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Field Trials of Subsurface Chaotic Advection for Enhanced Reagent Delivery

Michelle S. Cho (mscho@uwaterloo.ca) and Neil R. Thomson (University of Waterloo, Waterloo, ON, Canada)

Background/Objectives. For most in situ remedial technologies, effective delivery of a reagent solution is a key requirement for success. However, effective delivery and subsequent mixing of reagents remains one of the most challenging components of an in situ treatment system. The concept of chaotic advection in a porous medium is relatively new, and has the potential to increase spatial distribution and overcome preferential flow paths. Chaotic advection refers to the mixing of fluid elements which arise from repeated stretching and folding of fluid parcels. Chaotic advection can be engineered in a porous medium by time-dependent Darcy flows and has the potential to enhance mixing under laminar conditions. If chaotic advection can be generated and controlled in situ, treatment efficiency may be significantly increased by enhanced mixing between the injected reagents and target contaminants. To assess whether chaotic advection can be invoked in a natural porous medium, a field trial was designed in the sandpit area at the University of Waterloo Groundwater Research Facility at CFB Borden located near Alliston, ON, Canada. The unconfined, homogeneous aquifer is composed primarily of approximately 9 m of unconsolidated fine to medium-grained well-sorted sand and underlain by a clayey and sandy silt aquitard. The horizontal hydraulic conductivity ranges from 3.30×10^{-5} to 9.85×10^{-5} m/s. For this field investigation, an 8 m x 11 m segment of the aquifer was isolated by sheet piling that penetrated 2 m below ground surface. In the initial phase of investigation, the behavior of a conservative tracer within the aquifer was studied under chaotic groundwater flows.

Approach/Activities. To evaluate whether engineered chaotic advection can be achieved at the field scale, a series of tracer tests was conducted in the experimental cell. After delivery of a sodium chloride solution, chaotic advection was invoked by the transient switching of eight dipole pairs in a circular array. Changes in water levels were monitored using continuous pressure transducers in all pumping wells. Tracer movement was captured using in situ resistivity probes installed at 73 depth-specific locations within the experimental cell. These resistivity probes are able to provide continuous readings of ionic signatures in the pore fluid, which was used as an analogous measure of tracer concentrations. To assess the quality of data obtained from the resistivity probes, manual sampling was conducted at select times during the tracer test from 34 multi-level samplers installed within the experimental cell.

Results/Lessons Learned. Hydraulic data from the pressure transducers show that the dipole pumping system generally operated as designed and indicating that the necessary hydraulic conditions were created for chaotic advection to occur. Visual assessment of the contours and breakthrough curves generated from the resistivity data suggest that the mixing protocol used to invoke chaotic advection led to improved spatial distribution of the tracer mass within the target area over time. Further analysis of the resistivity data using various quantitative tools also suggest that chaotic groundwater flow led to enhanced tracer spreading. This presentation will highlight key findings from the chaotic advection tracer tests conducted to date within the experimental cell, as well as discuss strategies to optimize chaotic advection to enhance reagent delivery for in situ remediation.