Modelling thermohydraulic processes in shallow Quaternary aquifers under groundwater management aspects

U. LANG[1], M. BAUER[2], M. KLIPFEL[3] & A. DURACH[1]

[1] Engineering Consultant Prof. Kobus and Partners, Wilhelmstr. 11, 70182 Stuttgart, Germany

[2] Regierungspräsidium Freiburg Landesamt für Geologie Rohstoffe und Bergbau Baden-Württemberg, Freiburg, Germany

[3] Klipfel and Lenhardt Consult, Endingen, Germany

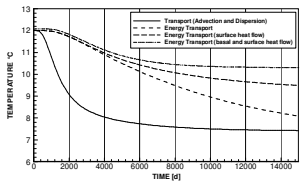
Objective

- To quantifiy the effects of geothermal energy use in the Quaternary aquifer east of the Kaiserstuhl in the Upper Rhine Graben in south western Germany
- To identify the relevant processes of thermo hydraulic measures:
  - Advection and dispersion
  - Thermal heat conduction
  - Basal heat flow
  - Surface heat flow
- to assess the impact of the geothermal wells
- to develop a management plan for future sustainable geothermal usage of the aquifer

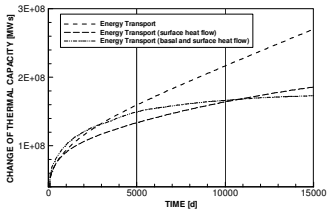
Test Model

- Simplified aquifer: length 10,000 m, width 5,000 m, thickness 52 m
- 2 hydrogeological units, unconfined conditions
- Injection of 10 l/s, temperature difference of 5 °C
  => 200 KW
- Simulation period 15,000 days

Parameter	Value	Unit
Hydraulic conductivity unsaturated zone	0.000003	(ms^{-1})
Hydraulic conductivity upper unit	0.003	(ms^{-1})
Hydraulic conductivity lower unit	0.0003	(ms^{-1})
Hydraulic gradient	0.004	(-)
Porosity	0.15	(-)
Dispersivity longitudinal/transversal	100 / 10	(m)
Specific heat capacity matrix	1000	$(J(sm°C)^{-1})$
Specific heat capacity fluid	4182	$(J(sm°C)^{-1})$
Thermal conductivity matrix	1.5	$(J(kg°C)^{-1})$
Thermal conductivity fluid	0.6	$(J(kg°C)^{-1})$
Basal heat flow	0.06	(Wm^{-2})



Calculated temperature curves in 600 m distance of the injection well under consideration of different energy transport processes



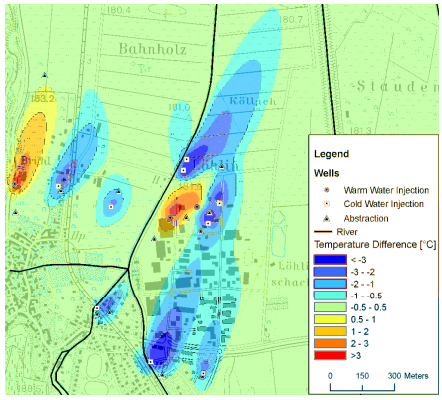
Calculated change of thermal capacity (note: the total thermal capacity decreases due to cold water injection)

Results of Test Model

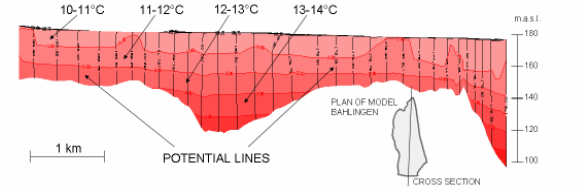
- The transport simulation without energy overestimates the temperature plume
- 36 % of the injected energy will be compensated by surface heat exchange. Therefore, the unsatturated zone has to be included into the model
- The effect of the basal heat flow can be neglected
- The basal heat flow is required for the determination of the natural vertical temperature distribution
- The thermal conductivity leads to an additional diffusion mainly in the transverse direction

Test Site Bahlingen

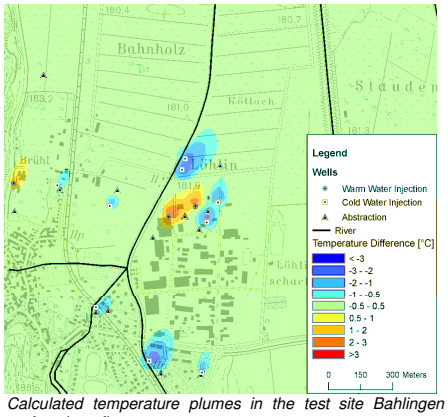
- Steady state flow calibration:
  - Minimize the difference between observed and calculated heads
  - Variation of the hydraulic conductivities and the leakage coefficient
- 12 thermal measures
- 2 test scenarios for energy transport:
  - including surface heat exchange
  - neglecting surface heat exchange



Calculated temperature plumes in the test site Bahlingen under consideration of advection, dispersion and thermal conduction but without surface heat flow



Calculated natural temperature distribution in a vertical cross section in flow direction of the test site model Bahlingen



Calculated temperature plumes in the test site Bahlingen with basal and surface heat flow

Results of Test Site Bahlingen

- The initial vertical temperature distribution has to be calculated under natural conditions. Exchange with surface water and the natural flow field affect the temperature distribution.
- Large temperature plumes develop if the surface heat exchange is neglected
- An interference of the different thermal measures is expected for the northern part of the industrial zone
- Further development
- Possibilities for further geothermal usage are located upstream of the existing wells.
- The sustainable geothermal capacity of further plants can be determined with the existing model in detail. A thermal management plan for sustainable use can be developed