

TCE Source Area Remediation by Soil Vapor Extraction and In-Well Stripping

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ABSTRACT: A combined soil vapor extraction (SVE) and in-well stripping (IWS) system was installed in 2004 to remove the source contributing to a plume of volatile organic compounds (VOCs) in groundwater, primarily trichloroethene (TCE). Within one year of system startup, the SVE system successfully removed the majority of VOC mass from the vadose zone. The IWS system reduced average TCE concentrations in groundwater (within the source area) by more than 98 percent. At startup, 10 compliance monitoring wells indicated TCE concentrations exceeding the cleanup level of 5 micrograms per liter ($\mu\text{g/L}$). Concentrations in those wells ranged from 8 to 1,200 $\mu\text{g/L}$. After 3 years of operation, 5 compliance wells exhibited groundwater concentrations exceeding the cleanup level (with TCE concentrations ranging from 6.1 to 30 $\mu\text{g/L}$), of those, only two are more than twice the cleanup level. At the time of system startup, the maximum TCE concentration in groundwater within the source area hot spot was 1,200 $\mu\text{g/L}$; it is currently 30 $\mu\text{g/L}$ (a 97% reduction). The cleanup of the source area (approximately 1 acre) has been rapid and overall plume-wide monitoring indicates a reduction in the plume length. The calculated mass flux across the downgradient compliance monitoring points has decreased more than 98%. A closure process for both systems was included in the remedial design and approved by the EPA. Since then, the SVE system and five of the nine IWS treatment wells have been shut down.

INTRODUCTION

The Boomsnub/Airco Superfund Site (Site) is located in Hazel Dell, Washington, just north of the city limits of Vancouver, Washington and includes two adjacent facilities, the former Boomsnub Corporation (Boomsnub) chrome plating facility and The Linde, Inc. (Linde, formerly Airco) gas production facility.

The Site is divided into three operable units (OUs) to manage cleanup activities, Boomsnub Soil (OU-1), BOC (now Linde) Soil (OU-2), and Site Wide Groundwater (OU-3).

In 1987, the Washington State Department of Ecology (Ecology) determined that a plume of chromium-contaminated groundwater was emanating from the Boomsnub facility. While cleanup activities were being conducted by Ecology at the Boomsnub facility, VOCs were detected in groundwater samples and were suspected of coming from the Linde property across the street. Linde began investigating the nature and extent of VOCs in 1991. In June 1994, United States Environmental Protection Agency (EPA) took over the role of lead regulatory agency from Ecology and in April 1995, the Site was placed on the National Priorities List. Ultimately, chromium and VOCs in groundwater, emanating from two separate release points, were found to extend approximately 4,400 feet (ft) (1320 meters) downgradient in a west-northwest direction. Linde requested EPA approval of a source control removal action in 2000.

A Record of Decision (ROD) was issued in February 2000 (EPA 2000) describing the remedies for OU-1 and OU-3. EPA issued an Action Memorandum in September 2001 for a non-time critical removal action at OU-2 to address the source of the VOC plume. This paper describes the implementation and performance monitoring associated with the OU-2 removal action. The remedial action objectives established in the OU-2 Action Memorandum included the following performance objectives:

- Remove VOCs from the vadose zone that may be acting as the source to groundwater
- Remove VOCs from groundwater on the western portion of the Linde property (the source area)
- Halt off-property migration of VOCs in groundwater.

Nature and Extent of Contamination. Historically, the VOCs detected in the groundwater were 1,1,1 trichloroethane, TCE, tetrachloroethene and freon-11. TCE is typically detected at 10 to 100 times the concentration of other VOCs, and therefore is used as the indicator when assessing the performance of the removal action. The ROD established the remediation goal for groundwater to meet the cleanup level for TCE of 5 µg/L.

At the startup of this remedial action, the maximum concentration of TCE detected in water samples collected from onsite monitoring wells was 1,200 µg/L. The relatively high concentrations of VOCs in groundwater indicate residual VOCs in the soil, but the relatively low concentrations detected in soil during extensive investigations do not provide evidence of a single source. TCE was detected in soil at concentrations ranging from 5 to 470 micrograms per kilogram (µg/kg). Prior historical sampling indicated TCE concentrations up to 2000 µg/kg detected in soil samples below the water table.

MATERIALS AND METHODS

The system selected for the removal action through the Engineering Evaluation/Cost Analysis (EE/CA) process was a combination of in-well stripping (IWS) and soil vapor extraction (SVE) to remediate soil and groundwater contamination in the source area. The system is composed of three components.

- For treatment of the vadose zone soil, to remove any residual contaminants that may be contributing to groundwater contamination, SVE was selected. SVE is an in-situ soil treatment process where a vacuum is applied to a well screened above the groundwater table to remove air from the soil pore space. Along with the air, VOCs are extracted.
- For treatment of the saturated soil and groundwater, IWS was selected. IWS is an in-situ treatment process where air lift pumping is used to move groundwater through a vertical circulation well. The VOCs dissolved in the water are stripped from the groundwater within the well casing by the injected air. For this site Density-Driven Convection IWS Technology was utilized.
- For off-gas collection and treatment granular activated carbon (GAC) was selected for both IWS and SVE systems.

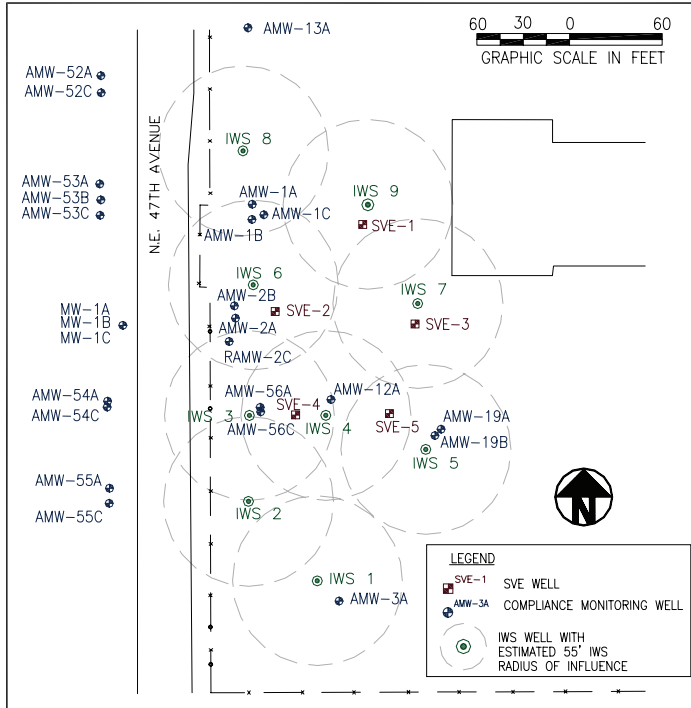


FIGURE 1. Site Layout.

The general layout of the treatment system and network of monitoring wells (both on site and down gradient) is shown in Figure 1. The system started operation in February 2004. System operation included a significant amount of performance monitoring to demonstrate the efficacy in meeting the EPA mandated performance objectives.

Performance Criteria. The performance evaluation for the removal action is based on the reduction of VOCs in onsite soil, groundwater and the prevention of further offsite migration.

SVE System. The SVE system performance is monitored by VOC analysis of samples of the vapor extracted from the soil by the system. The measured concentration is used to calculate the quantity of VOCs removed. When the operation and maintenance manual was prepared for these systems, it was determined that the SVE system would be operated until asymptotic removal levels are obtained. The operational definition of “asymptotic removal rate” used in the design and closure plan refers to the point where the declining mass removal rates (by the SVE system) make continued operation of the system ineffective and indicate operations should be terminated. The performance objectives did not establish specific soil vapor criteria but rather an evaluation of declining removal rates for determining the point at which system operations are no longer effective. Once the removal rates declined and stabilized, the system has undergone rebound testing (a series of periodic operation and rest periods) to determine if significant VOCs remain in the vadose zone. The closure procedures allow the system to be shut down following successful completion of three rebound tests.

IWS System. IWS system performance is monitored using a set of monitoring wells located within and downgradient of the VOC plume/treatment area. These wells are shown in Figure 1, and include a total of twenty five wells located within the center of the plume, on the “sides” of the plume, and downgradient of the plume. Compliance monitoring has been conducted on a quarterly basis since system start-up. The plan for system closure is attainment of cleanup levels for TCE in the treatment well and associated monitoring wells. If asymptotic conditions are met in these wells, termination of treatment may occur prior to meeting cleanup levels with approval from EPA.

RESULTS AND DISCUSSION

SVE System. A vapor sample from the SVE system was collected at system startup in February 2004. This sample indicated a TCE concentration of 7,100 micrograms per cubic meter ($\mu\text{g}/\text{m}^3$). The second vapor sample, collected in April 2004, indicated a TCE concentration of $420 \mu\text{g}/\text{m}^3$, a 94 percent decrease from the initial concentration. As expected, and as depicted in Figure 2, the concentration of VOCs in the vapor samples has rapidly declined over time and removal rates are considered asymptotic.

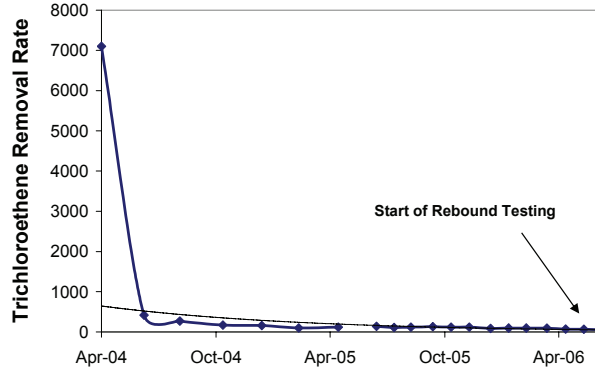


FIGURE 2. Change in SVE Removal Concentrations over Time ($\mu\text{g}/\text{m}^3$).

The TCE removal rates continued to decline throughout 2004, with an average decline of 20 percent between samples. In 2005, the average decline in removal rates between samples was 1 percent. Rebound testing was initiated in 2006, and the system was shut down following completion of rebound testing.

IWS System. Since starting IWS operations in February 2004, TCE concentrations have decreased significantly in all monitoring wells across the VOC source area and in the downgradient monitoring well network. Quarterly groundwater monitoring has been used to track the performance of the IWS operations using TCE concentrations in the groundwater. Figure 3 shows how groundwater concentrations have changed over time, as measured by well groupings. The wells are grouped by areas to evaluate changes in TCE concentrations in groundwater over representative areas of the plume. These areas of well groupings are the “Center of Plume”, “Side gradient” and “Down gradient Wells”. The grouping of downgradient wells represents a significant array of multi-level monitoring points positioned throughout the cross-section of the plume (see Figure 1). This grouping of downgradient wells has been used in the performance monitoring to evaluate the off site flux of TCE within groundwater. Since system startup, TCE concentrations have decreased 99% in center of plume wells, 91% in sidegradient wells, and 98% in downgradient monitoring wells. The average concentration of TCE in each of the well groups is currently less than the cleanup limit, but some

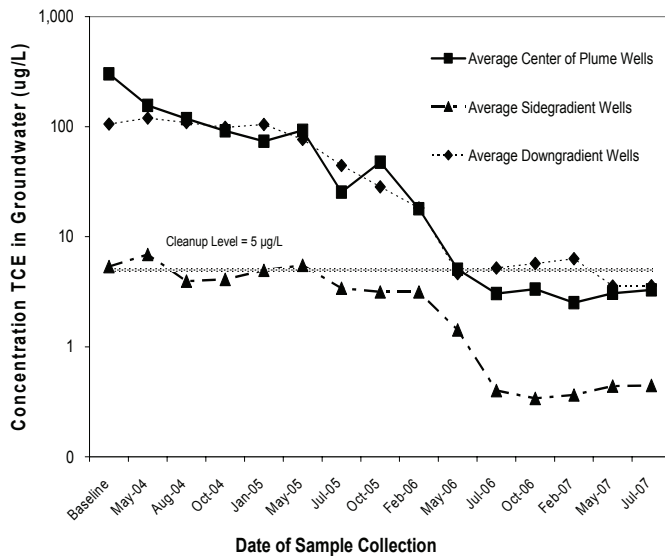


FIGURE 3. TCE Concentrations in Groundwater over Time, by Well Grouping.

individual wells remain above the cleanup level. TCE concentrations exceed the cleanup level in five groundwater monitoring wells.

In the fall of 2006, in accordance with the preliminary closure process for the IWS system, and with concurrence from the EPA, three treatment wells on the periphery of the treatment area were shut down. The shutdown was initiated since the concentration of TCE in the IWS wells and the associated compliance monitoring wells were all less than the cleanup level of 5 µg/L. In the summer of 2007, another two IWS treatment wells attained cleanup levels and were shut down.

At this time, four of the original nine IWS wells are currently operating. TCE concentrations in AMW-12A appear to have reached a plateau (above the cleanup level), with concentrations ranging between 25 and 35 µg/L for the last 2 years. This well is at the center of the source area, and has historically had the highest TCE concentrations within the source area. At this time, the operational conditions for the currently operating IWS wells will be modified (changing air flows, pulse pumping, or temporary shutdown of individual wells) to determine if further TCE can be removed from the subsurface.

CONCLUSIONS

Overall the combined SVE/IWS systems has been effective in rapidly achieving and/or approaching the removal action goals identified in the EE/CA (EA 2000). The SVE system was operated until asymptotic conditions were achieved. Even with rebound testing and modifications to flow rates, appreciable mass could no longer be removed from the vadose zone. Figure 4 and Figure 5 show a plume map that depicts the changes in TCE concentrations in groundwater since system startup to the present time. Within 24 months of system startup, the IWS system has successfully reduced the measured TCE concentrations in the center of the plume by more than 99% and has reduced the estimated mass flux of TCE off the Linde property by more than 98%.

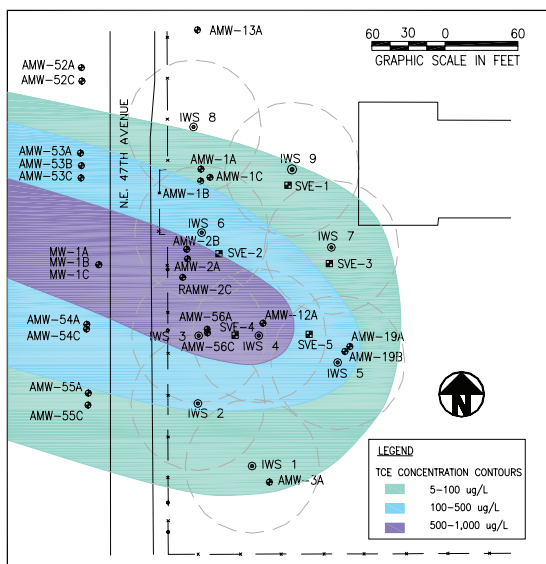


FIGURE 4. TCE Plume Map before System Startup (2003).

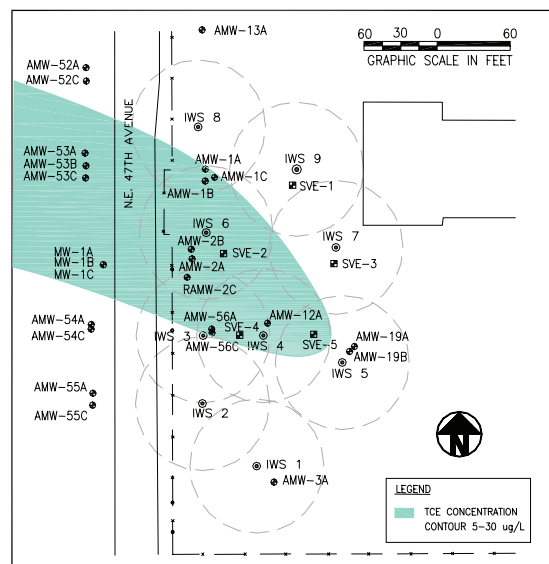


FIGURE 5. TCE Plume Map 2007.

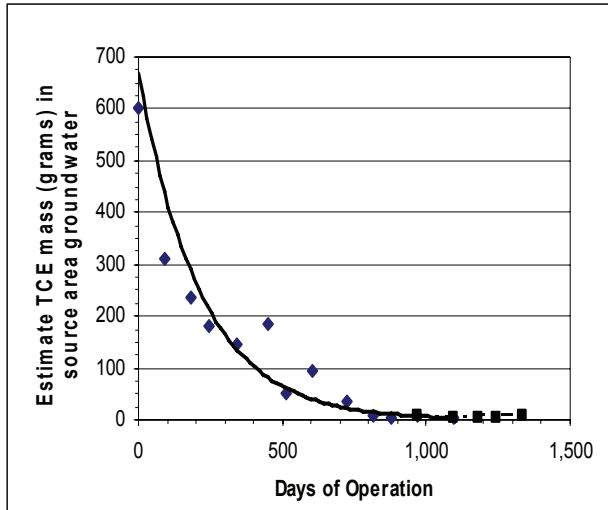


FIGURE 6. Mass of TCE over Time.

lbs of TCE (600 grams) and the present estimate of mass is approximately 0.02 lbs (8 grams), ranging between 4-8 grams over the last year.

The estimated TCE inventory over time is plotted in Figure 6 along with an exponential regression equation based on the assumption of a first order removal process (i.e., the removal rate is proportional to the mass present). The first-order removal process provides a reasonable fit to the performance data (i.e., the calculated inventory based on measured concentrations). Figure 7 presents the same data on a logarithmic scale. The data in Figure 7 suggests the system has removed the majority of contaminant mass that is technically feasible with this technology and approximately 5 to 8 grams of TCE remains. Interpretation of the results indicates that a point of diminishing returns for further operation may have been reached (99% reduction in inventory and 98% reduction in down gradient flux). Over the next year, this conclusion will be evaluated by system modifications that will attempt to draw some of the remaining mass out of the aquifer.

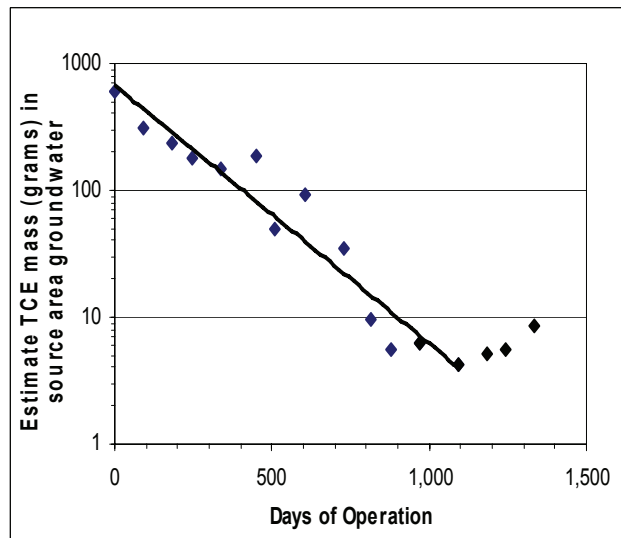


FIGURE 7. Mass of TCE over Time (log scale).

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