Unraveling Complex Hydrogeologic Systems Using Field Tracer Tests

Tracking the movement of underground contaminants is vital to protecting public health and the environment worldwide. Scientific efforts using field tracer techniques to solve contaminant migration problems are rapidly evolving to fill critical information gaps and provide confirmation of laboratory data and numerical models. Various chemical tracers are being used to formulate and evaluate alternative conceptual hydrogeologic models, namely to constrain hydraulic properties of geologic systems; identify sources of groundwater, flow paths and rates; and determine mechanisms that affect contaminant transport. Naturally occurring elements and environment isotopes from atmospheric and underground nuclear testing can make excellent tracers. In addition, characterizing sites of future waste disposal, such as the potential high-level nuclear waste repository at Yucca Mountain, requires new and innovative techniques like injecting surrogate tracers that simulate potential contaminants and shed light on mechanisms that could control future contaminant migration. Earth scientists at the Spring 2000 AGU Meeting reported on these recent advances.

In the underground test facility at Busted Butte, Nevada, near Yucca Mountain, field-scale transport properties of the unsaturated zone were investigated by injecting a mixture of reactive and non reactive tracers into non-welded tuffs. Fluorescein dye tracer injected continuously into horizontal boreholes for several months and illuminated by UV light during mineback and overcoring operations, emphasized the importance of capillary forces in the tuffs. Even at relatively high injection flow rates (10-50ml/h), the downward migration of tracers was significantly attenuated by fracture-matrix interactions (imbibition and matrix diffusion) and heterogeneities (lithologic boundaries). In contrast, the interbedded basalts and sediments at the Idaho National Engineering and Environmental Laboratory, provide evidence of rapid, long-range horizontal transport. In response to seasonal ponded infiltration, water and contaminants could move farther than one km in less than three months within the unsaturated zone.

Tracer tests in saturated fractured volcanic rocks at Yucca Mountain using reactive and non-reactive tracers suggest matrix diffusion (the exchange of mass between relatively mobile fracture fluid and relatively immobile matrix fluid) may be an important mechanism for reducing radionuclide concentrations and attenuating radionuclide transport rates in fractured tuffs. Laboratory experiments were run in parallel with the field tests to investigate transport parameter scaling issues and the applicability of laboratory-derived transport data to field-scale predictions. In general, the laboratory data predicted less tracer sorption than observed in the field, and more matrix diffusion. In fractured granitic schist at Mirror Lake, New Hampshire, tracers of varying diffusive properties produced identical late-time breakthrough. This suggests that advective, and not diffusive, processes may control transport of the injected tracers. Lower effective porosity in the schist (as compared to tuffaceous rock) and shorter tracer residence times may partially explain the differences between the findings at Mirror Lake and those at Yucca Mountain.

An investigation at the Nevada Test Site (NTS) sampled previously injected tracers using a pumping well for 87 days at a rate of 120 gallons per minute (654 cubic meters per day). Similar to the tracer test results at Yucca Mountain, evidence of matrix diffusion in fractured volcanics was indicated by differences in solute transport behavior. Microsphere tracer breakthrough curves displayed double peaks, suggesting remobilization during flow transients. The NTS tracer test results indicated that effective porosity values are higher than values found in the literature. Interpretation of experiments in fractured rocks requires a better understanding of heterogeneities. Radioisotopes also provide reactive and non reactive tracers from NTS

underground nuclear device tests. Several radionuclides sorbed onto colloids have been detected in groundwater samples taken from fractured aquifers at significant distances from these tests. In a sedimentary aquifer in Germany, humic colloids migrated unretarded 25 km in 15,000 years, which attest to their stability.

Several presenters discussed the use of natural isotopic variations in groundwater to evaluate contaminant transport. Differences in the strontium isotope ratios between process water and regional groundwater provide an effective tracer for evaluating wastewater infiltration from the Hanford tanks located in Washington state. Stable isotope and fluid inclusion studies on fracture minerals provide indicators of paleohydrology at Benken, a potential nuclear waste repository site in Switzerland. Specifically, minerals above and below the Opalinus Clay indicate intrusion of low salinity fluids, possibly of meteoric origin.

In summary, scientific efforts using tracer techniques to solve contaminant migration problems are rapidly evolving and resulting in the merging of geology, hydrology, and geochemistry disciplines. Results of field tracer tests are filling critical information gaps by addressing data needs and providing confirmation of laboratory data and numerical models. Field tracer test data at various scales are needed to enhance confidence in performance assessment models used to quantify transport of sorbing radionuclides. Additional and repeated tracer studies using different hydraulic configurations and multiple tracers are warranted to evaluate spatial and temporal scaling phenomena and heterogeneities of geologic materials.

For further information about the AGU sessions, visit the AGU Web site at: http://www.agu.org/meetings/waissm00.html.

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