Simulation of Pumping Induced Groundwater Flow in Unconfined Aquifer Using Arbitrary Lagrangian-Eulerian Method

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Abstract

Extensive research has been conducted to accurately characterize unconfined aquifers in the subject of groundwater hydrology. Analyzing pressure response data (i.e. hydraulic head or the changes in head) from pumping and recovery tests is commonly used to determine the aquifer properties. Mathematically, the difficulties of modeling unconfined situation lies on the non-linear problem resulted by changing groundwater table, while it is linear in confined aquifer. Classical approach following Dupuit-assumption (1863) has been developed during the last decades, which only considers groundwater flow horizontally. However, recent literature on analyzing complex pumping induced flow process in unconfined aquifers has demonstrated the importance of considering vertical flow especially in the vicinity of the pumped wells. Moreover, the classical approach is not sufficient to describe the influence of complex conditions, i.e. aquifer anisotropy and heterogeneity, partially penetrated well, on drawdown. Aside from the inaccuracies due to the fact that Dupuit assumption does not hold, the classical approach does not suffice to describe some application problems. For example, "Pumping and Injecting in a Single Borehole" (see Y.Jin et.al, COMSOL News 2012) at different depths cannot be treated with classical method, if the aquifer is not separated by impermeable or semi-permeable layers. We developed innovative numerical model that not only takes non-zero velocity components in vertical directions, but also flexible to adapt complex aquifer conditions. The model is set up by using Darcy's Law and Moving Mesh physics interface from COMSOL Multiphysics 4.2a. The groundwater table is considered as unknown free surface, where atmospheric pressure condition is applied. The groundwater flow is driven by flux condition in Darcy's Law physics interface, while the drawdown is calculated by applying arbitrary Lagrangian-Eulerian (ALE) method and presented via deformed mesh. We coupled these two physics by connecting the flow equation with the movement of the boundary. The deformed mesh for steady state groundwater drawdown problem is depicted in Figure 1. We compared the numerical model result with steady state analytical solution (Thiem equation) as well. Regardless of the small deviation in the vicinity of the pumping well, our simulation agrees well with Thiem solution. The well agreement promises further applications of our model for more mentioned complex situations. As an application example, we also demonstrate the case of partially penetrated well in Figure 2. For the next step, we will characterize the aquifer of Korschenborich in Germany (DSI Project) with our model. In the model, we attempt to include the influence of ambient groundwater flow as well as seasonal change of groundwater recharge and/or discharge.

Reference

1. Dupuit J., Etudes théoretiques et practiques et pratiques sur le mouvement des eaux dans les canaux découverts et à travers les terrains perméables, Paris, 1863.

Figures used in the abstract

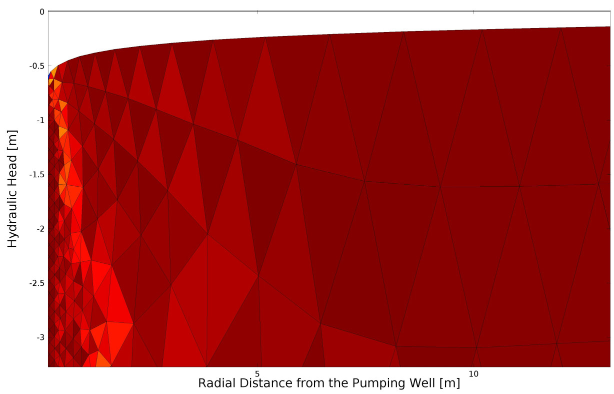

Figure 1: Hydraulic Head (drawdown) presented by deformed mesh.

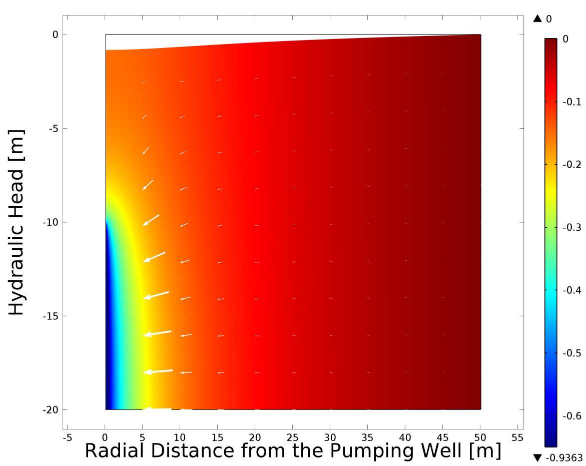

Figure 2: Drawdown induced by partial penetration of well.