Modeling thermal evolution caused by thermal water production and injection wells

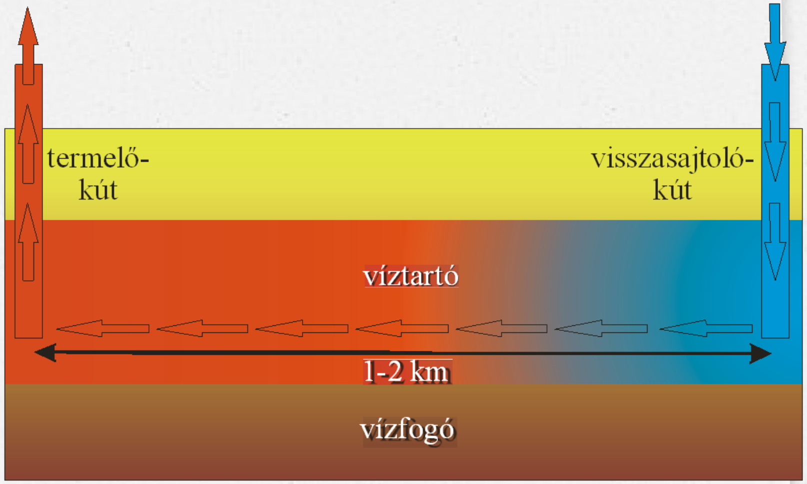
Róbert Farkas

Dept. of Geophysics & Space Sciences, Eötvös University, Budapest

Aims of modeling

Geothermal systems and their cooling

- production time
- geometry of the wells, distance
- effects of 30 years production



What?

How?

Equation of subsurface water flow+ heat transport

Numerical modeling, finite element method (Feflow 6.0x)

Equations

Darcy's Law

Governing equation of water flow in porous medium

$$\underline{u} = -K\nabla h$$

K - hydraulic conductivity [m/s]

$\underline{u}$ - Darcy velocity [m^3/m^2 s]=[m/s]

h - hydraulic head

$$h = \frac{p - p_{hidr}}{\rho g}$$

Continuity equation

$$s_0 \frac{\partial h}{\partial t} = \mathrm{K}\nabla^2 \mathrm{h} + Q$$

s_0- specific storage [1/m]

Q - source [m^3/m^3s]

t - time [s]

Heat transport

$$c_{p\,m}\rho_m \frac{\partial T}{\partial t} = c_{p\,f}\rho_f\,\underline{u}\nabla T + \lambda\nabla^2 T + Q_T$$

1: change of heat energy, 2: advection, 3: conduction, 4: source

T – temperature [°C]

λ – thermal conductivity [W/m°C]

Q_T – heat source [W/m3]

c_p – heat capacity [J/kg°C], ρ – density [kg/m^3]

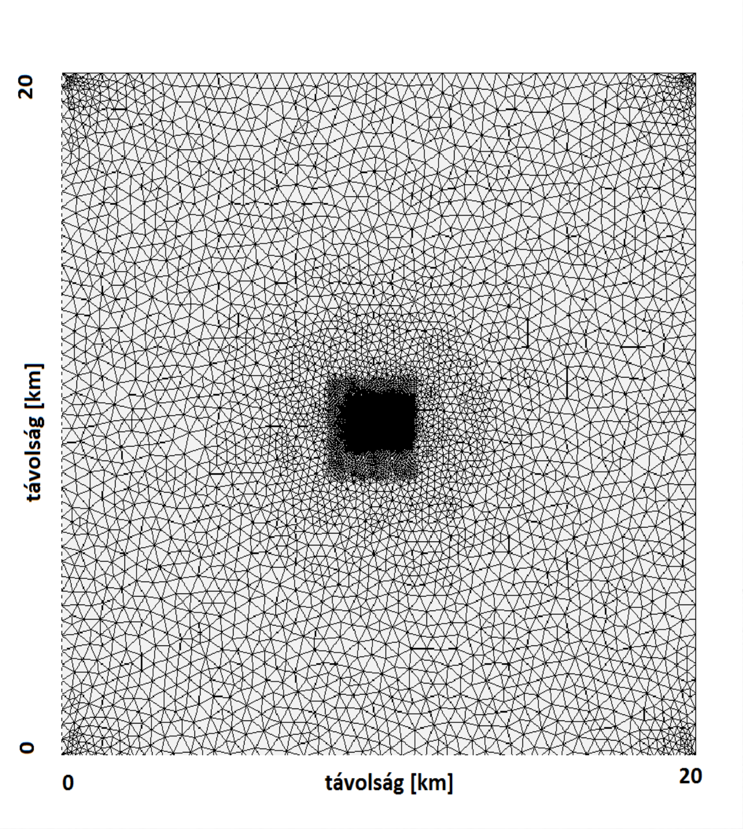
Numerical solution:

Calculation of *h* → Darcy's Law -u → heat transport

Finite element method

- The model area consists of finite elements and nodes
- Number of nodes ⟶ number of equation

- Initial and boundary conditions
- Calculating: hydraulic head, temperature
- Time-iteration with Adams-Bashforth method (hydraulic head,
  T change ↔ time-step size)
- model geometry x=20 km, y=20 km, z=3,5 km



Used mesh geometry

Comparison of numerical solution with analitical solution

Point source

1. Hydraulic head

- depending on the time of production

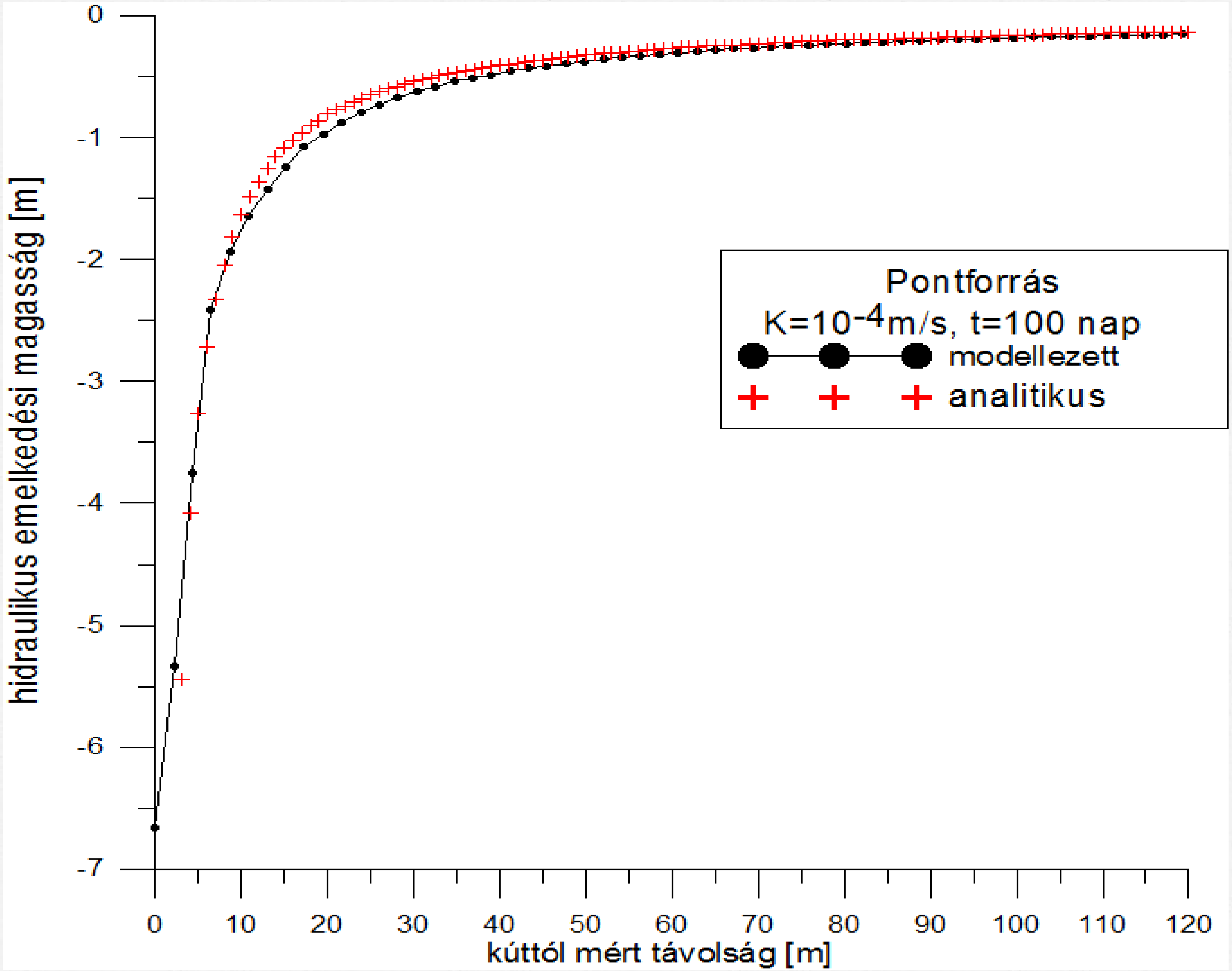
2. Temperature

Eqaution of hydraulic head:

$$\frac{\partial h}{\partial t} = \frac{K}{s_0}\left(\frac{\partial^2 h}{\partial r^2} + \frac{2}{r}\frac{\partial h}{\partial r}\right) + \frac{Q_\rho}{s_0}$$

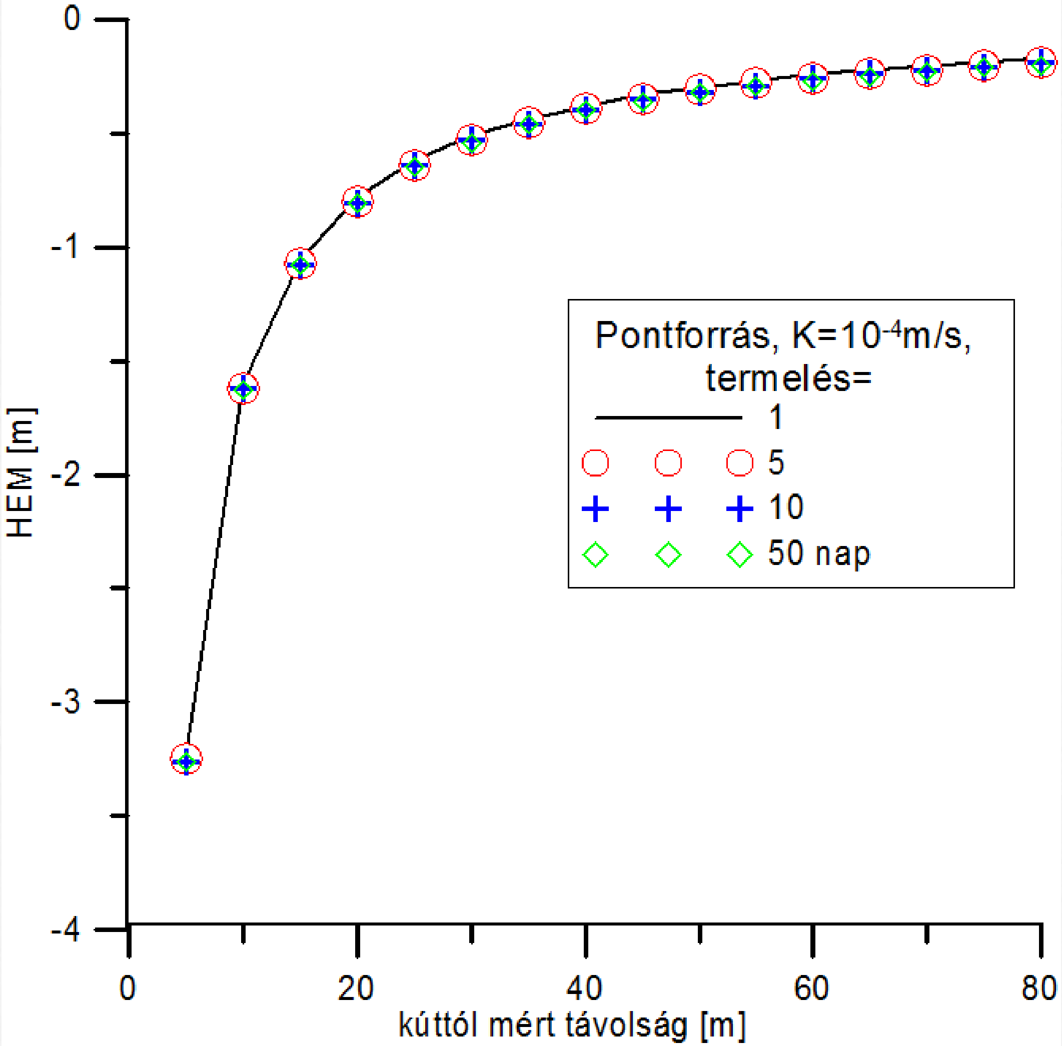
initial and boundary condition:

- $h(0,r) = h_0$
- The model boundary-h_0: $\lim_{r\to\infty} h(t,r) = h_0$
- the pumping rate is constant : $\lim_{r\to 0}\left(r\frac{\partial h}{\partial r}\right) = \frac{Q}{4\pi\frac{K}{s_0}}$



Pontforrás
K=10-4m/s, t=100 nap
modellezett
analitikus
hidraulikus emelkedési magasság [m]
kúttól mért távolság [m]
0
-1
-2
-3
-4
-5
-6
-7
0
10
20
30
40
50
60
70
80
90
100
110
120

Analytic solution of hydraulic head as a function of production time. Hydraulic head is stationary after the first day.



Point source

2. Temperature

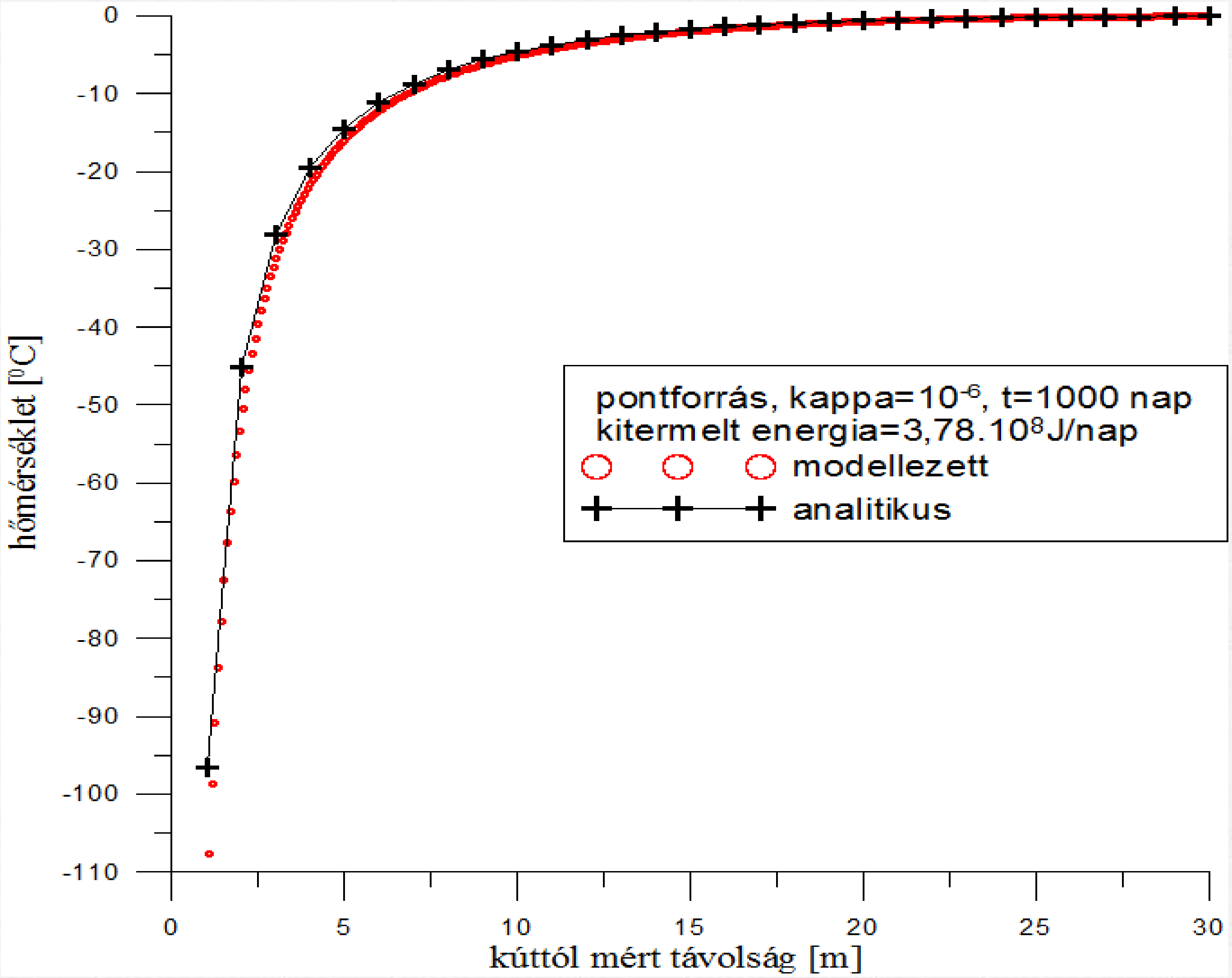
- Comparison of analytical and numerical calculation

Eqaution of temperature:

$$\frac{\partial T}{\partial t} = \kappa\left(\frac{\partial^2 T}{\partial r^2} + \frac{2}{r}\frac{\partial T}{\partial r}\right) + \frac{Q_T}{c\rho}$$

initial and boundary condition:

- initial temperature : $T(0, r) = 0$
- amount of heat produced at $r=0$ Q_T=0
- Q_T=3,78.10^8J/day
- Thermal diffusivity: κ =10^{-6} m^2/s



heat production: Q_T=3,78.10^{8}J/day

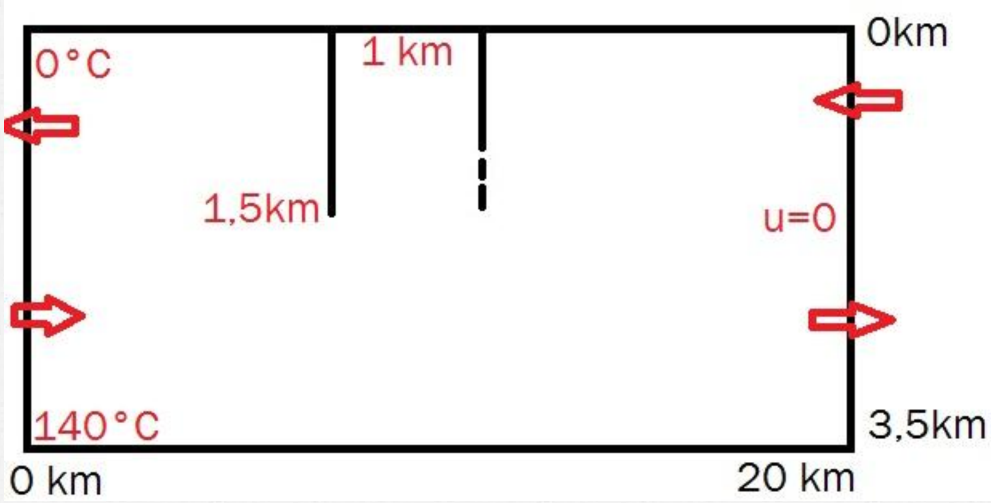
Modeling production and injection wells

Initial and boundary condition :

- initial hydraulic head:
  $h(x, y, z, t = 0) = 0$
- amount of production and injection: 2000 m^3/day
- Temperature of produced water: 60°C
- Temperature of injected water: 20°C

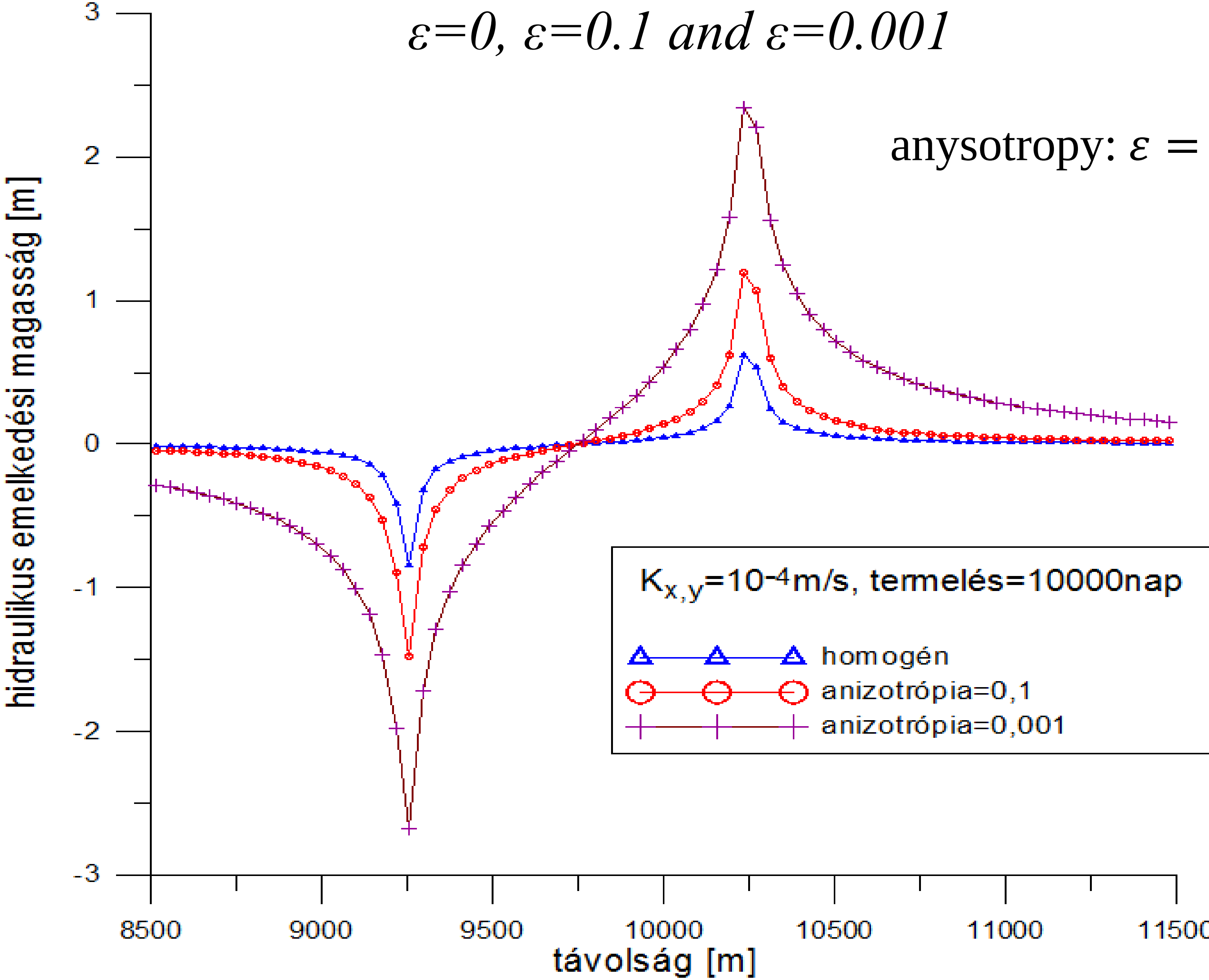
Two case-studies :

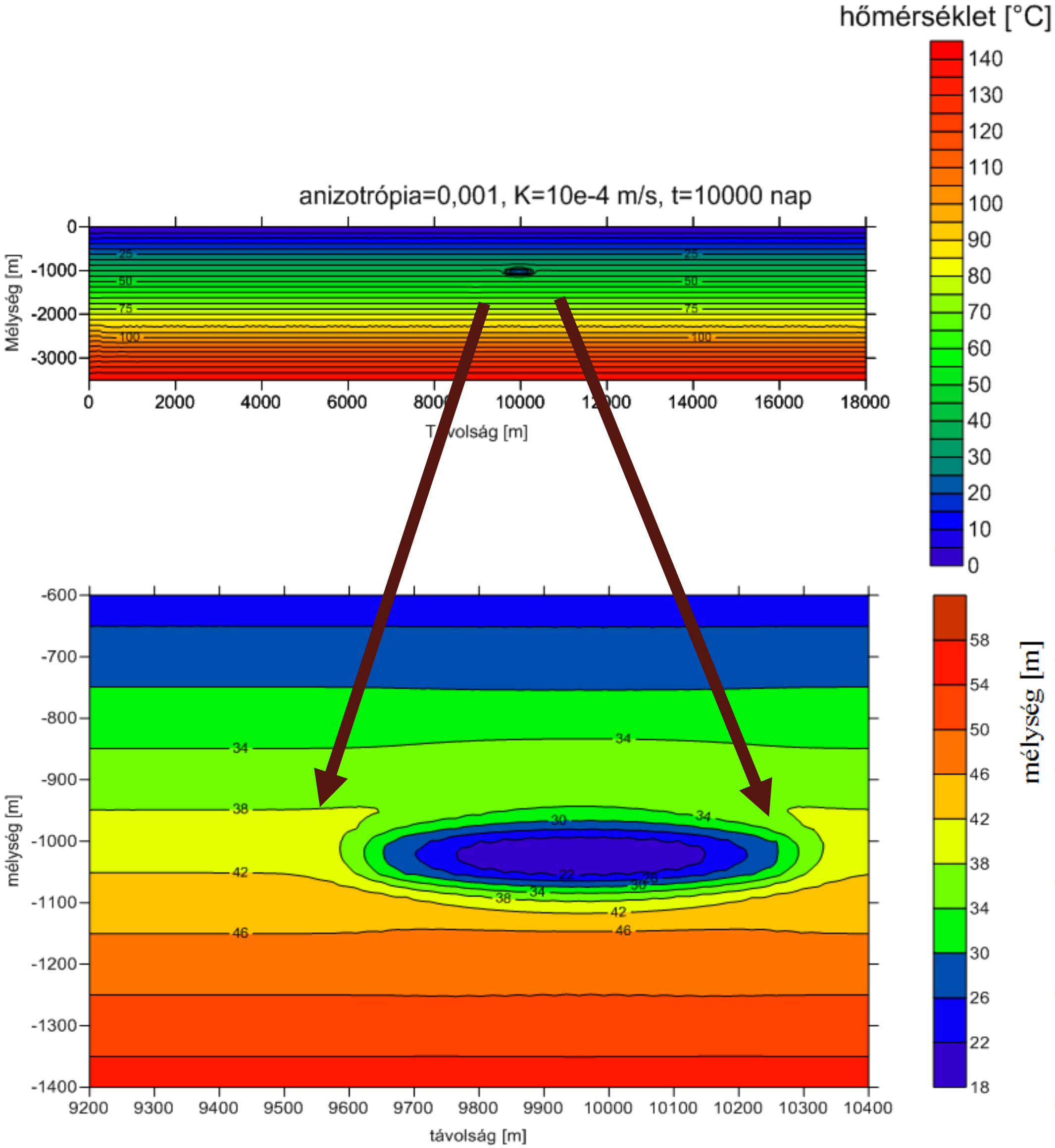
- injection into the same layer (1500-1550 m)
- into a different layer (1000-1050 m)



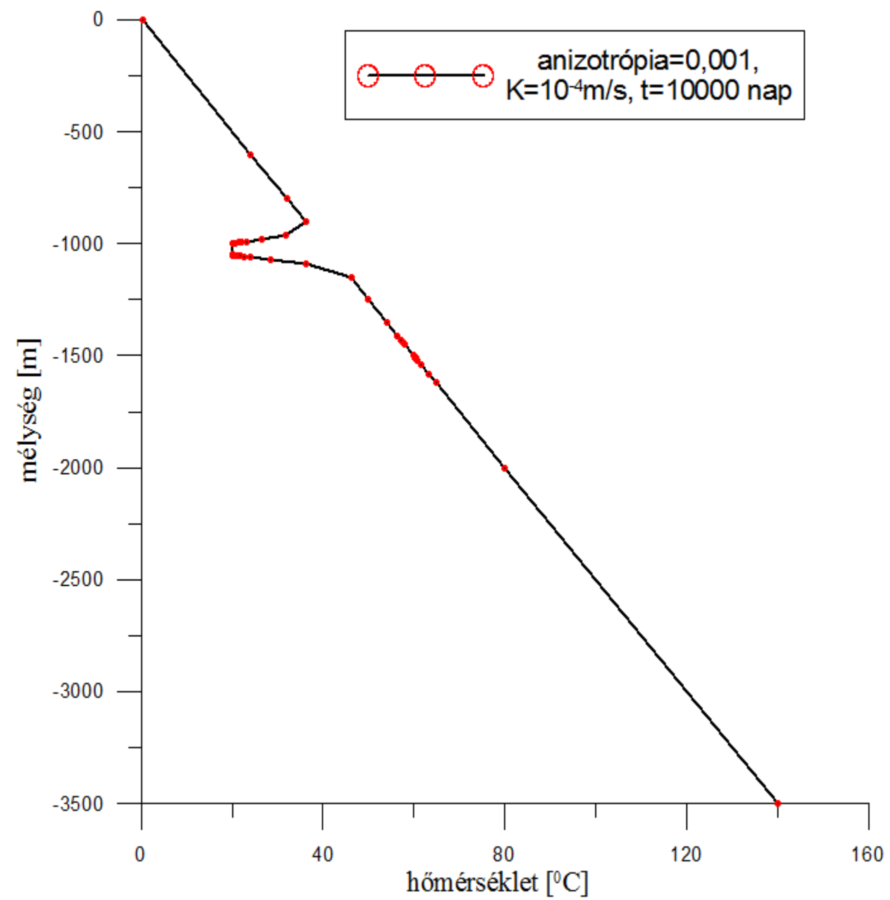
Hydraulic head in case of different anysotropies: ε=0, ε=0.1 and ε=0.001

anysotropy: $\varepsilon = \frac{K_z}{K_{x,y}}$





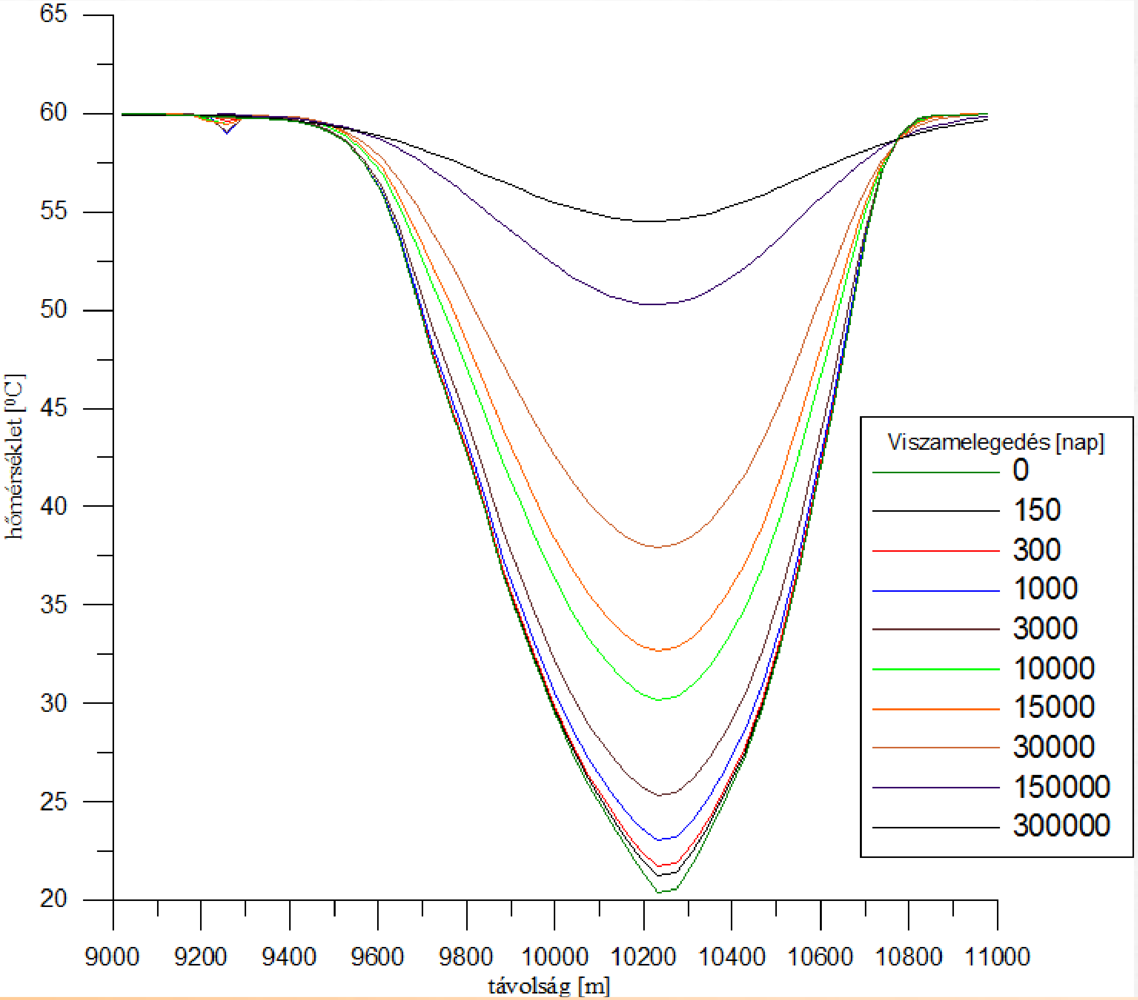
Enlarged vertical section of a cooled-down environment around an injection well



Temperature-depth profile at the injection well

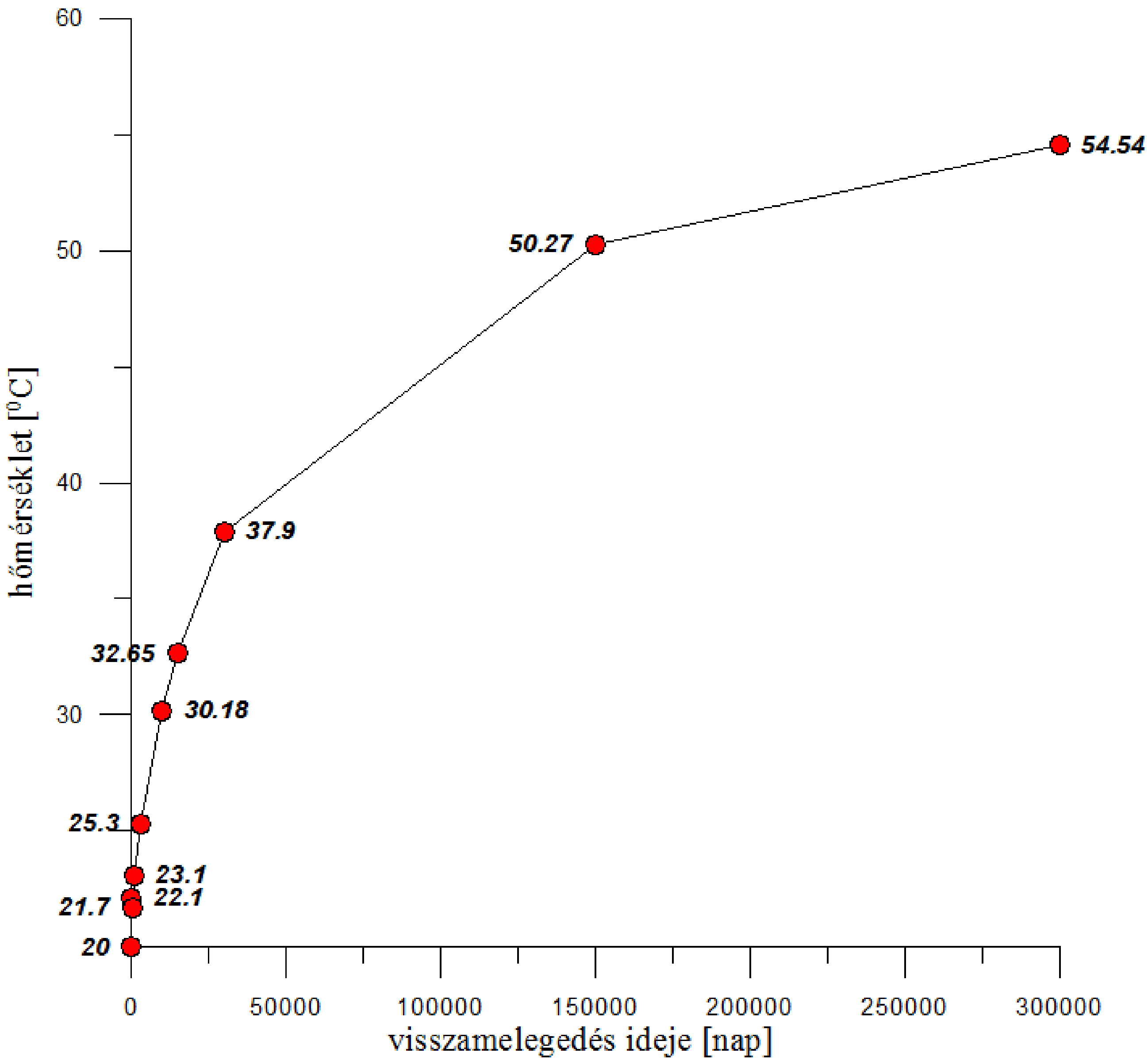
Thermal equilibration

Production time: 30 years



300000 days (1000 years) are needed to reach the 90 % of the original temperature.

Warming of the cold layer



Summary

- Comparision of analytical and numerical solutions
- 30 years of production does not have effect on the temperature of the produced water in case of wells located 1 km from each other
- 1000 years of reheating

Thank you for your attention!