Strategies towards a sustainable thermal use of the shallow subsurface

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ABSTRACT

The thermal use of the shallow subsurface has constantly increased over the last years. Frequently applied techniques that are nowadays used to heat or cool entire residential neighborhoods or industrial facilities include borehole heat exchangers and aquifer thermal energy storage. Despite the capabilities to reduce CO_2-emissions several concerns arise from the intensive thermal use of the subsurface. Potential effects include depletion of groundwater quality with resulting reduction of groundwater ecosystem services and over-exploitation of the thermal potential with resulting reduction of system efficiency. Heat and mass transport by groundwater dispersion and convection may lead to a carryover of effects into groundwater dependent ecosystems. Conflicts between thermal energy use and groundwater protection as well as conflicts between thermal energy users are expected to arise. Therefore, an emerging demand exists to assess potential effects and to develop strategies towards a sustainable thermal use of the shallow subsurface.

1. INTRODUCTION

In Germany, like in other European countries, a rapid increase in the thermal use of the shallow subsurface has developed over the last years to nowadays heat or cool entire residential neighborhoods and industrial facilities. Frequently applied techniques include the exploitation of the shallow geothermal potential, e.g. using borehole heat exchangers (BHE) or aquifer thermal energy storage. The increase in the use of geothermal energy for heat supply in Germany (including shallow and deep geothermal energy as well as ambient heat) during the period 1990-2011 is shown in Fig. 1. In 2011 greenhouse gas emissions in Germany were reduced by 500,000t by the use of geothermal energy for heat supply (BMU 2012). However, as installation numbers rise many areas are developed without sufficient geothermal exploration and monitoring leaving concerns about the potential effects of the intensive thermal use of the shallow subsurface. Potential effects include depletion of groundwater quality with resulting reduction of groundwater ecosystem services and over-exploitation of the thermal potential with reduction of system efficiency. Heat and mass transport by groundwater dispersion and convection may, in addition, lead to a carryover of effects into groundwater dependent ecosystems. Therefore, conflicting interests between geothermal energy use and groundwater protection as well as conflicting use between geothermal energy users are expected to arise especially in densely populated urban areas where the highest demand for the use of shallow geothermal energy is located but exploitation of shallow geothermal energy is limited and, at the same time, groundwater vulnerability is at its highest.

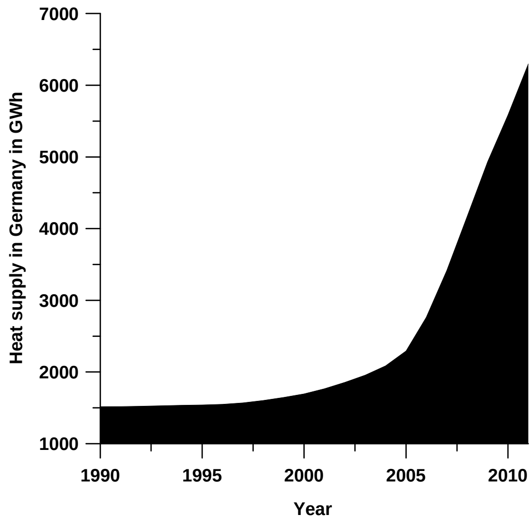

Figure 1: Development of geothermal heat supply in Germany (including shallow and deep geothermal energy, as well as ambient heat).

Until present, a sufficient geothermal exploration and monitoring is performed only in rare cases. A quantitative assessment of potential effects of the intensive use of shallow geothermal energy can often not be made and requires information about small scale groundwater flow fields, local geology, soil matrix properties, and temperature regime. This information is often not obtained prior to system design and planning during individual-based thermal development due to the resulting costs. Research must focus on the development of exploration and monitoring strategies for impact mitigation and quantification to guarantee a sustainable thermal use of the shallow subsurface.

2. GEOTHERMAL EXPLORATION

Different recommendations and guidelines about the exploitation of shallow geothermal energy exist throughout Europe (see Hähnlein et al. 2011) which differ on national level. The high number of guidelines and their limited ambit indicate the problems of setting generally applicable standards. This is mainly caused by the lack of exploration and long-term monitoring data that would allow formulation of standards and guidelines on a scientific basis instead of often limited operating experience. In many real cases, system design is solely based on literature values. Only for large scale applications thermal response tests are performed to determine the thermal conductivity of the subsurface. However, before testing a BHE needs to be readily installed and the information retrieved generally resembles an integral value of thermal conductivity over the entire BHE length. On-site decision making and adaption of geothermal systems are hardly possible using this test. In addition, systems such as BHE are often seen as being decoupled from adjacent systems. System interactions, effects of subsurface heterogeneity, and groundwater dynamics are not considered during planning. This is mainly caused by the simplified assumptions that are needed to reduce calculation and planning efforts. Fig. 2 shows a simplified 2D modeling example to demonstrate the influence of groundwater dynamics on temperature distribution and system efficiency. In case of static groundwater conditions, no interaction of the individual BHE is observed after 209 days of 3^{O} C heat extraction from the groundwater. In contrast, Fig. 2 middle and lower parts show a clear formation of a cool water plume and strong interaction between different BHE's after 209 days heat extraction due to groundwater dynamics despite meeting the recommended minimum distances between BHE's. Especially in areas of intensive thermal use local groundwater flow fields, local geology, soil matrix properties, and temperature regime must be considered as a suitable exploration will contribute to saving resources during installation and guarantee better performance of the system over the proposed system duration time.

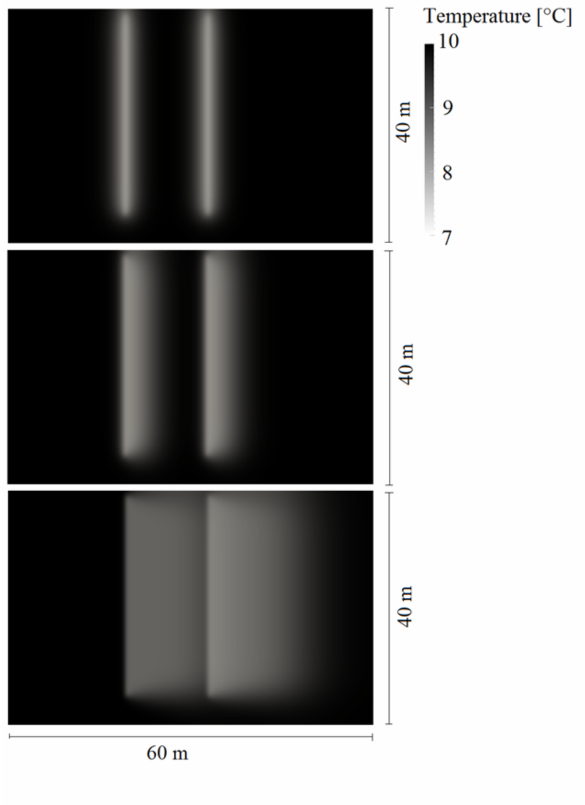

Figure 2: Simulated temperature distribution profiles of two borehole head exchangers within the saturated zone (hydraulic conductivity= $5.0*10^{-4}$ m/s, porosity= 0.2) after 209 days of continuous 3^{o}C heat extraction. Top: No flow, gradient (i)= 0, Middle: i=$5*10^{-4}$; Bottom. i=$1.5*10^{-3}$.

3. IMPACT MONITORING

In general a reduction of groundwater temperature is not considered as adverse effect, e.g. in areas of anthropogenic increased soil and groundwater temperatures. However, groundwater temperature variations may lead to changes in chemical equilibriums and impact the biological biocenosis with possible reduction of ecosystem services. This is of special concern regarding transfer of building heat into aquifers during summer or subsurface heat storage. Arning et al. (2006), Jesußek et al. (2012a) among others investigate temperature induced geochemical reactions. Brielmann et al. (2009), Brielmann et al. (2011) and Jesußek et al. (2012b) focus on potential changes in microbial behavior and activity connected to geothermal applications. Groundwater temperature monitoring is generally performed in groundwater monitoring wells, e.g. by using electric contact meters for reference date measurements or groundwater temperature logging devices for automated continuous temperature logging. The investigation on the variability and induced temperature variations in urban areas started with initial case studies, e.g. Cologne (see Balke 1974), almost 40 years ago. Today, this data is still useful and monitoring of urban groundwater temperature distribution is ongoing in many cities. However, monitoring data is often retrieved from groundwater quality monitoring wells of varying diameter and with different filter depth and length. Current monitoring results indicate a potential effect of well design and filter length on measured groundwater temperatures even for monitoring wells of two inch diameter and less. Fig. 3 indicates an offset in measured groundwater temperature by 0.5 degrees in 1.5 and 2" groundwater temperature monitoring wells depending on the screen length. Monitoring strategies must be developed in regards to design of monitoring wells and spatial and temporal monitoring resolution. Suitable measurement techniques must be identified and evaluated regarding their precision and accuracy.

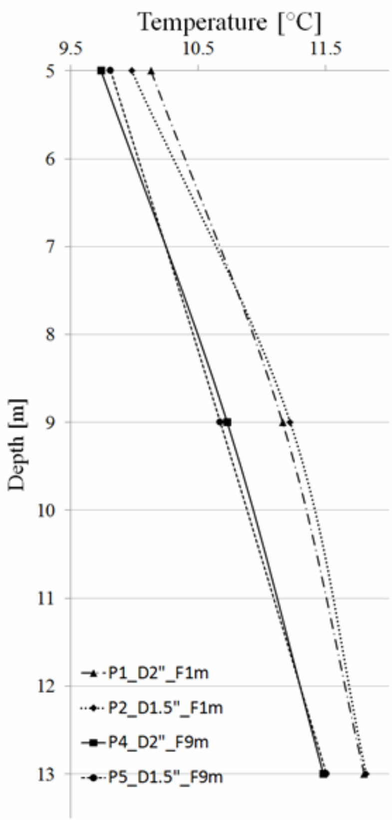

Figure 3: Influence of screen length on the measured groundwater temperature in small diameter temperature monitoring wells. Compared were 1.5" (P2_D1.5" and P5_1.5") and 2" (P1_D2" and P4_D2") diameter monitoring wells with 1 (F1m) and 9 m (F9m) screen length.

3. CONCLUSIONS

The thermal use of the shallow subsurface has been increasing over the last decade while efficient exploration and monitoring strategies are yet missing. Quantitative assessments of potential effects of the intensive thermal use of the shallow subsurface cannot be made in many cases. The development of exploration and monitoring strategies is needed to:

- reduce environmental impacts
- increase resource efficiency
- prevent over-exploitation
- reduce costs during installation and operation

Furthermore, research must focus on the collection of reliable temperature and hydrogeological monitoring data from actual application sites with intensive thermal use of the shallow subsurface as a basis for a better understanding of involved processes and implications under actual geohydraulic conditions for the formulation of guidelines in the framework of a sustainable resource management.

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