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Tide-induced fingering flow during submarine groundwater discharge

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Submarine groundwater discharge (SGD) is a relevant component of the hydrological cycle (Moore, 2010). The discharge of fresh groundwater that originated from precipitation on the land typically occurs at the near shore scale ($\sim$ 10m-100m) and the embayment scale ($\sim$ 100m – 10km) (Bratton, 2010). In the recent years a number of studies revealed that tidal forcing has an important effect on the fresh SGD pattern in the beach zone, i.e. it leads to the formation of an upper saline recirculation cell and a lower "freshwater discharge tube" (Boufadel, 2000, Robinson et al., 2007; Kuan et al., 2012). Thereby the discharge of the fresh groundwater occurs near the low-tide mark. The shape and extent of the upper saline recirculation cell is mainly defined by the tidal amplitude, beach slope, fresh groundwater discharge rate and hydraulic conductivity (Robinson et al., 2007). In spite of fact that in this case sea water overlies less denser freshwater, all previous modeling studies suggested that the saline recirculation cell and the freshwater tube are rather stable. However, new numerical investigations indicate that there maybe realistic cases where the upper saline recirculation cell becomes unstable as a result of the density contrast to the underlying freshwater tube. In these cases salt water fingers develop and move downward, thereby penetrating the freshwater tube.
To the author's knowledge, the present study is the first that illustrate the possibility of density induced fingering flow during near shore SGD. A total of 240 high resolution simulations with the density dependent groundwater modelling software SEAWAT-2000 (Langevin et al., 2007) has been carried out to identify the conditions under which salt water fingering starts to occur.
The simulations are based on the field-scale model setup employed in Robinson et al. (2007). The simulation results indicate that a very flat beach slope of less than 1:35, a hydraulic conductivity of 10 m/d and already a tidal range of 2 m initiates fingering flow. Flatter beach slope, higher hydraulic conductivity and increasing tidal range support this behavior. In the cases of fingering flow, freshwater is squeezed upward and pinches out within the inter-tidal zone. Once pinched out, the discharge point slowly moves along at the beach surface towards the low-tide mark. Overall, the fingering process further complicates the flow pattern and the mixing of salt and freshwater in the inter-tidal zone compared to the cases where the saline recirculation cell remains stable. This may have an important implication for the hydrogeochemical processes in this zone and thus the mass flux of reactive chemicals from the land to the ocean.

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