Controls on the simulated shape of a freshwater-seawater transition zone in homogeneous anisotropic aquifers

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ABSTRACT

The spatial distribution of total dissolved solids in freshwater-seawater transition zones (TZs), both under steady state and transient conditions, is a key determinant of water quality in coastal aquifers. It is thus vital to understand the controls on this distribution when numerical models of coastal aquifers are to be effectively used to inform management decisions. When the seawater intrusion process is represented in numerical models, the value of model parameters in the fluid and solute mass balance equations control the simulated TZ shape (i.e. distribution of salinity within the TZ). This study elucidates the controlling parameters in the flow and transport equations and indicates which aspects of TZ shape and temporal evolution are controlled by which parameters and factors.

This evaluation is based on a homogeneous anisotropic cross-sectional representation of a layered basalt coastal aquifer in Oahu, Hawaii, USA, for which the USGS-SUTRA code was applied to simulate the groundwater system. Whereas most other codes allow only one longitudinal and one transverse dispersivity value for two-dimensional models, the SUTRA transport process provides the possibility to specify two longitudinal and two transverse dispersivity values, one for flow that is parallel to layering and one for flow that is perpendicular to layering (i.e., parallel to and perpendicular to the principal directions of permeability anisotropy). The effective dispersivity value for flow in intermediate directions varies smoothly between the two specified values. This enhancement allows the effects of vertically-oriented dispersion to be separated from the effects of horizontally-oriented dispersion, and thereby, distinct controls on simulated TZ shape can be found.

In particular, for the studied aquifer with much lower vertical than horizontal permeability along any vertical profile, vertical flow occurs through most of the TZ. However, the balance of horizontal and vertical dispersive solute fluxes is such that longitudinal dispersion for vertical flow is the primary control on the width of the deeper part of the TZ, and transverse dispersion for horizontal flow is the primary control on the width of the upper part of the TZ. For unsteady TZ conditions, for example due to an increase in steady pumping stress, while the TZ migrates inland towards a new steady position, the deeper part of the TZ exhibits greater widening than does the upper part. Moreover, non-steady cyclic stresses in this aquifer, such as yearly pumping cycles, cause no widening in the upper part of the simulated TZ, but cause permanent widening of the lower part of the TZ. Thus simulations imply that transverse dispersion for horizontal flow is the main transport parameter impacting water quality of this coastal aquifer.

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