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In Situ Bioreactors (ISBRs) for Effective Bioremediation of Chlorinated Hydrocarbons in Deep, Fractured Bedrock Aquifers

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Background/Objectives. Deep, fractured bedrock aquifers can not only exhibit complex dissolved plume behavior but also pose substantial challenges to bioremediation efforts that rely on subsurface injection of amendments such as electron donors. Simply put, injected amendments may bypass or have limited contact time with impacted zones due to fractures and subsurface heterogeneity. With thorough characterization of site hydrology, innovative approaches, and systematic performance monitoring however, bioremediation can be successful in deep aquifers. The current study describes the use and performance of a small in situ bioreactor (ISBR) in promoting reductive dechlorination of trichloroethylene (TCE) to a saturated zone depth of 140 ft below ground surface (BGS).

Approach/Activities. The study site is a former chemical distribution facility where a deep, fractured aquifer had been impacted predominately by TCE (1,230 μg/L). An ISBR unit was installed in an existing monitoring well to promote reductive dechlorination. The ISBR was equipped with a timer unit for electron donor addition and a solid matrix (Bio-Sep® beads) that provided a large surface area for growth of high densities of indigenous, organohalide respiring bacteria. The ISBR was also equipped with a low flow, nitrogen sparge that created groundwater circulation not only through the bioreactor but also within the water column. The ISBR was deployed in an existing monitoring well at a depth of 60 ft BGS. Groundwater samples were routinely obtained at a depth of 140 ft to determine whether ISBR operation affected contaminant concentrations and geochemical conditions throughout the depth of the saturated zone. In addition, Bio-Trap® samplers deployed at depths of 60, 85, 105 and 140 ft BGS were periodically recovered for qPCR quantification of *Dehalococcoides* and functional genes (e.g., vinyl chloride reductases) to evaluate ISBR performance.

Results/Lessons Learned. Prior to ISBR deployment, cis-1,2-dichloroethylene (cDCE) was detected (133 μg/L) but vinyl chloride and ethene concentrations were below detection limits suggesting reductive dechlorination was limited under existing conditions. Consistent with historical groundwater monitoring, *Dehalococcoides* concentrations were low (10^0 cells/mL) and vinyl chloride reductase genes were not detected. After approximately 6 months of operation, geochemical monitoring at 140 ft BGS demonstrated sulfate consumption and methanogensis. After 9 months of operation, the *Dehalococcoides* concentration at 140 ft BGS had increased by four orders of magnitude, surpassing 1 million cells/mL. With the generation of highly anaerobic conditions throughout the saturated thickness of the monitoring well, *Dehalococcoides* populations and vinyl chloride reductase gene copies steadily increased at each of the four depths monitored. During ISBR operation, concentrations of TCE decreased to near or below detection limits. Transient increases in cDCE and vinyl chloride were observed at the 6- and 9-month marks, respectively, ultimately producing ethene (240 μg/L) after 9 months of operation. Overall, the results conclusively demonstrated that the ISBR successfully enhanced anaerobic bioremediation throughout the saturated thickness of the monitoring well and indicated that ISBRs can be an effective remediation approach even in a deep, fractured bedrock aquifer.