Paired Enhanced In Situ Bioremediation and In Situ Chemical Oxidation of Chlorinated VOCs in a Fine-Grained Aquifer

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Background/Objectives. Field-scale enhanced in situ bioremediation (EISB) and in situ chemical oxidation (ISCO) is being implemented at a mixed industrial/residential site where groundwater is impacted by chlorinated volatile organic compounds (CVOCs), primarily trichloroethene (TCE) and degradation products. The site is underlain with alluvium with fine-grained deposits including clays, silts, and fine-grained sands, and depth to groundwater ranges from approximately 5 to 8 feet below ground surface (ft bgs). Site investigations conducted since 1989 have established the lateral and vertical extent of CVOC impacts from approximately 15 to 45 ft bgs beneath the site and directly downgradient of the site. Laterally continuous fine-grained sand layers interbedded among the low-permeability clays and silts provide preferential pathways for CVOCs to migrate downgradient. Remediation efforts have been implemented at the site since 1994 including groundwater extraction and treatment (1994-2005), onsite in-situ chemical oxidation (ISCO, 2005-2009), permeable reactive ISCO barrier (2011-present), and offsite downgradient EISB injections (2018-present). The objective of the EISB addition to the existing ISCO treatment is to limit downgradient migration of site CVOCs and reduce CVOC concentrations in groundwater downgradient of the site.

Approach/Activities. A sodium permanganate ISCO barrier has been in place at the downgradient boundary of the site since 2011. Beginning in 2019, quarterly EISB injections have been applied to shallow, laterally continuous fine-grained sand units where TCE concentrations have been detected greater than or equal to 500 micrograms per liter. EISB injections have been implemented in two phases. Phase I began in spring 2019 and utilized 8 injection wells. Phase II began in spring of 2022 and incorporates 7 additional injection wells, for a total of 15 EISB injection wells in the current remedy program. The EISB injections include a combination of dilute (< 5% total organic carbon) carbohydrate electron donor and semiannual bioaugmentation of the indigenous microbial community with a microbial consortium (KB-1®) containing dehalococcoides bacteria known to support reductive dechlorination of TCE to ethene. Low pH KB-1® Plus was selected as the formula for site bioaugmentation based on the results of a treatability study, which indicated site groundwater has limited ability to buffer against formation of organic acids. Quarterly EISB injections are followed by semiannual performance monitoring, including the evaluation of CVOC, sulfate, and dissolved gas (ethane, ethene, and methane) concentrations.

Results/Lessons Learned. Performance monitoring data indicates established and expanding reducing conditions, indicated by the reduction of TCE concentrations in the vicinity of injection wells and the prevention of TCE migration downgradient of the ISCO barrier. Additional evidence of reductive dechlorination includes declining dissolved oxygen levels, negative oxidation-reduction potential (< -100 millivolts), sulfate reduction in monitoring wells downgradient of injection wells, and increased methane, ethane, and ethene production. Adjustments to injection volumes, flow rates, and solution composition have been made to mitigate biofouling that occurs in and around injection wells, in part due to the low-permeability subsurface geology.