# Application of Linear Regression Method to Track Remediation Progress and Predict Cleanup Time for a CVOC Groundwater Plume

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**Background/Objectives.** In situ bioremediation was applied to chlorinated volatile organic compounds (CVOCs) that were above groundwater action levels in a heterogeneous, low-permeability aquifer in a commercial/industrial area. The CVOCs at the site consisted primarily of trichloroethene (TCE), cis-1,2-dichloroethene (cDCE) and vinyl chloride (VC) at total CVOC concentrations that indicate the presence of dense, non-aqueous phase liquids (DNAPLs). After source treatment by in situ chemical oxidation, in situ bioremediation and monitored natural attenuation (MNA) have reduced dissolved CVOC concentrations below site-specific action levels in more than 85 percent of the site monitoring wells. The current objective is to evaluate the time required for CVOCs to achieve final groundwater cleanup goals.

**Approach/Activities.** In situ bioremediation was applied in on-site and off-site groundwater progressively over a period of several years to treat CVOCs by delivering substrates through a combination of permanent injection wells, an infiltration gallery and temporary borings. The substrate mixture was modified over time to optimize the treatment. The addition of a pH control reagent effectively maintained treatment efficiency after multiple injection events had reduced the natural buffering capacity of the soil. Bioaugmentation was applied where microbial indicators showed it would be effective. A linear regression method, described in the U.S. Environmental Protection Agency's natural-attenuation guidance, was applied to analyze CVOC concentrations versus time to predict the approximate time to reach cleanup goals.

**Results/Lessons Learned.** Combined source treatment and in situ bioremediation have reduced the total mass of CVOCs in the source area by approximately 99 percent, where initial concentrations exceeded 100 milligrams per liter. The total mass of CVOCs within the overall plume also decreased by an estimated 77 percent, providing significant progress toward plume cleanup. A log-linear regression of CVOC concentrations versus time at individual wells indicates remedial timeframes (i.e., time to reach final cleanup goals) of up to several decades, based on predicted values, which are timeframes consistent with the nature of long-term back-diffusion from finer-grained sediments. The method used in these calculations may overestimate remedial timeframes. Concentrations of CVOCs downgradient of the bioremediation treatment area have decreased more rapidly in recent years, and a clean water front has emanated from the treatment area.

Results will be presented to indicate the changes in CVOC concentrations and total mass within the source area and the rest of the plume during several years of treatment, as well as the effect of local heterogeneities on treatment effectiveness. Additionally, the range of forecasted remedial timeframes across the plume will be presented, as well as use of the forecasts to optimize treatment. Overall, quantitative methods for evaluating remedial timeframes have effectively justified the transition from bioremediation to MNA across most of the plume.