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Numerical Investigation of Reverse Water Level Fluctuations under Non-Isothermal Conditions with a Fully Coupled Thermal-Hydro-Mechanical Model for Geothermal Heat Pump Systems

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In the realm of harnessing geothermal energy, groundwater heat pumps exhibit superior thermal efficiency when compared to closed-loop geothermal heat pumps. However, the outlook for progress remains less than promising. A primary obstacle stems from the improper extraction of groundwater, which can disrupt the stress field in subsurface structures and potentially trigger land subsidence. This concern is particularly pronounced in unconsolidated soils found in coastal sedimentary plains, where the additional threat of severe flooding disasters looms. Furthermore, artificial pumping processes may give rise to coupled hydraulic phenomena, exemplified by the reverse water level fluctuations. This transient anomalous changes in hydraulic head occurs in adjacent aquifers during the initial stages of pumping from a confined aquifer, induced by strain propagation. The magnitude of the hydraulic head elevation varies from a few centimeters to several tens of centimeters, posing a challenge to the accurate interpretation of groundwater monitoring data for land subsidence prevention. Geothermal heat pump systems can also induce changes in the temperature and thermal strain of geological layers. Consequently, understanding how this strain-induced hydraulic head responds to temperature fluctuations becomes a research question. In our investigation, the hydraulic and mechanical responses of a three-layer aquifer system to groundwater pumping were assessed through thermoporoelastic numerical simulations. The simulated reverse hydraulic head changes align with field observations documented in the literature. The findings of this numerical investigation indicate that when we recharged the water into the ground, the initial head decrease is likely to occur in proximity to a recharge well within an unpumped clay layer. These deformation-induced head changes eventually dissipate following the hydraulic propagation of unsteady state drawdown from the pumped aquifer into adjacent layers. In the event of reverse water level fluctuation, it is shown that temperature has no obvious influence on the hydraulic variation, both the head variation and happening time. It is also suggested that the propagation of thermally induced strain is slower than that of hydraulically induced strain and the effect appears much later.