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How to assess the thermal plume of groundwater heat pump systems?

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The number of groundwater heat pump (GWHP) systems is growing in many countries and dense installations of urban areas lead to thermal interference among neighboring wells. The assessment of the thermal plumes caused by GWHP systems is a necessary step to sustainable manage the geothermal potential beneath cities and to validate the feasibility of a project. The presented work therefore focuses on the characterization of thermal plumes from GWHP systems: Should we use analytical solutions easy to implement or time-consuming numerical models? How accurate should be the used hydro-geo-thermal parameters to get a realistic representation of the thermal plume? How to represent transient thermal impacts of GWHP systems? The suitability of three analytical solutions – (1) radial, (2) linear advective and (3) planar advective models – is assessed by comparison with two-dimensional and three-dimensional numerical simulations under various background groundwater flow velocities. Additional numerical simulations are performed to scrutinize the role of key flow and heat transport parameters. The inspected analytical solutions are straightforward to use and reveal to be suitable for first-tier impact assessment and for supporting integrated spatial planning in cities. Furthermore, a sensitivity analysis is carried out to scrutinize the influence of (1) background flow velocity, (2) longitudinal and transverse dispersivity, (3) parameters describing the heat injection, and (4) temporal discretization of the energy load. This analysis is based on a maximum thermal plume representation that incorporates the variations of plume extension over a year after decades of seasonally imbalanced heat injection. It is demonstrated that the longitudinal and transverse dispersivities have a dominant influence on the plume extension and its transient evolution. A comparison with numerical simulations using averaging of the thermal load shows that background groundwater flow velocities and dispersity coefficients strongly influence the applicability of simplified analytical models. The simulation results do not only clarify the application windows of analytical models, but they also contribute to an improved understanding of the key factors for the thermal plumes caused by such open geothermal systems.