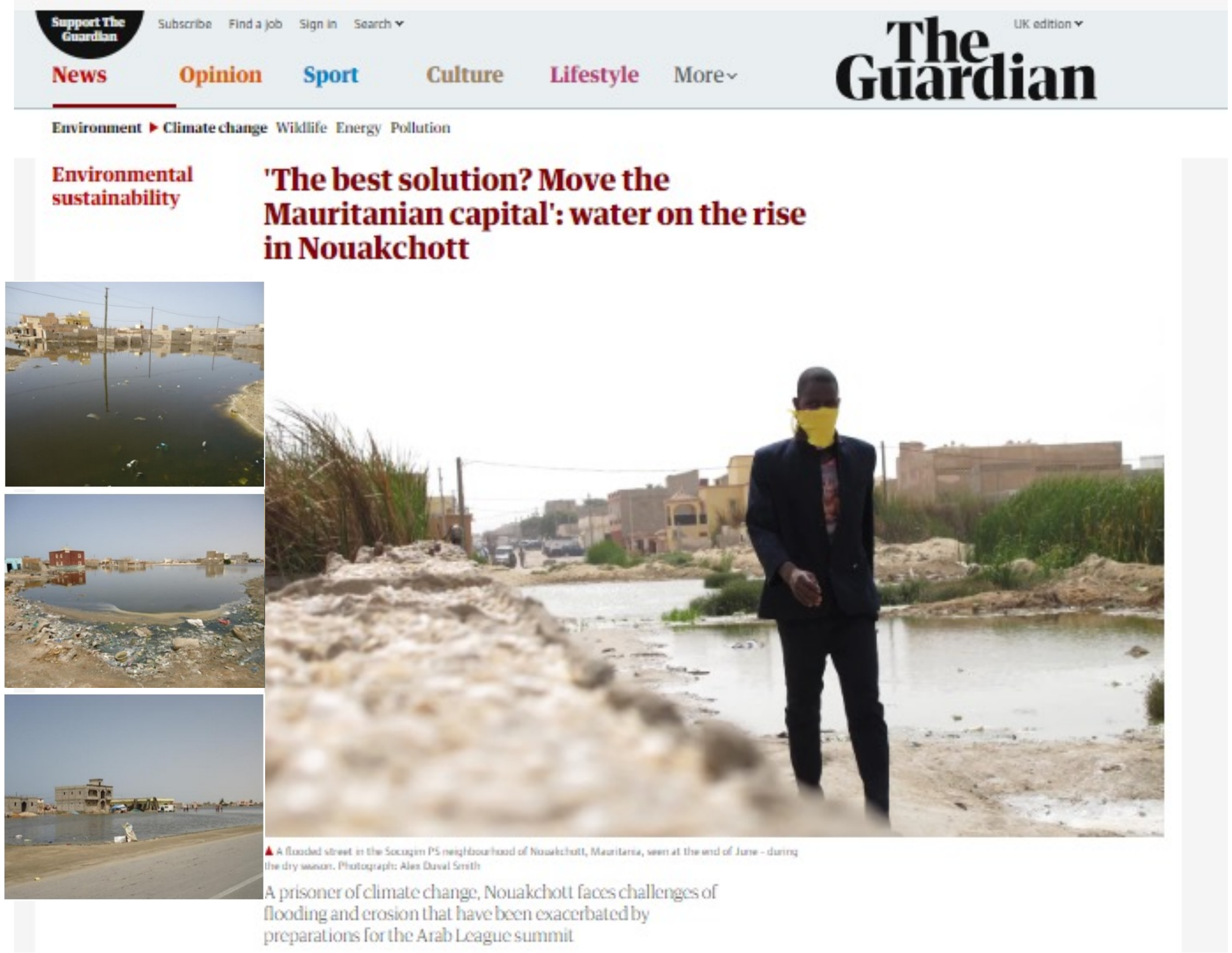
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Environmental sustainability

'The best solution? Move the Mauritanian capital': water on the rise in Nouakchott

▲ A flooded street in the Socogim PS neighbourhood of Nouakchott, Mauritania, seen at the end of June – during the dry season. Photograph: Alex Duval Smith

A prisoner of climate change, Nouakchott faces challenges of flooding and erosion that have been exacerbated by preparations for the Arab League summit

EIRA project (Enhancing Infrastructure Resilience to flooding using Afforestation)

https://eira.epfl.ch

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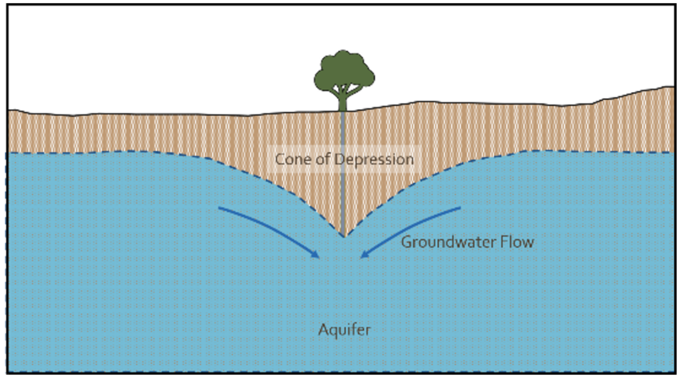
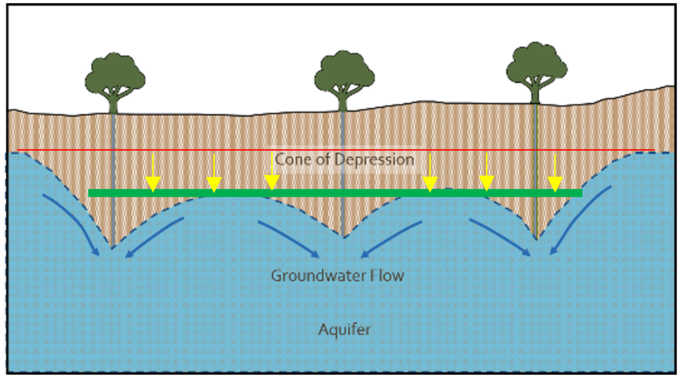
To increase the resilience to flooding of the city of Nouakchott by modelling the likelihood of success of an integrated afforestation program with salt-tolerant tree species



(a) Single abstraction point



(b) Multiple abstraction points

Objectives

- To understand current groundwater functioning (Data analysis);
- To quantify potential and actual transpiration of some existing tree species as well as soil-plant-atmosphere energy and mass exchanges (Plant physiology);
- To implement an urban-scale quasi-3D groundwater model including surface flows and soil- atmosphere flux exchanges (Hydraulic modelling);
- To use the groundwater model and the aforesaid impact scenarios to build risk maps of integrated afforestation measures and residual risks (Sustainable water management);

Recent situation (13-20/02/2023)

https://www.epfl.ch/schools/enac/eira/








Take home messages from these three lectures

- L2.1 I can describe the hydrological cycle (but not need to remember the volvume of trasnferred water across the globe)
- L2.1 I can remember the volume fractions of saltwater and freshwater as well as the corresponding percentages
- L2.1 I can explain the concept of water renewal and remember three or four time scales for chosen water bodies
- L2.1 I understand why and which human activities affect the water cycle

- L2.2 I can explain the main rainfall-runoff generation processes and link them to groundwater dynamics
- L2.2 I can understand and rember five river attributes and describe their meaning and functions
- L2.2 I can explain why thermal stratification in artificial reservoir can be an environmental issue
- L2.2 I can remember by heart and explain the lake mass balance equation

- L2.3 I know the difference between Phreatic and Artesian aquifers and remember the three Swiss types
- L2.3 I can explain and remember Darcy's law and the potential well formulas for the interception and the stagnant point downstream
- L2.3 I know how to use (but I don't need to rememebr by heart) the hydraulic conductivity well equations
- L2.3 I can remember and explain the three protection zones of the Swiss WPA
- L2.3 I can derive the Ghiben-Herzerg model for salt water intrusion