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Long term evolution of the urban heat island beneath the city of Karlsruhe, Germany

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Increased air and surface temperature in urban areas are a widely spread phenomenon commonly referred to as urban heat islands (UHI). However, changes in the urban environment also lead to increased subsurface temperatures and cause extensive thermal anomalies in shallow urban aquifers. The reasons for this heating are manifold as several possible heat sources exist in the urban subsurface. Previous studies have primarily discussed basements and increased surface temperature as possible cause for heterogeneous groundwater temperature distribution. But also, sewers and district heating networks are likely to influence the temperature of the surrounding subsurface. In this study, the spatial distribution of groundwater temperature in the city Karlsruhe, Germany, is analyzed using a data set from 1977 and recent measurements from 2011. Furthermore, the anthropogenic heat input in the urban groundwater is quantified by a spatially resolved heat flux model. In the latter, several heat transport processes are considered, such as heat flux from basements and sewers, heat loss from district heating networks and heat input due to increased ground surface temperatures (GST) and reinjections of thermal waste water. Uncertainties are accounted for in a Monte Carlo simulation. In order to investigate the long-term evolution of the subsurface thermal regime, we compared the heat fluxes for the years 1977 and 2011. In both years, the spatial distribution of groundwater temperatures exhibits the highest temperatures under the city center and a large industrial site. Compared to 1977 background temperatures in 2011 have increased by approximately 1 K, while the maximum temperature is nearly equal. However, the area of the thermal anomaly has spread notably in the last 30 years. In both years the largest mean heat fluxes occurred from increased GST and basements. The development of the heat flux from increased GST reflects the evolution of surface air temperature (SAT), while the gain in heat flux from buildings is caused by increasing building density in the urban area of Karlsruhe. The other processes yield considerably lower heat fluxes and play only a minor role for the heating of the subsurface. Yet, given that only around 20% of the study area are covered by buildings, the dominant heat source regarding the mean energy amount are the elevated GST. They contribute with 13 MW in 1977 and 19 MW in 2011 to the total anthropogenic heat input of around 33 MW for both years.