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Multi-scale groundwater modelling for the assessment of sustainable borehole yields under drought

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A new multi-scale groundwater modelling methodology is presented for simulating abstraction boreholes in regional groundwater models. This provides a robust tool for assessing the sustainable yield of supply boreholes, thus improving our understanding of groundwater availability during droughts.

The yield of an abstraction well is dependent on a number of factors. These include antecedent recharge and groundwater conditions; the properties of a regional aquifer system; requirements on a groundwater system to maintain river flows or sites of ecological significance; the properties of an individual abstraction borehole; small-scale aquifer heterogeneity around a borehole; the rate of abstraction; and the way in which neighboring abstraction boreholes interact. These factors can all be represented in the multi-scale model, which couples a small-scale radial flow model of an abstraction borehole with a regional-scale groundwater model. The regional groundwater model, ZOOMQ3D, represents the large-scale groundwater system, including lateral and vertical aquifer heterogeneity, rivers, and spatially varying recharge. The 3D radial flow model, SPIDERR, represents linear and non-linear flow to a borehole, local vertical heterogeneity, well storage and pump location.

The multi-scale model is applied to a supply borehole (operated by Thames Water) located in the Chalk aquifer within the catchment of the River Thames in southern England. Groundwater abstraction from the Chalk aquifer accounts for 40-70% of the total public water supply in this region. Drought is a recurring feature of the UK climate, and in particular the south and east of England. Since 1850, nine major groundwater droughts have occurred, all of which lasted longer than one year. The most recent occurred in 2010-2012, during which seven water supply companies introduced water usage restrictions, affecting over 20 million people.

The radial flow model is initially calibrated against pumping test data from the supply borehole. It is then coupled with an existing regional groundwater model, which covers a significant part of the unconfined Chalk aquifer within the Thames Basin. The fully coupled model is run over the historic simulation period, 1971-2012, using operational abstraction rates at the supply borehole. Simulated heads at the borehole are compared with observed data over the period 2003-2012 allowing further calibration of the small-scale model. Several abstraction scenarios are then applied over the historic simulation period. Analysis of the pumped water levels allows us to develop an improved understanding of the sustainable yield of the source under drought conditions.

The multi-scale model also provides a tool for assessing future changes to groundwater availability due to potential changes in the frequency, duration and intensity of droughts under climate change, and under scenarios of increasing demand.