Seawater intrusion in fractured coastal aquifers: preliminary investigation using a discretely fractured Henry problem

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ABSTRACT

Coastal aquifers globally are under threat from seawater intrusion (SWI) (Chang and Yeh 2010). The extent of saltwater and of SWI in heterogeneous (e.g. fractured) aquifers is not well-understood relative to homogeneous (unfractured) aquifers (Allen et al. 2002). SWI in fractured coastal aquifers has been observed at several field sites (e.g. Caswell 1979; Barcelona et al. 2006), where fractures provide preferential flow paths that either facilitate or inhibit the inland migration of seawater. Despite this, numerical investigations that explore SWI processes and the persistence of seawater in fractured versus unfractured aquifers, are rare. Groundwater flow in fractured systems can be approximated using an equivalent porous media (EPM) model if the representative elementary volume is large enough (Pankow et al. 1986; Scanlon et al. 2003). However, accurate simulation of transport processes remains problematic due to difficulties with establishing the geologic controls on these systems (e.g. fracture spacing and fracture aperture) (Krásný and Sharp 2007). For this reason, discrete fracture network (DFN) models are useful tools for investigating groundwater flow and solute transport in fractured aquifers because they allow the validity (or otherwise) of EPM approximations to be tested (e.g. Vujević et al. submitted).

The purpose of this study is to determine how the structural properties of fracture networks influence both groundwater flow and solute transport processes (i.e. SWI) in fractured coastal aquifers. We examine the role of fracture location, orientation and density in SWI by applying DFNs to modified forms of the Henry (1964) seawater intrusion benchmark problem. Groundwater flow and solute transport are simulated for aquifers containing either a single fracture (anisotropic problem) or a network of regularly spaced, continuous, orthogonal fractures (isotropic problem) embedded within a permeable matrix. Simulations are carried out using HydroGeoSphere (Therrien et al. 2009), which solves 3D variable-density flow and solute transport in discretely fractured porous media. We compare metrics of SWI (e.g. the saltwater wedge toe location and width of the mixing zone) in the fractured cases with an EPM model, for steady-state groundwater flow conditions.

Our results show that the EPM model can predict reasonably well the inland extent of seawater (i.e. the saltwater wedge toe location) in the anisotropic, fractured Henry problem if the aquifer contains a single horizontal, centrally located fracture. The toe location in the fractured Henry problem is either under or overestimated (5-60%) by the EPM model if the horizontal fracture is positioned in the top or bottom halves of the aquifer, respectively. Horizontal fractures in the upper half of the aquifer facilitate the landward intrusion of seawater beneath the fracture. Conversely, horizontal fractures positioned in the lower half of the aquifer inhibit seawater intrusion and increase the width of the seawater-freshwater mixing zone.

We further demonstrate that predictions using the EPM model overestimate (4-10%) the toe location and underestimate the width of the seawater-freshwater mixing zone in aquifers containing a single, continuous vertical fracture. Vertical fractures in the saltwater wedge enhance transverse dispersion, increasing the width of the mixing zone. The EPM model predictions fail to capture the enhanced vertical mixing of incoming seawater and outgoing freshwater.

EPM model predictions do not represent adequately the extent of SWI in the isotropic, fractured Henry problem (containing networks of continuous, orthogonal fractures). Our simulations show that the steady-state seawater distribution is influenced strongly by the fracture density, i.e. the saltwater wedge typically retreats seawards and the width of the mixing zone increases as the fracture density increases. Predictions from the EPM model overestimate the position of the saltwater wedge toe by 10-20%.

Our results provide insight into how SWI is influenced by the structural properties of fracture networks. Further, we demonstrate that knowledge of the fracture network geometry is required to predict adequately the extent of saltwater contamination in fractured coastal aquifers.

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