CTU
CZECH TECHNICAL
UNIVERSITY
IN PRAGUE

# Groundwater hydraulics
# 2
# Definition of properties

# Continuous (macroscopic) approach

Observation of water fluxes in porous medium is possible at focus on level

Molecular

Microscopic

Macroscopic

Molecular scale: movement of water and solute molecules

Microscopic – at pore scale

real phases (water, air, solids) is replaced by microcontinuum which fills partial spaces,

There is one microcontinuum at one time and space only

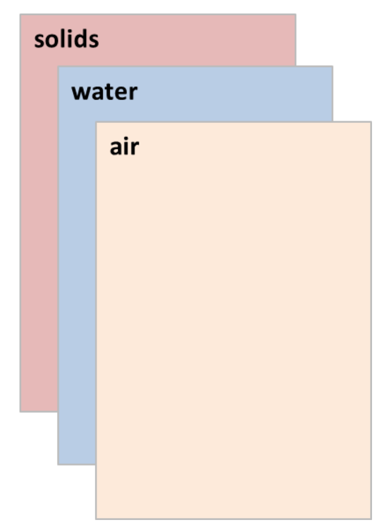
**Macroscopic scale**

all phases are mutually overlapped

in fictious macrocontinua

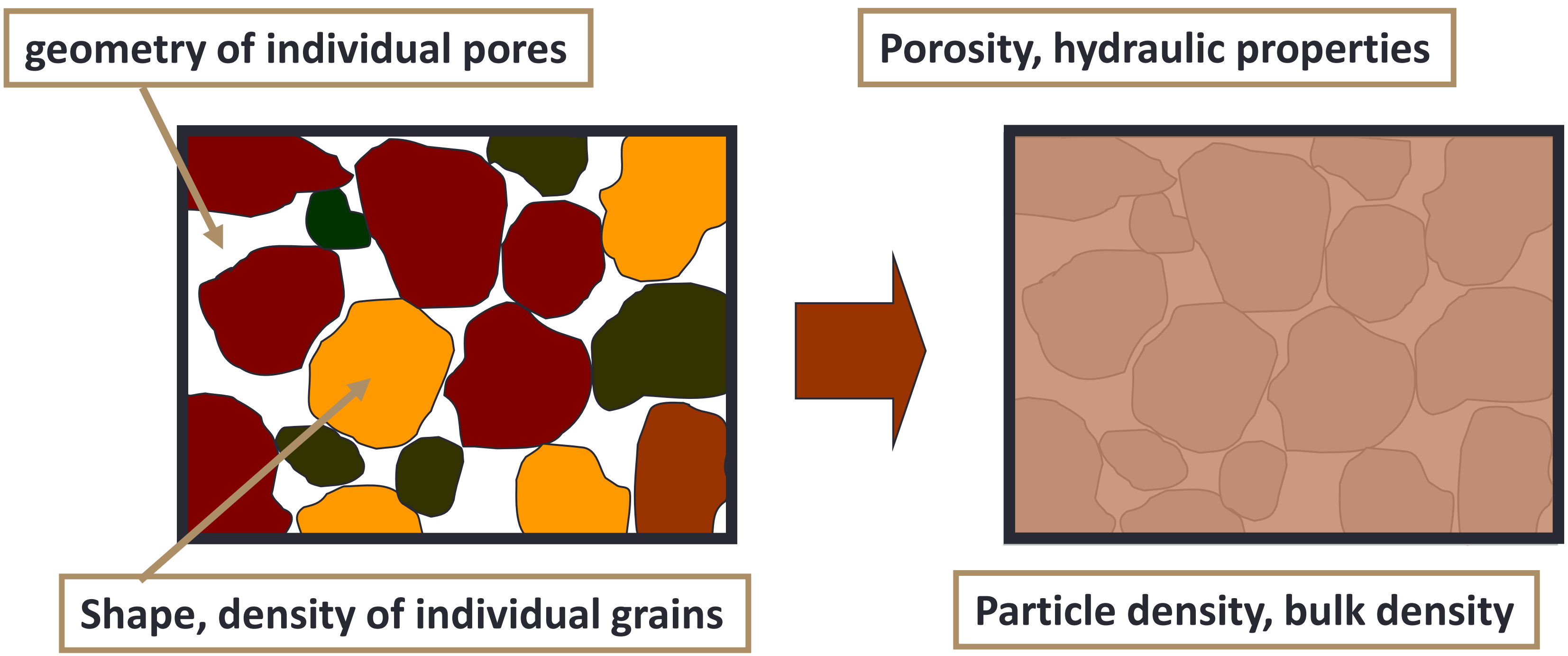
filling the flow zone entirely

at one space, there is unlimited number of macrocontinua



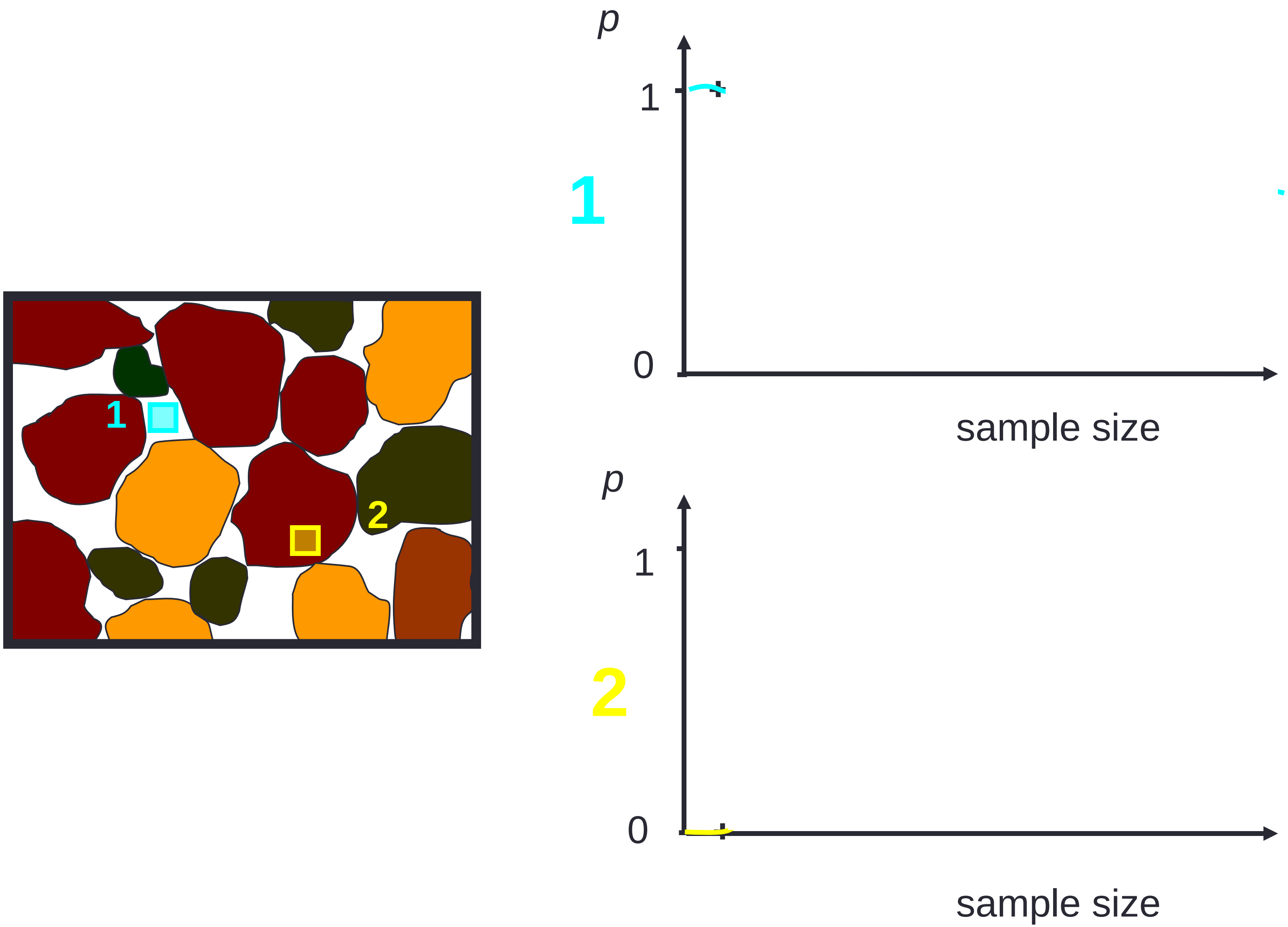
# From microscopic to macroscopic approach

Description of the water flow and solute transport in soil (porous media) is (so far) not possible at the pore scale level. Therefore the **macroscopic approach** is used.




pore scale macroscopic

# Representative elementary volume (REV)



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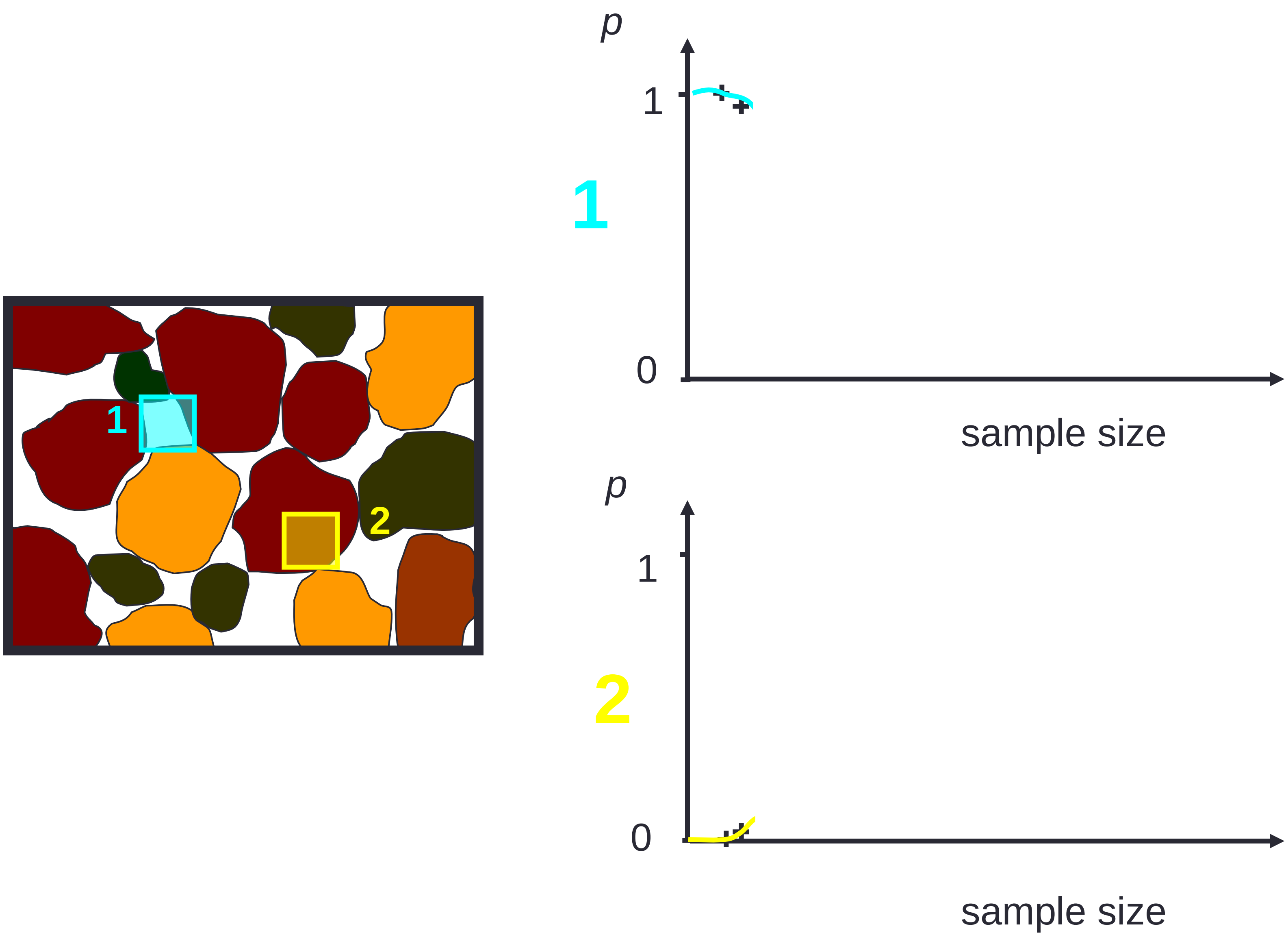
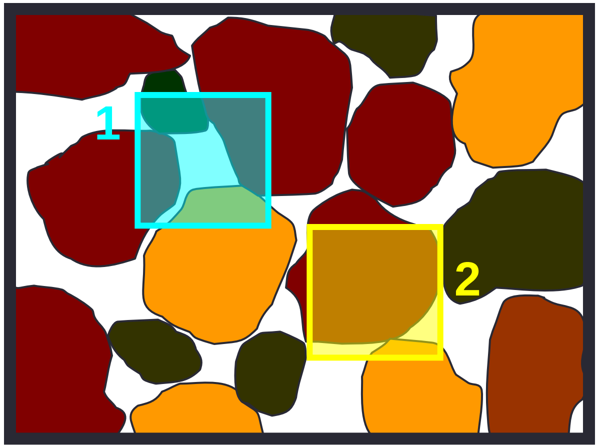
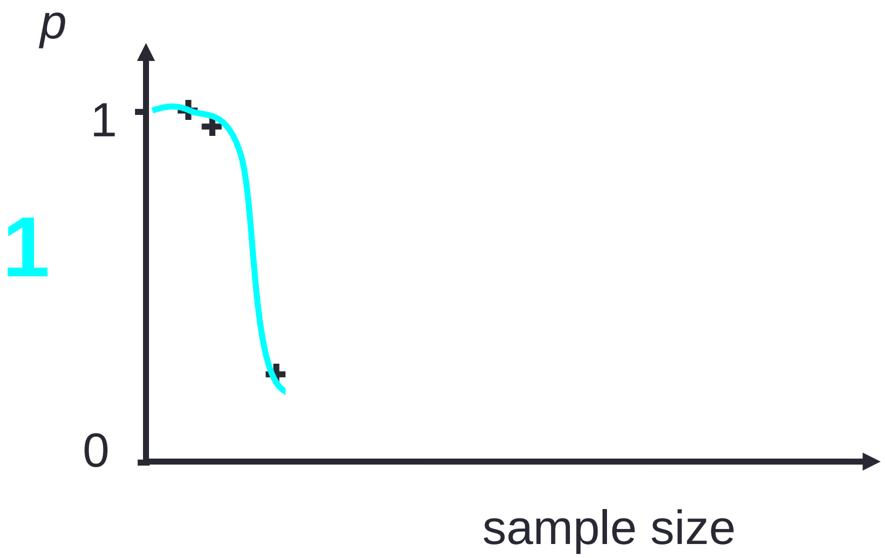
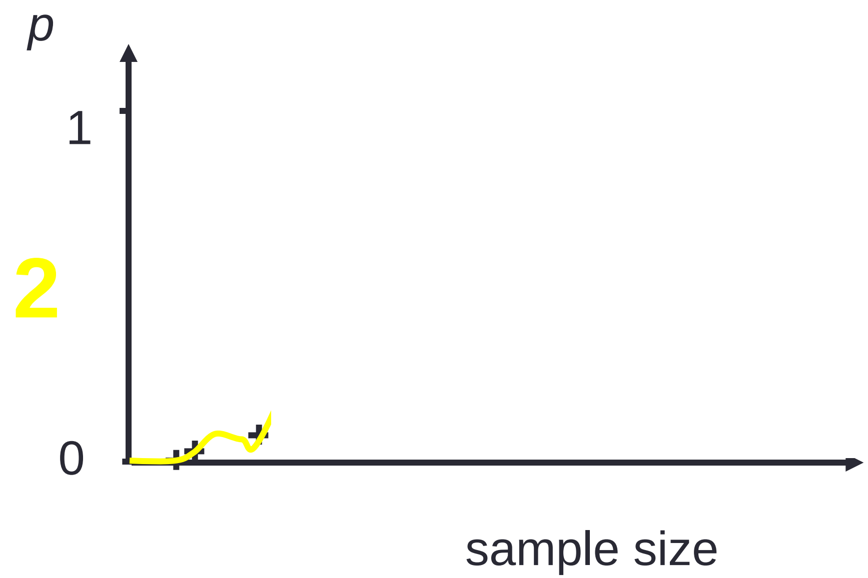


# Representative elementary volume (REV)



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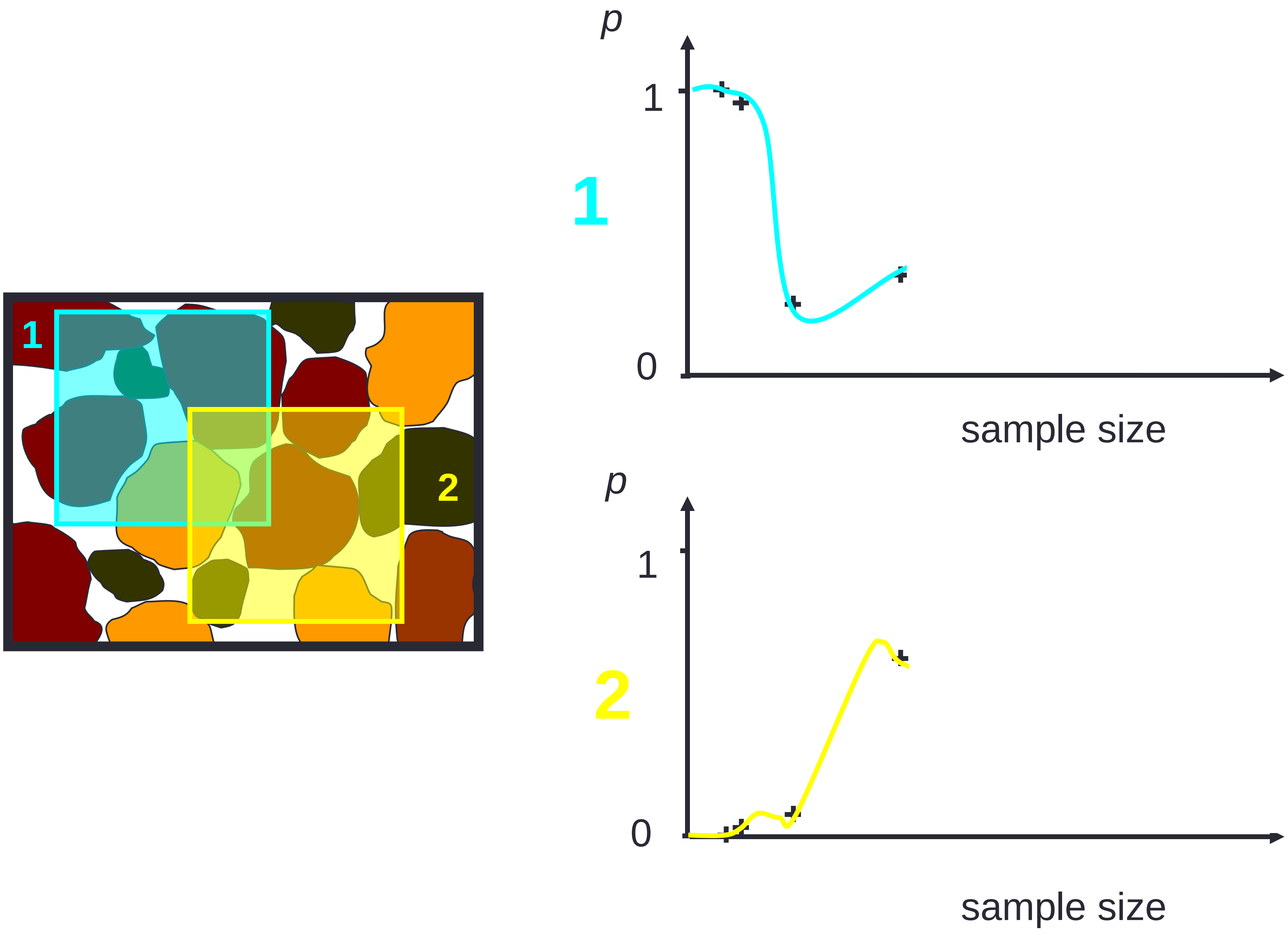

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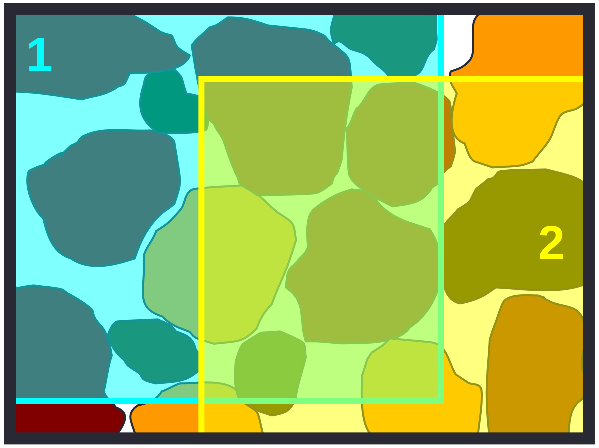
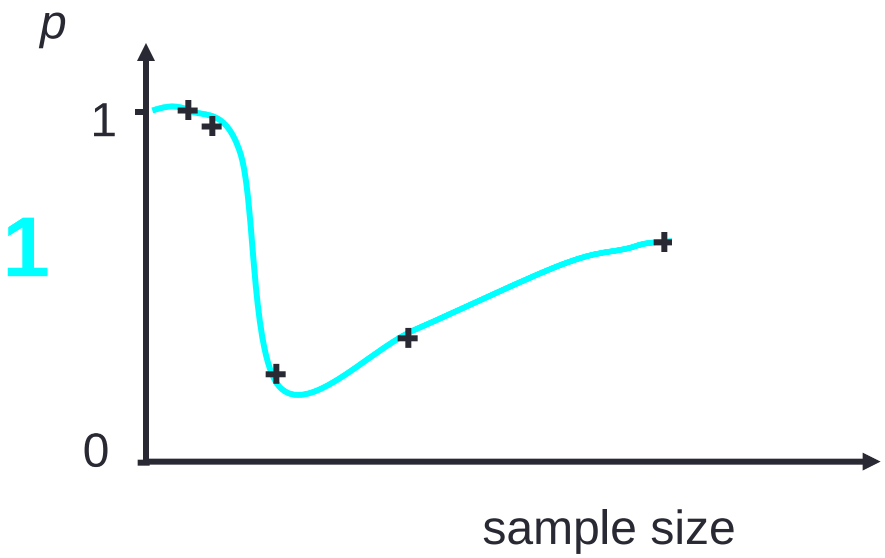
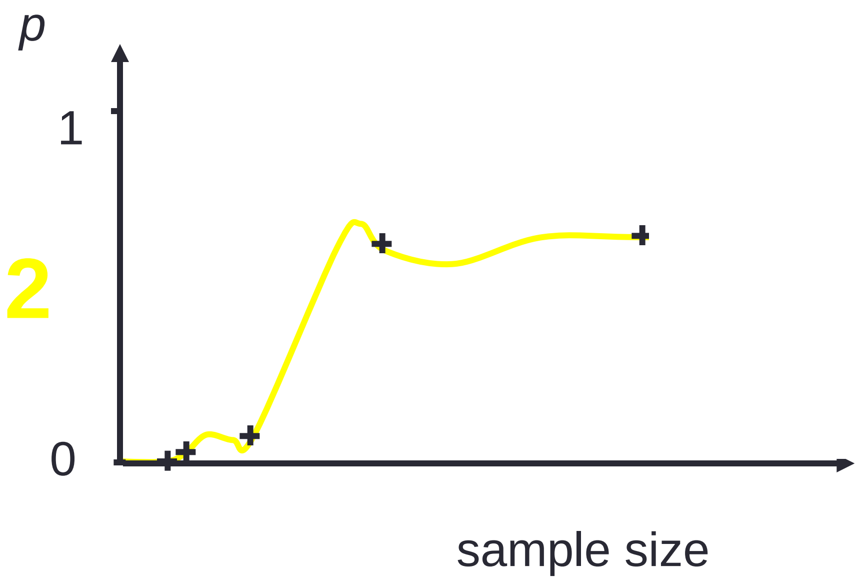


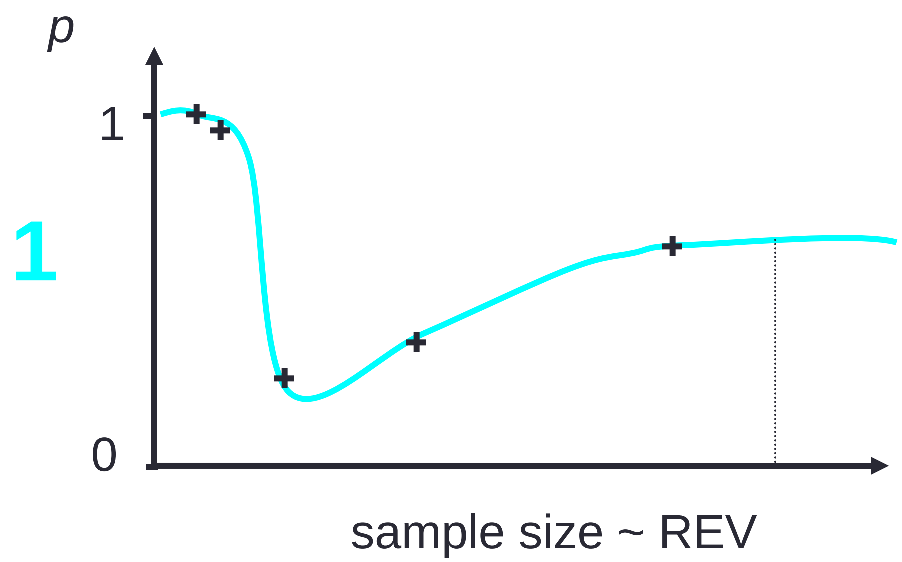



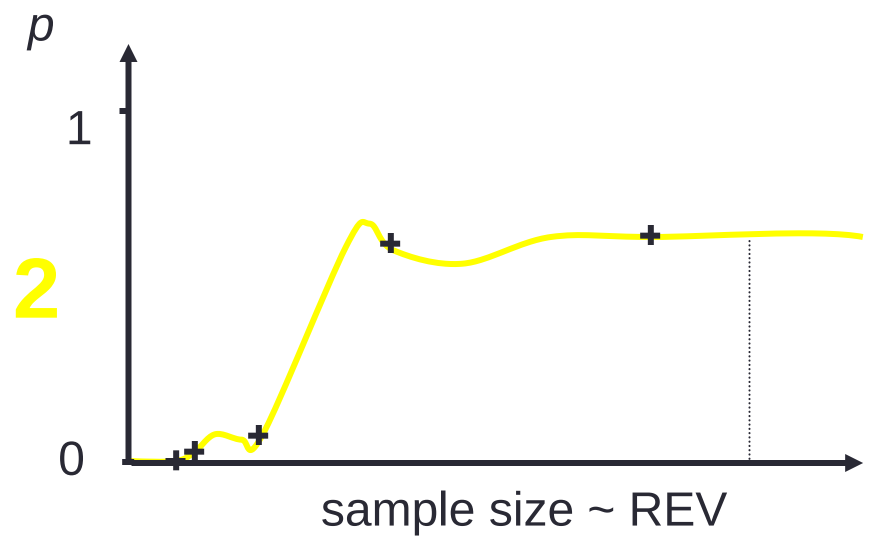



# Representative elementary volume (REV)

**R**EV (**R**epresentative **E**lementary **V**olume) is the smallest volume over which a measurement can be made that will yield a value representative of the whole

REV depends on soil heterogeneity. REV of soils is mostly in range of $10^2 - 10^3$ cm$^3$.



# From microscopic to macroscopic

By averaging through representative elementary (REV) volume where microscopic $P^{mic}$ are transformed to macroscopic $P^{mac}$ (P is any of the properties of the phase (density, porosity…)
REV – is a volume in orders of magnitude higher than characteristic pore size and orders of magnitude smaller then area of interest

Averaging at entire REV:

$$\overline{P}_{\alpha}^{mac} = \frac{1}{V}\int_{V} P_{\alpha}^{mic} dV$$

Averaging at part of the volume with phase α:

$$P_{\alpha}^{mac} = \frac{1}{V_{\alpha}}\int_{V_{\alpha}} P_{\alpha}^{mic} dV$$

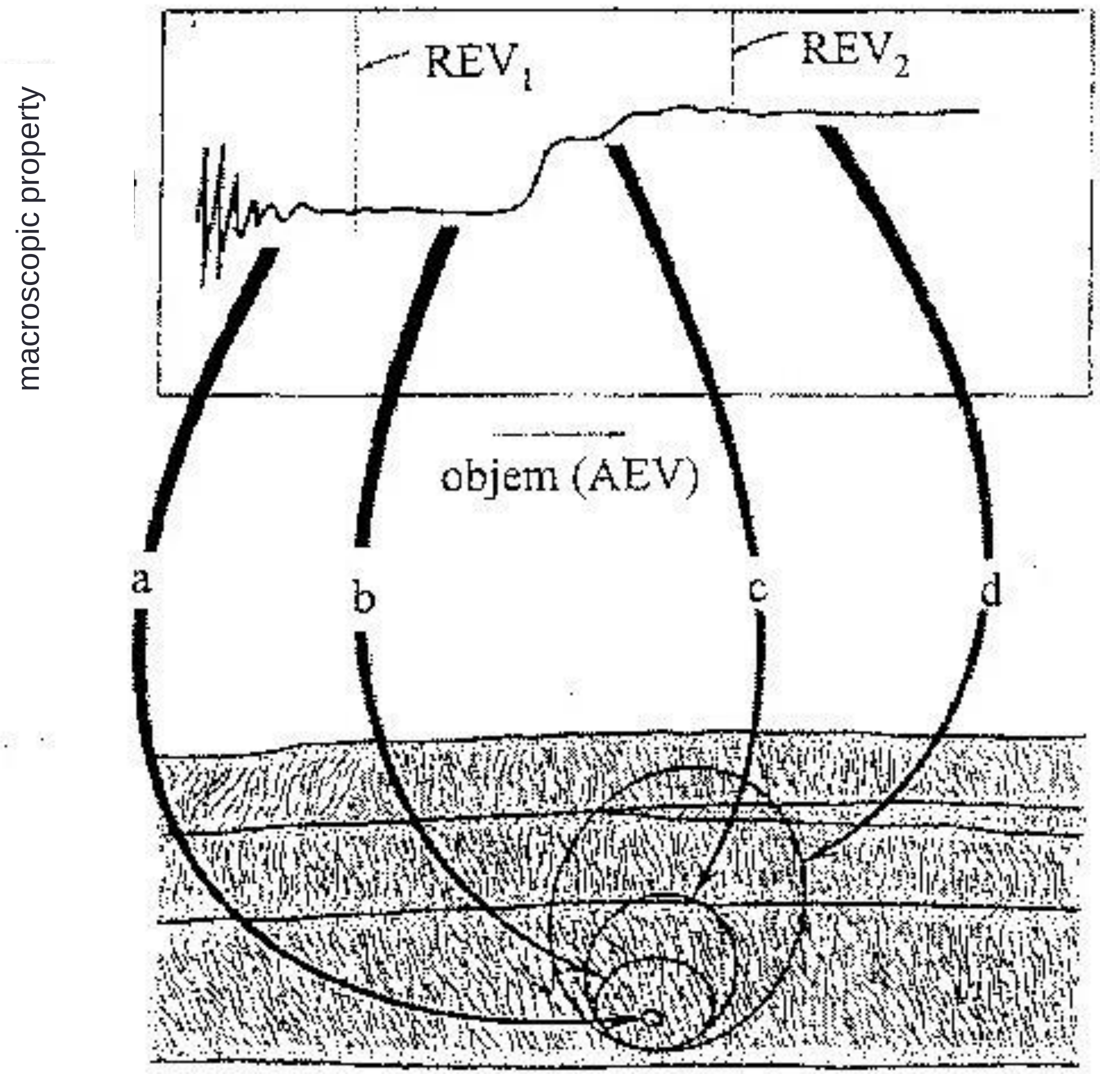
Relation of those above

where $$\varepsilon_{\alpha} = \frac{V_{\alpha}}{V}$$

Is volumetric ratio of phase α

Value of macroscopic property is assigned at center of REV. Running REV throughthe area of interest, continuous field of P values is obtained

# Macroscopically heterogeneous environment



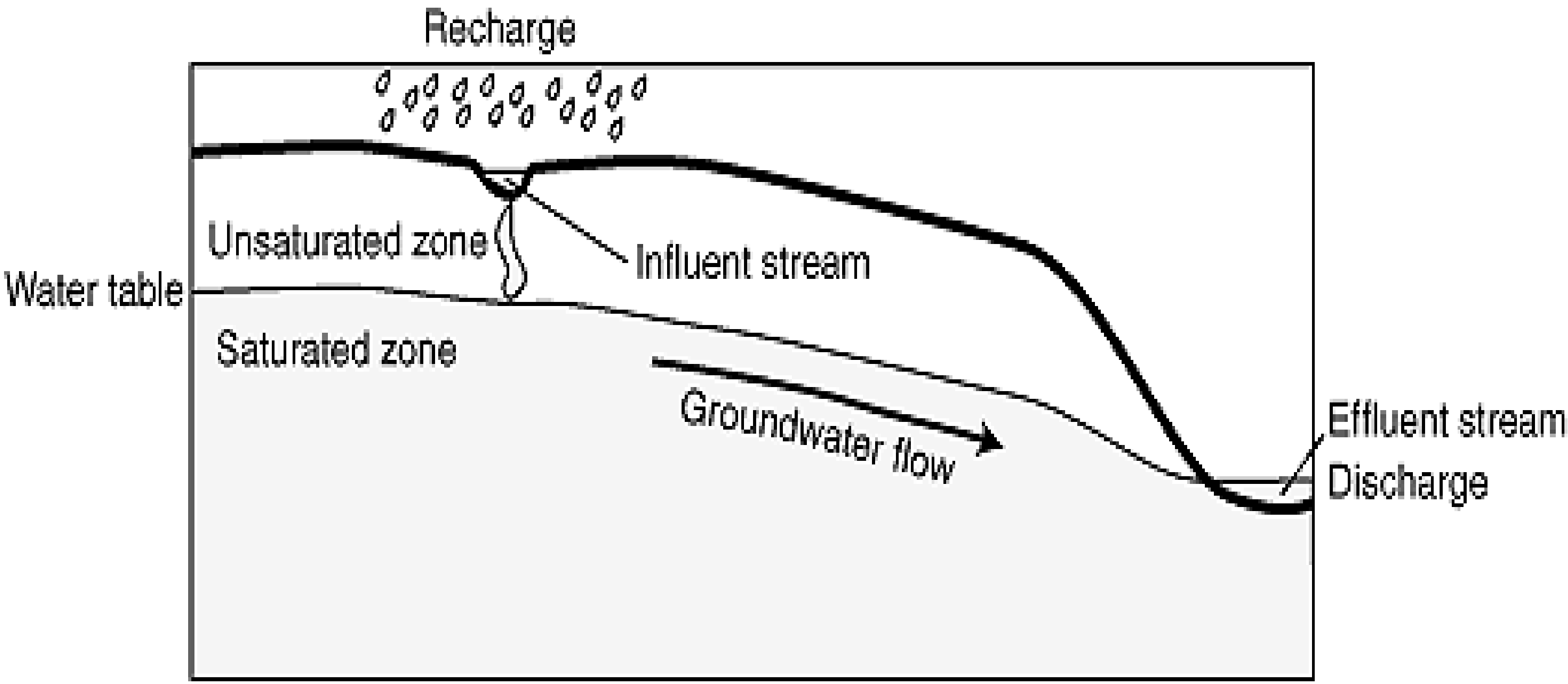

a – at individual pores
b – in one layer
c – at layers interface
d – set of layers

Císlerová, Vogel 1997

# Fundaments for groundwater movement

Groundwater movement as part of the hydrological cycle occurs from areas of natural or artificial infiltration (recharge) of water to areas of natural or artificial discharge (stream or pumping well). While moving, groundwater overcomes resistance of the environment – inner friction of water and friction of water on grains, resulting in loss of mechanical energy of flowing water. **Ability of water to move in porous medium is determined by its mechanical energy.**

**Potential of the liquid is a measure of this ability**



# Fundaments for groundwater movement

Flow potential = mechanical energy of water weight unit
in saturated flow in porous media consist of two parts
gravity and pressure potential

Gravity potential is defined as energy necessary to move
the weight unit of water from the zero level to level z

$$\psi_1 = g\,z$$

Pressure potential is defined ad energy necessary to increase pressure
From $p_0$ na p:

$$\psi_2 = \int_{p_0}^{p} \frac{dp}{\rho}$$

Gravity and pressure
potential combined

$$\Phi = g\,z + \int_{p_0}^{p} \frac{d\,p}{\rho}$$

# Fundaments for groundwater movement

Flow potential for incompressible fluid (ρ=const.):

$$\Phi = g\,z + \frac{p - p_0}{\rho}$$

Water pressure is typically assigned at zero level equal to atmospheric pressure $p_0$, then

flow potential is defined as

$$\Phi = g\,z + \frac{p}{\rho}$$

Water flow in between two points in porous space occurs in case of different potentials of water and simultaneously, there is continuous passage permeable for water. Water moves from level of higher to lower potential.

Groundwater hydraulics typically describes potential as hydraulic head H

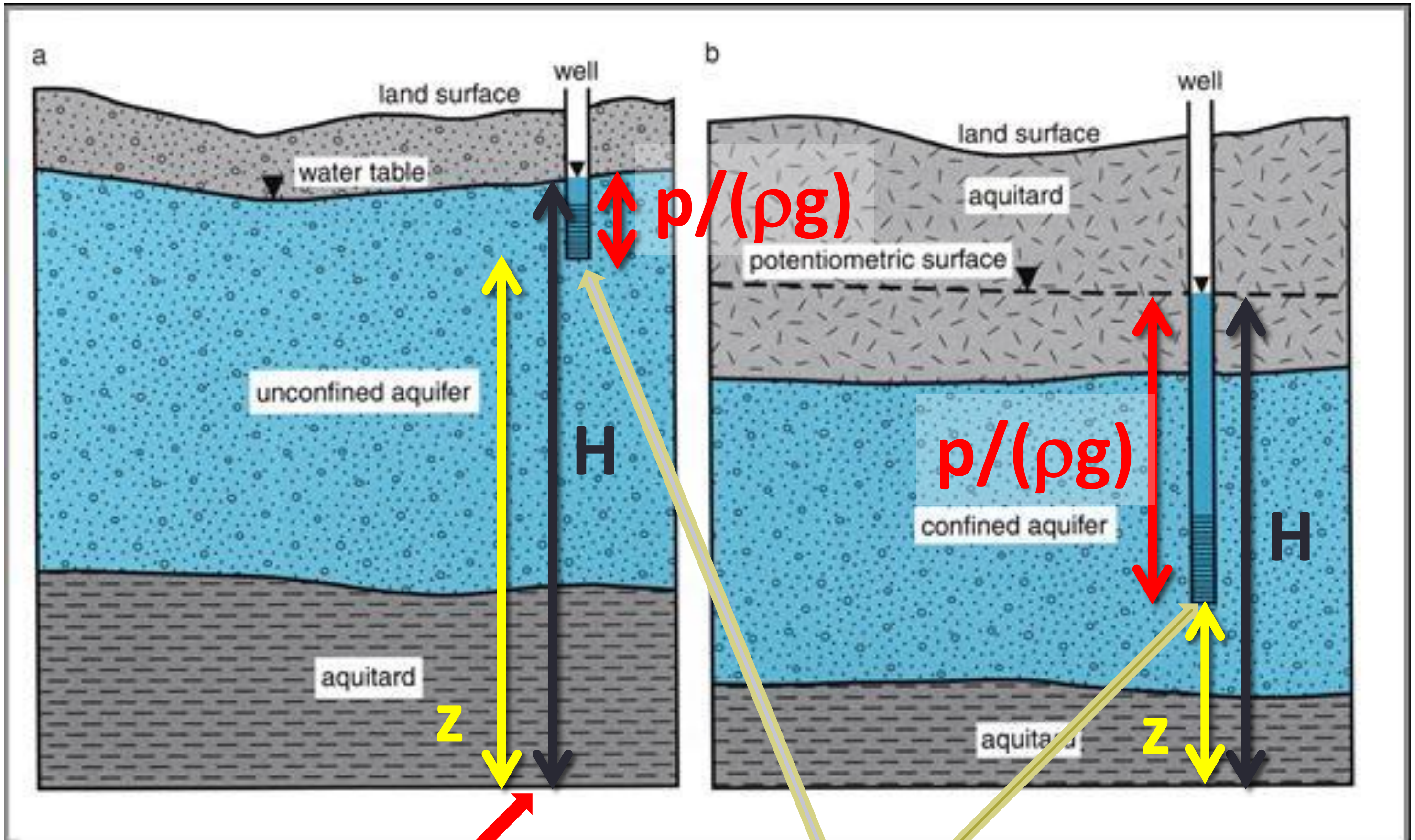
$$H = \frac{\Phi}{g} \qquad H = z + \frac{p}{\rho\, g}$$

$$p = h_p\, \rho\, g \quad ,$$

Hydraulic head is summation of geodetic and pressure head

# Measurement of hydraulic head – piezometer

**free head** **pressurized head**

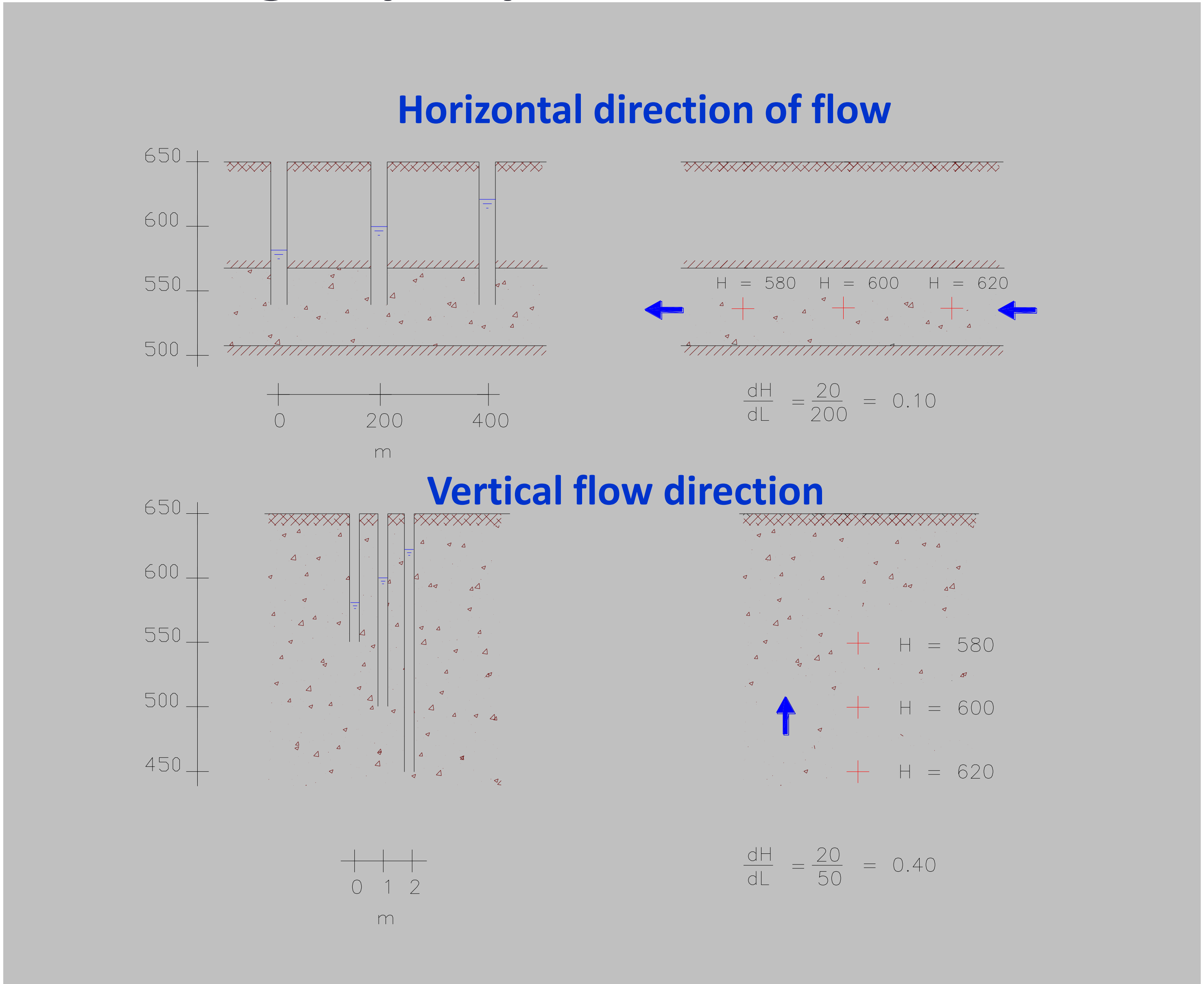



datum z=0

measured point

$$H = \frac{\Phi}{g} \qquad H = z + \frac{p}{\rho g}$$

# Determination of groundwater flow direction based on group of piezometers



# Groundwater levels and water flow description

Free (phreatic) groundwater surface  map of  hydroisohypse

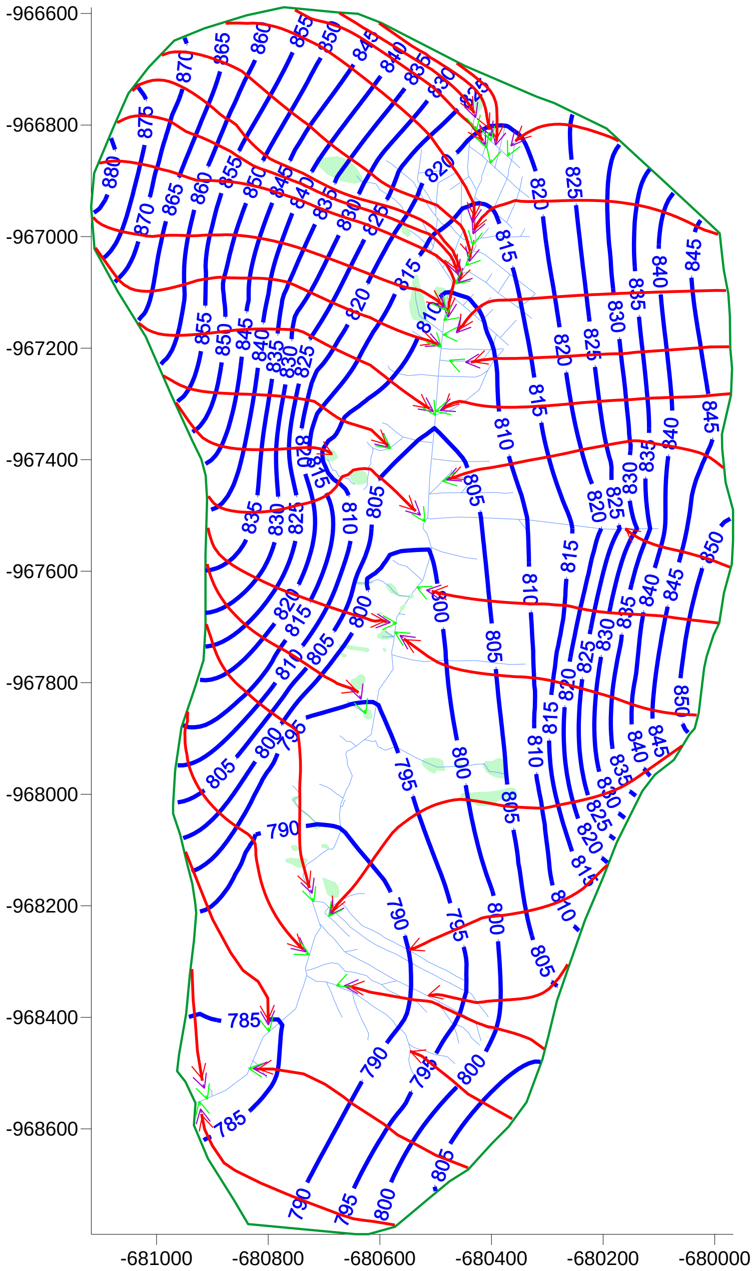
HYDROIZOHYPSE = connects points of the same level of free groundwater at the same time

Pressurized (confined) aquifer - map of piezometric heads

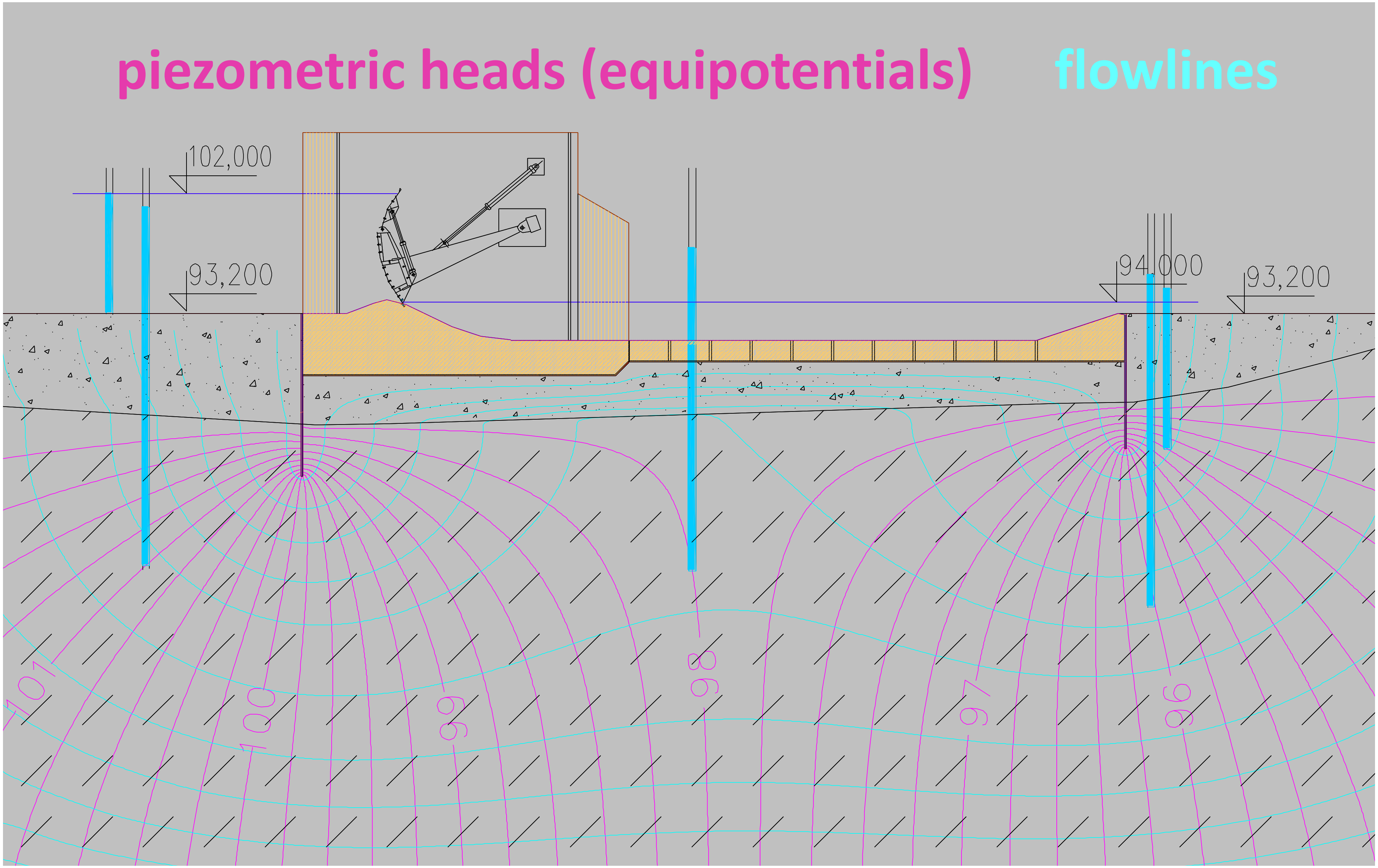
Piezometric surface connects points of the same level of piezometric  level of groundwater at the same time

Trajectory - map of travel directions of groundwater considering flow time history

(for assumption of steady state flow perpendicular to piezometric heads)



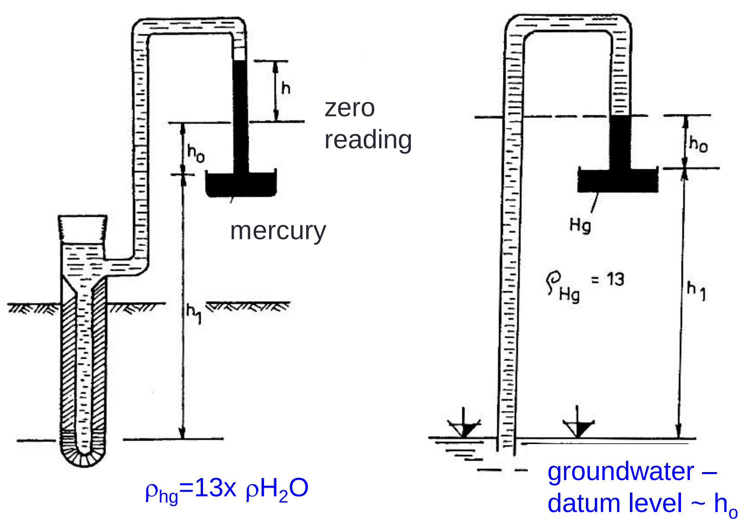
# Groundwater under river construction (segment weir)



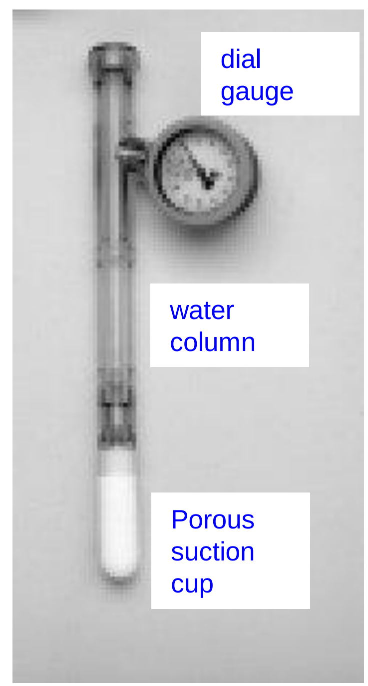

Valentová

# Capillary potential – pressure in vadose zone

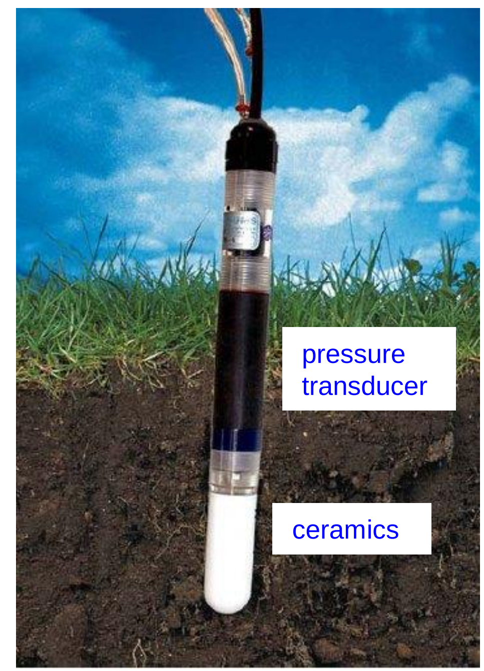
Thin tube inserted in the soil. Capillary potential sampled in the porous suction cup, but measured at the gauge above it with linear increase of suction Pressure head can be referenced at the surface. Generally total potential (in pressure head) equals to $H = p/(\rho g) - z$. ($h = p/(\rho g)$ : capillary, $z$: vertical distance)




tensiometer with mercury manometers




dial gauge




transducer

**For details see Soil physics and soil science course**

# Groundwater vocabulary

## Hydrogeological structure

**Structurally and geologically defined environment, where infiltration, accumulation and drainage of groundwater occurs**

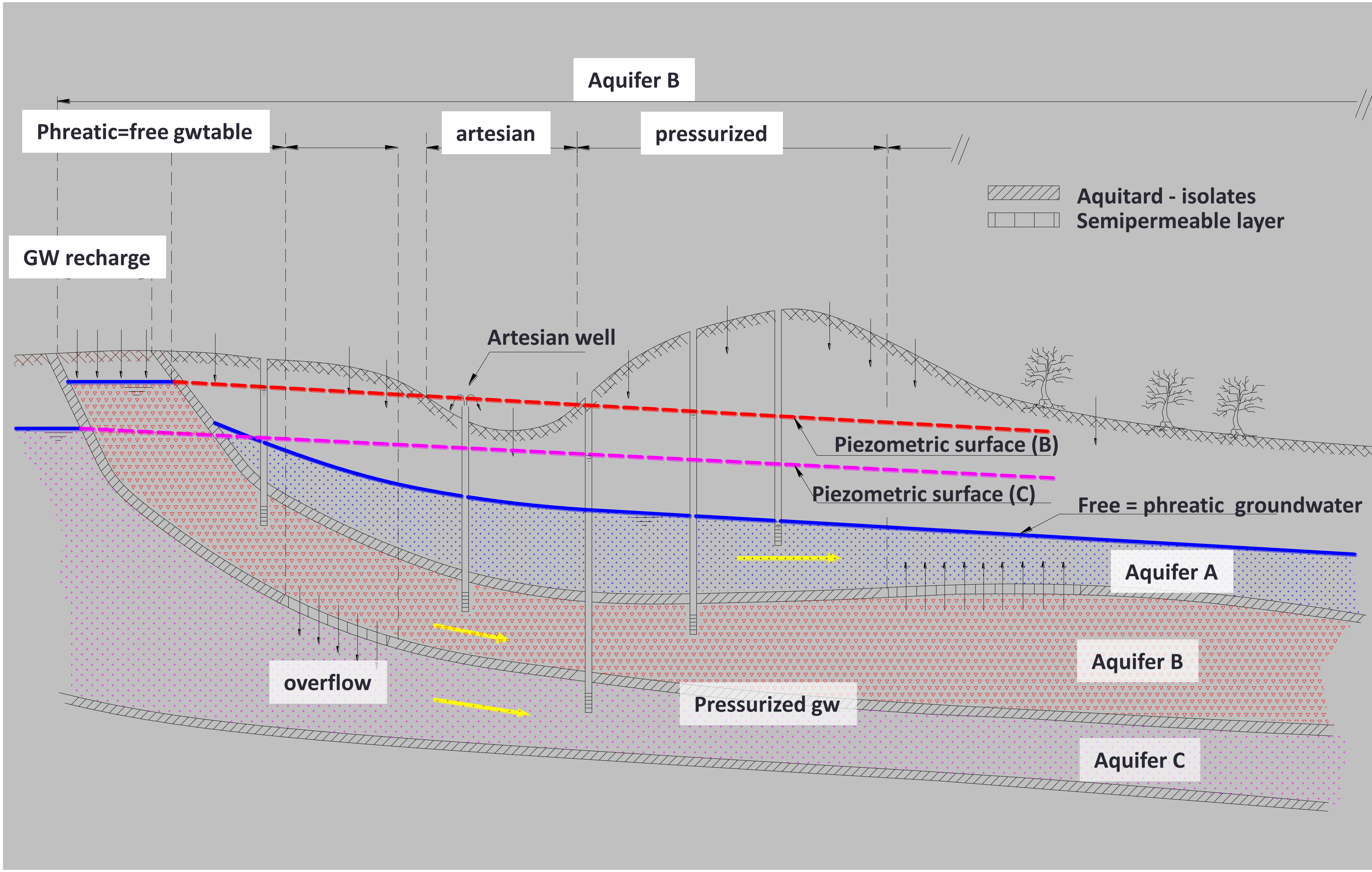
## Aquifer

**Geological body, with permeability for water significantly higher than surrounding environment, enabling gravity water to move much more freely under same hydraulic (pressure) conditions**

## Aquitard

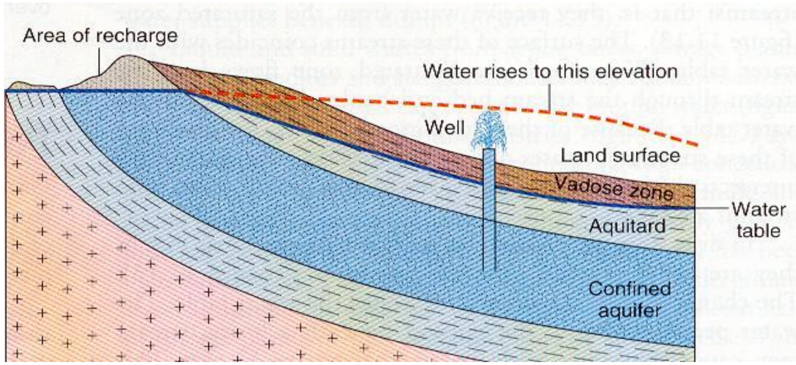
**Geological body, with permeability for water significantly lower than surrounding environment, non-enabling gravity water to move, or enabling to move much worse under same hydraulic (pressure) conditions**

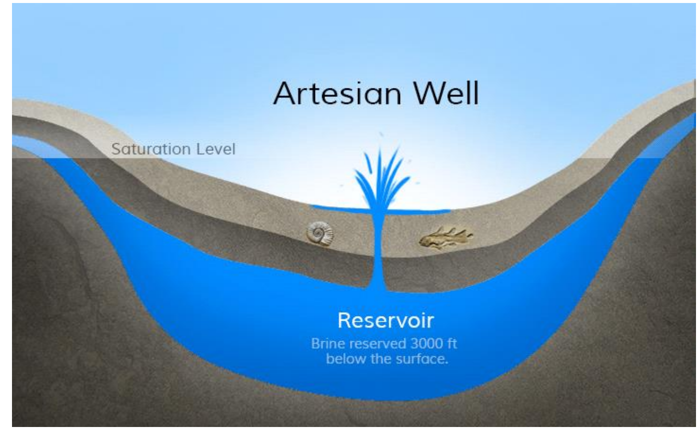
# Types of aquifers



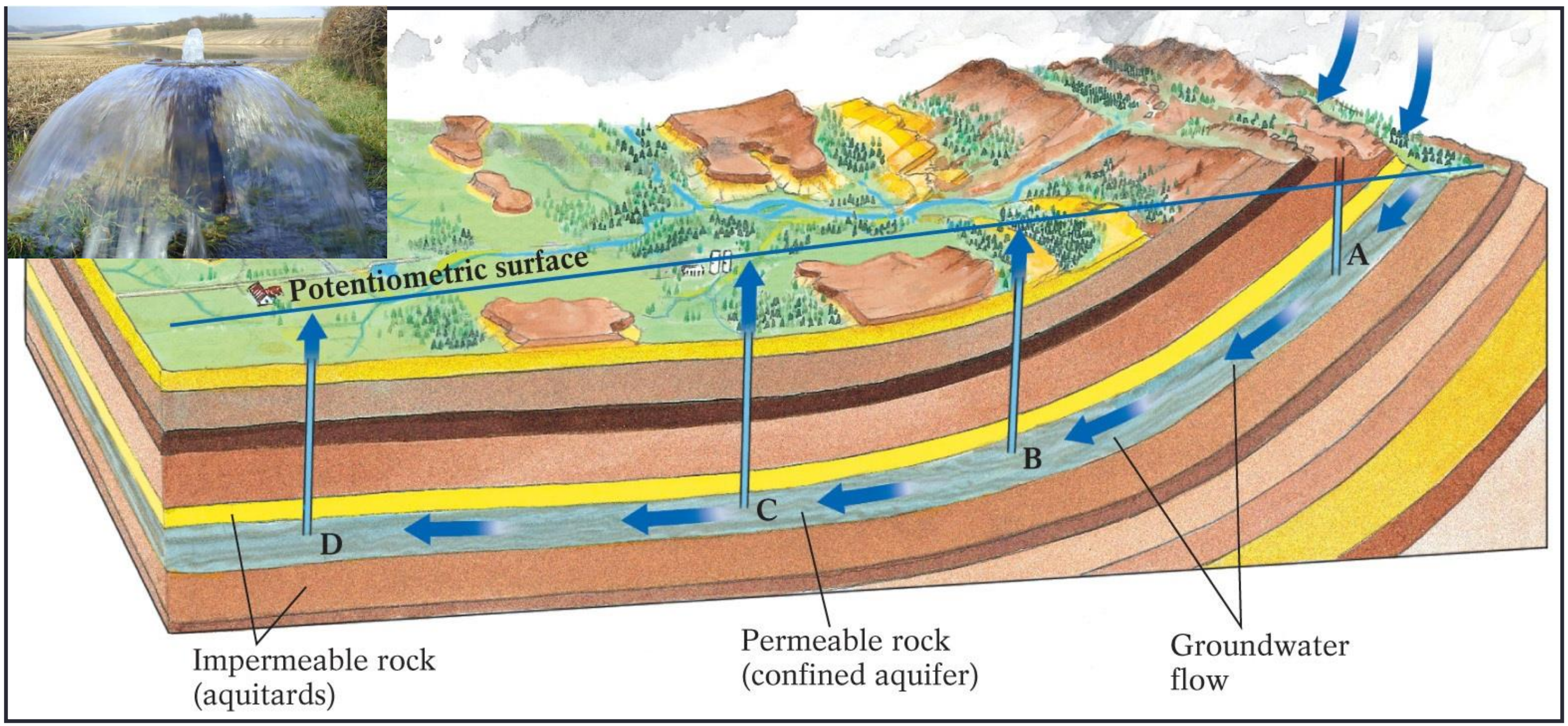

Designed by J. Valentová

# Artesian aquifer



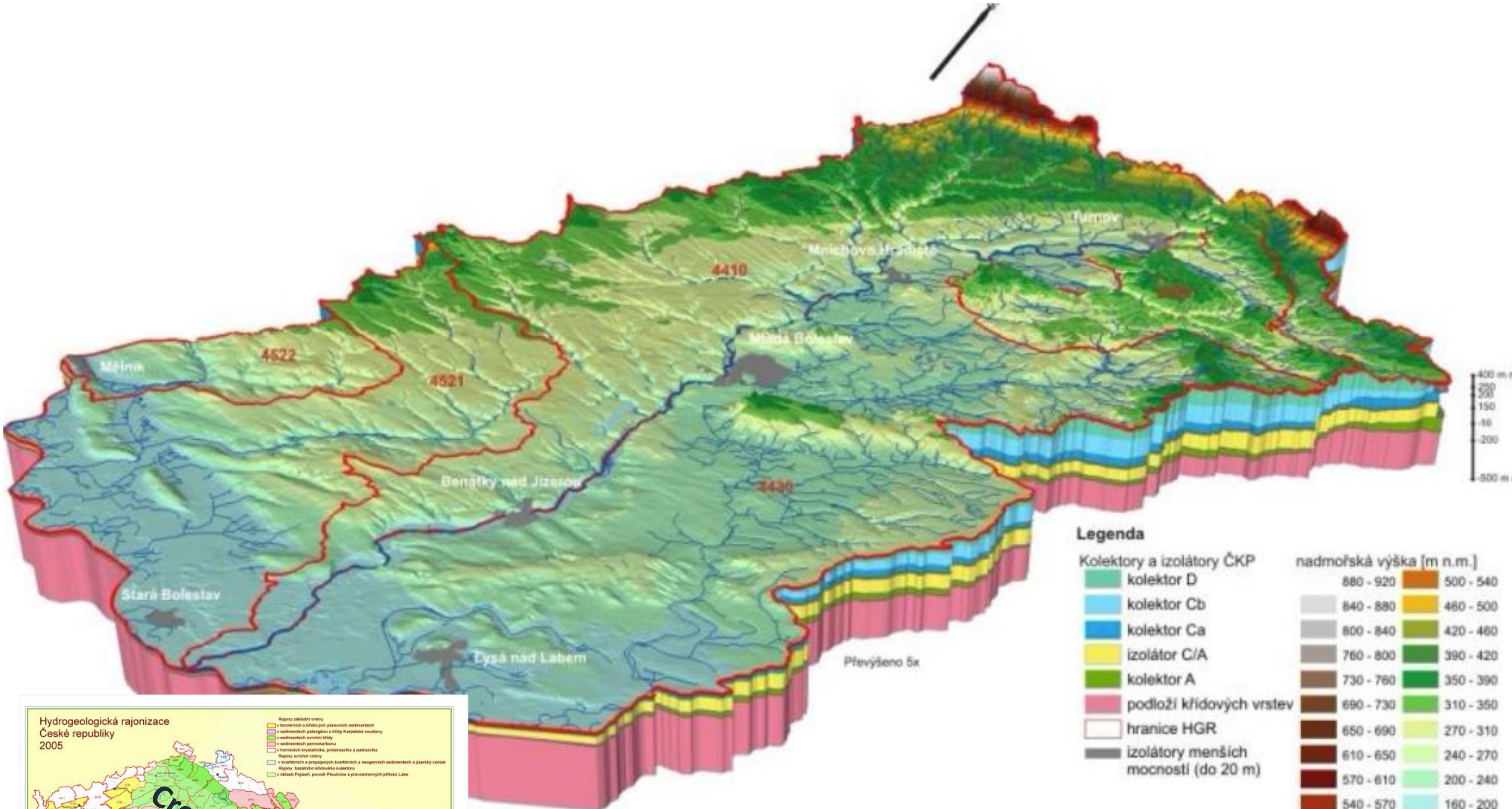




<u>Potentiometric surface</u>: Level to which over-pressured water will rise



# Hydrogeological structures of CZ

# Detail of Jizera river aquifers in Cretaceous basin

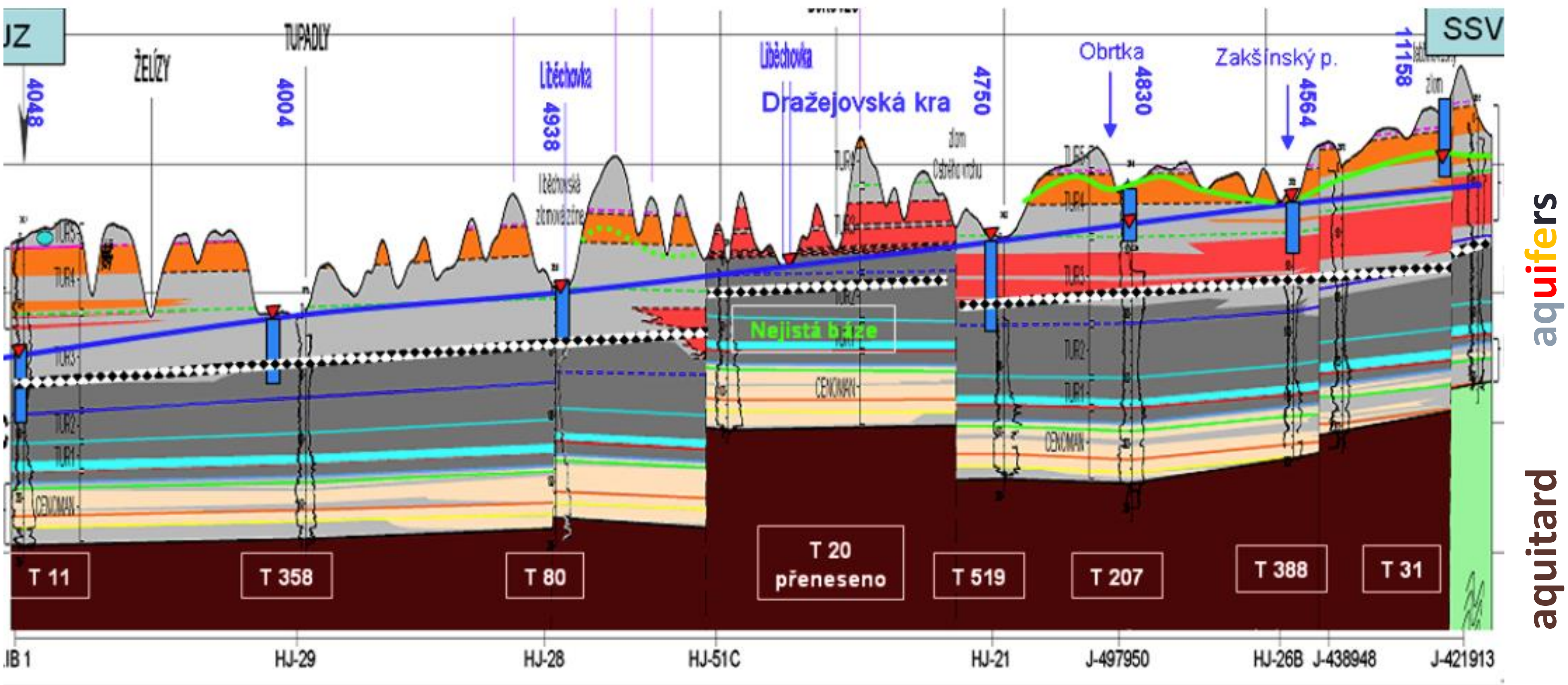




**Kolektor in CZ=aquifer**
**Izolátor in CZ=aquitard**

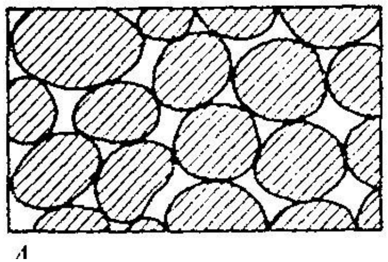
# Cross-section of hydrogeological structure of upper Cretacesous basin in CZ, area of Kokořín

surface streams

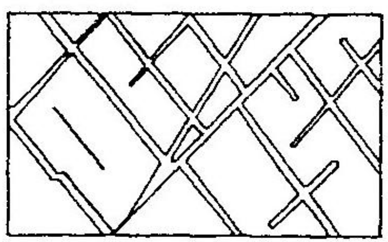



monitoring wells

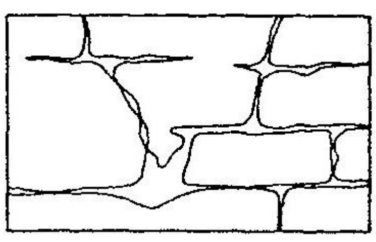
# Types of permeability in aquifers (rock materials)



**Matrix** permeability
Clastic sediments free or fortified (connected)



**Fractures and fissures** permeability
Igneou srocks



**Karstic** permeability
Soluble rocks – limestones, dolomites or lava channels

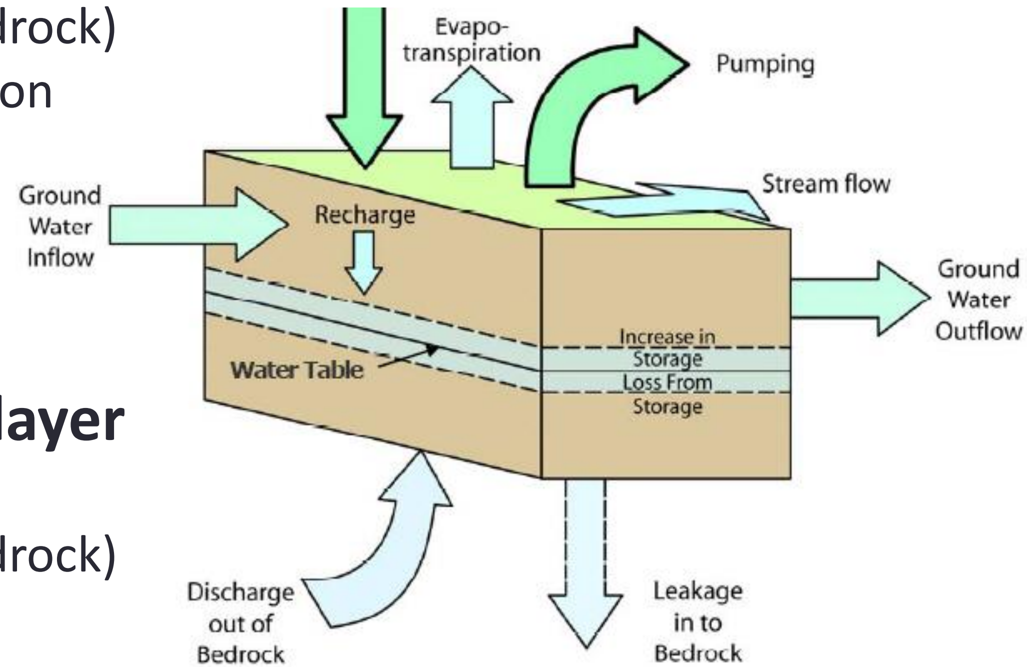
# Water balance

**Sum of inflow – sum of outflow = change of volume in aquifer**

Time frame for the inflows, outflow and change

## Inflows to water bearing layer

Across horizontal boundaries
Between aquifers (or fractured bedrock)
Natural infiltration from precipitation
Returned water from irrigation
Artificial inflow
Lake and river discharge




## Outflows to water bearing layer

Across horizontal boundaries
Between aquifers (or fractured bedrock)
Pumping, drainage
Seepage to rivers and lakes
Springs
Evapotranspiration

**Magnitude of natural surplus of water to the aquifer relies on**

Type of precipitation (water, snow, drizzle, storm, long light rain....)
Climate conditions (dry, wet, cold, hot)
Antecedent soil moisture
Topography
Vegetation cover

# Infiltration as irrigation loss

20-40% of irrigation amount acc. To type of irrigation (ponding worst, drip best)

Irrigation may activate latent pollution in the subsurface or cause soil salinization

# Artificial inflow

Process of addition of water into the aquifer in space and time, managing water quantity and quality

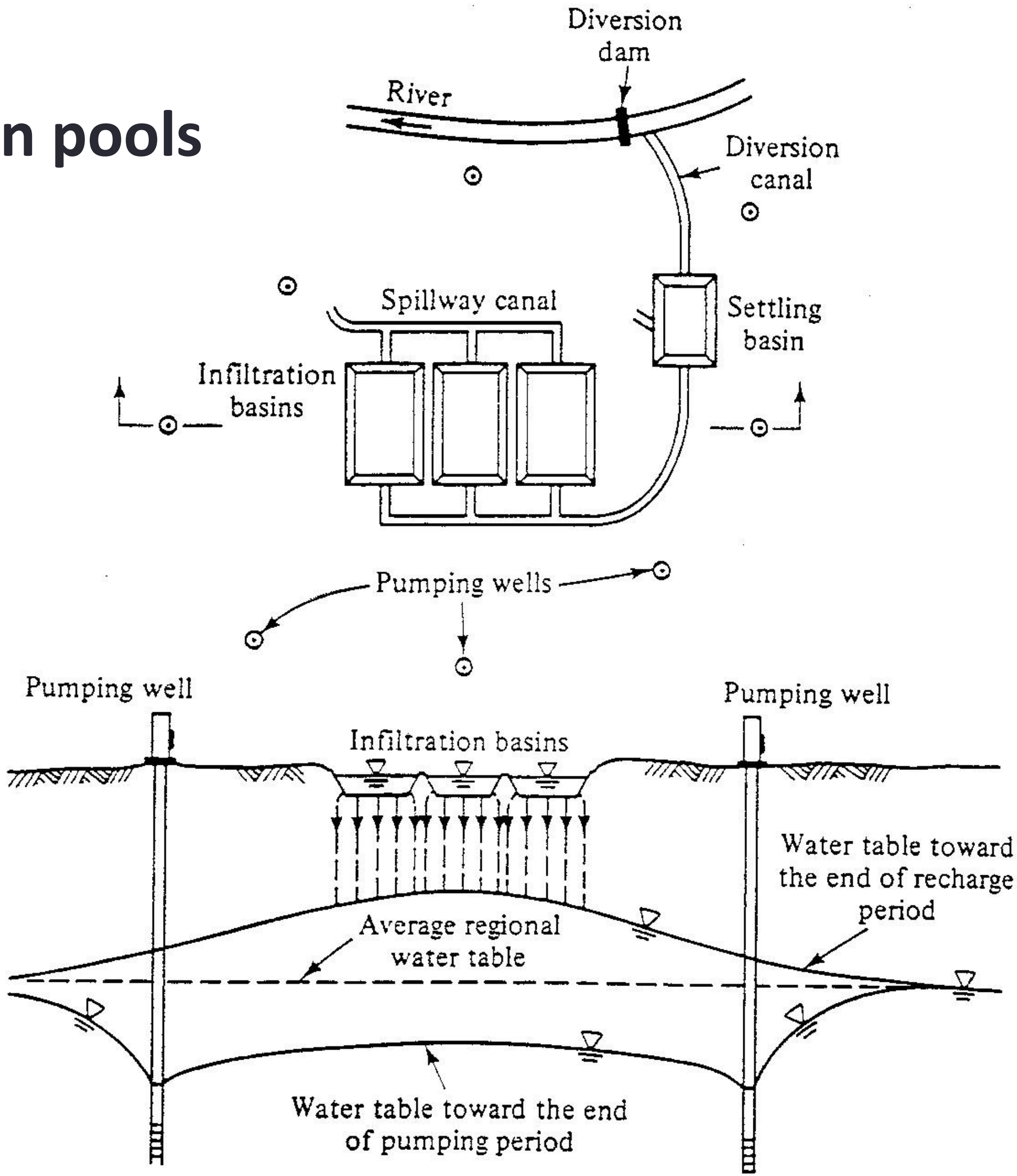
**Aims:**

- Hydrological regime management
- Water storage in porous media reservoirs
- Water quality management

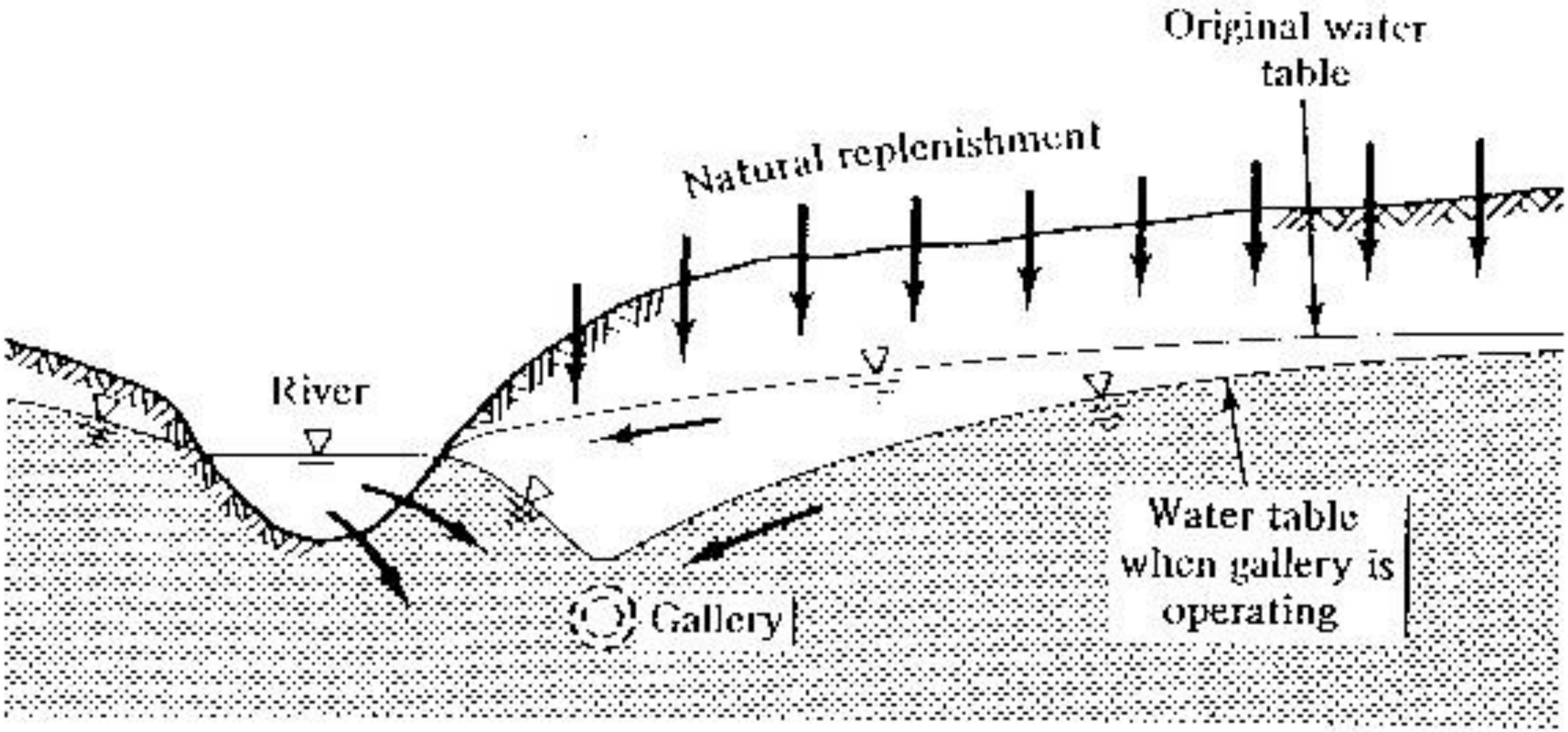
**Methods:**

- Increased infiltration in agriculture, small reservoirs
- Infiltration ponds and infiltration wells
- Induced inflow by horizontal pumping near surface sources (water filtration)

# Infiltration pools

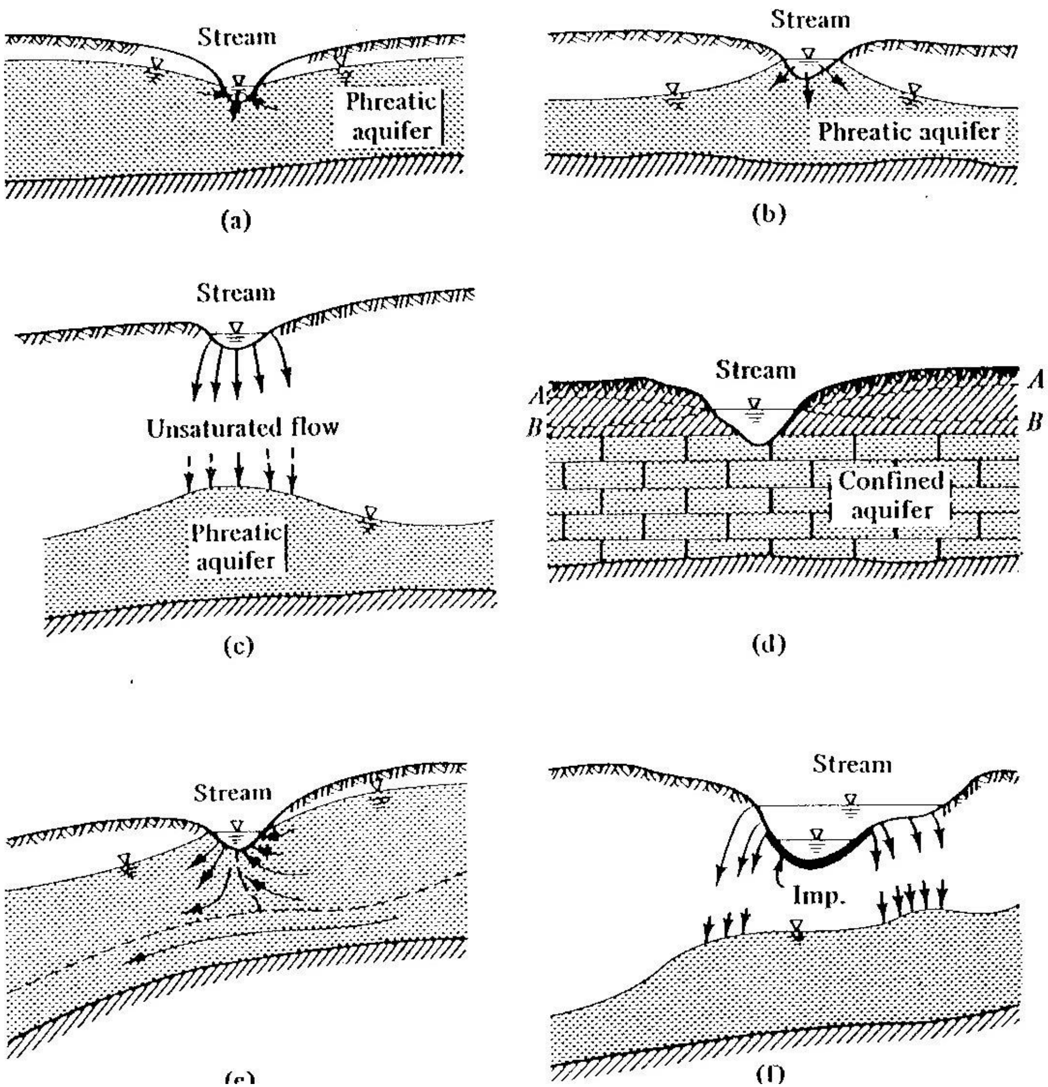


# Increased inflow near collecting gallery



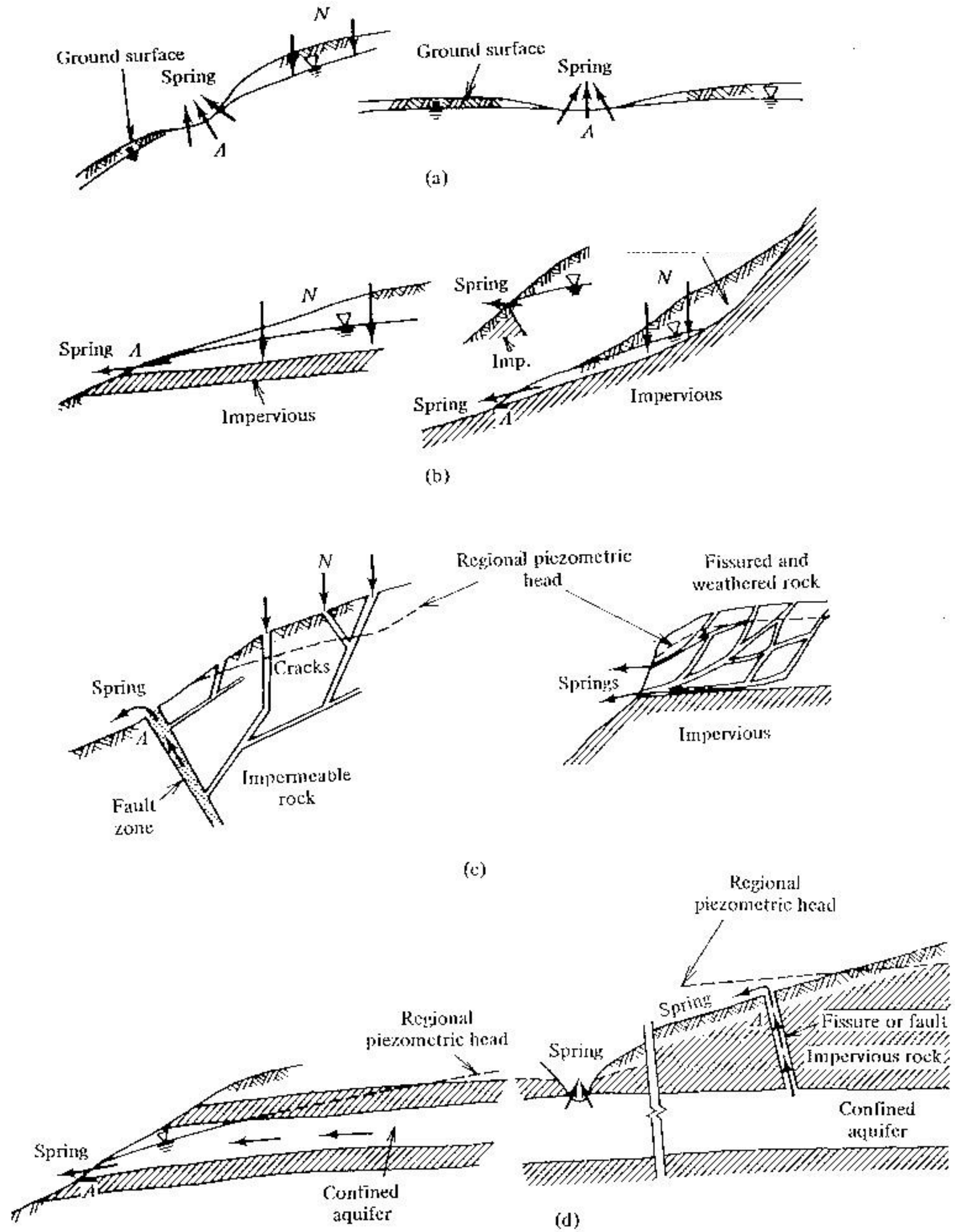
# Interaction between surface water and aquifer

**River can drain or feed groundwater**



# Springs

**Springs with high water yield remarkably influece groundwater flow in surroundings**



## Evapotranspiration

**Evaporation – loss of water from bare soil, open water or snow cover into the atmosphere**

**Transpiration - loss of water from soil by plants into the atmosphere**

**Evapotranspiration – total loss of water by combination of evaporatin and transpiration**

**Potential evapotranspiration – possible when interface (soil surface) is fed by water fully all times**

**Actual evapotranspiration – based on meteorological factors (lower than potential)**

## Pumping and drainage

**Wells (point sink),**
**galleries, open ditches, subsurface drainage (line sink)**

## Change of volume in aquifer

**Free aquifer – increase of water table, confined aquifer – increase of pressure**