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Mathematical modelling of surface water-groundwater flow and salinity interactions in the coastal zone

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Coastal areas are the most densely-populated areas in the world. Consequently water demand is high, posing great pressure on fresh water resources. Climatic change and its direct impacts on meteorological variables (e.g. precipitation) and indirect impact on sea level rise, as well as anthropogenic pressures (e.g. groundwater abstraction), are strong drivers causing groundwater salinisation and subsequently affecting coastal wetlands salinity with adverse effects on the corresponding ecosystems.

Coastal zones are a difficult hydrologic environment to represent with a mathematical model due to the large number of contributing hydrologic processes and variable-density flow conditions. Simulation of sea level rise and tidal effects on aquifer salinisation and accurate prediction of interactions between coastal waters, groundwater and neighbouring wetlands requires the use of integrated surface water-groundwater models. In the past few decades several computer codes have been developed to simulate coupled surface and groundwater flow. In these numerical models surface water flow is usually described by the 1-D Saint Venant equations (e.g. Swain and Wexler, 1996) or the 2D shallow water equations (e.g. Liang et al., 2007). Further simplified equations, such as the diffusion and kinematic wave approximations to the Saint Venant equations, are also employed for the description of 2D overland flow and 1D stream flow (e.g. Gunduz and Aral, 2005). However, for coastal bays, estuaries and wetlands it is often desirable to solve the 3D shallow water equations to simulate surface water flow. This is the case e.g. for wind-driven flows or density-stratified flows. Furthermore, most integrated models are based on the assumption of constant fluid density and therefore their applicability to coastal regions is questionable. Thus, most of the existing codes are not well-suited to represent surface water-groundwater interactions in coastal areas.

To this end, the 3D integrated surface water-groundwater model IRENE (Spanoudaki et al., 2009; Spanoudaki, 2010) has been modified in order to simulate surface water-groundwater flow and salinity interactions in the coastal zone. IRENE, in its original form, 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. 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. The model has been further developed to include the effects of density variations on surface water and groundwater flow, while the already built-in solute transport capabilities are used to simulate salinity interactions. Initial results show that IRENE can accurately predict surface water-groundwater flow and salinity interactions in coastal areas. Important research issues that can be investigated using IRENE include: (a) sea level rise and tidal effects on aquifer salinisation and the configuration of the saltwater wedge, (b) the effects of surface water-groundwater interaction on salinity increase of coastal wetlands and (c) the estimation of the location and magnitude of groundwater discharge to coasts.

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