Geophysical Research Abstracts
Vol. 17, EGU2015-14842-1, 2015
EGU General Assembly 2015

Experimental and numerical modelling of surface water-groundwater flow and pollution interactions under tidal forcing

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Surface water and groundwater are integral components of the hydrologic continuum and the interaction between them affects both their quantity and quality. However, surface water and groundwater are often considered as two separate systems and are analysed independently. This separation is partly due to the different time scales, which apply in surface water and groundwater flows and partly due to the difficulties in measuring and modelling their interactions (Winter et al., 1998). Coastal areas in particular are a difficult hydrologic environment to represent with a mathematical model due to the large number of contributing hydrologic processes. Accurate prediction of interactions between coastal waters, groundwater and neighbouring wetlands, for example, requires the use of integrated surface water-groundwater models.

In the past few decades a large number of mathematical models and field methods have been developed in order to quantify the interaction between groundwater and hydraulically connected surface water bodies. Field studies may provide the best data (Hughes, 1995) but are usually expensive and involve too many parameters. In addition, the interpretation of field measurements and linking with modelling tools often proves to be difficult. In contrast, experimental studies are less expensive and provide controlled data. However, experimental studies of surface water-groundwater interaction are less frequently encountered in the literature than filed studies (e.g. Ebrahimi et al., 2007; Kuan et al., 2012; Sparks et al., 2013). To this end, an experimental model has been constructed at the Hyder Hydraulics Laboratory at Cardiff University to enable measurements to be made of groundwater transport through a sand embankment between a tidal water body such as an estuary and a non-tidal water body such as a wetland. The transport behaviour of a conservative tracer was studied for a constant water level on the wetland side of the embankment, while running a continuous tide on the coastal side. The integrated surface water-groundwater numerical model IRENE (Spanoudaki et al., 2009, Spanoudaki, 2010) was also used in the study, with the numerical model predictions being compared with experimental results, which provide a valuable database for model calibration and validation. IRENE couples the 3D, non-steady state Navier-Stokes equations, after Reynolds averaging and with the assumption of hydrostatic pressure distribution, to the equations describing 3D saturated groundwater flow of constant density. The model uses the finite volume method with a cell-centered structured grid providing thus flexibility and accuracy in simulating irregular boundary geometries. A semi-implicit finite difference scheme is used to solve the surface water flow equations, while a fully implicit finite difference scheme is used for the groundwater equations. Pollution interactions are simulated by coupling the advection-diffusion equation describing the fate and transport of contaminants introduced in a 3D turbulent flow field to the partial differential equation describing the fate and transport of contaminants in 3D transient groundwater flow systems.

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