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Role of oxygen in the mobilization of geogenic contaminants from heterogeneous sediments during managed aquifer recharge

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As groundwater overdraft intensifies, Managed Aquifer Recharge (MAR) is a key strategy to mitigate aquifer depletion. However, rapid recharge can introduce oxygenated water into anoxic aquifers, perturbing redox conditions and mobilizing geogenic contaminants including arsenic (As), uranium (U), and chromium (Cr). We investigate mechanisms controlling geogenic contaminant release during dry-well MAR injection and evaluate implications for groundwater quality.

We hypothesize that injection of oxygenated recharge water via dry wells generates transient oxic conditions that oxidize iron (Fe) and manganese (Mn), altering host mineral phases and affecting the mobilization of As, U, and Cr. We further hypothesize that Fe and Mn oxidation leads to the formation of (oxyhydr)oxide colloids that enhance colloid-facilitated transport of oxyanions.

To test this hypothesis, groundwater and sediment samples were collected at depths of 18, 30, and 54 m at an agricultural field site in California's Central Valley undergoing surface-water direct injection. Sediments were used in batch dissolution experiments where oxygen was varied to simulate aquifer redox conditions. Field porewater and reactor filtrate samples were analyzed via inductively coupled plasma-mass spectrometry (ICP-MS) to quantify metal and metalloid mobilization over time. Initial Fe, Mn, As, and Cr distributions were characterized using X-ray fluorescence (XRF) mapping, with Fe speciation assessed by point Fe K-edge X-ray absorption near-edge spectroscopy (XANES), which was measured at the Fe K-edge to characterize the Fe speciation. Colloids in field porewaters and sediments (pre and post-batch dissolution) were also analyzed using XANES.

Preliminary batch dissolution results show increasing aqueous concentrations of Fe, Mn, and As under oxic conditions, indicating potential groundwater quality risks during MAR. XRF mapping and point XANES of bulk sediments reveal mineralogical heterogeneity within sediment samples, influencing reactivity and contaminant mobilization. XANES analysis of post-reaction sediments remains similar to initial sediments, but differs from colloids present in pore-water, suggesting distinct formation mechanisms under in-situ aquifer conditions. Integrating field and laboratory analyses improves understanding of contaminant transport to make safer and more informed groundwater management decisions, benefiting environmental and public health.