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Process-Based Insights into Cadmium Transport in Saturated Porous Media from Two-Dimensional Laboratory Experiments.

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Cadmium (Cd) is a persistent and highly toxic heavy metal, and its mobility in groundwater systems poses serious risks to human health and aquatic ecosystems. Accurate prediction of cadmium fate requires a detailed understanding of transport processes under controlled hydrogeological conditions. This study examines cadmium transport behaviour in a saturated, homogeneous porous medium using a two-dimensional laboratory sand tank designed to generate high-resolution experimental data for process interpretation. A conservative tracer experiment using sodium chloride (NaCl) was first conducted to establish steady and uniform flow conditions and to characterise advective–dispersive transport within the sand tank. Following flow stabilisation, a cadmium transport experiment was conducted by introducing a low-concentration Cd solution under constant hydraulic conditions. Temporal variations in cadmium concentrations were monitored over an extended period through systematic sampling at multiple observation points and analysed using inductively coupled plasma mass spectrometry (ICP-MS). Breakthrough curve analysis revealed delayed cadmium arrival and pronounced tailing compared to the conservative tracer, indicating the influence of non-ideal transport processes such as hydrodynamic dispersion and sorption, even within a nominally homogeneous medium. These findings demonstrate that simplified assumptions of conservative behaviour may underestimate heavy-metal persistence in groundwater systems. The experimental dataset provides valuable insights for constraining and evaluating reactive transport representations and offers a controlled baseline for future investigations incorporating subsurface heterogeneity and geochemical complexity. The outcomes contribute to an improved understanding of contaminant transport processes and support the development of more reliable predictive tools for groundwater quality assessment and contaminated site management.