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Electrical Resistivity Imaging and Hydrodynamic Modeling of Convective Fingering in a Sabkha Aquifer

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Free convection, or fluid motion driven by density differences, is an important groundwater flow mechanism that can enhance transport and mixing of heat and solutes in the subsurface. Various issues of environmental and societal relevance are exacerbated convective mixing; it has been studied in the context of dense contaminant plumes, nuclear waste disposal, greenhouse gas sequestration, the impacts of sea level rise and saline intrusion on drinking water resources. The basic theory behind convective flow in porous media is well understood, but important questions regarding this process in natural systems remain unanswered. Most previous research on this topic has focused on theory and modeling, with only limited attention to experimental studies and field measurements. The few published studies present single snapshots, making it difficult to quantify transient changes in these systems.

Non-invasive electrical methods have the potential to exploit the relation between solute concentrations and electrical conductance of a fluid, and thereby estimate fluid salinity differences in time and space. We present the results of a two-year experimental study at a shallow sabkha aquifer in the United Arab Emirates, about 50 km southwest of the city of Abu Dhabi along the coast of the Arabian Gulf, that was designed to explore the transient nature of free convection. Electrical resistivity tomography (ERT) data documented the presence of convective fingers following a significant rainfall event. One year later, the complex fingering pattern had completely disappeared. This observation is supported by analysis of the aquifer solute budget as well as hydrodynamic modeling of the system. The transient dynamics of the gravitational instabilities in the modeling results are in agreement with the timing observed in the time-lapse ERT data.

Our experimental observations and modeling are consistent with the hypothesis that the instabilities arose from a dense brine that infiltrated into the aquifer from a surficial source and that the finite nature of this brine and dispersive mixing led to the decay of the complex fingers with time. Our work provides direct field measurements in a discipline where such data are quite rare. This work is likely the first to provide such direct evidence, coupled with time series data from numerical modeling, to allow quantification of the speed and the dynamics of complex free convective fingering in a field setting. This is a major step forward for this field.