Enhanced DNAPL Dissolution and Rapid, Complete Reductive Dechlorination of Trichloroethene in a Pilot Test in a Perched Aquifer

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Background/Objectives. Residual dense non-aqueous phase liquids (DNAPLs) and high sorbed concentrations are a continuing source of trichloroethene (TCE) in a shallow perched aquifer at the former Twin Cities Army Ammunition Plant, Minnesota. Concentrations of TCE and other volatile organic compounds (VOCs) have remained stable in the plume since groundwater extraction and air stripping treatment began in 1986, causing the Army to be interested in bioremediation as a destructive remedy. Anaerobic biodegradation by reductive dechlorination can completely break down TCE to non-chlorinated daughter products, including ethene, and enhance dissolution/desorption of DNAPL. We used microcosm experiments in conjunction with site characterization to design a phased biostimulation and bioaugmentation strategy for bioremediation. We then conducted a field pilot test that included over a year of performance monitoring, to verify biodegradation processes and rates, and to evaluate the effect on DNAPL.

Approach/Activities. The pilot test design included biostimulation by injection of emulsified vegetable oil as a donor, followed by injection of a dechlorinating consortium (WBC-2) after confirmation of reducing conditions and movement of the donor (4 to 6 weeks). Bromide was added as a tracer with the donor. Three treatment plots, each consisting of one injection well with 13 monitoring wells in a grid, were installed to allow for variable groundwater flow in the shallow aquifer. Performance monitoring included (1) quarterly monitoring for VOCs, redox sensitive constituents, non-volatile dissolved organic carbon, low-molecular weight organic acids, major ions, bromide, trace metals, and microbial community analyses; (2) monthly sampling of select wells for VOCs, methane, ethene, and ethane; and (3) hydrologic measurements including synoptic and continuous water levels and slug tests to evaluate hydraulic conductivity changes. Samples for stable carbon isotope analyses of TCE and the daughter products 1,2-dichloroethylene (DCE) and vinyl chloride (VC) also were collected.

Results/Lessons Learned. Water table elevations varied by 6 to 8 feet, causing shifts in flow directions that affected movement of the amendments. Donor movement coincided with changing concentrations and molar compositions of VOCs and increases in concentrations of acetate and methane. In some areas, TCE concentrations decreased to below detection while transient DCE concentrations peaked above the initial aqueous TCE and DCE concentrations, indicating residual DNAPL dissolution and subsequent degradation to DCE. After WBC-2 injection, TCE and DCE concentrations decreased with little accumulation of VC. Ethene production was approximately two times higher than VC production, showing rapid complete reductive dechlorination. First-order attenuation rates calculated from the total moles of organic chlorine associated with the VOCs gave half-lives of 19 to 36 days at various locations in the treatment plots. Results indicate that amendments maintain suitable reducing conditions, despite hydrologic fluctuations in the perched aquifer, and complete biodegradation occurs at a faster rate than enhanced DNAPL dissolution/desorption. Thus, bioremediation could be a successful destructive remedy in the shallow aquifer. Stable carbon isotope results confirmed DCE and VC biodegradation, although some results are complicated by DNAPL dissolution.

Further analysis will use microbial community results to verify biodegradation.