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Numerical evaluation and optimization of depth-oriented temperature measurements for the investigation of thermal influences on groundwater

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Increasing groundwater temperatures have been observed in many urban areas such as London (UK), Tokyo (Japan) and also in Basel (Switzerland). Elevated groundwater temperatures are a result of different direct and indirect thermal impacts. Groundwater heat pumps, building structures located within the groundwater and district heating pipes, among others, can be addressed to direct impacts, whereas indirect impacts result from the change in climate in urban regions (i.e. reduced wind, diffuse heat sources). A better understanding of the thermal processes within the subsurface is urgently needed for decision makers as a basis for the selection of appropriate measures to reduce the ongoing increase of groundwater temperatures. However, often only limited temperature data is available that derives from measurements in conventional boreholes, which differ in construction and instrumental setup resulting in measurements that are often biased and not comparable.

For three locations in the City of Basel models were implemented to study selected thermal processes and to investigate if heat-transport models can reproduce thermal measurements. Therefore, and to overcome the limitations of conventional borehole measurements, high-resolution depth-oriented temperature measurement systems have been introduced in the urban area of Basel. In total seven devices were installed with up to 16 sensors which are located in the unsaturated and saturated zone (0.5 to 1 m separation distance). Measurements were performed over a period of 4 years (ongoing) and provide sufficient data to set up and calibrate high-resolution local numerical heat transport models which allow studying selected local thermal processes.

In a first setup two- and three-dimensional models were created to evaluate the impact of the atmosphere boundary on groundwater temperatures (see EGU Poster EGU2013-9230: Modelling Strategies for the Thermal Management of Shallow Rural and Urban Groundwater bodies). For Basel, where the mean thickness of the unsaturated zone amounts to 19 m, it could be observed that atmospheric seasonal temperature variations are small compared to advective groundwater heat transport.

At chosen locations: i) near the river Rhine to study river-groundwater interaction processes, ii) downstream of a thermal groundwater user who uses water for cooling and infiltrates water with elevated temperatures and iii) downstream of a building structure reaching into the groundwater saturated zone, models were further extended to study selected thermal processes in detail and to investigate if these models can reproduce thermal impacts in the vicinity of the temperature measurement devices. Calibration, based on the depth-oriented temperature measurements, was performed for the saturated and unsaturated zone, respectively.

Model results show that, although depth-oriented measurements provide valuable insights into local thermal processes, the identification of the governing impacts is strongly dependent on an appropriate positioning of the measurement device. Numerical simulations based on existing flow- and heat transport models, considering the site specific local hydraulic and thermal boundary conditions, allow optimizing the location of such systems before installation. Furthermore, the results of the local heat transport models can be transferred to regional scale models which are an important tool for thermal management in urban areas.