

## Designing artificial tracer experiments in the unsaturated zone of decommissioned mining sites: a numerical modeling approach

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### Abstract

The former uranium mine Le Cellier, located in southeastern France, offers a valuable natural laboratory for investigating groundwater flow and solute transport under unsaturated conditions within a tailings pile generated by heap leaching operations. Numerical simulations of one of the tailings piles were conducted to characterize the dynamics of groundwater flow. To validate the hydrogeological model and enhance our understanding of solute transport processes in this system, we plan to carry out artificial tracer experiments. Preliminary solute transport models have been developed to support the design of these forthcoming experiments. Conceptual one-dimensional (1D) representations of the pile were simulated using the HYDRUS code to model groundwater flow and non-reactive solute transport. The model produces breakthrough curves that exhibit similar dynamics, with their relative amplitudes proportional to the ratio of the concentrations of the non-reactive solute injected at the top of the pile. The influence on groundwater flow varies across parameters: high hydraulic conductivity and longitudinal dispersivity values accelerate solute transport, leading to shorter restitution times. The impact of climatic conditions during tracer injection was also assessed. High rainfall reduces restitution time and increases concentration peaks, which become markedly shorter than under dry conditions, suggesting that artificial tracer experiments should preferably be conducted during wet periods. The numerical simulation approach provides valuable insights for designing effective and realistic artificial tracer experiments. Our findings demonstrates that integrating field investigations with modeling approaches for tracer testing can substantially support mine water management strategies.

**Keywords:** Uranium, tailings piles, groundwater flow, solute transport, unsaturated conditions, tracer experiments.

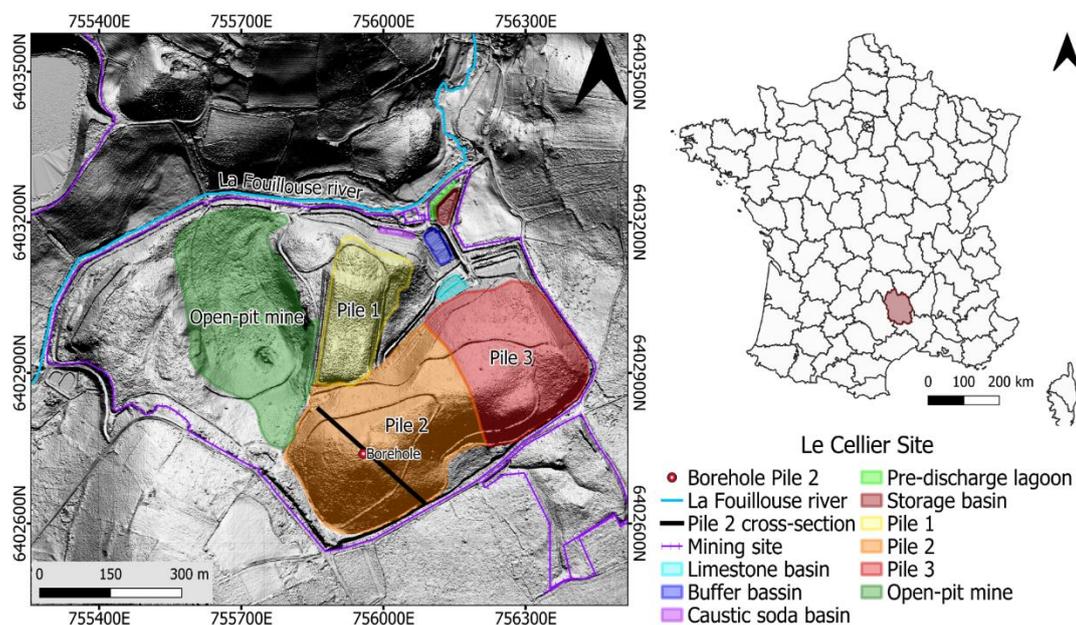


Figure. Geographical location of the former Le Cellier uranium mine.