Source Area Bioremediation in Fractured Bedrock with Karst Features Revisited as Sustainable and Resilient Remediation

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Background/Objectives. A manufacturing facility operating since the late 1940s in central Pennsylvania experienced releases of solvents (primarily tetra and trichloroethene), through leaking underground storage tanks (USTs) that were installed on top of fractured bedrock. The USTs and a small amount of the surrounding soil were removed in the late 1980s. Soil samples collected in the area of the former USTs during Site decommissioning activities in the early 2000s identified tetrachloroethene and trichloroethene (PCE and TCE, respectively) above the state agency medium specific concentrations for soil. Subsequent high resolution Site characterization including sorbers to refine the conceptual site model also identified elevated concentrations of TCE and daughter products in the bedrock aquifer at depths of between 95 and almost 200 feet below ground surface (bgs) at concentrations exceeding 250,000 µg/L. Concerns regarding off-site migration of the solvent plume in the bedrock aquifer towards a large nearby river approximately 1,000 feet to the southeast, caused the state agency to request that an aggressive remediation strategy be implemented. A focused feasibility study and semi-quantitative sustainability assessment were conducted comparing pump and treat, thermal, in situ chemical oxidation and in situ bioremediation. Phased in situ bioremediation (biostimulation and bioaugmentation) was selected as the remedy to achieve the risk-based remedial goals.

Approach/Activities. The sustainable and resilient remedial approach was initiated in March 2012 and included installation of nine injection points ranging in depth from 100 to 170 feet below ground surface (bgs), using a 6% emulsified vegetable oil solution to establish the anaerobic reducing treatment zone. Nine more injection points were installed targeting the source area and to create a downgradient biobarrier to depths ranging from 110 to 180 feet bgs in 2014, targeting the most transmissive fractures using subsurface geophysics. Supplemental injections that included laboratory cultured microcosms were implemented at 10 of the 19 injection points after review of the pilot test data and observation of concentrations of TCE exceeding 250,000 µg/L in 2014. A longer lasting locally-sourced organic carbon/electron donor in the form of hardwood mulch placed in large diameter borings (bioborings) was considered in 2019 to replace fouled injection points when DNAPL was identified in one of the pilot borings at approximately 90 feet bgs. Nine bioborings were installed in 2021 to replace several fouled injection points backfilled with hardwood mulch and gravel.

Results/Lessons Learned. Anaerobic reducing conditions were observed in adjacent shallow and intermediate monitoring wells (depth to 140 feet bgs) within 6 months of the initial substrate injections including low dissolved oxygen, negative oxidation-reduction potential and increase in daughter products ethene and ethane concentrations. Reduction of TCE has been observed in the source area of approximately 98% in the shallow well and 99% in the intermediate well over the 10-year treatment period. The initial injections mobilized potential separate phase TCE (dense non-aqueous phase liquid or DNAPL) from solution channels in the fractured rock that had not been previously identified during investigations. Adaptive management strategies were used to adjust the scope of remediation to include additional injection points, bioborings and bioaugmentation to address and reduce both DNAPL and dissolved phase TCE.