Density-Driven Groundwater Flow: Seawater Intrusion, Natural Convection, and Other Phenomena

Difficulties in understanding and managing hydrogeologic systems with variable-density groundwater flow are often due to the common notion that groundwater flow is driven in the direction of decreasing water-table elevation or hydraulic head; i.e. 'downhill'. However, even small variations in groundwater density can drive flow in directions that have no relation to decreasing elevation or head. Groundwater density varies due to spatial or temporal differences in temperature and concentration of dissolved solids. These differences in density can lead to interesting and sometimes unexpected flow patterns. In coastal aquifers, seawater intrusion (and contamination of groundwater supplies) occurs because denser salty sub-sea groundwater pushes laterally inland below less-dense fresh groundwater flowing seaward. Saltwater also occurs above fresher groundwater (in sabkhas, salt ponds, areas of coastal sea incursion) and here, denser saltwater 'falls' downward through the fresher less-dense groundwater, also salinizing the aquifer. Vertical density-driven flow giving rise to natural convection similarly occurs where warmer groundwater exists below cooler water, such as in geothermal, volcanic and ocean-ridge regions. This presentation reviews variable-density groundwater flow phenomena and their importance in practical settings. It is shown that the flow pattern in cases of lateral density differences is rather uniform in comparison with the flow pattern generated by vertical density differences, which exhibits fascinating variety and evolution. Examples of lateral and vertical density-driven flows in coastal aquifers show how modeling variable-density groundwater flow can be used to understand and effectively manage coastal resources.