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Relaxation factor for geothermal use development – Criteria for a more fair and sustainable geothermal use of shallow energy resources

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ABSTRACT

This study attempts to promote new groundwater thermal management policies for the shallow geothermal energy sector, which is currently at risk of stalling due to the existing uncertainty of its international legal status. The physical constraints affecting groundwater thermal management policies are described as a basis for a later proposal of an approval process protocol for new shallow geothermal installations. The policy proposed for this process is based on numerical modeling and a relaxation factor which reserves a fraction of shallow geothermal energy resources for possible third party installations thus preventing its monopolization. The policy is then applied to simulate a concession process in a real urban groundwater body highly affected by ground source heat pumps. A calibrated numerical groundwater flow and heat-transport model has been utilized for the evaluation of the thermal response of the aquifer to a new projected installation and the thermal interference risk associated. The results obtained from the protocol application have proven its practical value in the sustainable management of shallow geothermal energy resources and in ensuring stakeholders water rights. In addition, a specific policy impact indicator was derived that should be of interest for numerical water policy assessment initiatives.

1. Introduction

Heating represents an essential part of the energy needs of modern society. In the European Union, in 2010, heating accounted for 47% of total energy consumption (Sanner et al., 2011). Traditionally, heating and cooling is provided by combustion of fossil fuels, causing not only society dependence on those finite resources but also greenhouse gas emissions influencing the global climate (IPCC, 2007, 2013). In this context, shallow geothermal energy (<400 m depth) represents a renewable energy source with potential energy and environmental savings (Jaudin, 2013). As reported by Lund et al. (2011), among global geothermal direct applications in 2010, ground-source heat pumps (GSHP) were the largest application, with an installed capacity of 33,134 MWt and an annual energy use of 200,149 TJ/yr. The size of individual installations ranges from 5.5 kW for residential use to large installations of over 150 kW for commercial and institutional installations. Considering an equivalent installation of 12 kW (typical of US and Western European homes), the estimated number of installed geothermal installations in 2010 was approximately 2.76 million, four times more than in 2000. In addition, the increasing popularity of GSHPs reveals the great potential of this technology for the future, as has been seen in the European Union, where a total of 3.7 Mt of CO_2 emissions were avoided in 2008 (Bayer et al., 2012).

In urban areas, the use of water as a cheap cooling medium is expected to continue increasing with the rates presented above, but there are still two main barriers at different levels that affect the implementation of geothermal systems.

One barrier is thermal interference, where the production wells (or borehole heat exchanger) may be exposed to intra-system as well as inter-system interference, compromising the usable lifetime of geothermal systems. Intra-system thermal interference is known as a thermal short circuit (Galgaro and Cultrera, 2013), where the thermal energy loaded by the heat pump is finally recirculated through the heat pump itself, drastically reducing the efficiency of the system. Inter-system thermal interference is produced when the production wells (or borehole heat exchanger) are influenced by an affected thermal groundwater regime, whether

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due to natural causes (e.g., river–aquifer interaction, surface recharge, atmosphere temperature fluctuation, among others) or to anthropogenic changes such as groundwater use by other external GSHP systems (Ferguson and Woodbury, 2007; Herbert et al., 2013; Taniguchi et al., 2005; Zhu et al., 2011).

The second barrier is uncertain legislative development. Water authorities promote the use of shallow geothermal energy, but simultaneously, they also demand the adherence of existing legislations concerning the good quantitative and qualitative status of groundwater bodies. Because unrestricted shallow geothermal energy use compromises groundwater quality energetically, chemically and biologically, a clear regulatory and legislative framework is required. Administrative regulations that restrict groundwater thermal regime changes are still evolving worldwide. A recent comprehensive review (Haehnlein et al., 2010) has shown the diverse international legal status of the use of shallow geothermal energy; in most of the countries, there are no regulations or recommendations for temperature limits for the thermal exploitation of aquifers. If regulations are considered, the criteria adopted can vary substantially and appear to be empirically defined rather than scientifically and technically evaluated. Moreover, this review of the legal status of the use of shallow geothermal energy has shown that even countries with similar climate and hydrogeological conditions might adopt completely different regulations.

There is clearly a need to converge uneven regulatory frameworks into objective and scientifically motivated criteria. A crucial challenge is to allay uncertainties with the achievement of a clear regulatory and legislative framework so that the only barriers to the development of the shallow geothermal energy sector are environmental or economic in nature. The existent complex transient boundary conditions typically found in urban environments exclude the possibility of an analytic-generalized approach which resulted in a lack of success to date in management policies. Therefore, there is a generalized agreement among experts in the literature (e.g., Banks, 2009; Epting and Huggenberger, 2013) indicating that numerical modeling is the best tool to face this challenge. Although some approximations to concession granting process criteria of deep geothermal resources (>400 m depth) exploitation can be found in the literature (Rman et al., 2011), to date, no specific research analyzes and discusses the thresholds, indicators and assumptions that must be taken into account in this concession granting process for shallow geothermal resources exploitation.

The first objective of this study was to propose the fundamental criteria needed for the concession process of new licenses to exploit shallow geothermal resources. This criteria should take into account, to the greatest possible extent, three main principles: (1) sustainability which guarantees an energetically balanced system and therefore a renewable utilization of the resources, (2) legal certainty which guarantees the stakeholders investments and (3) equal opportunity which guarantees a fair exploitation of the resources. The second objective is to propose a concession process protocol as an approach for the assessment of shallow geothermal energy resources following the previously defined criteria. Finally, as an example application and protocol utility verification, we simulate a complete concession process for a new theoretical shallow geothermal exploitation in a real alluvial urban aquifer in Zaragoza (Spain) that is highly affected by GSHPs.

2. Problem approach and the relaxation factor (RF) concept

2.1. Implications of urban hydrogeology complexity in thermal management of aquifers

The importance of groundwater flux in advective heat transport processes reveals the need for a conceptual and 3D numerical hydrogeological model for the prediction of the aquifer response to shallow geothermal energy exploitation and hence the thermal management of the aquifer. Complexity becomes of special relevance in an urban environment, not just due to the heterogeneity of the hydraulic and thermal parameters but also because of numerous subsurface structures as well as diverse groundwater use activities that vary temporally and spatially. The number of the different flow and heat-transport processes and boundary conditions which are relevant for urban subsurface resources are numerous namely elevated ground surface temperatures, basements, sewage systems, metro tunnels, district heating networks, surface recharge, groundwater withdrawal, shallow geothermal installations or river-aquifer interaction. In the case of ground water heat pumps (GWHP) systems the extraction of groundwater is involved. As this volume of water is re-injected back into the aquifer, the hydraulic response of the aquifer is negligible at a regional scale. At a local scale, however, the hydraulic response determines the possibility of a thermal short circuit, which would compromise the usable lifetime of the geothermal system (Galgaro and Cultrera, 2013). When pumped groundwater is discharged to the sewer system, a drawdown of the piezometric surface is produced. Because no temperature change occurs due to injection of heated (or cooled) water, there is no thermal impact to the aquifer, but the hydraulic gradients in the aquifer are modified. These modifications change the thermal regime of the aquifer and hence potentially affect the efficiency of other geothermal installations. These potential efficiency changes need to be evaluated whether from an analytical approach or a numerical one when the grade of complexity cannot be handled by simple analytical models (Banks, 2009). Moreover, the consumptive use of groundwater (i.e., a pumping rate higher than the reinjection rate) produces a drawdown or cone of depression that needs to be regulated by means of a maximum drawdown or pumping rate which is usually adopted depending on the unique and diverse characteristics of the groundwater resources managed. In the case of ground-coupled heat pump (GCHP) systems the heat pump is connected to a closed-loop network buried in the ground and a water solution is circulated through the pipe network transferring heat between the ground and the heat exchanger. Although this systems do not produce any kind of hydraulic impact in the aquifer, the advection of heat takes place in aquifers due to groundwater flow giving as a result similar heat plumes to the ones generated by GWHPs. Consequently, the implementation of these systems in a numerical model are similar, even simpler for GCHPs since the groundwater regime is not altered by these systems.

Previous management approaches considering GIS-systems or analytical simplified models which do not take into account non-stationary flow and thermal processes were designed for authorities which not necessarily employ hydrogeological specialists, and the regulations have attempted to provide a simple tool for the wide range of complex problems in urban environments as seen above, therefore sacrificing the accuracy needed. These simplified approaches seem to be less effective and have resulted in a rather diverse international legal status that is a barrier to shallow geothermal energy development (Abesser, 2010; Haehnlein et al., 2010; Jaudin, 2013). Another negative consequence of ambiguous, not scientific-based regulation is a monopolization of shallow geothermal resources, resulting in the rule “first come, first served” (Epting et al., 2013), which is against sharing resources and the principle of public domain as well as the sustainable use of resources in general.

2.2. Effective decision support tools

One of the best ways to improve policy guidance for urban decision-makers seems to be the ability to see “the big