Steam-Enhanced Biodegradation of TCE in Mixed LNAPL Under Active Building Naval Air Station North Island

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Background/Objective. Building 379 at Naval Air Station North Island has a footprint of 172,000 square feet and overlies a light non-aqueous-phase liquid (LNAPL) plume comprised of total petroleum hydrocarbons (TPH) with dissolved trichloroethene (TCE) and 1,1,1-trichloroethane (1,1,1-TCA). The TPH is composed of jet fuel and Stoddard solvent. Estimates of LNAPL volumes range from tens to hundreds of thousands of gallons. Approximately 40% of the LNAPL footprint includes cVOCs. The depth to the top of LNAPL is approximately 23 feet below ground surface, and thickness exceeds 1 foot in some parts. LNAPL temperatures were elevated proximal to former steam lines (as high as 43^{o}C) as of 2017 (the lines were decommissioned in June 2018). Levels of *cis*-1,2-DCE in soil gas near the steam line are much higher than TCE, whereas TCE is much higher away from the steam line. Volatilization of cVOCs from the LNAPL has created a significant cVOC vapor plume underneath the building, with initial cVOC levels >10,000,000 µg/m^{3}. A soil vapor extraction (SVE) system has been in operation since May 2016, with recovery of >7,000 gallons of cVOCs. Three steam injection wells (screened below the LNAPL) were operated for 6 months in 2018 (using available steam) to enhance LNAPL volatilization and biodegradation, specifically the cVOCs. Steam injection was resumed in late 2021 using a steam boiler and is currently ongoing.

Approach/Activities. Analyses of the LNAPL composition between 1998 and 2023 indicate that TCE concentrations have decreased and *cis*-1,2-DCE concentrations have increased over time. Decreases in LNAPL thickness were also observed. After steam injection was done in the first two quarters of 2018, vinyl chloride was detected in the LNAPL. Temperature data for the LNAPL collected in 2016 indicate temperatures over 30^{o}C at a number of locations. Significant levels of *cis*-1,2-DCE were detected in soil gas, both in sub-slab and at depth. Laboratory microcosm tests using site aquifer material and LNAPL, incubated without amendments for one year at room temperature, showed dechlorination of TCE to *cis*-1,2-DCE, with concentrations of *cis*-1,2-DCE increasing in the LNAPL, consistent with field observations. The composition of cVOCs and TPH in extracted vapor and soil gas are being evaluated as a secondary indicator of biodegradation. Product samples collected at the NAPL-water interface were analyzed for *dehalococcoides* (DHC), which were detected at appreciable levels.

Result/Lessons Learned. Biodegradation of cVOCs dissolved in TPH NAPL is not commonly reported, possibly due to difficulty in measuring daughter products. However, given the right conditions (presence of electron donor and elevated temperatures), biodegradation is possible. Elevated temperatures are likely promoting biodegradation of TCE at the LNAPL-water interface, with TPH serving as a continuous/limitless source of electron donor. Active injection of steam further increased temperatures within the LNAPL plume, resulting in biodegradation of cVOCs, and significant increases in concentrations and monthly removal rates. The appearance of vinyl chloride in the LNAPL after steam injection confirms that steam-enhanced biodegradation can address TCE (and other cVOCs) under adverse conditions. Concurrent with anaerobic degradation, the TPH is being aerobically biodegraded, which further increases the mass removal due to SVE.