EGU21-7083, updated on 22 Jan 2022
https://doi.org/10.5194/egusphere-egu21-7083
EGU General Assembly 2021

Groundwater flow pattern and age distribution under transient conditions

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The distribution of groundwater ages under transient conditions are investigated by a numerical model coupled groundwater flow and age, and the nested pattern of groundwater flow are determined by the probability density function of residence time. The variation of local groundwater flow system to the fluctuation of upper boundary head evolves rapidly. During the process from the initial steady to the unsteady state, the groundwater age field evolves with simulation time and gradually reaches a new dynamic equilibrium after about 50 years. The age abrupt interface between the local and intermediate flow systems gradually shifts upward, and the scale of the local flow system gradually decreases. The groundwater ages of the regional and intermediate flow systems are mainly controlled by the long-term dynamic component of the upper boundary head, while the local flow systems are mainly influenced by the transient periodic fluctuation. The location of the stagnation points are mainly controlled by the upper boundary head. The larger head difference between recharge and discharge area is, the greater penetrated depth of the stagnation point is. The location of the stagnation point indicates the penetrated depth of the local flow system. The larger head fluctuates, the deeper stagnation point is, leading to a greater penetration depth of the local flow system. Molecular dispersion causes the scatters of residence time probability density function to aggregate near the inflection point, and the aggregation area mainly locates at the junction of basin-scale flow systems. The transition of groundwater flow field will intensify the mixing of old and new water, leading to the blurring or even disappearance of the residence time abrupt interface. The dispersion of groundwater mixing is poor in steady state, and the convective-dispersive effect gradually increases with time in unsteady state. Traditional hydraulics methods based on flow nets and stagnation points can effectively identify the groundwater flow system, but the differences in groundwater chemical characteristics and ages at long-term scales cannot be clearly described by these methods, as well as the evolution of groundwater flow system at long time scale. The groundwater residence time distribution expressed by the probability density function, which comprehensively involves the spatial and temporal information of groundwater interaction, can help accurately distinguish different groundwater flow systems at long time scales. The methods proposed in this study will act as a meaningful guidance for the delineation of groundwater flow system in the real world.