Characteristics of active seawater intrusion

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A B S T R A C T
The inland migration of seawater in coastal aquifers, known as seawater intrusion (SWI), can be categorised as passive or active, depending on whether the hydraulic gradient slopes downwards towards the sea or the land, respectively. Despite active SWI occurring in many locations, it has received considerably less attention than passive SWI. In this study, active SWI caused by an inland freshwater head decline (FHD) is characterised using numerical modelling of various idealised unconfined coastal aquifer settings. Relationships between key features of active SWI (e.g., interface characteristics and SWI response time-scales) and the parameters of the problem (e.g., inland FHD, freshwater-seawater density contrast, dispersivity, hydraulic conductivity, porosity and aquifer thickness) are explored for the first time. Sensitivity analyses show that the SWI response time-scales under active SWI situations are influenced by both the initial and final boundary head differences. The interface is found to be steeper under stronger advection (i.e., caused by the inland FHD), higher dispersivity and hydraulic conductivity, and lower aquifer thickness, seawater density and porosity. The interface movement is faster and the mixing zone is wider with larger hydraulic conductivity, seawater-freshwater density difference, and aquifer thickness, and with lower porosity. Dimensionless parameters (Peclet number and mixed convection ratio) from previous steady-state analyses offer only limited application to the controlling factors of passive SWI, and are not applicable to active SWI. The current study of active SWI highlights important functional relationships that improve the general understanding of SWI, which has otherwise been founded primarily on steady-state and passive SWI.

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1. Introduction

Seawater intrusion (SWI) is a phenomenon where seawater displaces fresh groundwater in coastal aquifers (Bear, 1979). The global significance of SWI is well-established (Wu et al., 1993; Bocanegra et al., 2010; Custodio, 2010; Werner et al., 2013b). Previous studies have recognized two types of SWI: passive and active (Mahesha, 1995; Morgan et al., 2012; Werner et al., 2012). In passive SWI, the hydraulic gradient slopes towards the sea. This results in density-induced forces acting in the opposite direction to fresh groundwater flow, creating the classical wedge-shaped seawater plumes that are traditionally associated with SWI (e.g., Pinder and Cooper, 1970). In active SWI, the hydraulic gradient slopes towards the land, and forces caused by density differences and fresh groundwater flow act in the same direction, causing more aggressive salinization.

The current understanding of SWI is based primarily on studies that assume a steady-state condition (Werner et al., 2013a). For example, a considerable body of SWI research adopts the Henry problem (Henry, 1964), and modifications thereof, to investigate the effects of density, heterogeneities and dispersion on steady-state SWI (e.g., Simpson and Clement, 2003; Held et al., 2005; Abarca et al., 2007; Sebben et al., 2015). Several studies use the shift in the interface between one steady-state condition and another in evaluating long-term extents of SWI (e.g., Werner and Simmons, 2009; Morgan et al., 2012), thereby neglecting altogether transient effects and precluding the evaluation of active SWI processes. Morgan et al. (2012) showed that if the freshwater-saltwater interface moves slowly enough, steady-state solutions reproduce approximately the transient interface. This permits use of quasi-equilibrium predictions of the transient interface, thereby avoiding the numerical burden of transient analyses.