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Research papers

An upscaling procedure for the optimal implementation of open-loop geothermal energy systems into hydrogeological models

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ABSTRACT

Different aspects of management policies for shallow geothermal systems are currently under development. Although this technology has been used for a long time, doubts and concerns have been raised in the last years due to the massive implementation of new systems. To assess possible environmental impacts and manage subsurface energy resources, collecting data from operating shallow geothermal systems is becoming mandatory in Europe. This study presents novel advances in the upscaling of operation datasets obtained from open-loop geothermal energy systems for an optimal integration in hydrogeological models. The proposed procedure allows efficient numerical simulations to be performed at an urban scale. Specifically, this work proposes a novel methodology to optimize the data treatment of highly transient real exploitation regimes by integrating energy transfer in the environment to reduce more than 90% registered raw datasets. The proposed methodology is then applied to and validated on five different real optimization scenarios in which upscaling transformation of the injection temperature series of 15-min sampling frequency has been considered. The error derived from each approach was evaluated and compared for validation purposes. The results obtained from the upscaling procedures have proven the usefulness and transferability of the proposed method for achieving daily time functions to efficiently reproduce the exploitation regimes of these systems with an acceptable error in a sustainable resource management framework.

1. Introduction

Shallow geothermal systems are based on obtaining the heat energy from materials of the most superficial layers (< 250 m) of the Earths crust and the water that flows through them. The heat transfer from the Earth's core to the outer areas of the crust and the capacity of the ground to dampen thermal oscillations occurring on the surface make thermal stability possible, starting at a depth of approximately 15 m. After the damping of thermal oscillations with depth, the ground temperature is similar to the annual average temperature of the region plus 1 °C or 2 °C (Parsons, 1970). This terrain feature justifies the development of these important systems as an adaptative measure to climate change for renewable energy development (Bayer et al., 2012). The 'potential natural state of the aquifer' is defined as a state without anthropogenic influences (Epting and Huggenberger, 2013). Heat exchange with the ground can be performed by different types of ground source energy (GSE) systems, including closed or open systems, by using heat pumps coupled with heat exchangers. Open systems, also called groundwater heat pumps (GWHPs), take direct advantage of the heat or cold of pumped groundwater and subsequently reinject pumped water into the aquifer (García-Gil et al., 2014a). GWHPs, and GSE in general, are widely used worldwide and their demand is expected to increase in the next years (Epting et al., 2017; Jaudin, 2013; Lund and Boyd, 2016). The increasing trend of GWHPs has resulted in an additional heat load in urban aquifers, caused both by thermal interference between systems and interference between well doublets, that is, the thermal autointerference effect (Galgaro and Cultrera, 2013; Garrido et al., 2010b). Because the geothermal exploitation of the aquifer is not

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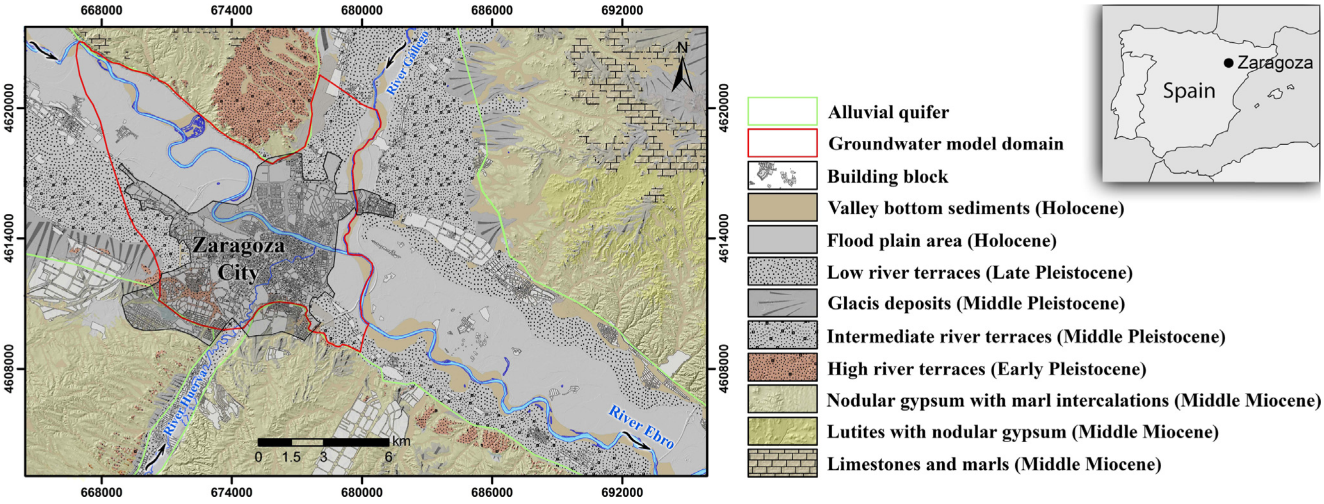

Fig. 1. Study area covering the metropolitan area of Zaragoza in the central sector of the Ebro River Basin (Spain), the confluence zone of the Gállego and Huerva River tributaries.

consumptive, thermal pollution derived from these systems is the main impact on the aquifer (Lo Russo et al., 2014). The problems associated to the implementation of GWHPs originate both from the lack of energy sustainability of the facilities due to thermal interference events (Garrido et al., 2016) and from an insufficient legal framework. The required regulatory frameworks to ensure sustainable exploitation of aquifer heat energy resources, particularly beneath cities where there may be overlapping and conflicting demands on the resource, are still being developed, therefore generating great uncertainty for users (García-Gil et al., 2015).

One of the possible ways to enhance the management of geothermal systems is using numerical models to simulate the thermal regime in the urban aquifer and to establish effective management strategies (Banks, 2009). This approach allows considering the high complexity of these facilities, the heterogeneity of the medium, and the temporal variability of their operations in an integrated way. On the other hand, these methods have two limitations, that is, the high volume of data and the time requirements (García-Gil et al., 2014a). The modelling process of GWHP systems was carried out using data from specific discrete measurements in previous studies (Epting et al., 2013; Gropius, 2010; Herbert et al., 2013). This simplification was applied as an appropriate approximation considering the inherent difficulties in the monitoring of such complex installations and the consequent lack of exploitation regime datasets. Currently, regulators are increasingly requiring monitoring data on the operation of GWHP systems. These systems typically operate following a design power, and thus, as building demand varies, the schemes may operate continuously or rather intermittently. Particularly, the system may have a rather short operational cycling period at locations where a scheme delivers a high proportion of the total heating or cooling demand. This leads to the need for very high frequency monitoring data to characterise the system's operation. In contrast, numerical modelling becomes computationally expensive and time consuming if this short cycling detail is to be represented explicitly.

The main purpose of this study is to develop and validate a methodology to obtain, as optimally and efficiently as possible, a subset of maximal representative data, which can be easily implemented in numerical heat transport models, that is, to obtain data subsets for numerical models resulting in minimum deviations when compared with original data. Validation of the proposed methodology under standard hydrogeological parameters is carried out to ensure its transferability to other aquifers operated by GWHPs. This objective achievement will constitute an improvement in attaining a scientific-based management tool, which allows the reproduction of real exploitation regimes and, therefore, the aquifer response to intensive shallow geothermal exploitation, a requirement in obtaining a global vision necessary for aquifer management. Accomplishing this objective will help to understand the hydrodynamics and existing heat transport processes beneath urban environments, thus contributing to the improvement of sustainable management of shallow geothermal resources (Epting et al., 2013; Spitler, 2005). To reach this goal, different upscaling techniques were considered in this work, to transform high-resolution datasets obtained from high frequency data logging into lower frequency data subsets (Bierkens et al., 2000; Finke et al., 2002). The upscaling procedure has been widely used and developed in applied research typical in environmental science, where specific questions raised by society's decision makers (policy scale) and observation scale are not met. The scale transfer procedure or upscaling has been classified by Bierkens et al. (2000) depending on the involvement or non-involvement of a model in the research cycle, the possible linear relationship between the model and input variables and parameters, the applicability of the model to different locations/time steps, the form of the model at different scales or the possibility of deriving analytically a different scale model. The major classes of upscaling methods consist of averaging the observations or output variables (Brus and de Gruijter, 1997; Viscarra Rossel et al., 2016), finding representative parameters or input variables (Dagan, 1981; Wu et al., 2006), averaging the model equations (Bedrikovetsky, 2008; Whitaker, 1986) and performing a model simplification (de Vries et al., 1998; Vogler et al., 2018). The upscaling procedure applied in this paper corresponds to the methods finding representative parameters since the input variables of the model involved are non-linear, so it cannot be applied at many time steps and the model has the same form at the two scales involved (Bierkens et al., 2000). Furthermore, since it is not possible to obtain output variables at the larger scale and input data at the source scale is exhaustive, deterministic methods have been applied in accordance with previous studies (Bierkens and van der Gaast, 1998; Johannes Dolman and Blyth, 1997; Yu et al., 2016). Finally, a sensitivity analysis was performed by numerically modelling different upscale scenarios to optimize the procedure and to perform and conduct an error assessment.

2. Study site

The present work was carried out within the framework of the urban alluvial aquifer of Zaragoza (Fig. 1) located in the central sector of the Ebro River Basin (Spain). This basin constitutes the last stage in the evolution of the southern foreland basin of the Pyrenees (Barnolas and Robador, 1991; Pardo et al., 2004). The portion of the aquifer covering