Spatiotemporal patterns of saltwater intrusion associated to geological heterogeneities and complex tidal forcing: insights from field-scale, high-resolution investigations

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ABSTRACT

Real-world coastal aquifers are characterized by various degrees of geological heterogeneity and complex beach slope geometries, both of which resulting in complex spatiotemporal patterns of saltwater intrusion in the coastal subsurface. Accurate characterization of these patterns in the field is important for sustainable development and management of freshwater resources in coastal aquifers. The Sherwood sandstone aquifer in Northern Ireland is intruded by complex networks of low permeability, meter-wide volcanic dykes of different orientations with respect to the shoreline. The dykes, more resistant to erosion, also complicate the tidal flat morphology and therefore the varying spatial extent of tide inundation-recession. A suite of high-resolution hydrogeophysical investigations was deployed to resolve the three-dimensional, spatiotemporal patterns of groundwater flow and saltwater intrusion. Passive magnetic surveys were applied to map and model the geometry of the dykes, which revealed deep-rooted with high (near vertical) dipping angle. Groundwater levels were recorded at high temporal resolution over a groundwater recharge event and several spring-neap tidal cycles. Using the simple Jacob-Ferris model, the analysis of the groundwater response to the local tidal fluctuations revealed a variable aquifer hydrodynamic connectivity over time during tidal cycles, controlled by the location of the dykes beneath the tidal flat. Electrical resistivity tomography lines were acquired both parallel and perpendicular to the shoreline cross-cutting several dyke-bounded sandstone compartments. They revealed that freshwater accumulated on land-facing side of dykes that are oblique to the coastline, and that freshwater thickness varied across different dyke-bounded compartments. A transient, three-dimensional, finite-element, groundwater model incorporating the dyke network structure and the variable tidal extent was further applied, and assessed against groundwater and resistivity records. In agreement with the observations, the simulations showed that dykes acted as relative barriers to groundwater flow and saltwater intrusion through creating preferential flow paths parallel to observed dyke orientations. When dykes were not perpendicular to the coastline, freshwater inflows from upland recharge areas concentrated on the dykes' land-facing side and saltwater penetration was higher on their sea-facing side. Overall, high dyke density areas as well as compartments with large inland recharge capture zone promoted thicker freshwater wedges. Understanding these complex patterns is key to sustainable management of coastal well fields in heterogeneous aquifer systems.

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