A Soil Vapor Extraction Pilot Study in a Deep Arid Vadose Zone

Part 1: Field Study Summary

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ABSTRACT

Non-radioactive liquid chemical waste was disposed at Material Disposal Area (MDA) L within Technical Area 54 (TA-54) at the Los Alamos National Laboratory (LANL) from the early 1960s until 1985. Three surface impoundments, one pit, and 34 vertical shafts comprise the MDA L disposal facilities. None of the disposal areas were lined. Under LANL's Environmental Program, extensive sampling and analysis have been conducted to characterize the vadose zone beneath MDA L and to determine the nature and extent of contaminant releases from the former disposal units. The major contaminant release at the site is a subsurface organic solvent vapor-phase plume consisting primarily of several chlorinated volatile organic compounds (CVOCs) including 1,1,1-trichloroethane (TCA), trichloroethene (TCE), Freon, tetrachloroethene (PCE). TCA was found in the greatest concentration, constituting the majority of the plume mass, and it also exhibits the greatest lateral and vertical extent in the organic vapor plume. A numerical model to characterize the subsurface plume has been developed based on the site conceptual model and refined using data from ongoing compliance monitoring. The primary goal of the pilot test was to provide information necessary to determine the effectiveness of SVE as a treatment method for the VOC vapor plume. To achieve this objective, commercially available SVE equipment meeting functional requirements established by previous vapor extraction testing and extensive vadose zone characterization activities was leased, temporarily installed, and operated at each of two test extraction wells in sequence. Granular activated carbon was used to treat the SVE emissions. Subsurface vapor monitoring captured the reduction in soil vapor concentrations and subsurface pressure changes. Active extraction was conducted from extraction wells constructed near the source term over a two-month period, resulting in the removal of more than 800 lbs of VOCs. Rebound monitoring was conducted to provide information on the nature of the source. Rebound monitoring indicated a fairly rapid source response, with preliminary data showing concentrations in monitoring boreholes closest to the source reaching steady state at concentrations lower than pre-test levels. Data from this study will be used to refine the MDAL L numerical model in order to assess the long term effectiveness of SVE as a remedy for the subsurface vapor-phase plume at MDA L in support of the corrective measure evaluation for MDA L.

INTRODUCTION

A pilot test was conducted to evaluate soil vapor extraction (SVE) at Material Disposal Area (MDA) L within Technical Area 54 (TA-54) as a method to remove organic vapor from the subsurface, and as a potential method to minimize plume growth in the event that the source term changes substantially (e.g. one or more containers holding the liquid waste fails). The results of the pilot study will be used to support the MDA L Corrective Measures Evaluation (CME), by documenting the data collected on the performance of SVE technology.

Previous SVE investigations conducted at MDA L include a Pilot Extraction Study Plan (PESP), and an independent Technical Advisory Group (TAG) study to evaluate potential plume treatment alternatives. Included in the PESP was a Pilot Vapor Extraction Test (PVET), in which a SVE system was constructed and operated near the outer boundary of the plume. The results of this test demonstrated the potential effectiveness of SVE at MDA L. Based on a detailed data review, including the results of the PVET, the TAG concluded that SVE would be an effective method for VOC removal at the site.

Data from the pilot test will be used to evaluate the potential of SVE for remediating the current MDA L vapor plume and for controlling future releases from the vertical shaft source zone. LANL will use these data to simulate the movement of VOCs in the subsurface using the computer code Finite Element Heat and Mass to simulate the venting tests, develop extraction rates over time and estimate zone of influences for remediating the plumes. The LANL modeling will then be used during the MDA L Corrective Measures Evaluation (CME) to evaluate the effectiveness of SVE in remediating the plumes. If SVE is selected as part of the final remedy for the site, then design criteria will be developed in the Corrective Measure Implementation report.

BACKGROUND

MDA L, an approximately 2.5 acre site, was used for subsurface disposal of Laboratory-generated non-radiological liquid chemical waste. From the early 1960s until 1985, both containerized and uncontainerized liquid chemical wastes, including chlorinated solvents, were disposed of at the site. Three surface impoundments, one pit, and 34 vertical shafts comprised the MDA L disposal facilities, as shown in Figure 1. None of the disposal units were lined.

The 34 disposal shafts are split into two areas on either end of MDA L. Shafts 1–28 operated between 1975 and 1985 and are grouped on the east end of MDA L around Pit A; Shafts 29–34 were operated between 1983 and 1985, and are grouped on the west end of MDA L. The majority of the shafts are 60 ft deep and range from 3 ft to 8 ft in diameter. The shafts primarily received 55-gal. metal drums containing chemical liquid waste. The drums were layered with one to six barrels per layer. Each layer was covered with approximately 6 in. of crushed tuff to provide absorbent material for any leaks as well as structural support for the drums. Before 1982, containerized liquids were disposed of without adding absorbents to the containers in which they were placed. In addition to the drums, unknown quantities of small containers and free product were disposed of in the shafts. The shafts are considered to be the contaminant sources for the VOC plume. No existing records provide estimated waste volumes in the shafts.

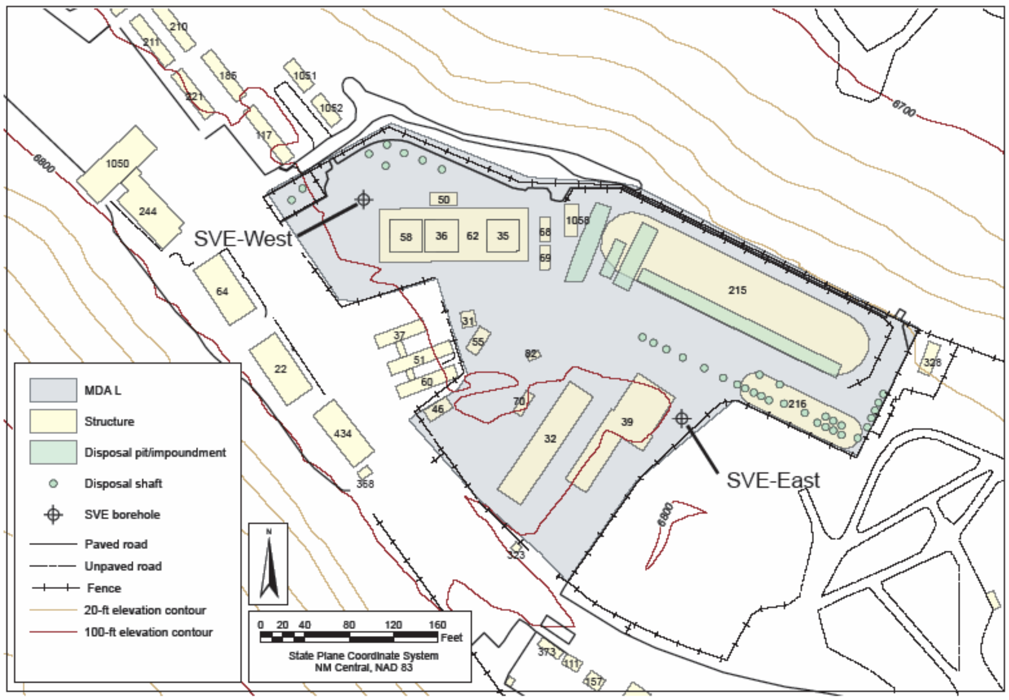

Figure 1. Material Disposal Area L SVE Pilot Test Extraction Borehole Locations

Characterization of the site began in 1985. The site is contaminated by a subsurface volatile organic compound (VOC) vapor plume. LANL has conducted quarterly sampling of VOC pore gas throughout the subsurface area since 1997. This monitoring and completion of activities defined in the MDA L Investigation Work Plan (LANL 2004, 87624) has provided sufficient data to determine the nature and extent of the VOC vapor plume. Extraction data from a previous soil vapor extraction (SVE) pilot study carried out between 1994 and 1995 showed that the contaminant movement through the media was not retarded. This, coupled with the fact that rock samples from boreholes as deep as 300 ft showed no condensed liquid VOC or sorption of organic compounds on the matrix, indicates that there is no free liquid form of contaminant present. This observation is consistent with expectation based on the absence of organic carbon, low moisture content, and low specific surface area of the media and is supported by equilibrium partitioning calculations using data from tuff samples and collocated vapor samples. Based on observations from both long-term monitoring and modeling, the conceptual model of the site assumes that organic liquids leak slowly from the buried containers and volatilize rapidly into the tuff pore space, and that the VOC vapor phase plume is at near-steady state.

After subsurface disposal activities at the site ended, the surface was covered with asphalt. Area L is currently used for Resource Conservation and Recovery Act (RCRA)-

permitted hazardous waste storage and treatment and for storage of mixed-waste under interim status.

SITE DESCRIPTION and GEOLOGIC SETTING

The Laboratory lies on the Pajarito Plateau between the Jemez Mountains and the Rio Grande. Bandelier Tuff, a thick sequence of ash-fall pyroclastics, caps the plateau. Erosion of the tuff over time has created a series of canyons separating the narrow, finger-like mesas that comprise Pajarito Plateau. MDA L is situated atop one such mesa, Mesita del Buey.

The strata below MDA L are composed of nonwelded to moderately welded rhyolitic ash-flow and ash-fall tuffs interbedded within pumice beds. The rhyolitic units overlie a thick basalt unit, which, in turn, overlies a conglomerate formation. Canyons on either side of MDA L (Cañada del Buey to the north and Pajarito Canyon to the south) lie approximately 100 ft below the steep-sided mesa. The regional aquifer is located approximately 985 ft below the disposal pits. No perched aquifers are known to occur below the mesa (LANL 1998, 59599) and perched water was not encountered in a borehole drilled to a depth of 660 ft. Figure 2. Subsurface Stratigraphy at Material Disposal L.

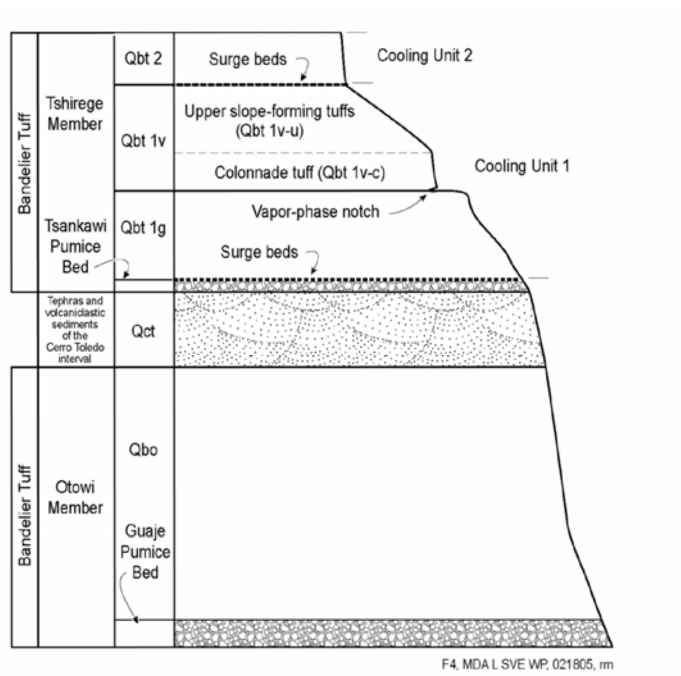

Figure 2. Subsurface Stratigraphy at Material Disposal L

The Bandelier Tuff is the is upper most formation and is comprised of the Tshirege and Otowi Members by the Cerro Toledo. Three upper units make up the Tshirege Member of the Bandelier Tuff. Unit 2 (Qbt 2) and the upper portion of unit 1v (Qbt 1v) are fractured, and the fractures are often filled with calcite and/or clay. The Cerro Toledo strata (Qct) is made up of volcanoclastic sediments interbedded with minor pyroclastic flows. The Otowi Member (Qbo) underlies the Cerro Toledo and is comprised of nonwelded to poorly welded tuff containing little evidence of fracturing (Vaniman et al.1996, 58032.17).

The Cerros del Rio basalts lie beneath the tuffs and make up roughly 35% of the vadose zone. Characteristics of this unit vary widely, ranging from extremely dense with no effective porosity to highly fractured to very vesicular so as to appear foamy (Turin 1995, 70225.1). The Puye Formation underlies the Cerros del Rio basalts and extends from the base of the vadose zone well into the saturated zone. A complete summary of the site geology and geologic properties can be found in the MDA L investigation work plan (LANL 2004, 87624).

The Vapor Plume

Pore-gas analytical results from quarterly sampling continue to indicate that the highest concentrations of vapor-phase VOCs exist in close proximity to the two shaft clusters (at the east and west ends of MDA L). TCA has consistently been the most prevalent VOC detected in pore-gas samples and is the best indicator of the extent of the plume.

Since 1999, the long-axis areal extent of the plume, defined by the 10 parts per million by volume (ppmv) contour of TCA, has fluctuated between 700 and 1000 ft. The short-axis extent has not fluctuated significantly because of the physical constraint of the mesa walls (zero-concentration boundaries). Vertically, the maximum extent of the 10 ppmv TCA contour is approximately 300 ft below the mesa top (pore-gas samples are monitored to a depth of 607 ft bgs). The extent has not fluctuated significantly since 1999. The 10 ppmv TCA contour is approximately 650 ft above the regional aquifer. Data analysis of pore-gas pressures and chemical constituents at boreholes 54-01015 and 54-01016 during 1995 and 1996 indicate that the Cerros del Rio basalt layer is connected to the atmosphere at a remote, unknown location. The plume decreases to field screening detection limit concentrations before the basalt contact; thus, any contaminant entering the basalt layer is at or below field screening detection levels. A pore gas sample collected from the basalt during 2005 contained approximately 40 ppbv TCA.

The plume is in a near steady state condition. Stauffer et al. (2002, 69794) modeled the plume evolution using a three-dimensional finite element program. The model assumed vapor diffusion emanating from two source areas located at the two shaft fields at MDA L. The model was calibrated using the quarterly pore-gas monitoring data. The resulting modeled plume closely matches the shape, concentration gradients, and extent of the plume as measured. The model also predicted that the plume should be at or near steady state. This modeling supported the conclusion that the VOC plume exists predominantly in the vapor phase, that the VOCs move by diffusion, and that the plume is stable. Stauffer et al. (2002, 69794) predicted plume's evolution over time, concluding that if the assumed source remains constant, the plume will continue to grow slowly. The model fit was improved by allowing for the partitioning of VOC into pore water. If a constant source was removed in the simulations, the plume decreased in mass as VOC is lost to the atmospheric boundary, with the 10 ppmv contour contracting back toward the source region.

Given the relatively constant state of the plume, it can be deduced that the mass of contaminant added to the source by small leaks from the containers must be balanced by the atmospheric emissions through the mesa sides, basalt layer, and atmospheric boundary. However, wastes in the 34 disposal shafts represent a significant uncertainty for any future predictions because the magnitude of future contaminant release rates cannot be predicted. The number of intact drums, bottles, or other containers is not known, and it is not possible to predict when or if they will fail. The Laboratory recognizes the need to consider future drum failures in managing the site and, therefore, proposed this pilot study.

The major findings of plume characterization activities to date include:

- Releases from disposal units at MDA L resulted in a subsurface vapor-phase VOC plume extending beneath the site and beyond the boundary of MDA L
- Vertically, the 10 ppmv TCA contour is approximately 300 ft bgs; VOCs have been detected at low ppbv concentrations in vapor samples from the basalt
- The long-axis extent of the plume along the length of the mesa, as defined by the 10 ppmv TCA contour, has fluctuated between 700 and 1000 ft; the short-axis extent is defined by the width of the mesa (approximately 450 ft across)
- VOCs are transported from the source areas in the vapor phase
- TCA is the primary constituent of the VOC plume
- TCA concentrations vary across the plume
- The plume is changing very little in area or contaminant concentrations since 1999\
- Uncertainties associated with potential increases in the source term due to future container failure are significant

METHODOLOGY

The primary goal of the pilot test was to provide information necessary to perform the following activities during the CME in order to evaluate SVE as an alternative for remediating the MDA L vapor plume.

- Specify system components such as vacuum blowers, extraction boreholes, effluent air treatment, pipes and other system components, etc
- Verify operating conditions such as extraction vacuum levels, airflow rates, radius of influence, contaminant vapor concentrations, etc
- Estimate extraction rates and residual source term management (e.g. system pulsing)
- Evaluate costs

SVE Pilot Study Scope

This pilot consisted of the following activities:

- Installation of two boreholes drilled and configured specifically to be used as vapor extraction boreholes for this project. One borehole was located in the vicinity of each of the two source zones
- Active extraction

Analysis of the pilot study data will be used to determine extraction rates for reducing the extent of the plume. In addition, the study will assess the ability of an SVE system to respond to potential releases from the inventory due to future container failure.

SVE Pilot Test Summary

Two extraction boreholes were installed at MDA L: SVE-West, in the vicinity of shafts 26-38; and, SVE-East, in the vicinity of Shafts 1-25. Each borehole was constructed with an extraction interval extending from 65 ft bgs to approximately 215 ft bgs. The upper 65 feet was cased with steel casing, and the casing grouted in place; a basal grout plug was emplaced to eliminate the potential for short circuiting from below. The surface casing was set in concrete. Figure 1 shows the placement of the proposed extraction boreholes. The boreholes drilled for the pilot study were logged to provide information on subsurface stratigraphy.

A Brüel & Kjær (B&K) 1302 photoacoustic multi-gas analyzer was used to monitor primary contaminant concentrations [trichloroethane (TCA) , trichloroethylene (TCE), Freon-11 (freon), and tetrachloroethylene (PCE)], as well as carbon dioxide (CO_2) and water vapor (H_2O) in extracted pore gas and in sampling ports in SVE monitoring boreholes. Surrounding boreholes were monitored using the B&K, and differential pressure readings, measure in kilopascals (kPa) were collected using a Dwyer Series 475 Mark III Digital Manometer (the manometer measured the difference between surface (i.e. atmospheric) and subsurface pressures).

Atmospheric data (i.e. temperature, relative humidity, barometric pressure) from the TA-54 weather station was obtained from the LANL meteorology group. Once active extraction was stopped, several rounds of pore gas monitoring were conducted to show near field rebound.

Extraction process measurements (including the total flow from the borehole, borehole vacuum, extraction air temperature and relative humidity) were collected using a Campbell Scientific CS-13X datalogger. During the test, air flow from the extraction borehole was monitored using a Dwyer Series PE in-line orifice plate flow meter with a Dwyer model 677-8 differential pressure transducer. The orifice plate measures air flow by monitoring the differential pressure across the plate. The air flow rate was established by closing the SVE system's dilution valve to the differential pressure corresponding with the desired flow rate (calculated per equations provided by Dwyer). Temperature and relative humidity were collected using a Viasala HMP45AC humidity and temperature probe. Vacuum pressure at the top of the extraction borehole was monitored using a 0 – 20 in-Hg vacuum gauge.

The contaminated vapor effluent was directed for treatment through two epoxy-lined steel canisters containing 400 lbs of granular active carbon (supplied by US Filter

Corporation) connected in series. The treated effluent was released from the second GAC vessel through a 10-ft tall stack. Effluent samples were collected from between the two treatment vessels and from the stack to ensure maximum GAC utilization while maintaining compliance with site VOC standards.

Finally, in order to calculate total VOCs, it was assumed that the VOCs being monitored by the B&K multi-gas analyzer comprise approximately 80% of the mass of the plumes beneath MDA L, based on ongoing pore gas monitoring at MDA L.

SVE PILOT TEST

Active extraction at SVE-West occurred from 6/14/2006 through 7/13/2006; extraction was interrupted from 6/17/2006 to 6/21/2006 in order to repair a broken motor pulley. Active extraction at SVE-East took place from 7/18/2006 through 8/9/2006; the system operated continuously during that time.

SVE-West

The pilot test period of the SVE-West test lasted 28.7 days, with 24.8 days of active extraction due to the repair period. The air flow rate for the test was initially set to approximately 95 standard cubic feet per minute (scfm); the corresponding vacuum imparted on the extraction borehole was 3.9 in-Hg. On 7/7/2006, at 22.9 days (19.1 days of extraction), the air flow rate was increased to approximately 105 scfm, with a vacuum level of 4.4 in-Hg. This level was near the maximum capacity of the SVE unit; the dilution valve was approximately ¼ turn from being completely closed. B&K and manometer readings were collected from boreholes 24240, 02001, 02031, 02021 to evaluate the radius of influence of the SVE system, and to assess the overall impact of extraction on the VOC plume. During the SVE-West test, approximately 460 lbs of VOCs were extracted from the subsurface. Figure 3 shows total VOC concentrations from the extraction borehole during the test.

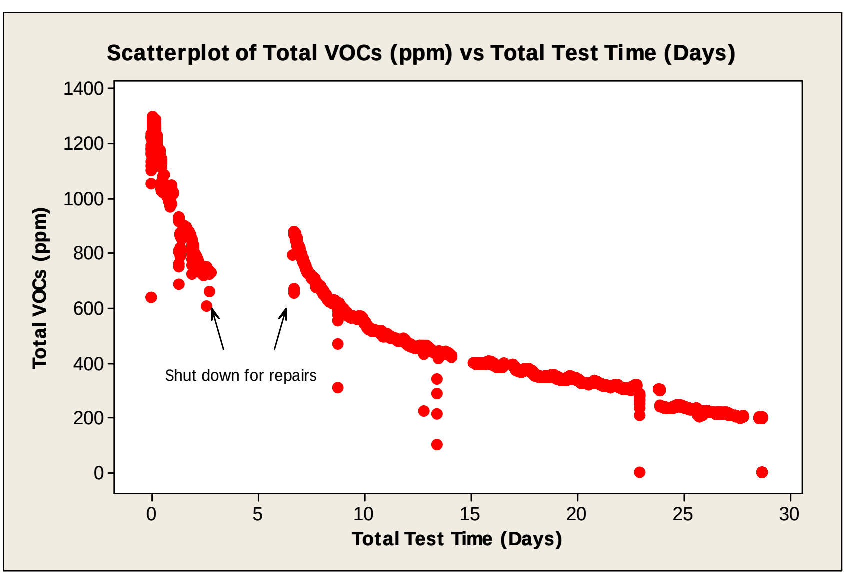

Figure 3. SVE-West Extraction Borehole Data: Total VOCs vs. Time

Monitoring Borehole 24240

Borehole 24240 was the closest monitoring point to the SVE-West extraction borehole, at a distance of 26 ft. Subsurface monitoring ports were at the following depths: 25 ft, 50 ft, 75 ft, 100 ft, and 117 ft. Figure 4 shows box plots from Borehole 24240 illustrating the strong pressure response at all depths, with the strongest response in the 50 ft to 100 ft interval.

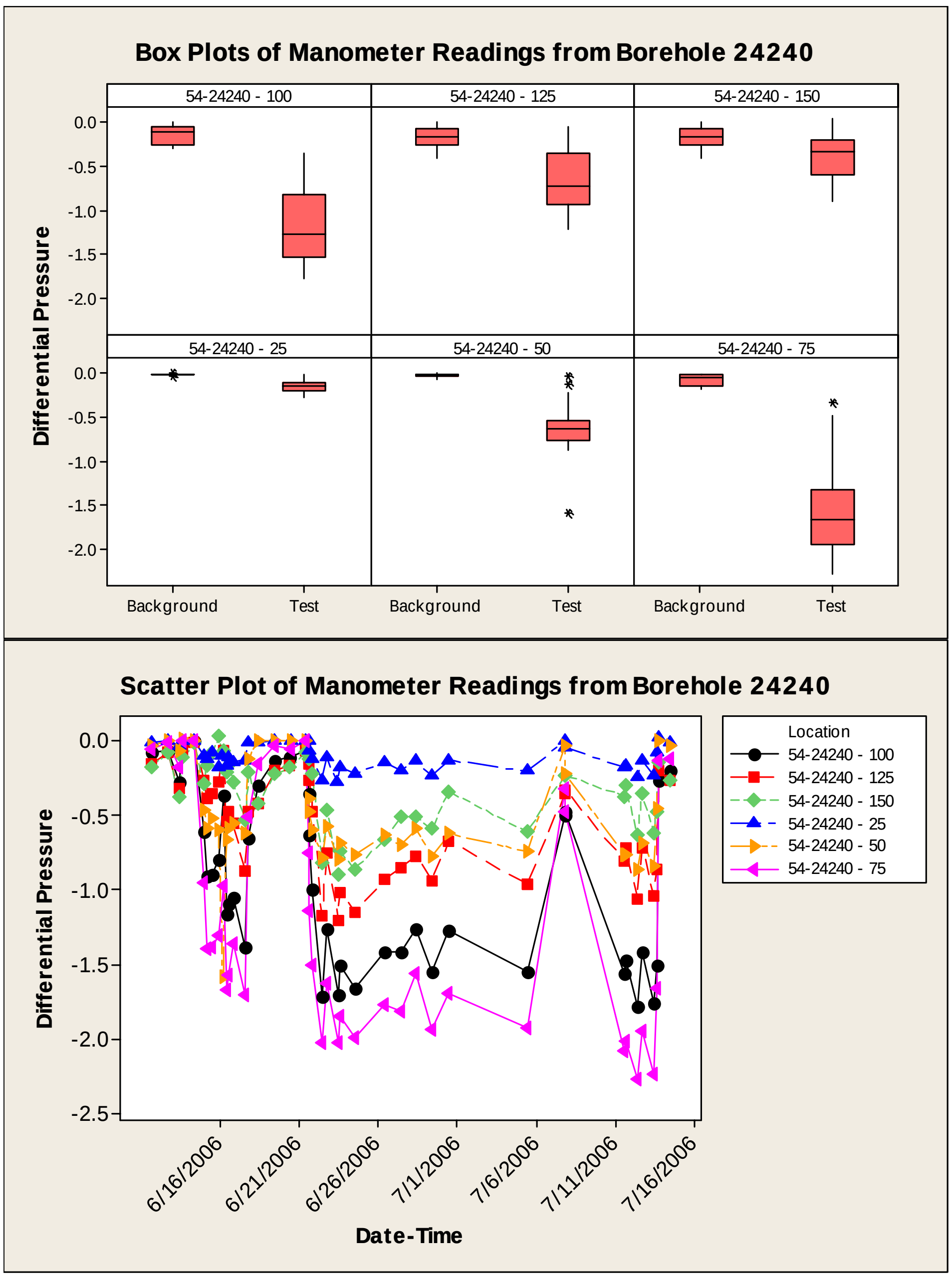

Figure 4. Differential Pressure Data from Borehole 24240

Figure 4 also provides a scatter plot of manometer readings from 24240. The strong response to the test is evidenced by the quick return of the differential pressure readings to near 0 kPa during the 6/18-21/2006 shut down period, and at the end of the test following final shut down.

TCA concentrations (ppm) in borehole 24240 showed a similar to TCA trends in the extraction borehole, TCA concentrations decreased at a fairly rapid rate at the beginning of the test. When the system was shut down for approximately 4 days for maintenance after 4 days of extraction, TCA in 24240 rebounded to near pre-test conditions. Approximately two weeks after the termination of extraction, TCA in ports at 75 ft, 100 ft, 125 ft, and 150 ft had rebounded to pre-test levels; the 25 ft and 50 ft ports were still well below pre-test levels.

Monitoring Borehole 02001

Borehole 02001 was the second closest monitoring point to SVE-West extraction borehole, located at a distance of 57 ft. Subsurface monitoring ports were at the following depths: 20 ft, 40 ft, 80 ft, 100 ft, 120 ft, and 200 ft. Manometer readings showed measurable responses to a depth of 140ft; a definitive response at 200ft could not be confirmed. Manometer data plotted as a function of time showed a rapid pressure response during the 6/18-21/2006 shut down period, and at the end of the test following final shut down. The data show that the response was strongest in the 40 ft, 80 ft, and 100 ft ports.

SVE-East

The extraction period for the SVE-east test started 7/18/2006 at 14:00 and lasted for 21.9 days. Extracted was stopped on 8/9/2006 at 07:15. The air flow rate for the test was set to approximately 105 scfm (the maximum capacity of the SVE system), resulting in a vacuum level of 4.9 in-Hg. B&K and manometer readings were collected from boreholes 02087, 02089, 24243, 02002, and 24244, to evaluate the radius of influence of the SVE system, and to assess the overall impact of extraction on the VOC plume.

B&K data from the extraction borehole shows TCA concentrations (ppmv) in the pore gas extracted from the subsurface peaked at 294 ppmv after 26 minutes and declined to 157 ppmv at the end of the extraction phase of the test. Based on measured concentrations trends and flow rates, approximately 175 lbs of TCA and approximately 300 lbs of total VOCs were extracted from the subsurface during active extraction.

Monitoring Borehole 24243

Borehole 24243 was approximately 53 ft east of the SVE-East extraction borehole. Subsurface monitoring ports were located at 25 ft, 50 ft, 75 ft, 100 ft, and 117 ft. Manometer readings from 24243 showed a measurable differential pressure response in the deeper ports, with the strongest response at 100 ft and 117.5 ft; with little response shown . TCA trends confirm a measurable drawdown response to the SVE-East vacuum.

Monitoring Borehole 02002

Borehole 02002 was approximately 132 ft east of the SVE-East extraction borehole. Monitoring ports were located at 20 ft, 40 ft, 60 ft, 80 ft, 100 ft, 120 ft, 140 ft, 157 ft, 180 ft and 200 ft. All ports were available for pressure testing, however, due to partial blockage, only the 60 ft, 100 ft, 140 ft, and 200 ft ports were able to be sampled with the B&K. Manometers readings from Borehole 02002 illustrated a measurable differential pressure response in ports below 60 ft. TCA readings in ports in Borehole 02002 also confirmed a measurable response of vacuum extraction at the SVE-East extraction borehole.

Monitoring Borehole 02089

Borehole 02089 was located approximately 59 ft north of the extraction borehole, immediately adjacent the eastern shaft field. Monitoring ports were located at 13 ft, 31 ft, 46 ft, and 86 ft below the surface. Manometer readings showed that during the extraction portion of the test, differential pressure readings were only measurably different in the 86 ft port. However, TCA concentration trends during the test showed that despite the lack of a strong pressure response TCA concentrations were impacted by the vacuum extraction process. All ports showed a decline in VOC concentrations during the extraction phase of the test, with concentrations returning to pre-test levels within a week of shutting off the vacuum blower.

Monitoring Borehole 24244

Borehole 24244 was the farthest monitoring borehole from the SVE-East extraction borehole, located approximately 200 feet northeast. Monitoring ports were located at 25 ft, 50 ft, 75 ft, 100 ft, and 118 ft. Manometer readings collected during the test showed more highly variable differential pressure readings during the active extraction phase, but the background and test median values were only slightly lower in the 100 ft and 118 ft ports.

CONCLUSION

The SVE pilot test provided data showing the potential effectiveness of vapor extraction for remediating the MDA L plume. As a result of extraction activities at both SVE pilot test locations, an estimated 800 lbs of VOCs were extracted during approximately 45 days of active vacuum extraction. Differential pressure readings collected using a handheld manometer showed a measurable response to the vacuum extraction process at distances up to 132 ft. Similarly, B&K readings showed a reduction in VOC concentrations at distances up to 132 ft, with the strongest response in sampling ports ranging from 40 ft to 150 ft below the surface.

The next step in the MDA L SVE Pilot project was to combine the data presented above with the existing site scale numerical model (Stauffer et al., 2005). The goal of this task was to gain a more complete understanding of how the dynamic SVE pumping affects flow and transport within the mesa.

The new higher resolution site scale model is now running with embedded boreholes. The preliminary simulations using a rough permeability distribution are giving results that are consistent with the SVE test data. The model has been calibrated to the pre-test concentration data and simulations of scenarios requested by a Corrective Measures Evaluation contractor are being completed.

The results of the modeling efforts are being presented as "A Soil Vapor Extraction Pilot Study in a Deep Arid Vadose Zone, Part 2: Simulations in Support of Decision Making Processes."

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