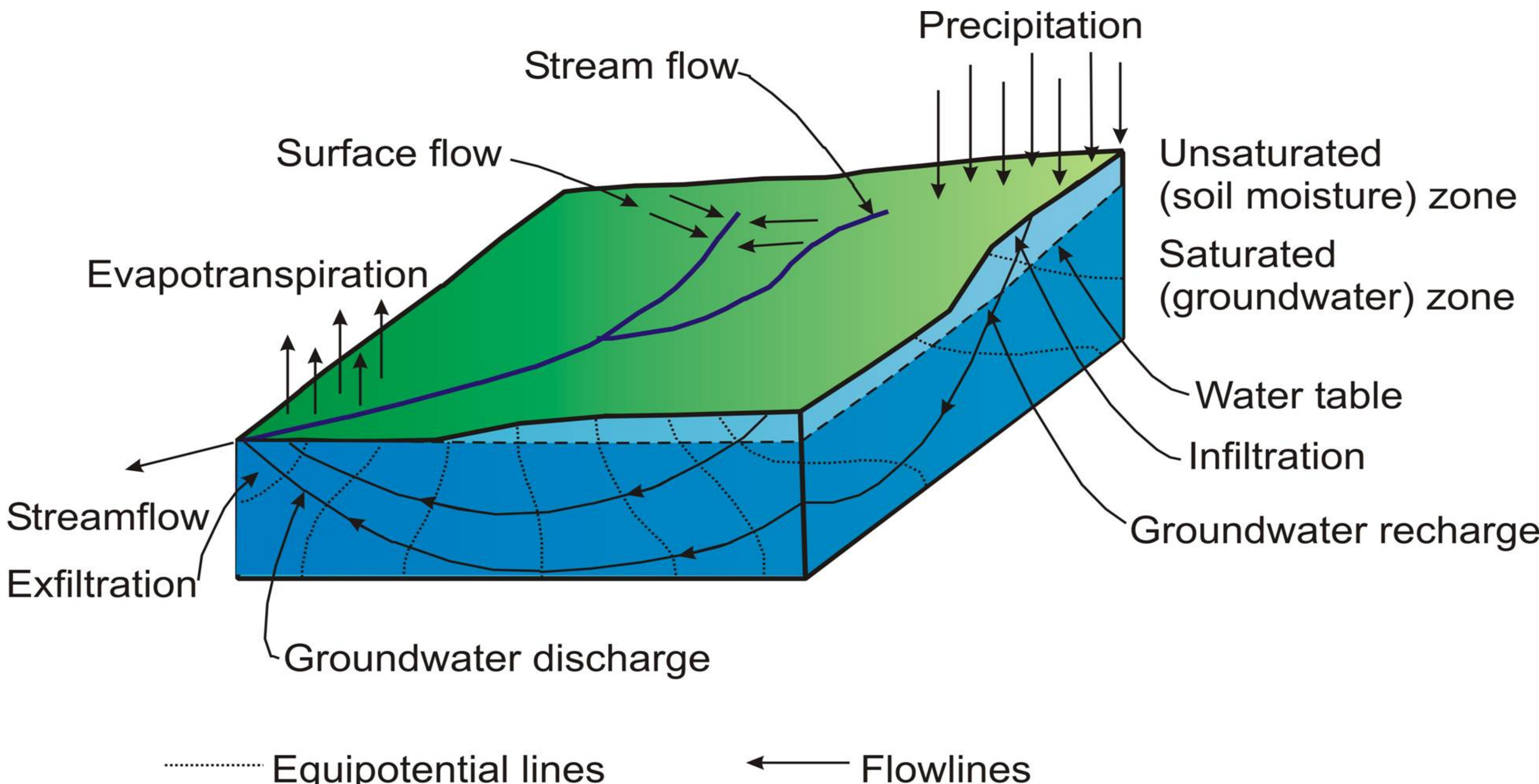
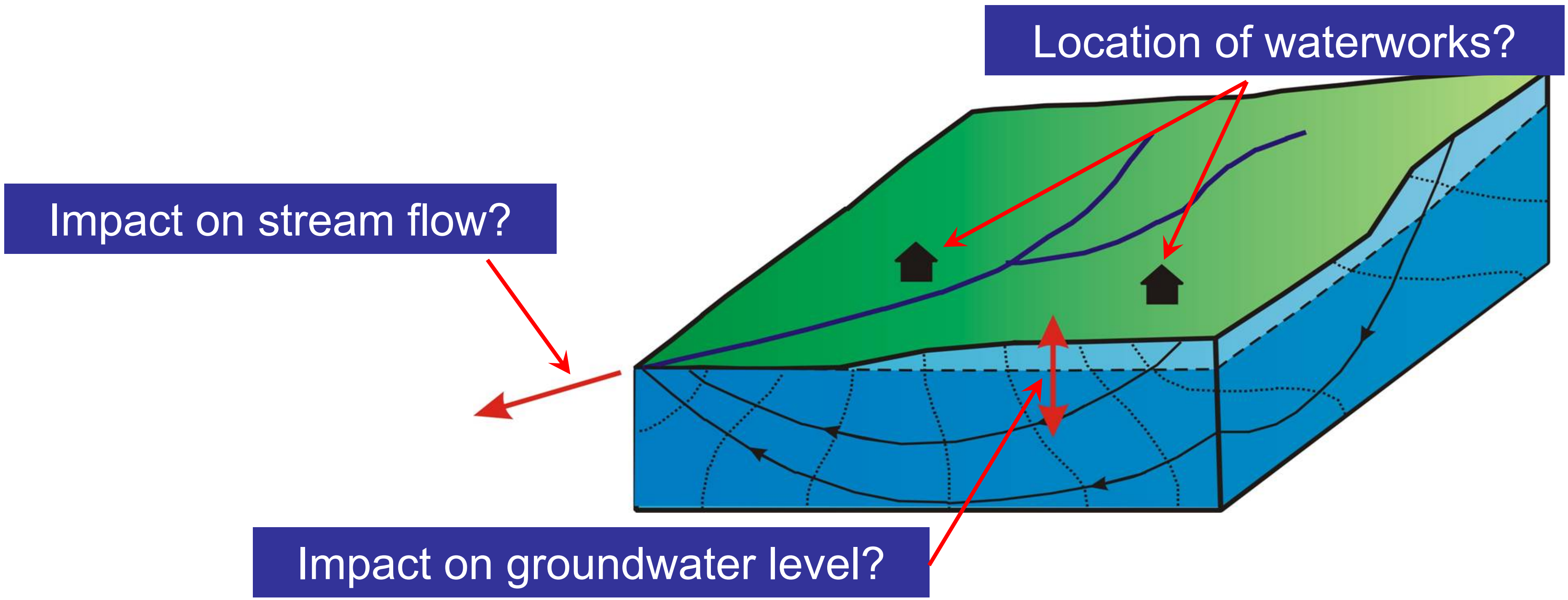
Groundwater modelling



Groundwater modelling - usage

Groundwater resource assessment

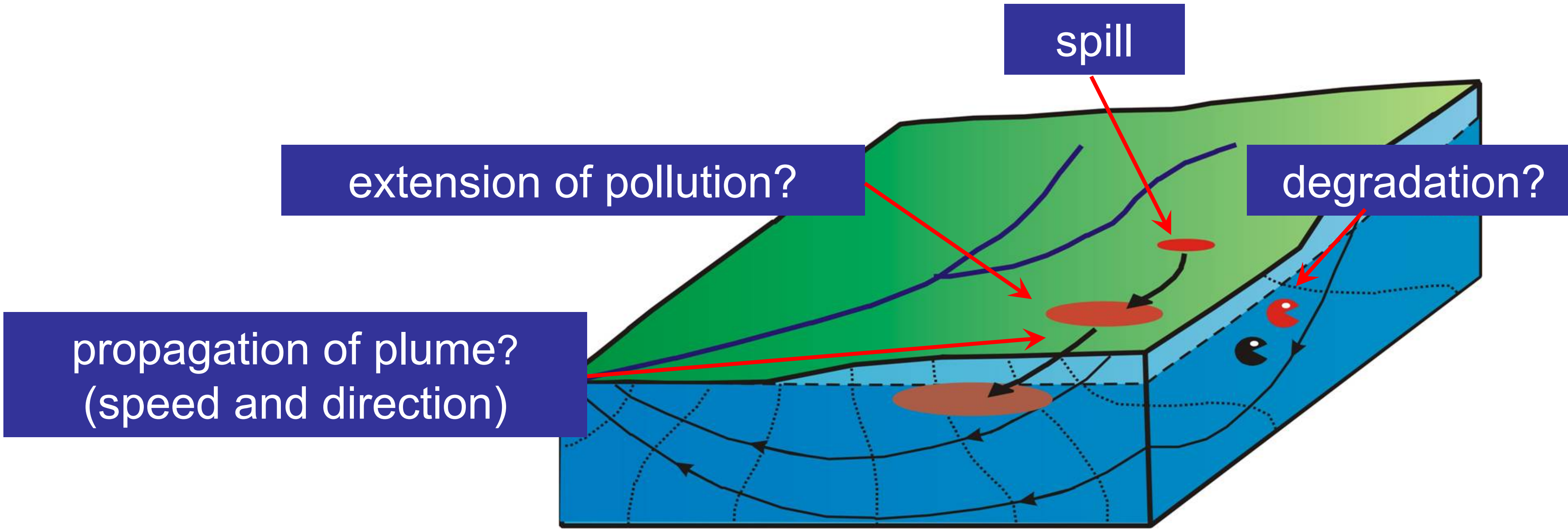
- effect of utilising the groundwater resource.



Groundwater modelling - usage

Groundwater pollution

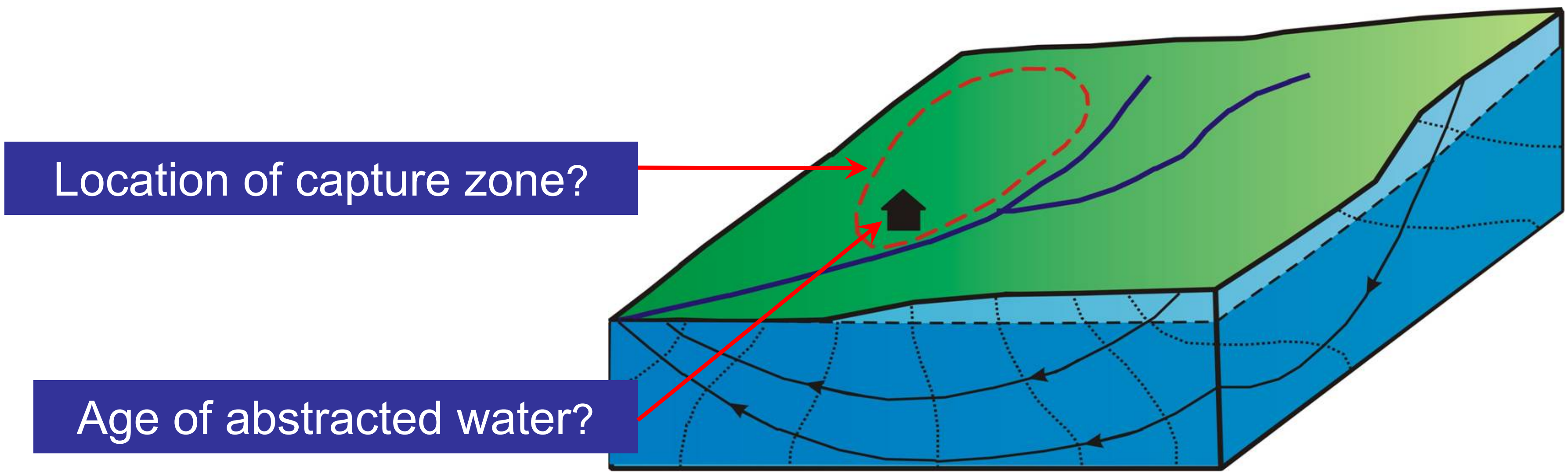
- risk assessment



Groundwater modelling - usage

Well capture zone delineation

- establishment of protection zones

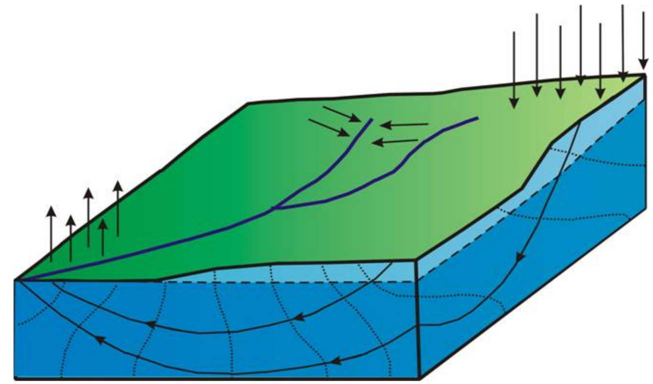


Groundwater modelling

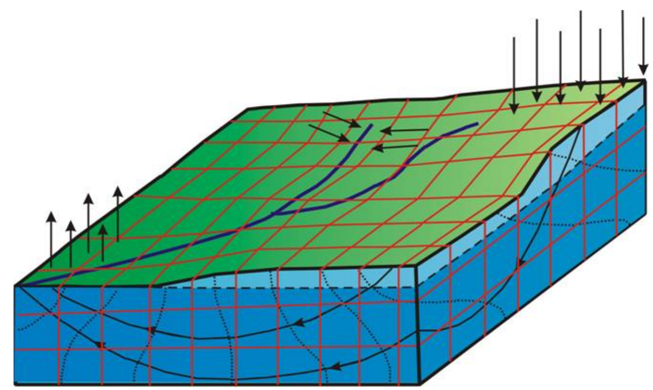
Real world

Conceptual model

- Hydrological processes
- Geology (layers and lenses)
- Boundary conditions
- Etc.



Numerical formulation



Set of equations

$$\mathbf{A}\psi^n = \mathbf{b}$$

Examples

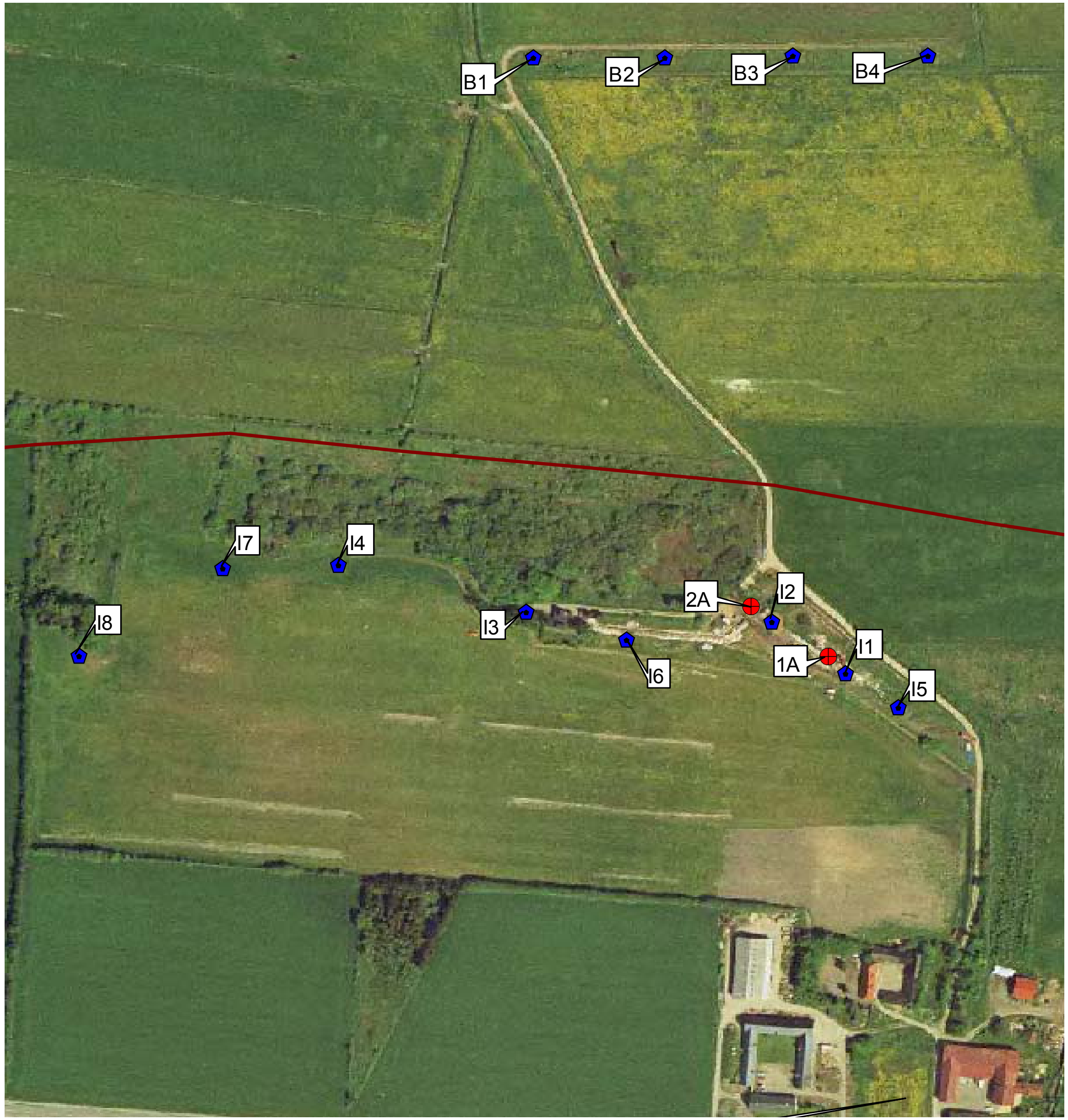
Drastrup

Volsted

Tornby

Rørdal

Drastrup well field (Aalborg water supply)



Tegnforklaring

Boringer

Indvindingsboring

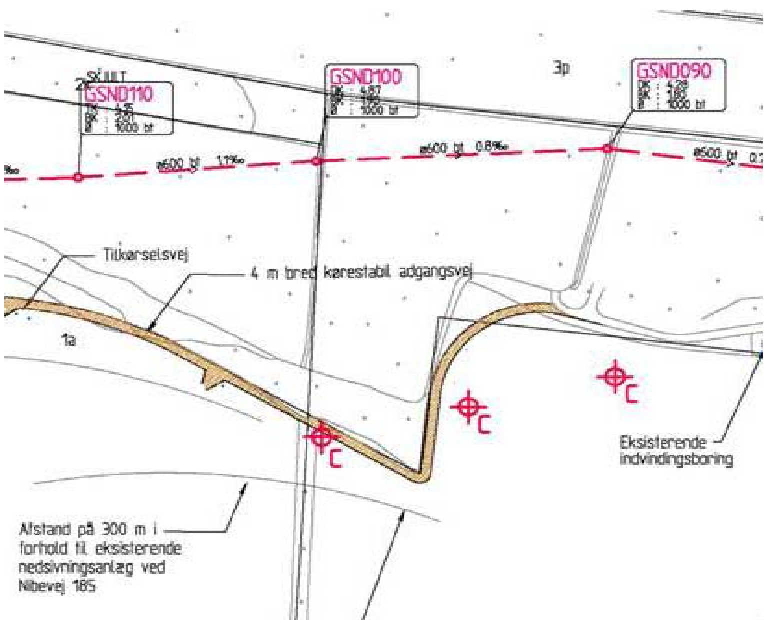
Afværgeboring

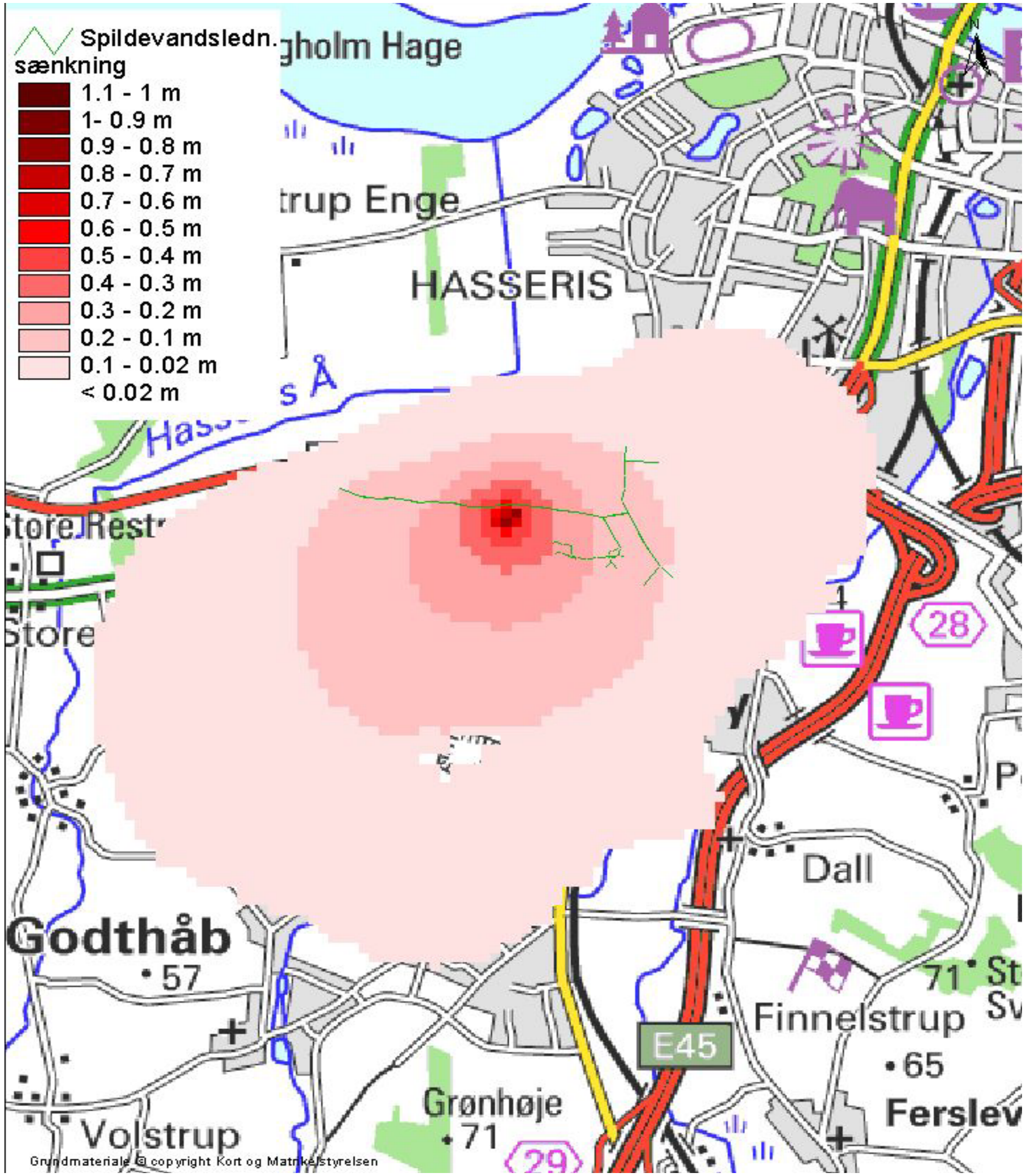
Spildevandsledning

Afskærende ledning

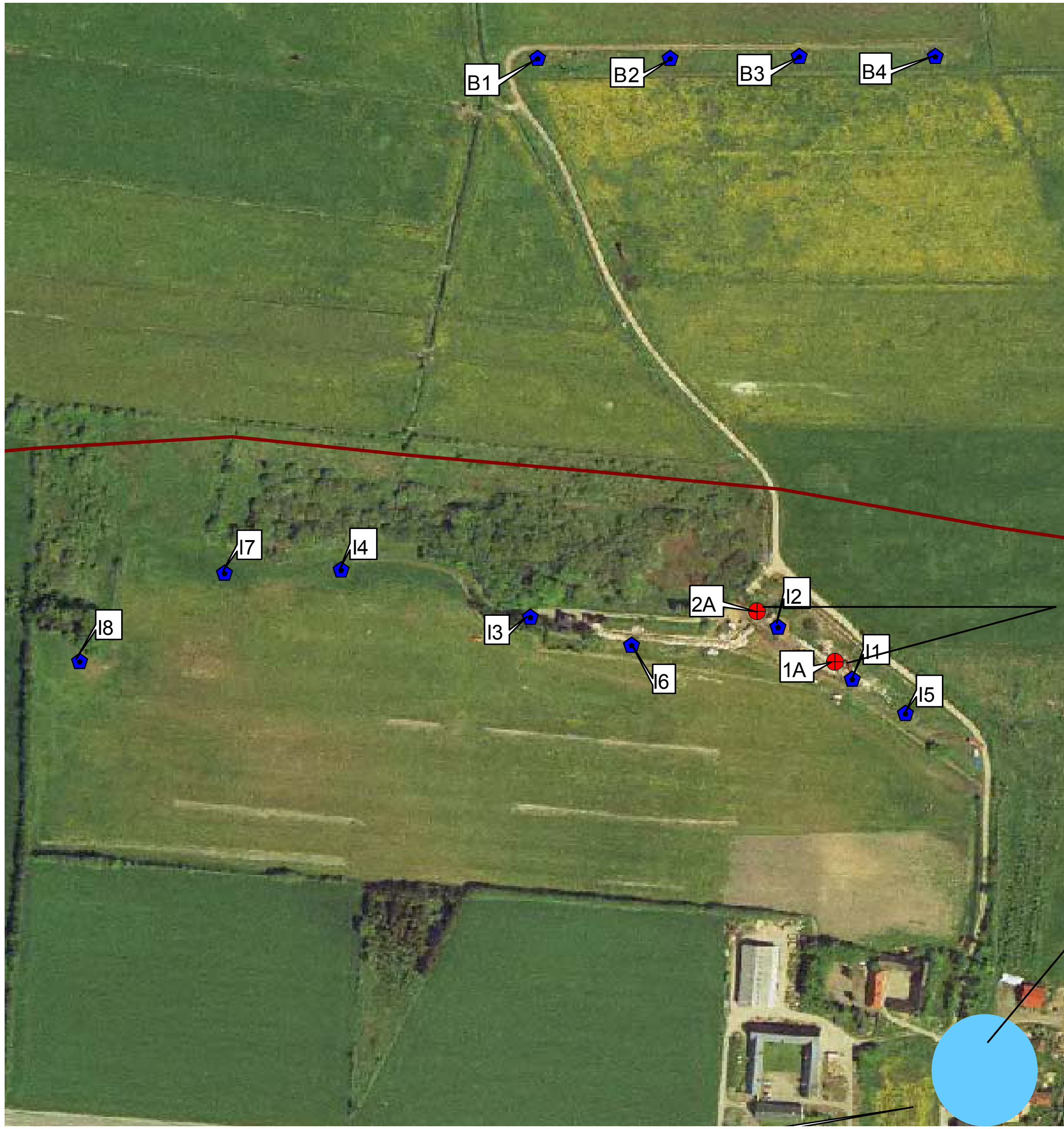
Extension of Drastrup well field

Drawdown due to extension





Pesticide contamination



Pump and treat wells

Pollution

Tegnforklaring

Boringer

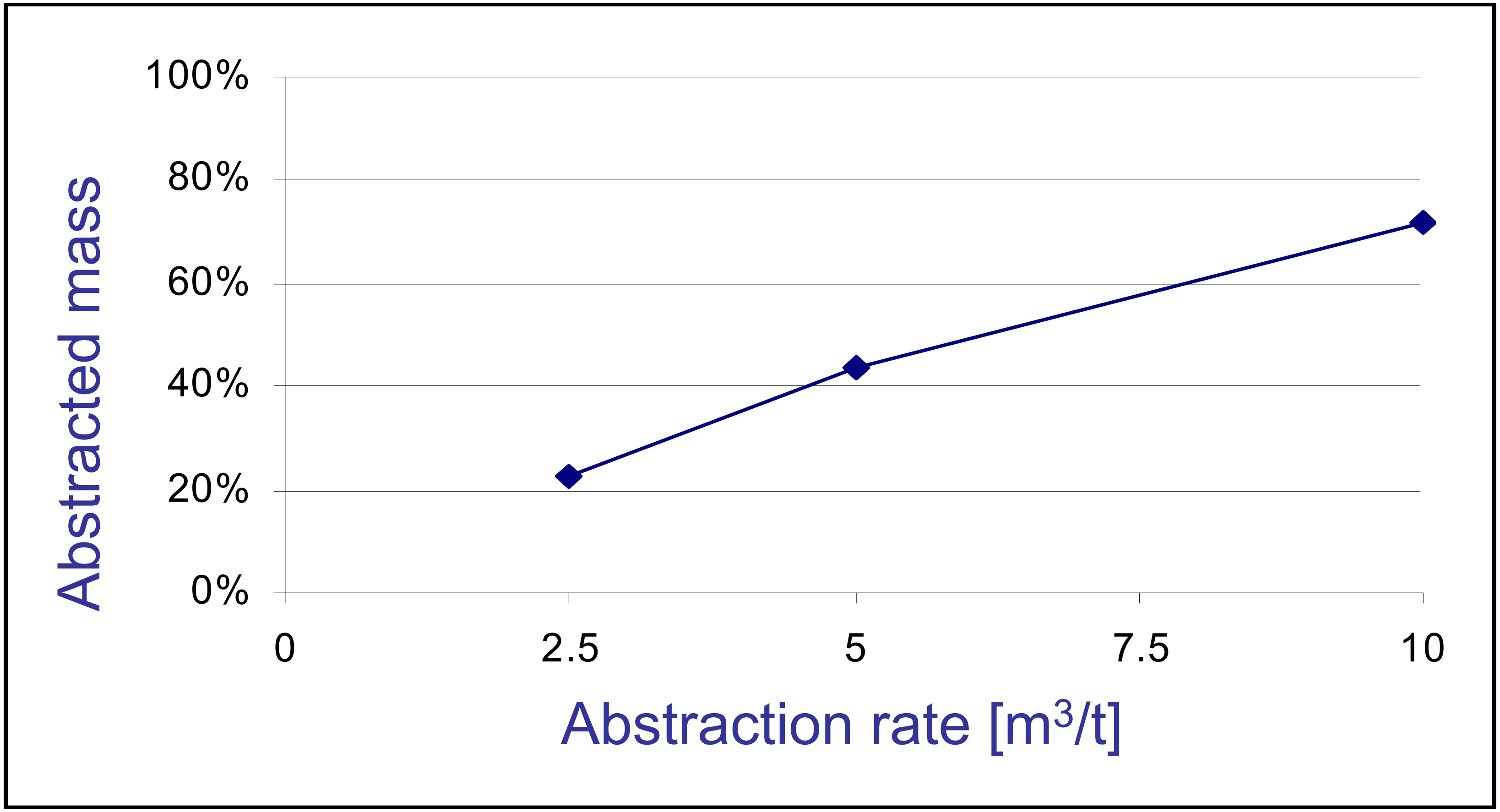
Indvindingsboring

Afværgeboring

Spildevandsledning

Afskærende ledning

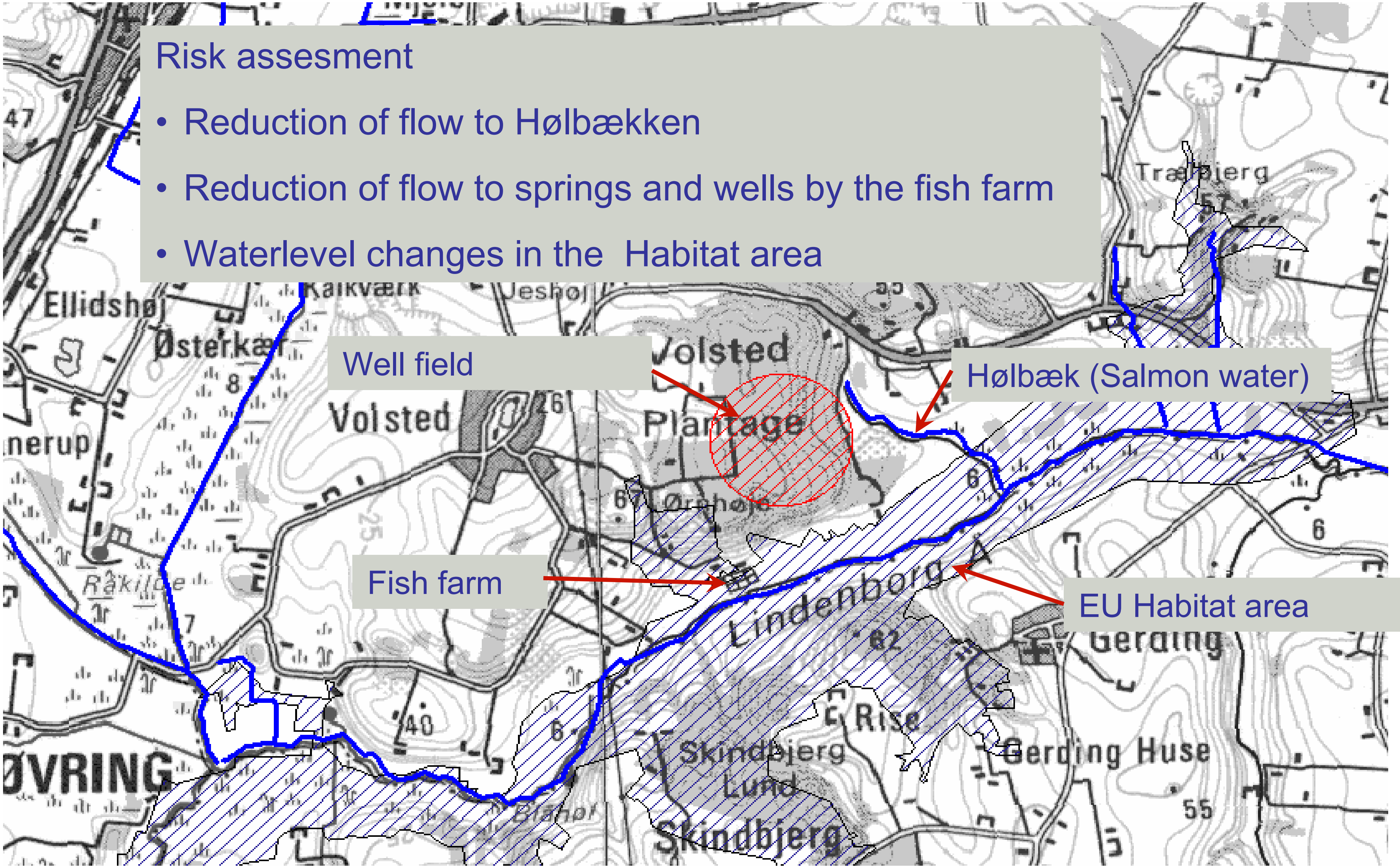
Pesticide contamination



New well field in Volsted Forest

Risk assesment

- Reduction of flow to Hølbækken
- Reduction of flow to springs and wells by the fish farm
- Waterlevel changes in the Habitat area



New well field in Volsted Forest

The different phases in the Volsted Project

Phase 1. Screening of possible locations

Phase 2. Establishment of two examination wells. General resource assessment. Preliminary groundwater model simulations ➔Capture zones, consequences for discharge to stream and wells.

Phase 3. Detailed investigation of the groundwater-surface water interaction in the nearby river valleys. Establishment of two pumping wells and five monitoring wells. Pumping tests. Monitoring of consequences for discharge and water levels. Detailed groundwater model simulations ➔ temporal long term effect of abstraction on streams and protected nature types. Simulation of abstraction alternatives. Simulation of compensation initiatives.

Phase 4. Establishment of well field. More simulations

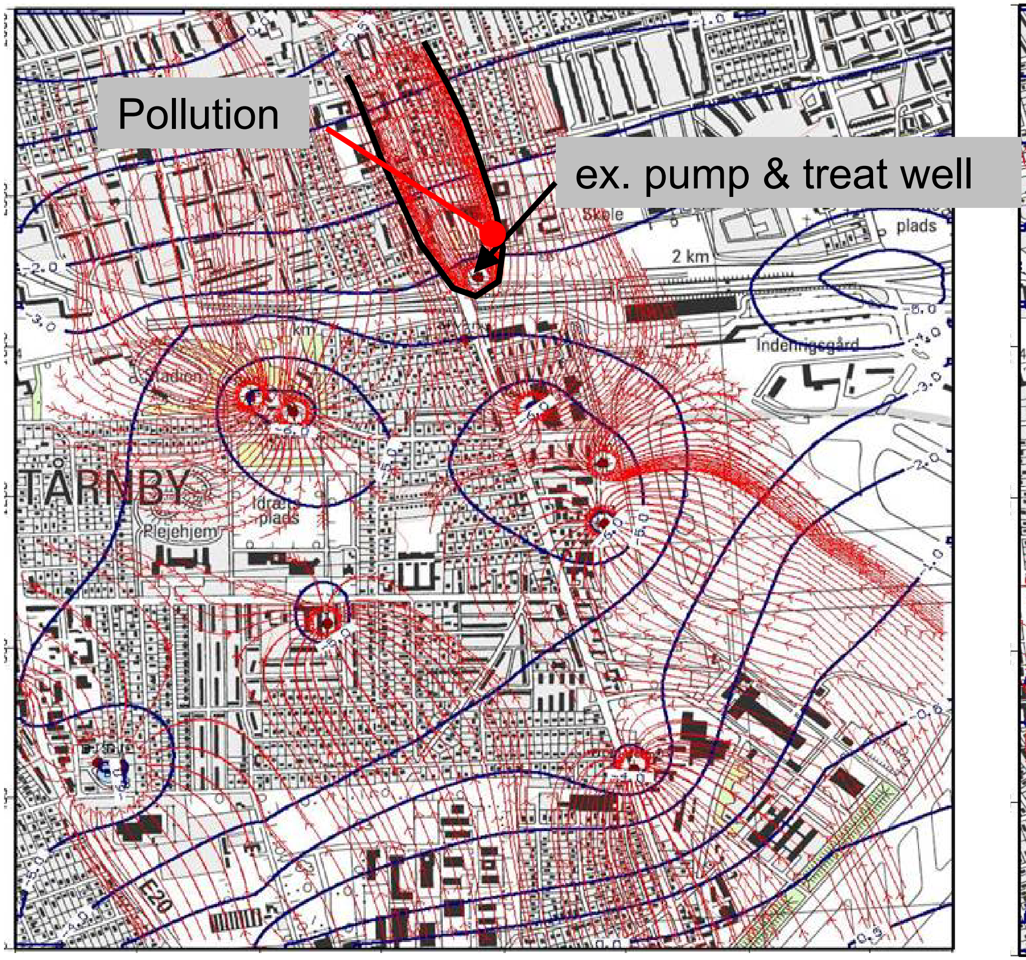
Tornby Hovedbibliotek

Purpose:

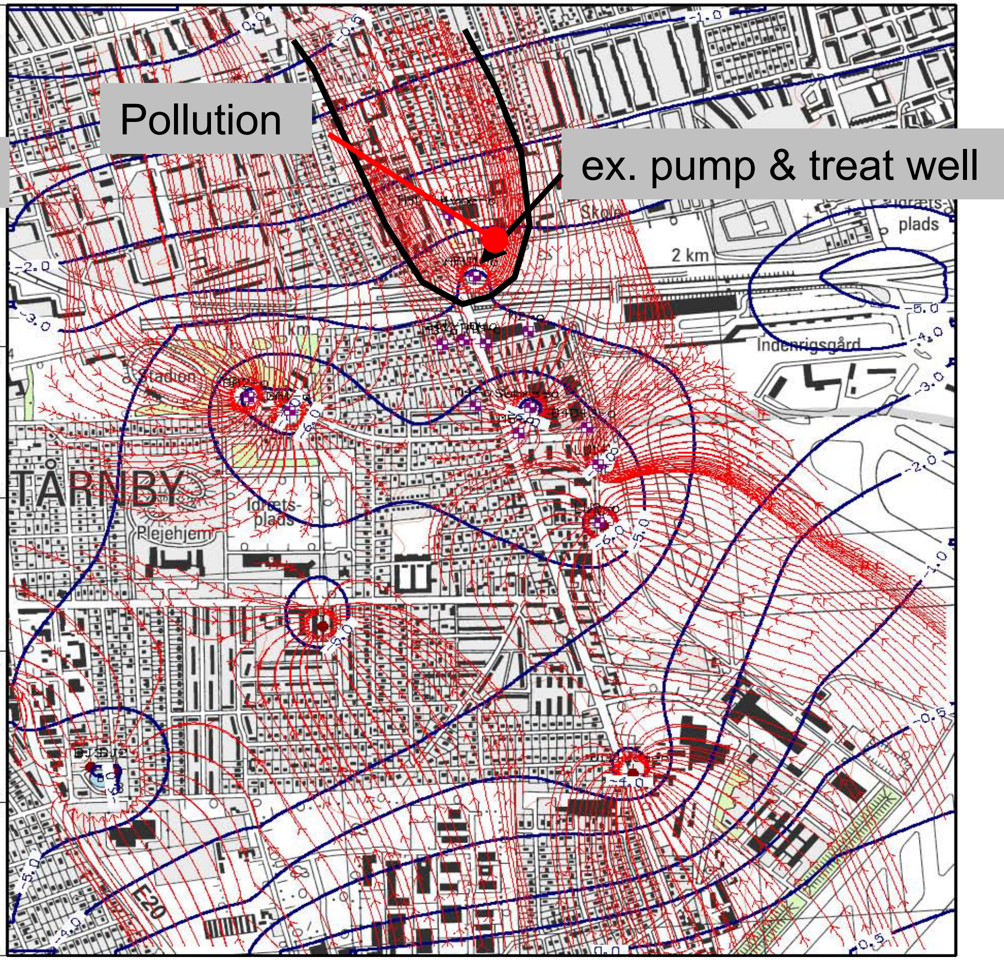
- Reassessment of the pump and treat strategy
- Setting of the strategy for supplemental investigations

Tornby Hovedbibliotek

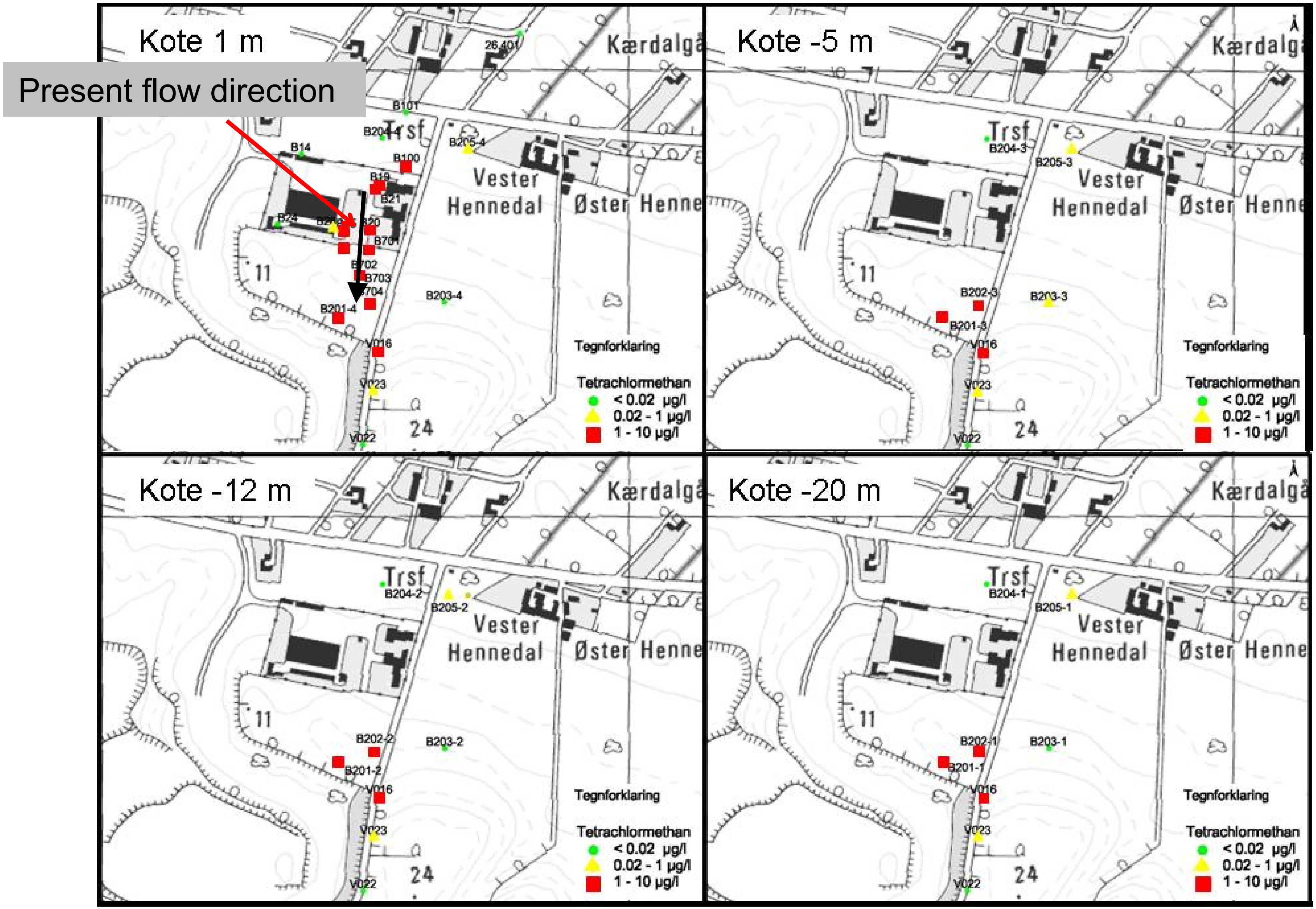
Pump & treat 2.5 m3/t



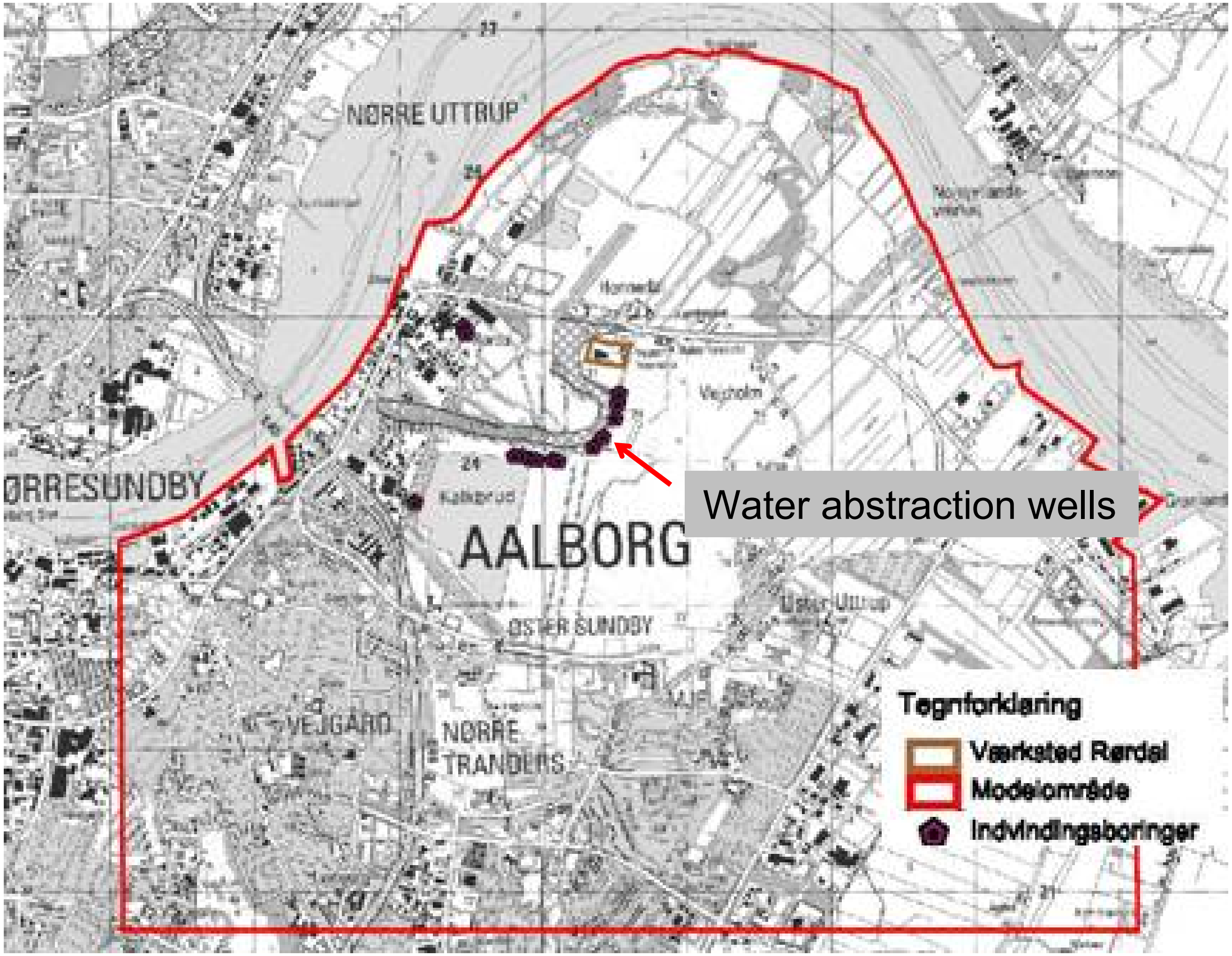
Pump & treat 5 m3/t



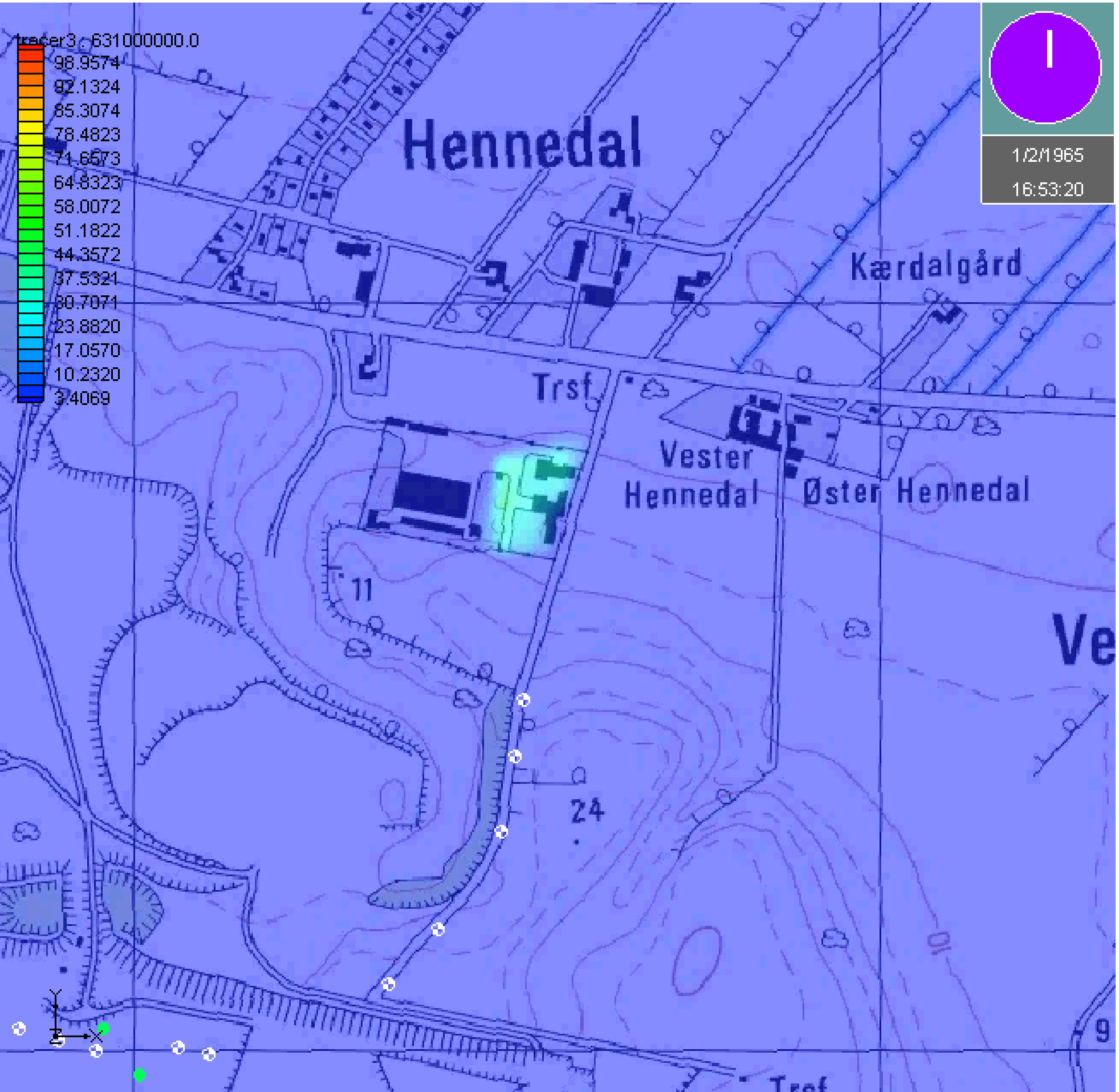
Værksted Rørdal (Military facility)

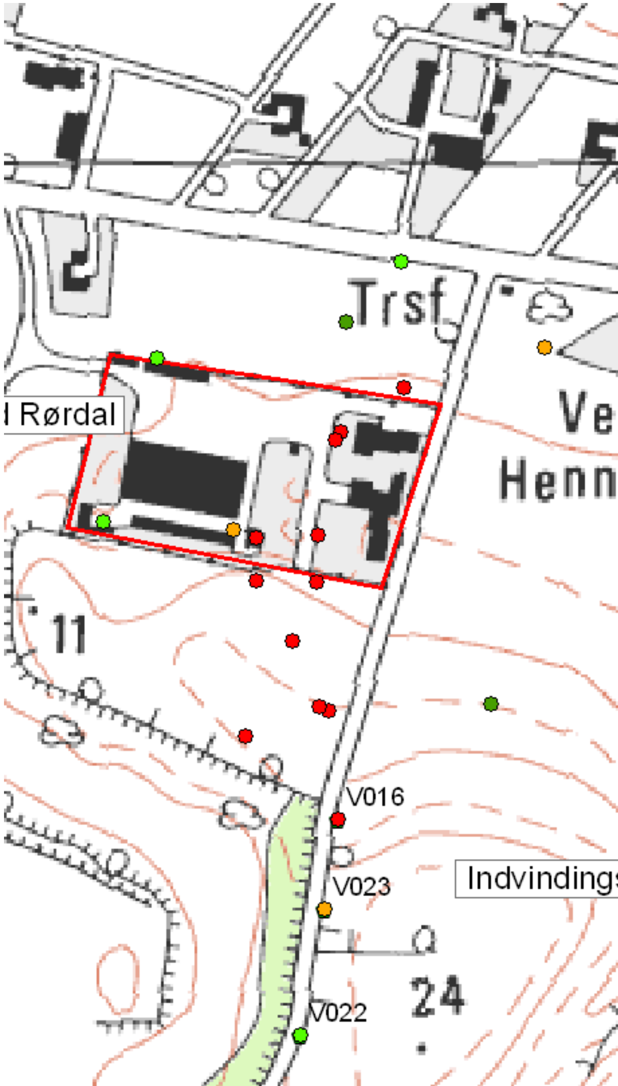


Værksted Rørdal – model area



Model results





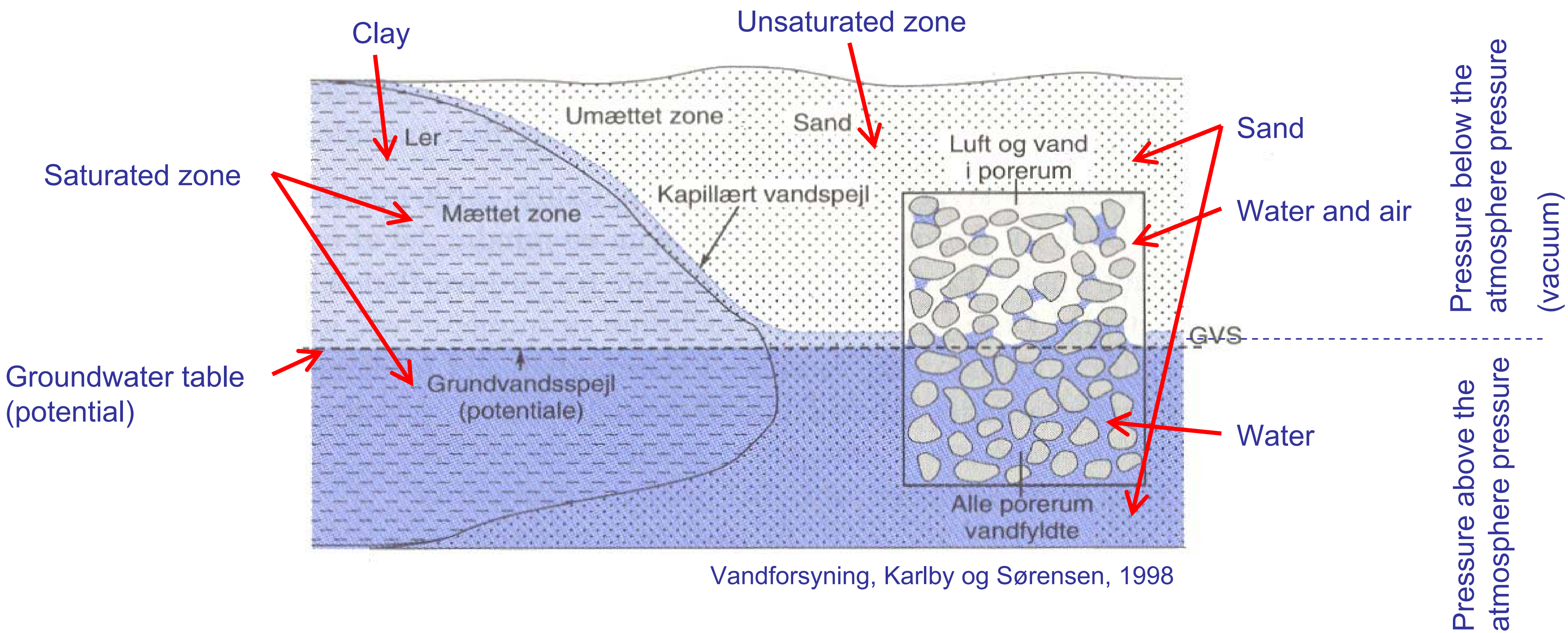
Exercise

1. What is a groundwater model?
2. What is the potential usage of a groundwater model?
   1. In general?
   2. On the project location?
3. What is your expected outcome of this course?
4. How do you think/hope that your skills within the field of groundwater modelling will be evaluated at the examine?

Groundwater

What is groundwater ?

Water that fills all pores and fissures in the soil



Vandforsyning, Karlby og Sørensen, 1998

Groundwater - definitions

Aquifer, groundwater reservoir:

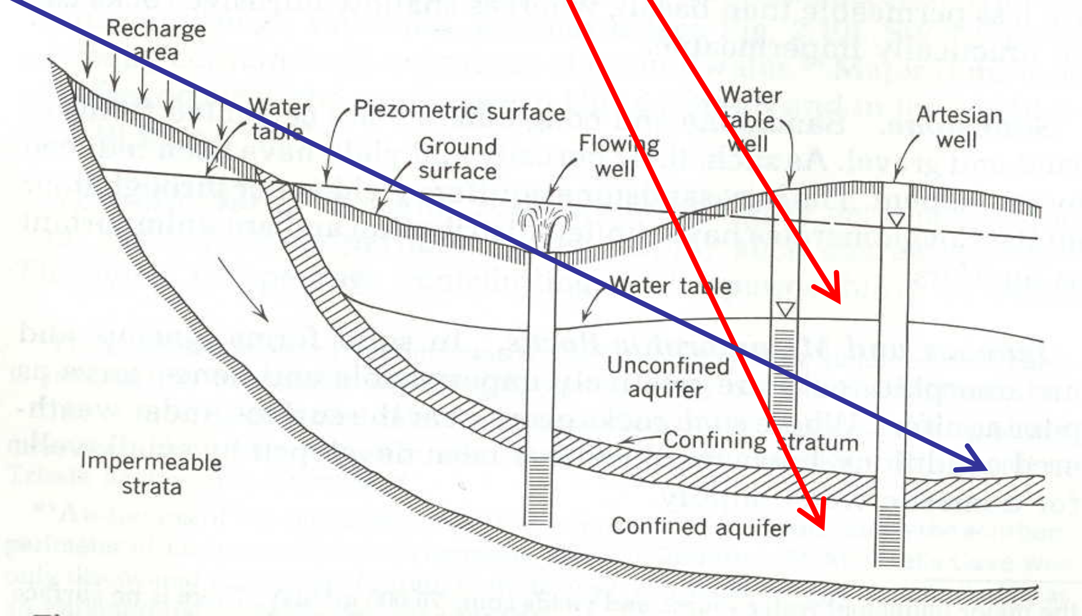
A geological formation that has the ability to transport large amounts of water or a permeable ubit that can yield water in usable quantities when tapped by a well. (sand, gravel, fractures rock, etc.)

Aquiclude:

A very low permeable formation (thick and fat clay)

Aquitard:

A geological formation of semi permeable nature that only allow a limit amount of water to pass.

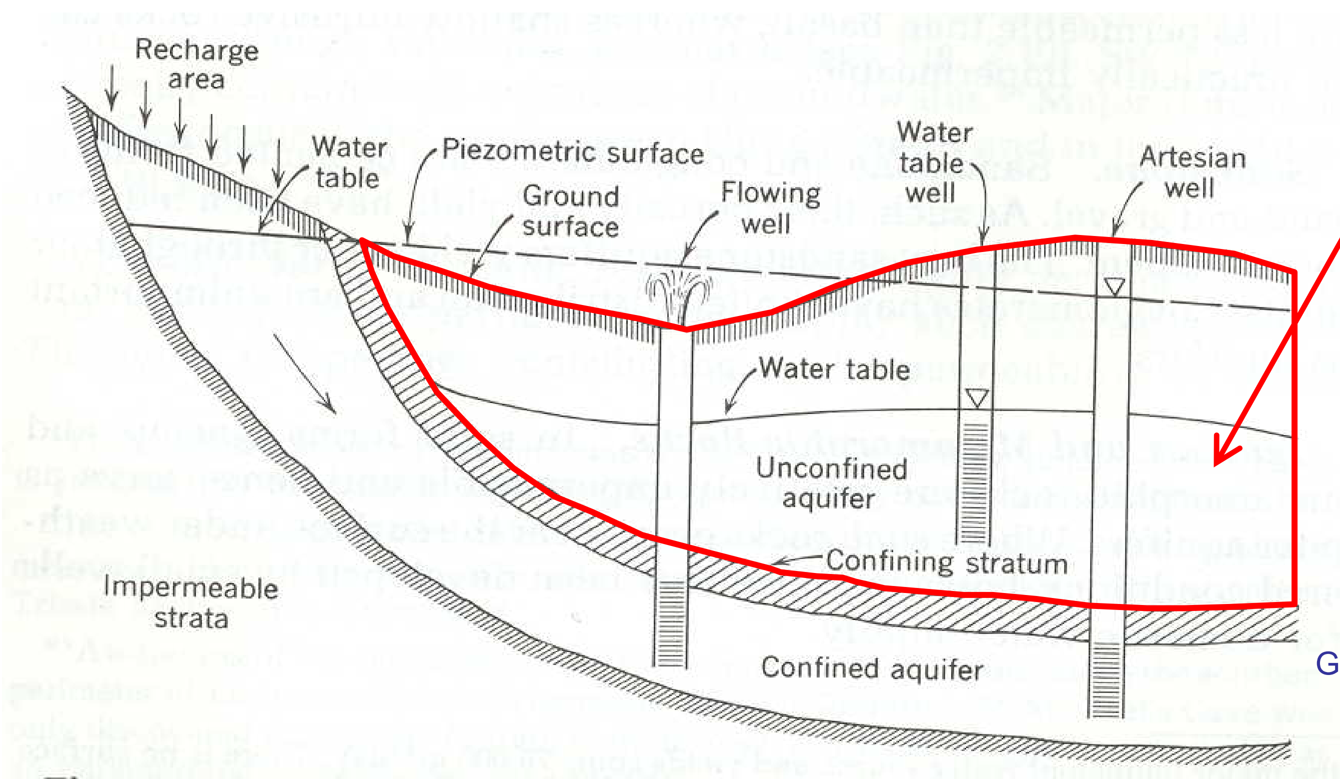


Groundwater hydrology, Todd, 1980

Groundwater – reservoir types

Unconfined aquifer, water table aquifer (frit magasin)

- Water table below the top of the reservoir
- The pressure at the water table equals the atmospherics pressure
- Large storage capacity

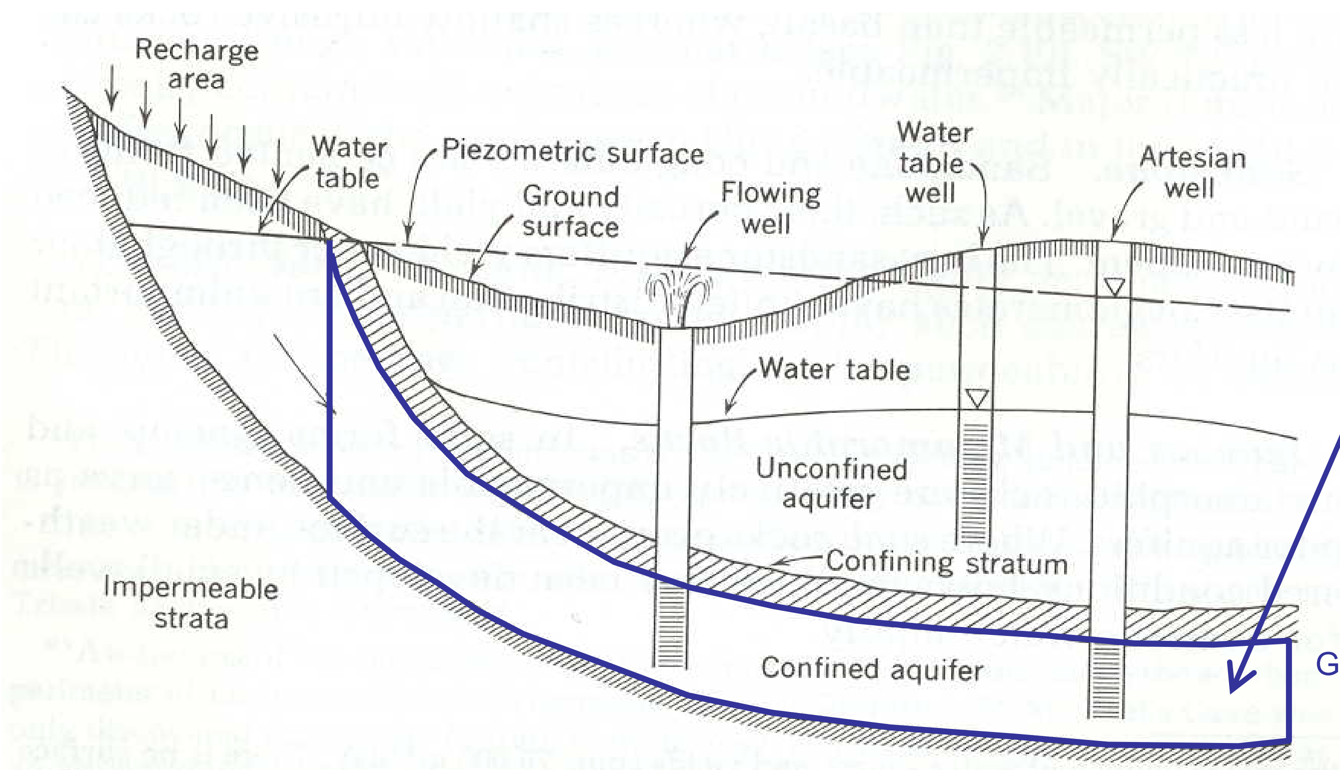


Groundwater hydrology, Todd, 1980

Groundwater – reservoir types

Confined aquifer, artesian reservoir (spændt magasin)

- Pressure level (water table in a well) is above the top of the reservoir.
- Small storage capacity



Groundwater hydrology, Todd, 1980

Storage capacity of a reservoir

Specific storage, Ss [m^{-1}]

Def.: Amount of water released form a **unit volume** of a confined reservoir due to a **unit decline** in pressure level

$$S_s = \gamma_w \left(\frac{1}{E_j} + \frac{\theta}{E_v} \right)$$

γ_w specific density of water [N m^{-3}]

E_v compressibility module of water [N m^{-2}]

θ porosity of the soil [-]

E_j Elasticity coefficient of the soil [N m^{-2}]

Note: Storage capacity of a reservoir i poorly describes in the textbook. Consult if necessary other text books or Google:

define: Specific storage and

define: Specific yield

Storage capacity of a reservoir

Specific yield, S_y [-]

Def.: Amount of water released form a **unit area** of a unconfined reservoir due to a **unit decline** in pressure level. (drainage of soil pores)

or

The amount of water a unit volume of saturated permeable rock will yield when drained by gravity.

$$S_y \approx \theta_S - \theta_{FC}$$

θ_s soil porosity (total water content) [-]

θ_{FC} water content at field capacity [-]

Storage capacity of a reservoir

Storage coefficient, S [-]

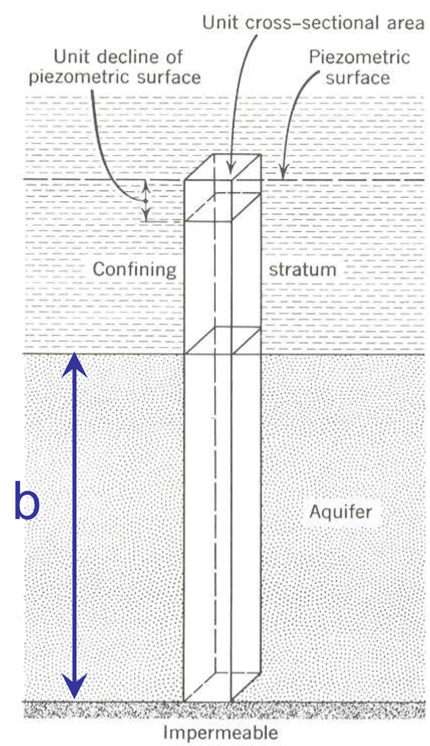
Def.: Amount of water released form a **unit area** of a reservoir due to a **unit decline** in pressure level.

Unconfined aquifer

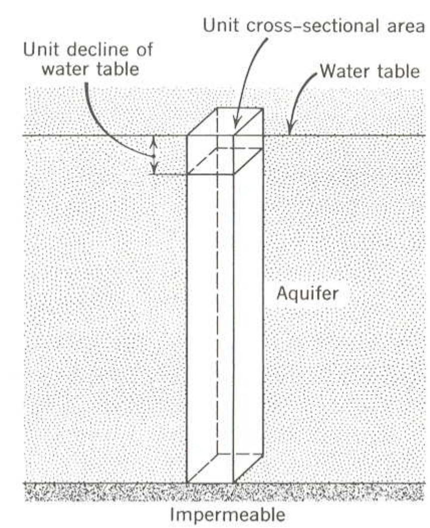
$$S = S_y + bS_s$$

Confined aquifer

$$S = bS_s$$



Confined aquifer



Unconfined aquifer

Groundwater hydrology, Todd, 1980

Storage capacity of a reservoir

Exercise:

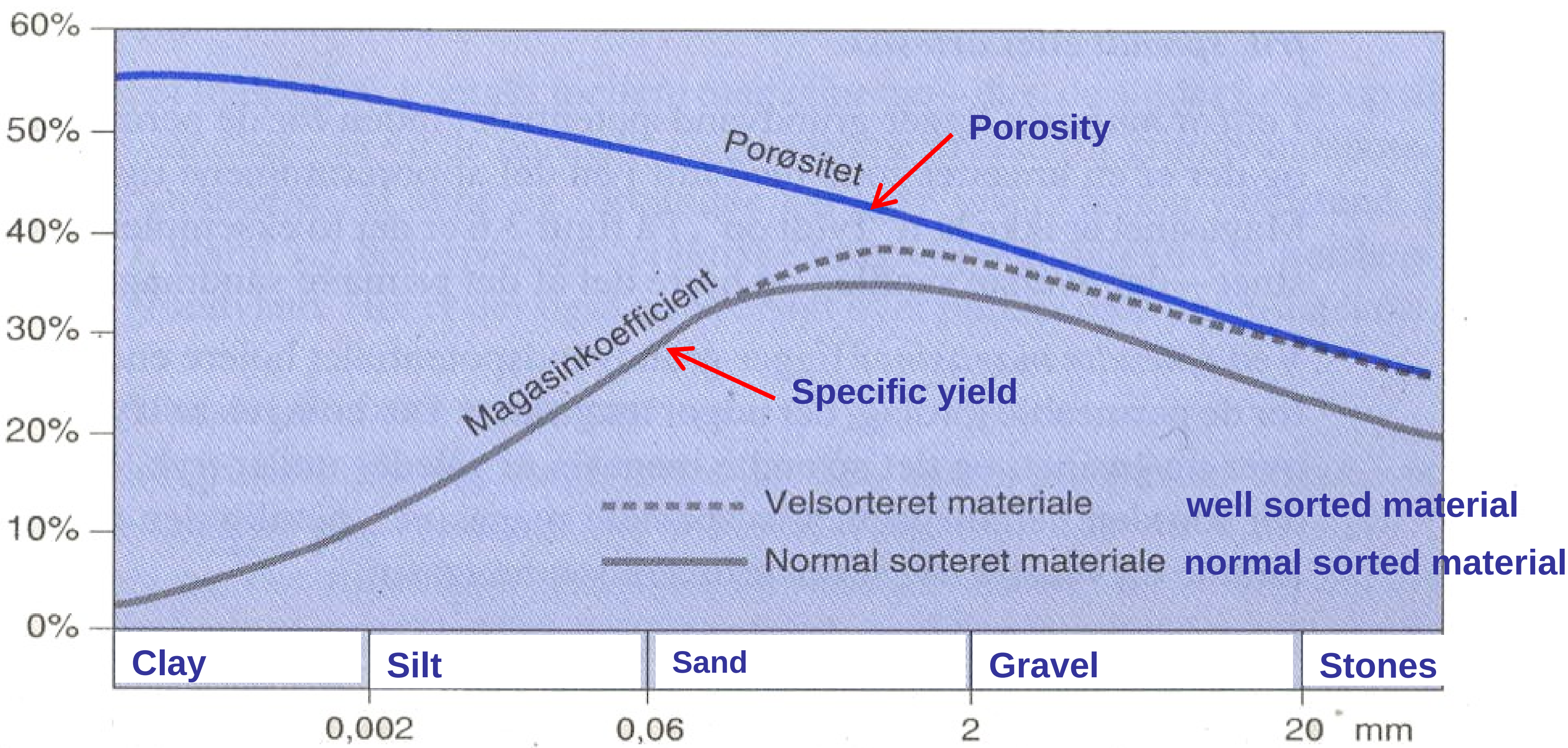
A clay soil, a sand soil and a gravel soil are considered.

Which soil has the larges and the smallest porosity?

Which soil has the larges and the smallest storage coefficient?

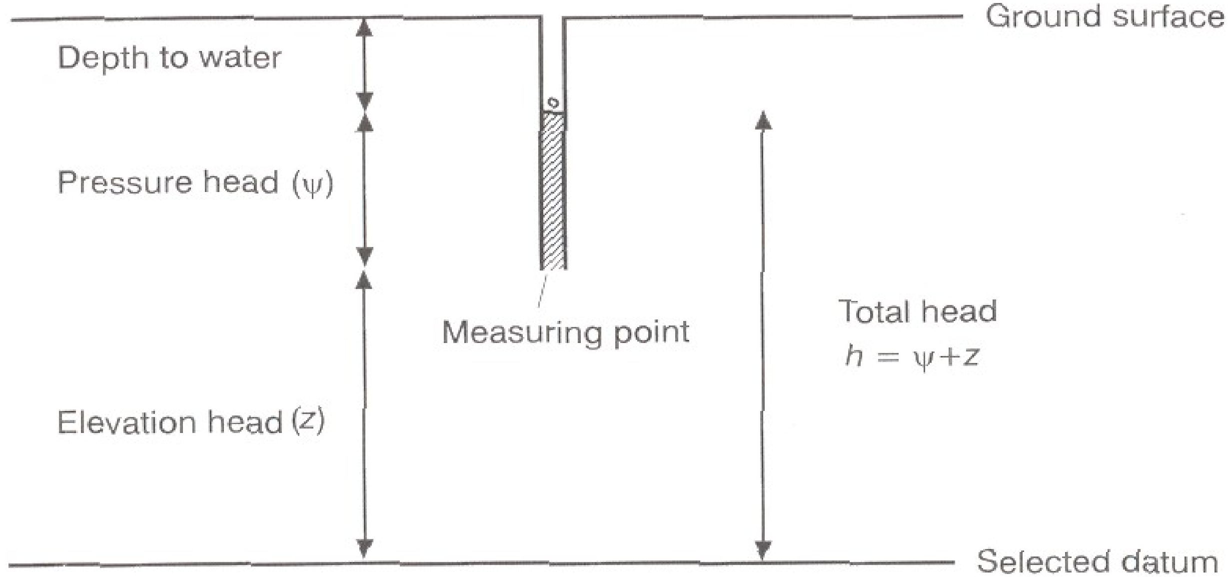
Storage capacity of a reservoir

Storage coefficient, S [-]



Driving forces

Total head, pressure head and elevation head



Groundwater hydrology, Todd, 1980

z elevation head [m]

y pressure head p/g [m]

h total head [m]

Soil as transport media

Darcy's law

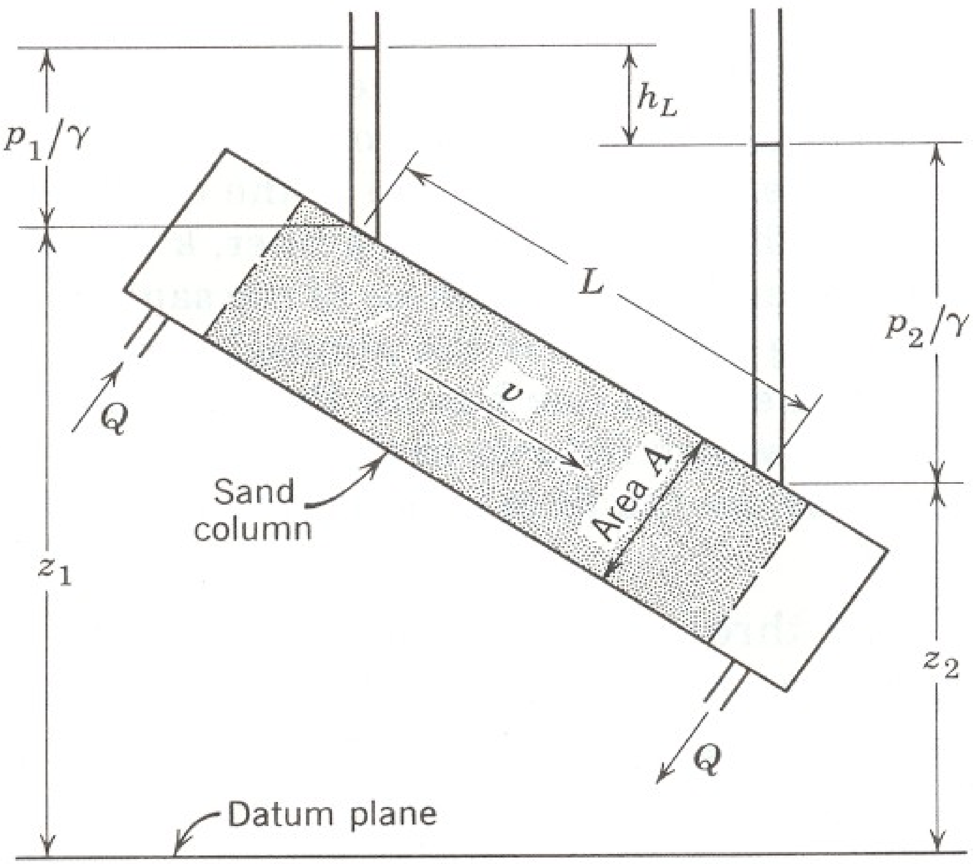
$$Q = -KA\frac{h_L}{L}$$

K hydraulic conductivity

$$Q = -KA\frac{dh}{dl}$$

Darcy flux, specific discharge, *v*

$$q = \frac{Q}{A} = -K\frac{dh}{dl}$$



Groundwater hydrology, Todd, 1980

Soil as transport media

Pore velocity or average interstitial velocity , *u*

$$v_a = u = \frac{q}{\alpha}$$

α effective porosity, also called n_e or n_{eff}

Soil as transport media

Hydraulic conductivity, K [m/s]

Fluid dependent measure for the ability of a given soil to transport water

Permeability, k [m^2]

Fluid in-dependent measure for the ability of a given soil to transport water

$$k = \frac{K\mu}{\rho g}$$

m   dynamic viscosity

r   fluid density

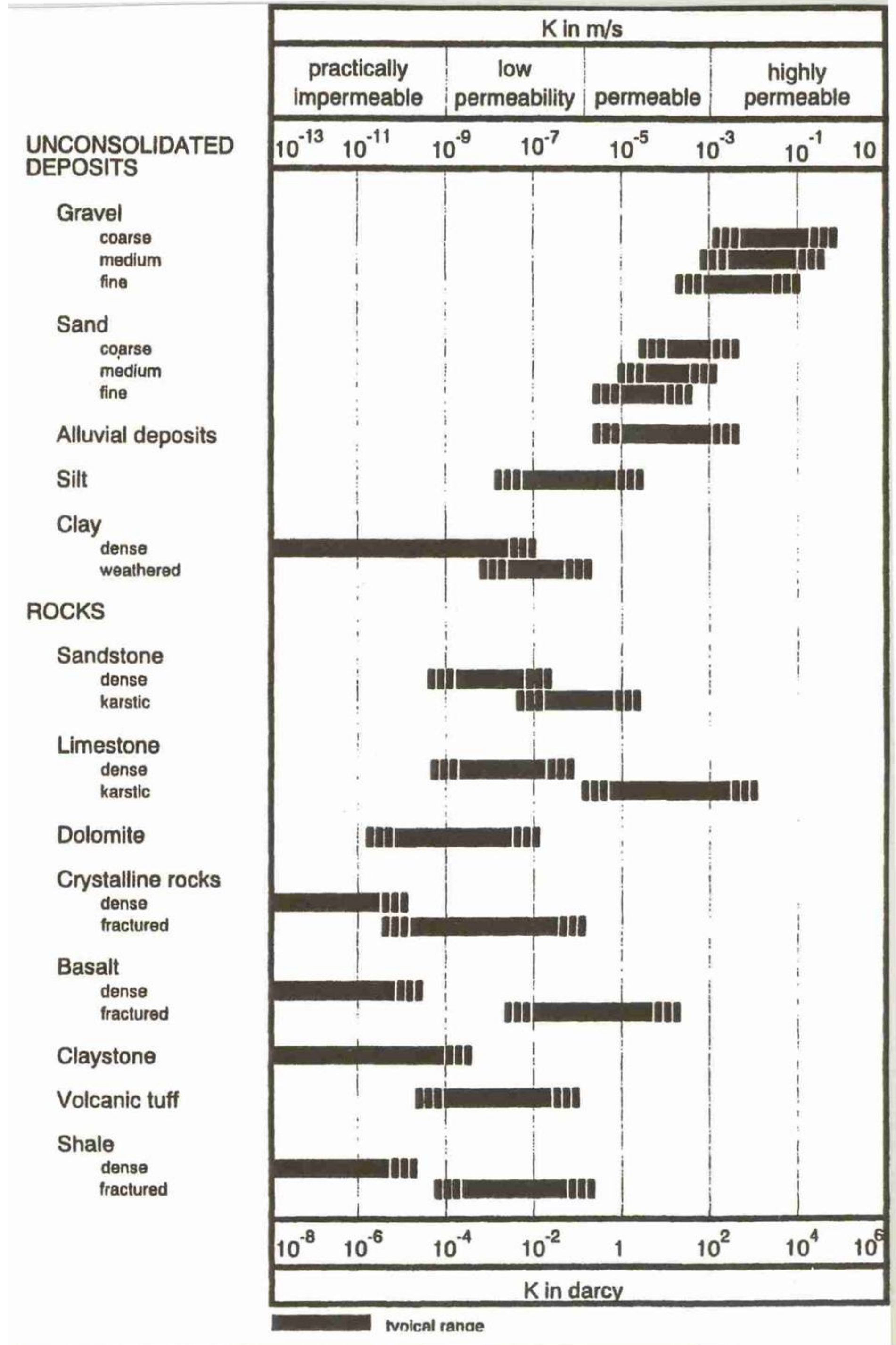
g   acceleration of gravity

Transmissivity, T [m^2/s]

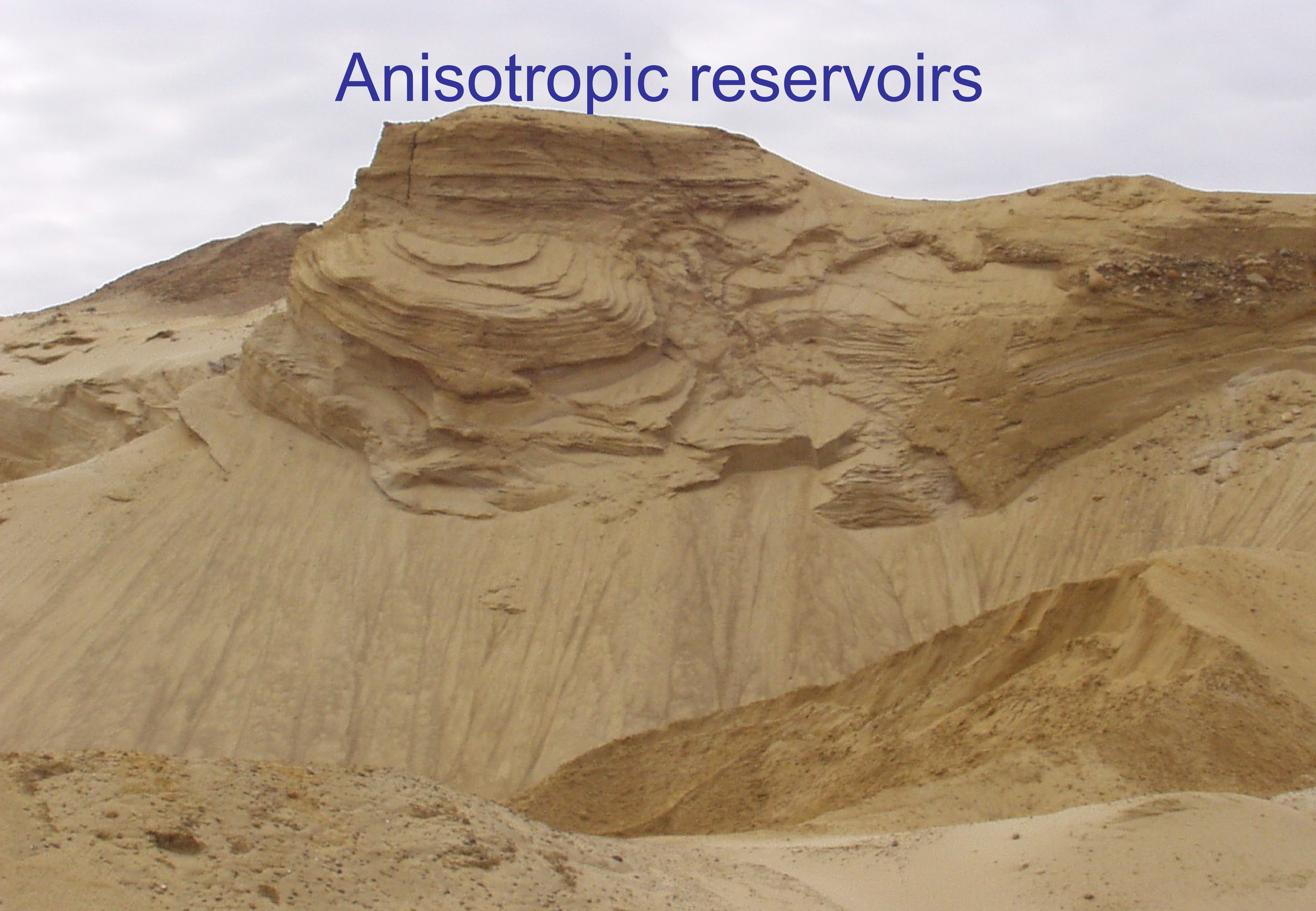
$$T = Kb$$

Hydraulic conductivity

Typical values:



Anisotropic reservoirs



Hydraulic conductivity

Anisotropic reservoirs – flow parallel with the stratification

$$Q_1 = K_1 \frac{dh}{dx} z_1 dy$$

$$Q_2 = K_2 \frac{dh}{dx} z_2 dy$$

$$\Downarrow$$

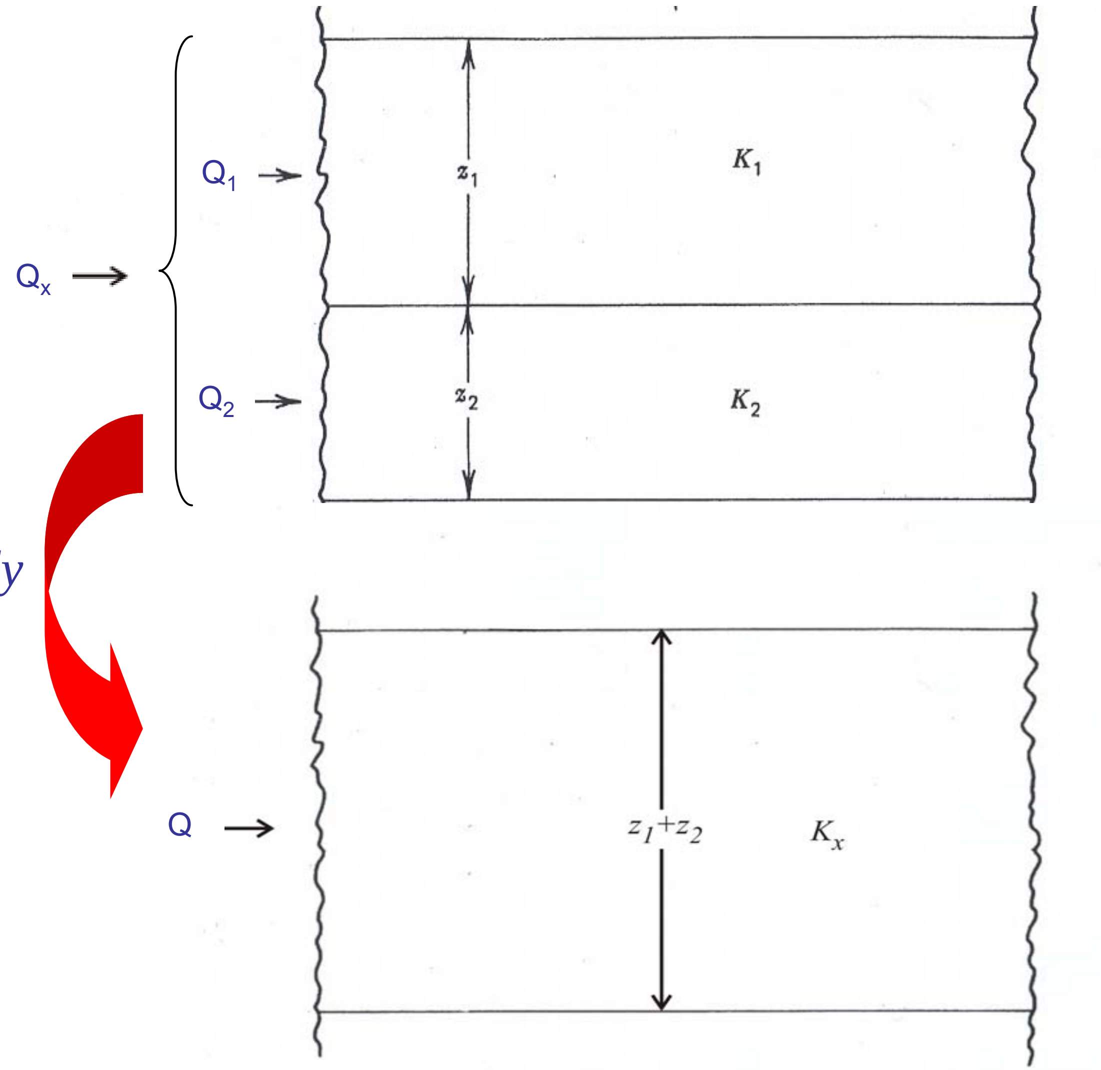
$$Q_x = Q_1 + Q_2 = \frac{dh}{dx}(K_1 z_1 + K_2 z_2) dy$$

$$Q_x = \frac{dh}{dx}(K_1 z_1 + K_2 z_2) dy = K_x \frac{dh}{dx}(z_1 + z_2) dy$$

$$\Downarrow$$

$$K_x = \frac{K_1 z_1 + K_2 z_2}{z_1 + z_2}$$

$$K_x = \frac{K_1 z_1 + K_2 z_2 + \ldots + K_n z_n}{z_1 + z_2 + \ldots + z_n}$$



Hydraulic conductivity

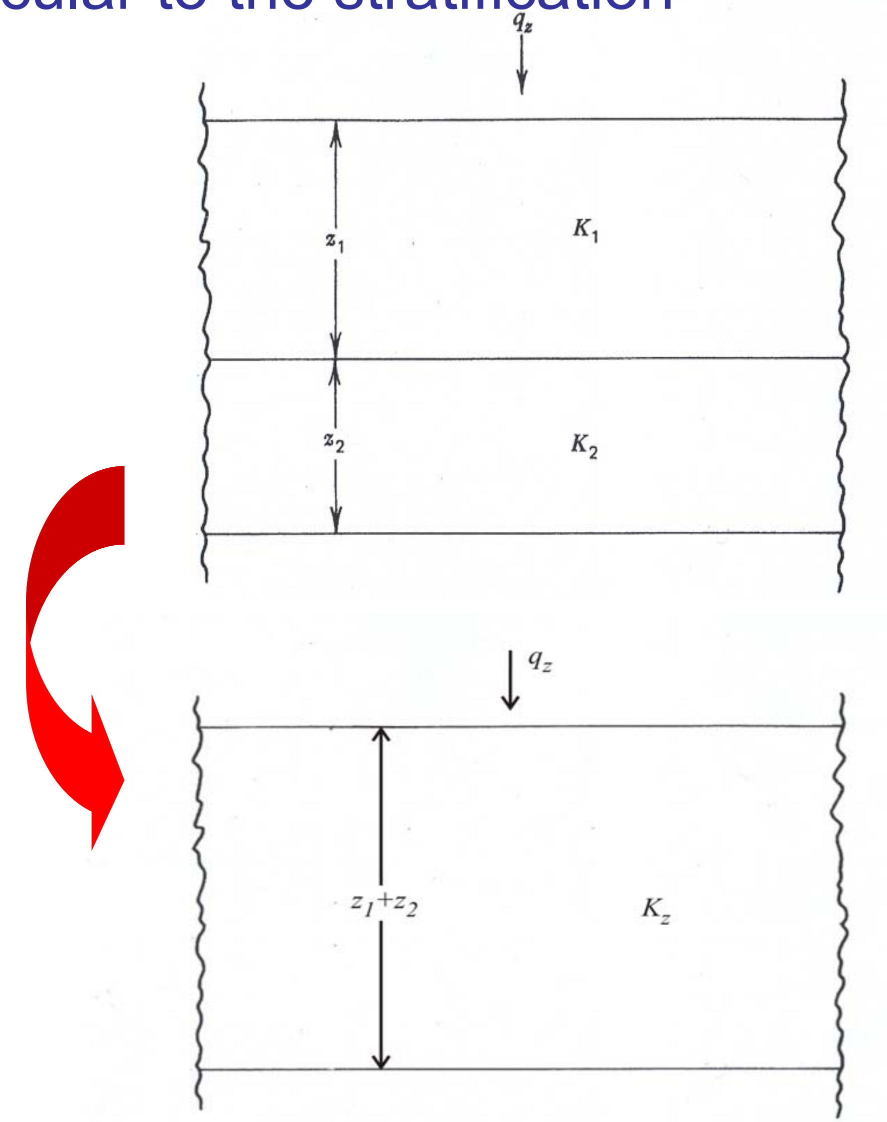
Anisotropic reservoirs – flow perpendicular to the stratification

$$q_z = K_1 \frac{dh_1}{z_1} = K_2 \frac{dh_2}{z_2} = K_z \frac{dh}{z_1 + z_2}$$

$$dh_1 = \frac{z_1}{K_1} q_z$$

$$dh_2 = \frac{z_2}{K_2} q_z$$

$$dh = dh_1 + dh_2 = \frac{z_1 + z_2}{K_z} q_z$$



Hydraulic conductivity

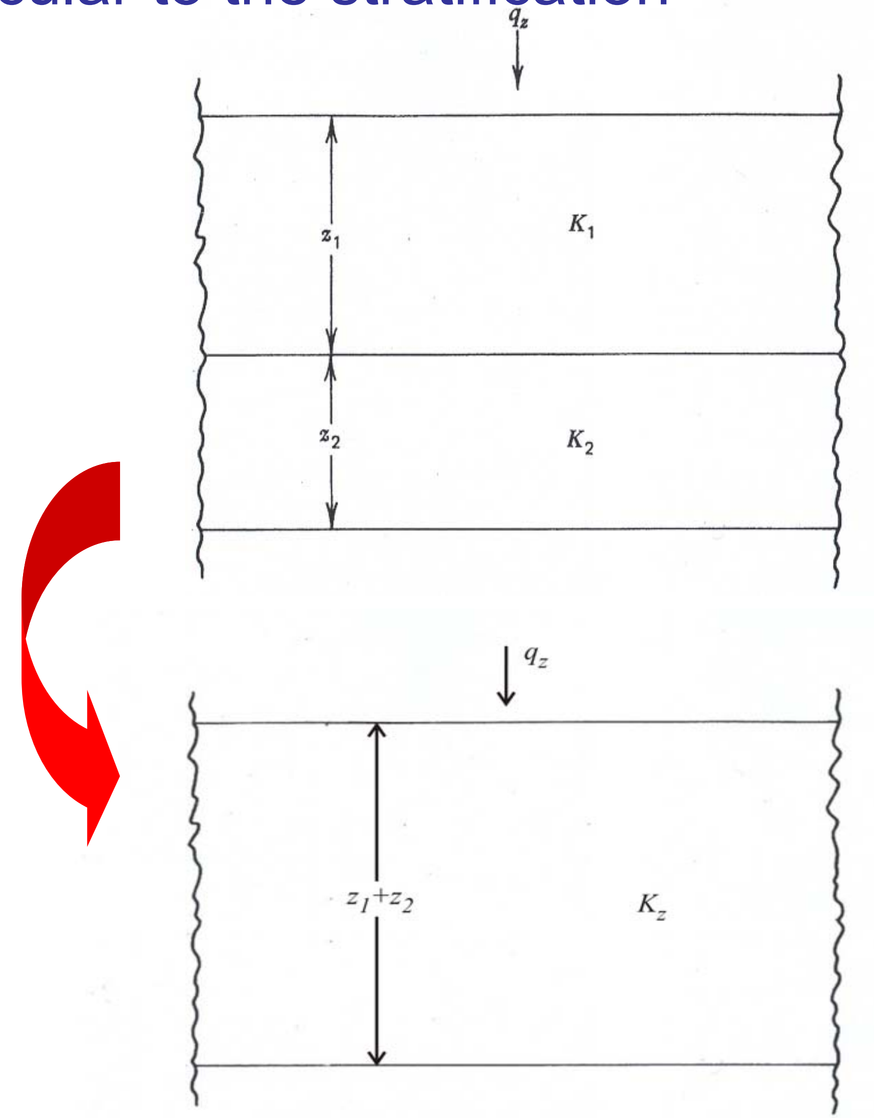
Anisotropic reservoirs – flow perpendicular to the stratification

$$\frac{z_1}{K_1} q_z + \frac{z_2}{K_2} q_z = \frac{z_1 + z_2}{K_z} q_z$$

$$\Downarrow$$

$$K_z = \frac{z_1 + z_2}{\dfrac{z_1}{K_1} + \dfrac{z_2}{K_2}}$$

$$K_z = \frac{z_1 + z_2 + \ldots + z_n}{\dfrac{z_1}{K_1} + \dfrac{z_2}{K_2} + \ldots + \dfrac{z_n}{K_n}}$$



Groundwater flow – equations

Water balance equation: in-out=change in storage

$$\left(Q_{x,i}-Q_{x,0}\right)+\left(Q_{y,i}-Q_{y,0}\right)=-SW^{2}\frac{\partial h}{\partial t}$$

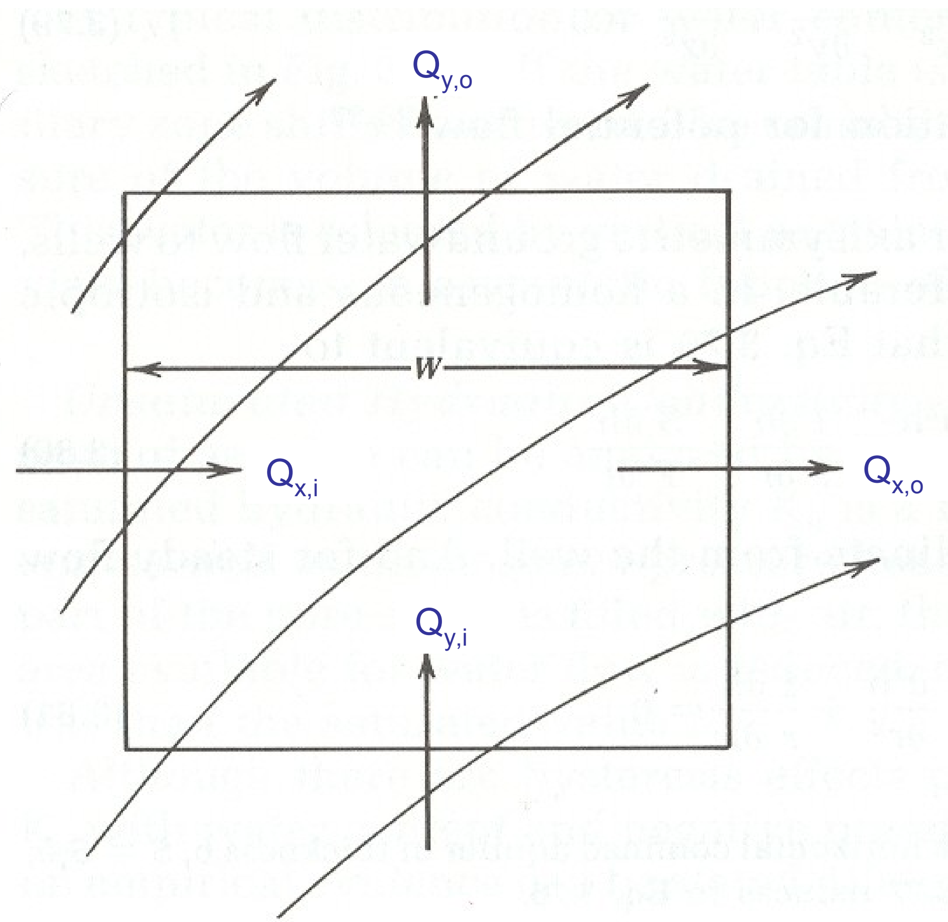
From the Darcy equation

$$Q_{x,i}=-K_x bW\left(\frac{\partial h}{\partial x}\right)_i=-T_x W\left(\frac{\partial h}{\partial x}\right)_i$$

$$Q_{x,0}=-K_x bW\left(\frac{\partial h}{\partial x}\right)_0=-T_x W\left(\frac{\partial h}{\partial x}\right)_0$$

$$Q_{y,i}=-K_y bW\left(\frac{\partial h}{\partial y}\right)_i=-T_y W\left(\frac{\partial h}{\partial y}\right)_i$$

$$Q_{y,0}=-K_y bW\left(\frac{\partial h}{\partial y}\right)_0=-T_y W\left(\frac{\partial h}{\partial y}\right)_0$$



Groundwater flow – equations

2-dimensional flow

$$-T_xW\left(\left(\partial h/\partial x\right)_i-\left(\partial h/\partial x\right)_0\right)-T_yW\left(\left(\partial h/\partial y\right)_i-\left(\partial h/\partial y\right)_0\right)=-SW^2\frac{\partial h}{\partial t}$$

$$\Updownarrow$$

$$-T_x\frac{\left(\partial h/\partial x\right)_i-\left(\left(\partial h/\partial x\right)_i+\dfrac{\partial\left(\partial h/\partial x\right)_i}{\partial x}W\right)}{W}-T_y\frac{\left(\partial h/\partial y\right)_i-\left(\left(\partial h/\partial y\right)_i+\dfrac{\partial\left(\partial h/\partial y\right)_i}{\partial y}W\right)}{W}=-S\frac{\partial h}{\partial t}$$

$$\Downarrow$$

$$T_x\frac{\partial^2 h}{\partial x^2}+T_y\frac{\partial^2 h}{\partial y^2}=S\frac{\partial h}{\partial t}$$

3-dimensional flow

$$K_x\frac{\partial^2 h}{\partial x^2}+K_y\frac{\partial^2 h}{\partial y^2}+K_z\frac{\partial^2 h}{\partial z^2}=S_S\frac{\partial h}{\partial t}$$

Groundwater flow – equations

Adding sink/source term, *R*

$$T_x \frac{\partial^2 h}{\partial x^2} + T_y \frac{\partial^2 h}{\partial y^2} \pm R = S \frac{dh}{dt}$$

$$K_x \frac{d^2 h}{dx^2} + K_x \frac{d^2 h}{dy^2} + K_x \frac{d^2 h}{dz^2} \pm R = S_S \frac{dh}{dt}$$

Questions

1. How is the saturated zone defined
2. What is an aquifer?
3. What is an aquitard?
4. What is an unconfined aquifer?
5. What is a confined aquifer?
6. What is a conceptual model?
7. How is specific storage defined ?
8. How is specific yield defined?
9. How is storage coefficient defined?
10. What is hydraulic conductivity?
11. What is the difference between hydraulic conductivity and permeability ?
12. What is transmissivity?
13. What is the typical range for hydraulic conductivity for sand?
14. What is the typical range for hydraulic conductivity for clay?
15. How is hydraulic head defined?
16. What is the Darcy velocity?
17. What is the pore water velocity?