Lines of Evidence for Injection Solution Distribution in a Groundwater Transition Zone

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Background/Objectives. Carbon substrate solution injection is a common chlorinated solvent remedial strategy for establishing conditions conducive to biologically-mediated reductive dechlorination. Many times, this injection approach is implemented within challenging hydrostratigraphy. At Vandenberg Air Force Base, California, in situ bioremediation (ISB) via carbon substrate injection was selected as the remedy to treat trichloroethene (TCE) at Space Launch Complex 3 (the site). TCE concentrations up to approximately 8,000 µg/L in groundwater resulted from historical launch operations conducted at an elevated mesa area. Conceptually, affected groundwater migrated from source area marine silts of the Careaga Formation toward Bear Creek Canyon where the water table is found within alluvial sediments, and is locally expressed as surface water. Groundwater gradient directions within the Careaga Formation approximate the surface topography, sloping from the elevated mesa to the southwest, west, and northwest toward the canyon. However, once within the canyon's alluvium the groundwater gradient direction is thought to change (within a transition zone) predominantly toward the north-northwest to be consistent with the canyon bottom's topographic slope, along a gaining reach of Bear Creek. An ISB pilot test injection area was located within this transition zone where groundwater migration changes from a quasi-westerly direction to a more northward direction. To better understand carbon substrate solution distribution in this area, both during and after injection, a multiple-lines-of-evidence approach was employed.

Approach/Activities. The ISB pilot test injected into one well 10,600 gallons of a 2 percent emulsified vegetable oil (EVO) mixed in hydrant water and 40 milligrams per liter fluorescein tracer dye solution. The monitoring network included one dose-response well to evaluate injection solution arrival during active injection (6-MW-1), one well to evaluate solution migration after injection (6-MW-38; northwest of 6-MW-1), and nearby surface water locations. Data collected during and after injection included volatile organic compounds, total organic carbon (TOC), turbidity, tracer dye, groundwater elevations, and visual observations. These data were used for a variety of analyses including breakthrough curve generation, correlations between field and laboratory data, and groundwater gradient 3-point solution calculations.

Results/Lessons Learned. Generally, the multiple-lines-of-evidence evaluation converged with the conceptual understanding. Tracer dye, TOC, and trihalomethanes (in the hydrant water) showed solution arrival at the dose-response monitoring well (6-MW-1) during injection, and groundwater transport to the solution migration monitoring well (6-MW-38) under ambient (post-injection) groundwater flow conditions. Conversely, visual observation of EVO droplets and field-measured turbidity were somewhat inconsistent with the other data collected during injection. While TCE results indicated groundwater displacement toward Bear Creek during injection, surface water monitoring did not indicate injection solution presence in Bear Creek. The 3-point solution calculations generally indicated a westerly groundwater gradient, consistent with the conceptual understanding; however, the calculated gradient azimuths varied over a range of 80 degrees in a year's time, interpreted as seasonal- and drought-cycle-related aquifer responses in the aquifer transition zone. The full-scale ISB treatment system was subsequently designed to account for the range in groundwater gradient directions.