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Analytical framework for borehole heat exchanger (BHE) simulation influenced by horizontal groundwater flow and complex top boundary conditions

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Borehole heat exchangers (BHE) are the most widely used technologies for tapping low-enthalpy energy resources in the shallow subsurface. Analysis of these systems requires a proper simulation of the relevant processes controlling the transfer of heat between the BHE and the ground. Among the available simulation approaches, analytical methods are broadly accepted, especially when low computational costs and comprehensive analyses are demanded. Moreover, these methods constitute the benchmark solutions to evaluate the performance of more complex numerical models. Within the spectrum of existing (semi-)analytical models, those based on the superposition of problem-specific Green's functions are particularly appealing. Green's functions can be derived, for instance, for nodal or line sources with constant or transient strengths. In the same manner, functional forms can be obtained for scenarios with complex top boundary conditions whose temperature may vary in space and time. Other relevant processes, such as advective heat transport, mechanical dispersion and heat transfer through the unsaturated zone could be incorporated as well. A keystone of the methodology is that individual solutions can be added up invoking the superposition principle. This leads to a flexible and robust framework for studying the interaction of multiple processes on thermal plumes of BHEs. In this contribution, we present a new analytical framework and its verification via comparison with a numerical model. It simulates a BHE as a line source, and it integrates both horizontal groundwater flow and the effect of top boundary effects due to variable land use. All these effects may be implemented as spatially and temporally variable. For validation, the analytical framework is successfully applied to study cases where highly resolved temperature data is available.