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1,4-Dioxane Vadose Remediation by Extreme Soil Vapor Extraction (XSVE)

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Background/Objectives. 1,4-Dioxane, a chlorinated solvent additive, can be a persistent groundwater contaminant. Although it is volatile, it is also totally miscible in water and resists biodegradation. Vadose remediation of 1,4-dioxane has proven difficult as it is sequestered in vadose zone water. Remediation by conventional soil vapor extraction (SVE) can remove the parent chlorinated solvent while leaving substantial 1,4-dioxane in the vadose zone to leach into groundwater. Extreme soil vapor extraction (XSVE) is SVE with focused extraction and heated dry air injection. Elevated soil temperatures improve the removal of 1,4-dioxane. The objective of this study was assess the performance of XSVE for the vadose zone remediation of 1,4-dioxane.

Approach/Activities. A 14-month field demonstration of XSVE was conducted at the former McClellan AFB, California. An existing SVE system removed the majority of volatile organic compounds including chlorinated solvents, however 1,4-dioxane persisted in the vadose zone soils. Pre-XSVE soil borings confirmed the location of significant concentrations of 1,4-dioxane in the vadose zone. The XSVE system was configured with four injection wells in a square pattern around a central extraction well and off-gas was treated with an existing treatment system. Well screen intervals corresponded to the soil interval containing the highest 1,4-dioxane concentrations. Soil vapor monitoring probes, temperature and soil moisture sensors were installed at various distances between the injection and extraction wells within the treatment zone. Flow rates for each of the injection wells and extraction well were maintained at roughly 100 scfm each. In-line heaters were used to heat the injected air, the goal of which was to raise and maintain mid-screen injection well temperatures at ~110 to 130°C. Extraction well and soil gas probes were periodically monitored using a vapor/condensate sampling apparatus to account for 1,4-dioxane in water condensate due to sampling humid soil gas as elevated temperatures. A screening-level mass and energy balance model for XSVE operation was developed for interpretation of field results and prediction of XSVE behavior under different conditions.

Results/Lessons Learned. Treatment zone soil temperatures reached as high as 90°C near the injection wells and the 40°C range near the extraction well. Soil moisture readings dropped to approximately zero near the injection wells, while remaining roughly constant near the extraction well. Soil moisture readings below the treatment zone increased modestly but did not indicate substantial condensation and downward migration. Post-demonstration soil sampling showed that XSVE reduced treatment zone 1,4-dioxane concentrations and soil moisture contents by 95% and 45%, respectively. 1,4-Dioxane did not increase below the treatment zone, indicating no downward migration due to condensation. Extraction well monitoring showed that the bulk of 1,4-dioxane removal occurred before treatment zone soil temperatures increased above 40°C. The XSVE screening model agreed substantially with the field results. Model shows that soil temperatures will be maintained near 40°C as long as soil moisture is present with the injection temperature range used. The model also predicts that the bulk of 1,4-dioxane would be removed early in XSVE operation as shown in the field results. Although focused extraction is central to XSVE, heated air injection substantially reduced cleanup time. XSVE provides a cost-effective, easily implemented remedial option for vadose 1,4-dioxane.