Mechanisms, configuration typology, and vulnerability of pumping-induced seawater intrusion in heterogeneous aquifers

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Abstract

The rising demand for freshwater places an increasing strain on the coastal aquifer systems. Numerical models are a precious tool for more realistic modeling of seawater intrusion processes, considering fresh and saline groundwater's nonlinearity, transience, and miscibility. Most salinization vulnerability research focuses on homogenous aquifers for management recommendations. However, in practice, geological structures are often diverse and heterogeneous. This complicates groundwater flow and salt transport processes depending on the prioritized flow. This study used SEAWAT software to simulate saline intrusion in aquifers and the intrusion configuration typology approach to assess vulnerability in heterogenous and homogenous aquifers.

The result shows that heterogeneous aquifers' salinization rates and patterns were far more intricate. It's related to pumping location, depth, aquifer geometry, and geology relationships between pumping sites, landward borders, and saline groundwater. The vulnerability was responsive to pumping distance to the shoreline for low-continuity aquifers and pumping depth for high-continuity aquifers. Besides that, The configurations can distinguish essential seawater intrusion characteristics linked with vulnerability levels (for example, Types I and IV are high vulnerability, Types II and V are medium vulnerability, and Types III and VI are low vulnerability). The heterogeneous models are helpful for simulating saltwater intrusion and providing accurate and realistic management scenarios.

Keywords: Seawater intrusion models, Heterogeneous aquifer

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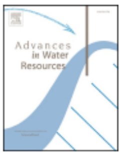

Mechanisms, configuration typology, and vulnerability of pumping-induced seawater intrusion in heterogeneous aquifers

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ABSTRACT

Coastal aquifers are vulnerable to seawater intrusion due to excessive groundwater pumping. Most research on salinization vulnerability considers homogeneous aquifers, forming the basis of management guidance. However, geologic structure can be highly heterogeneous, with preferential flow paths and low-permeability barriers that complicate flow and salt transport processes under pumping conditions. Here we use a series of variable-density groundwater flow and salt transport models with geostatistical representations of heterogeneity to illustrate characteristics of vulnerability in heterogeneous and homogeneous aquifers. Simulations showed that in homogeneous aquifers, salinization patterns were simple and related only to the hydraulic properties. In heterogeneous aquifers, salinization rates and patterns were much more complicated, and related to pumping location and depth, aquifer geometry, and geologic connections between pumping location, landward boundaries, and saline groundwater. An intrusion configuration typology approach was developed for both homogeneous and heterogeneous aquifers. The configuration approach was applied to heterogeneous aquifers of low, medium, and high geologic continuity, and vulnerability was assessed. The probability-based assessment was able to characterize the impact of pumping locations and rates in heterogeneous aquifers, considering different types of intrusion. The results showed that groundwater vulnerability to salinization was sensitive to pumping distance to the coastline for low-continuity aquifers and to pumping depth for high-continuity aquifers. The analysis provides new insights into the relationship between land-sea geologic connections and seawater intrusion vulnerability. The configuration approach plus probability-based assessment can be a starting point for large-scale aquifer characterization and more sophisticated groundwater management, including vulnerability assessment and optimization of pumping location, depth, and rate.