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INNOVATIVE STRATEGY TO LOCATE VOC SOURCES DEEP IN THE SUBSURFACE

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ABSTRACT: Since 1994, the U.S. Army has expended approximately $2M annually to operate a 8,000 gallons per minute (gpm) (30 x 10^3 liters per minute, or L/min) pump-and-treat system designed to remediate a large groundwater plume contaminated with organic solvents at the Tooele Army Depot (TEAD) in Tooele, Utah. Predictive computer modeling conducted in 1998 suggested that unless sources of volatile organic compounds (VOCs) in the vadose zone were identified and removed, impact to groundwater exceeding cleanup standards would continue for decades. The intent of the investigation was to locate VOC sources impacting the groundwater in an 800-acre (3.2 square kilometers, or km^2) area at TEAD. The investigation was designed in an "inverted pyramid" fashion, using broad-based, less expensive screening tools to zero in on potential source areas, followed by more sophisticated and expensive technologies to pinpoint vadose zone source locations. Results of the investigation lead to the discovery of a previously unidentified oil/water separator that contained liquids and sludge with high concentrations of trichloroethene (TCE). This system was identified as one of the major sources of the groundwater contamination and subsequently became the location of a deep soil vapor extraction (SVE) pilot test designed to evaluate the feasibility of removing solvents deep in the vadose zone across TEAD.

INTRODUCTION

TEAD is located in Tooele, Utah, approximately 35 miles (56.3 km) southwest of Salt Lake City, Utah. In its prime, the Depot was one of the major ammunition storage and vehicle maintenance installations in the U.S. and provided support for other Army installations throughout the western United States. Waste management facilities in the main industrial area included an industrial wastewater lagoon (IWL) and associated unlined wastewater ditches that received process wastewater from a number of industrial operations such as vehicle parts maintenance and cleaning, ammunition demilitarization, and equipment testing. By 1989, the IWL and ditches were closed, but not before the underlying groundwater had been impacted by chlorinated solvents, in particular TCE. In 1993, the Army began operating a treatment system to remediate the impacted groundwater, believed to consist of approximately 38 billion gallons (144 billion liters) of water with an average TCE concentration of 28 micrograms per liter (ug/L). The treatment plant has the capacity to treat up to 8,000 gpm (30 x 10^3 L/min) and costs the Army approximately $2M per year to operate, with an estimated life cycle of 30 years.

In 1998, TEAD asked Kleinfelder to perform an evaluation of the treatment system to identify alternatives for the pump and treat remediation with the intent of reducing these O&M costs. The study concluded that the observed stability of the plume (i.e., lack of remedial progress) required the existence of active sources in the upgradient area that were slowly releasing contaminants to the groundwater. Modeling also indicated the treatment system could operate for decades and the impacted groundwater may never reach remedial goals unless the sources were removed. Conversely, if the unidentified sources were located and removed, the plume could naturally attenuate in as little as 15 years, resulting in large cost savings to the military. These findings re-energized the search for continuing sources of VOCs to groundwater.

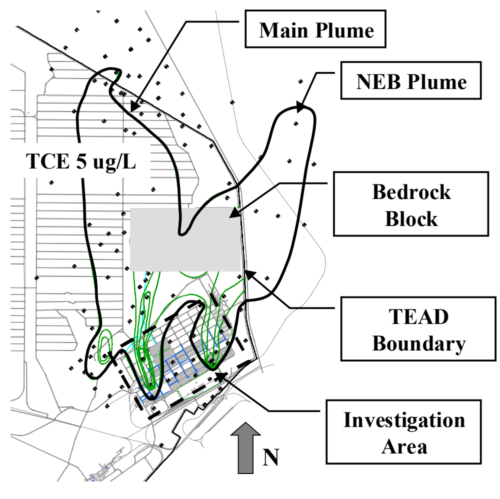

FIGURE 1: TEAD TCE plume.

Physical Setting. Groundwater investigations over the past 15 years have identified two separate groundwater plumes beneath the study area (see Figure 1). The "main plume" originates in an industrial area on TEAD and stretches approximately 3.1 miles (5.0 km) to the north-northwest. The Northeast Boundary (NEB) Plume, which appears to originate in the northeast portion of the industrial area, extends approximately 3 miles (4.8 km), crossing the Depot boundary and continuing beneath privately owned property to the northeast. Depth to groundwater across the study area ranges from about 100 ft (30.5 m) below ground surface (bgs) in the north to over 400 ft (121.9 m) bgs in the south. The primary aquifer consists mainly of poorly sorted granular material ranging from silt to gravel to cobbles. There is a subsurface bedrock configuration beneath part of the study area that appears to divide the groundwater into the observed northwesterly and northeasterly flows. The coarse sediments, combined with the depth of the groundwater, make subsurface investigation difficult and expensive.

Although previous investigations had identified several industrial facilities where large quantities of solvents had historically been used, surface and shallow subsurface soil samples had failed to identify any potential source areas that could have caused the groundwater contamination to the extent observed. In 1998, the Army enlisted Kleinfelder to locate the source(s) of the groundwater contamination.

Investigation Objectives and Strategy. The objective of the investigation was to design and carry out the most cost-effective investigation possible to locate and identify unknown source areas believed to be impacting the groundwater beneath the Depot. Technical challenges included:

- No obvious sources of groundwater contamination indicated by previous investigations.
- Over a 800 acres (3.2 km^2) of industrial area to investigate.
- Coarse-granular soils up to 400 feet (121.9 m) in thickness above the water table.
- Difficulty in detecting low concentrations of solvents in granular soils.
- The prohibitive cost of drilling monitoring wells to confirm impact to groundwater.

Kleinfelder's solution to these technical challenges was through the use of innovative technologies and a team approach to locate chlorinated solvent sources deep in the vadose zone. The key to the strategy and success of the project was the interactive, iterative approach. "Iterative" in that each phase of the investigation was built on the results from the previous phase, and "interactive" in terms of the cooperative team approach adopted by all of the stakeholders, including Depot, Army, State, and EPA personnel.

In July 1998, Kleinfelder began conducting a soil gas investigation designed in a "pyramid" fashion, using broad-based, less expensive screening tools to locate and identify potential source areas for further investigation with more sophisticated and expensive sampling technologies. The phased approach began with a passive soil gas (PSG) survey done over a broad area (approximately 800 acres, or 3.2 km^2) to identify the presence or absence of solvents. During the spring of 1999, 937 GORE-SORBER® Modules were installed from 3 to 6 ft (0.9 to 1.8 m) bgs and left in the ground for 14 days. Although the detectable presence of VOCs had not been confirmed previously during surface soil sampling efforts in this area, the intent of the passive soil gas investigation was to record the accumulated mass of contaminants sorbed to the modules over time. During the two-week exposure period, the modules acted as a "sink," sorbing contaminants present in the subsurface soil vapor. Once removed and analyzed for VOCs, contour maps of the primary contaminants of concern were created and electronically overlaid onto aerial photograph base maps (Figure 2 is a visual representation of the TCE data). This unique representation of the data allowed the Project Team to visually identify areas of higher mass accumulation, or "hot spots," while other locations were eliminated as potential source areas. As a result, subsequent sampling efforts were more focused.

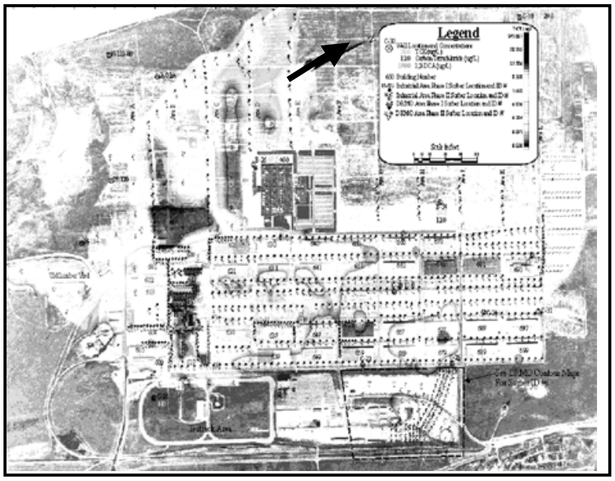

FIGURE 2: TCE passive soil gas

In the second phase, the PSG hotspot areas were confirmed for further investigation using active soil gas (ASG) sampling to quantify the amount of solvents in the subsurface soil gas. In the fall of 1999, twenty-four ASG points were installed in the passive soil gas hotspot areas to a depth of approximately 10 ft (3.0 m) and sampled using SUMA® canisters. At each spot, the ASG data confirmed the presence of elevated VOCs in the areas of highest PSG detections.

Once the results of the active soil gas survey confirmed elevated VOC detections in the shallow soils, the third phase of the investigation involved installing and sampling five vertical soil gas (VSG) monitoring stations from October through December 1999. The intent of the VSG wells was to assess the vertical extent of solvents in the vadose zone from the ground surface to 20 ft (6.1 m) above the water table. The main component of the VSG wells are polyethylene liners driven by low-pressure air into a pre-drilled, uncased borehole. The liners are pre-made with 10 sampling ports distributed along the length at predetermined locations. Soil gas samples are drawn from sampling lines at the wellhead that tie into the sampling ports. The sampling lines are grouped into sleeves on the inner surface of the liner, with each line drawing vapors from a discrete elevation, thus making vertical vapor profiling possible (see Figure 3). Once installed, the liners were filled with sand to prevent short-circuiting of the soil vapor and to make the wells permanent sampling stations. Analytical results of the soil gas samples confirmed the presence of solvents throughout the entire saturated zone at several locations.

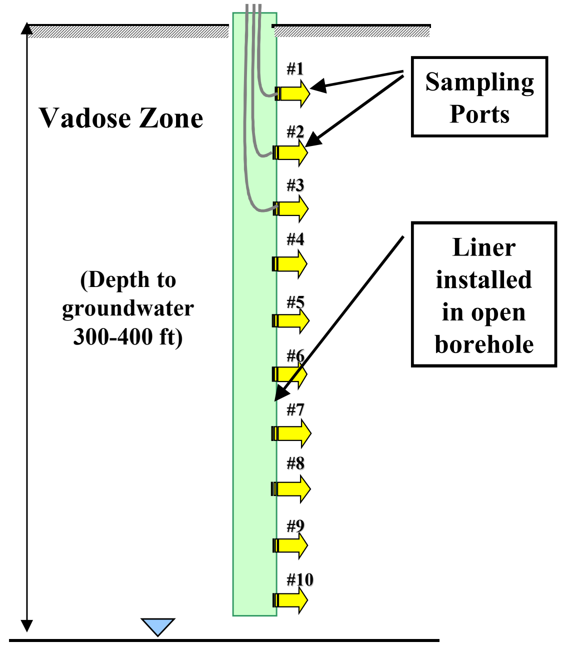

FIGURE 3: VSG schematic.

INVESTIGATION RESULTS

Based on the passive, active, and vertical soil gas data collected, three regions in the industrial area were identified as likely source areas contributing to groundwater contamination and a number of other areas were identified which require further investigation.

Most significantly, these findings aided Kleinfelder in locating a previously unidentified oil/water separator sump containing liquids and sludge. Analytical results of the contents from the sump found TCE in the percent range and suggested that releases from this facility had likely been a major source of solvent contamination impacting groundwater for some time. Subsequent investigations found an estimated 6,000 lbs (2721.6 kg) of TCE in the vadose zone beneath the site. Additionally, the impact to groundwater was later confirmed by installing and sampling a groundwater monitoring well immediately downgradient of the sump. TCE concentrations in the groundwater were as high as 3430 ug/L in January 2001. The contents of the sump and the sump itself were subsequently removed and the location became the site for a deep soil vapor extraction pilot test as described below.

SOIL VAPOR EXTRACTION PILOT TEST

In order to evaluate the best mechanism for removing the deep vadose zone sources as identified across the Depot during the investigation, the Army hired the SCA/Kleinfelder Team to design, install, and operate a deep soil vapor extraction (SVE) pilot test. The test was designed to evaluate the technical and economic feasibility of removing solvent vapors from the unconfined soil found across TEAD by venting to depths up to 350 ft (106.7 m) bgs.

System Design and Operation. The system was designed with two 4-inch (10 cm) diameter vent extraction wells (VEWs), one screened from 50 to 170 ft (15.2 to 51.8 m) bgs and the other from 225 to 345 ft (68.5 to 105.1 m) bgs. The system was a fully integrated, skid-mounted extraction unit with a catalytic oxidizer treatment component (referred to as the thermal treatment unit, or TTU) designed to comply with the State of Utah *de minimus* standards for air emissions. In order to draw air from the required depths, a 1000 standard cubic feet per minute (scfm) (2.8×10^7 cubic centimeters per minute) blower was used.

Four nested monitoring probes (MPs) were also installed at distances ranging from 100 to 350 ft (30.5 to 106.7 m) from the VEWs. Each MP had sampling points at three distinct depths that, along with a nearby VSG well, were used to monitor the effectiveness of the system throughout the 6-month period. The MPs and VSG were sampled immediately prior to the system startup to establish baseline conditions, and then monthly thereafter along with the VEWs and the treatment system output.

Operating Results. The effective system radius of influence (ROI) was evaluated using two methods: (1) a vacuum-based empirical method using pressure readings as observed in the MPs and (2) a calculated distance vs. travel time method using data derived from modeling using GASSOLVE. For the empirical method, the criterion of 0.1 inches (0.254 cm) of water column as observed in the MPs was used. Throughout the duration of the project, MP-4, the monitoring probe farthest from the VEWs at 350 ft (106.7 m), consistently met this criterion indicating an effective ROI of 350 ft (106.7 m) using this method. For the second method, travel time was evaluated using vacuum readings and the GASSOLVE model to estimate horizontal and vertical permeabilities. The data were in turn used to approximate travel times with respect to distance from the vent wells. By this method, the distance representing a maximum travel time of one week defined the limit of effective ROI, thus allowing one pore volume exchange per week at that distance. Using this method, an effective ROI of 240 ft (73.2 m) was calculated, which is about 30% less than the empirical result of 350 ft (106.7 m) but still reasonably consistent. Therefore, an effective ROI for the system ranged between 240 to 350 ft (73.2 to 106.7 m), which represents treatment of between 2.5 million to almost 5 million cubic yards (1.9 million to 3.8 million cubic meters) of soil with a single well.

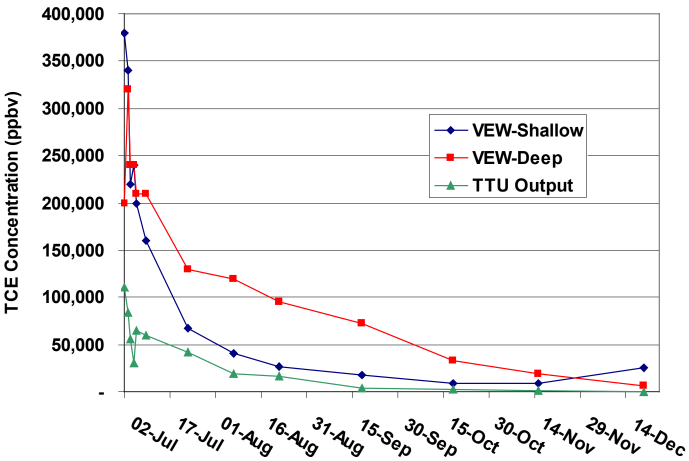

FIGURE 4:TCE concentration vs. time for vent wells and TTU output.

Figure 4 shows the TCE concentrations versus time for the VEWs and the TTU output throughout the 6-month period of operation. The cumulative TCE removed during the pilot test was estimated to be 2794 lbs (1267.3 kg) or 232 gallons (878.2 L). Additionally, six sampling ports on the nearby VSG were sampled monthly to evaluate changes in the

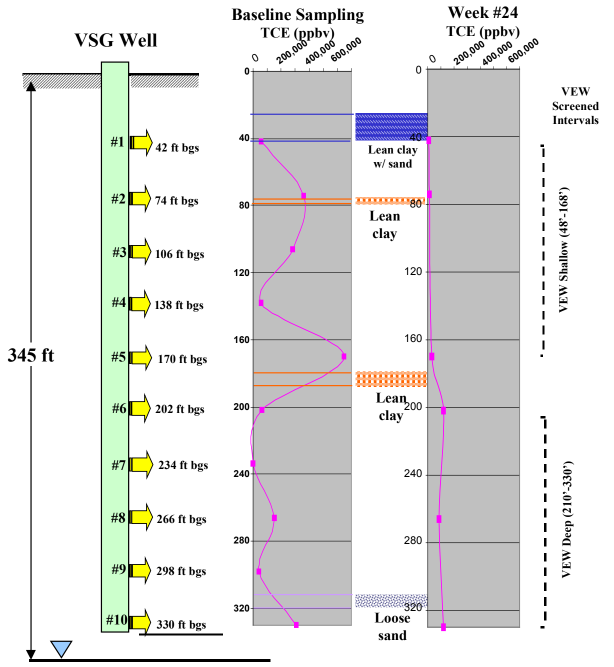

FIGURE 5: VSG well sampling results.

vertical soil gas profile during the system operation. Figure 5 depicts the baseline data compared to those from the final sampling event.

As can be seen from Figure 4, the TCE concentrations in both the shallow and deep vent wells showed a general decline for the duration of the pilot test. The one exception is the concentration increase in the shallow vent well during the final sampling event. This may be due to the fact that pumping of the shallow VEW was suspended for 2 weeks prior to sampling, allowing the soil gas concentration to rebound during this period.

The vertical soil gas profile in the VSG well also showed a decrease in the soil vapor concentration from the baseline sampling prior to startup through the final week of system operation (see Figure 5). Concentrations decreased from a high of 610,000 parts per billion by volume (ppbv) in sampling Port #5 at 170 ft (51.8 m) bgs during baseline sampling to a high of 120,000 ppbv found in both sampling Ports #6 (202 ft bgs) and #10 (330 ft bgs) after 24 weeks of system operation (61.6 m and 100.6 m bgs, respectively). Based on the data from the VSG and the deep vent well, there is an indication of contaminant mass still present deep in the vadose zone.

The effect that the SVE system operation had on the underlying groundwater is the subject of much discussion. Concentrations of TCE in the monitoring well installed immediately downgradient of the former sump location indicates a decrease in groundwater concentration, from 3,430 ug/L prior to system startup to 2,040 ug/L at the end of the test. The Army is considering whether to restart the system after a sufficient rebound period to address the apparent lingering vadose zone contamination and to further evaluate the effect of system operation on the underlying groundwater.

CONCLUSIONS

Although previous surface soil sampling was unable to identify vadose zone sources large enough to be impacting the groundwater beneath TEAD, a unique "inverted pyramid" investigative approach utilizing soil gas sampling was successful in locating and defining several potential vadose zone source areas. Passive soil gas sampling proved to be a cost effective tool in locating significant masses of residual VOCs in the vadose zone, while vertical soil gas sampling identified several locations where solvents appear to be impacting the groundwater below. Subsequent soil vapor extraction removed an estimated 2794 lbs (1267.3 kg) of TCE from the subsurface in one location and preliminary evaluations suggest a reduction in TCE concentrations in the underlying groundwater beneath the site. The substantial amount of TCE removed confirmed both the presence of significant soil contamination as identified by the soil gas investigation and presented convincing evidence of the effectiveness of SVE technology to treat VOCs in the vadose zone at TEAD.

Conclusions from the investigation are that by removing the residual VOCs from the vadose zone beneath the former sump, along with other now-identified source locations, the time, energy, and effort to remediate the groundwater beneath the Depot could be significantly reduced, with the added benefit of substantial cost savings to the government.

ACKNOWLEDGMENTS

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