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Progressive Remedial Strategy to Guide the Delivery of Biological and Abiotic Reagents for Treating Chloroethenes in Groundwater

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Background/Objectives. A commercial site among a residential area has gone several rounds of redevelopment and land uses, including a gasoline station, freight train trucking, and truck maintenance shop. Soil and groundwater had been impacted by petroleum hydrocarbons, chlorinated solvents, and heavy metals. Soil impacted by hydrocarbons and metals were excavated and removed from the site. A network of groundwater monitoring wells was installed into shallow and deep saturated zones that are primarily consisted of fine-grained sediments and separated by 80 feet of permeable sands. A periodic groundwater monitoring program has been ongoing for 10 years with chlorinated ethenes as the primary chemicals of concern (COCs), specifically trichloroethene (TCE) and cis-1,2-dichloroethene (c-DCE) at concentrations of up to 530 and 660 µg/L, respectively. Nitrate- and manganese-reducing conditions have contributed to slow reduction of TCE and accumulation of c-DCE over time. Regulatory requirements include treatment to maximum contaminant levels (MCLs) and an intensive groundwater monitoring program.

Approach/Activities. To advance the remedial strategy, high resolution site characterization and Environmental Sequence Stratigraphy (ESS)^{SM} methods were utilized to enhance and refine the conceptual site model (CSM). The revised CSM identified the target treatment zones in organic-rich fine sediments containing laminations or thin interbeds of fine-grained sand. Conceptually, COCs were retained within the organic-rich sediments and slowly diffused into the thin sand beddings conducive to their migration and formation of the dissolved-plume. Given the regulatory process requirements, a contingent remedy progression was designed starting with enhanced anaerobic bioremediation (EAB) using an extended-release emulsified vegetable oil (EVO), upgrading to bioaugmentation with *Dehalococcoides* (DHC), and culminating with biogeochemical transformations using zero-valent iron (ZVI), with the addition of a carbon source, nutrients, and red yeast extract. High background sulfate concentrations and geological evidence of accumulation of iron and manganese oxides were also supportive of the combined biological and abiotic reductive approach.

Results/Lessons Learned. EAB was effectively implemented via direct-push injections of EVO into the target treatment zones identified by the revised CSM. TCE concentrations have decreased by an order of magnitude corresponding to an increase in c-DCE and the generation of up to 21 mg/L of methane. Given the continued accumulation of c-DCE and lack of any detectable DHC population at the site, bioaugmentation was triggered at two treatment zone injection wells. The injections of DHC bacteria were combined with red yeast extract to control the excessive formation of methane due to methanogenic bioactivity. DHC growth was initially inhibited by a pH drop, which did not occur post-EVO injections. As pH naturally buffered, DHC levels increased to 10^5 – 10^6 cells per mL and full reductive dechlorination was exhibited via depletion of TCE, two-order of magnitude reductions in c-DCE, and accumulation and reduction of vinyl chloride. Methane concentrations post-bioaugmentation have slightly increased (maximum of 10 mg/L) but remained lower than post-EVO concentrations, indicating methane inhibition. The third phase of the remedy was implemented in April 2017 and included injections of 3,500 pounds of Provect-IR®, 14 liters of DHC, and anoxic/buffer solution via 15 direct-push points along and across the residual plume core.