# The Impact of Soil Vapor Extraction at Material Disposal Area L, Los Alamos National Laboratory - 17155

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## ABSTRACT

Material Disposal Area L (MDA L) is an inactive liquid-waste disposal site located within the Los Alamos National Laboratory property.  A subsurface vapor plume of volatile organic compounds (VOCs) is present in the unsaturated zone and site remediation is recommended so that the plume will not impact groundwater in the future.  Soil vapor extraction using two extraction wells was recently conducted at the site for 10 months as an interim remediation measure. We analyzed plume size, concentrations vs. time and depth in monitoring wells, predicted vs. measured extraction concentrations, and plume rebound to understand the impact of the interim measure and to obtain effective feedback on how to continue remediating the site.  We also recalibrated an existing model used to predict plume behavior with field data collected during extraction.  The vapor plume size decreased by 60%.  This paper presents the results for the removal of VOC mass from the subsurface and the spatially-dependent reduction of VOC concentrations in the plume; these reductions, as well as maintaining the plume in the upper unsaturated zone, are desired for reducing possible future impacts to groundwater.

## INTRODUCTION

From the 1960s to the 1980s, the 2.5 acre Material Disposal Area L (MDA L) site was used as a non-radiological liquid chemical waste disposal area at Los Alamos National Laboratory (LANL, the Laboratory) in Northern New Mexico.  MDA L consists of one pit, three impoundments, and 34 65-ft deep shafts [3 and 5].  Much of the non-radiological liquid wastes were volatile organic compounds (VOCs) stored in drums before being disposed in the shafts.  Small containers of free liquids were also placed in the shafts [1].  Little information is recorded about the specific chemicals, timing, and quantities of waste that were disposed of at this site.  VOCs have leaked from the buried drums and a VOC vapor plume is present in the upper unsaturated zone beneath the site, although no free liquid has ever been observed. The vapor plume extends laterally beyond the boundaries of the disposal area as well as to a depth greater than 300 ft in the unsaturated zone [6].

Vapor monitoring boreholes with sampling ports at multiple depths have been installed throughout the site [1].  Monitoring since the mid-1980s has shown the presence of the vapor plume, which has slowly expanded.  Two distinct lobes of the vapor plume have developed around two shaft fields located on the east and west sides of the site [1]. Plume growth is controlled primarily by vapor diffusion, so VOCs exit the subsurface by diffusive flux at the ground surface, which limits

downward expansion. Soil vapor extraction (SVE) has been proposed as a possible remedy for the site to keep the vapor plume from migrating towards groundwater. There are two SVE wells located at MDA L, one each on the east and west sides [1]. The SVE-West extraction well reaches a depth of 116 ft below ground surface (bgs), and the SVE-East extraction well reaches a depth of 196.9 ft bgs.  Contaminants are extracted from 65 ft bgs to 215 ft bgs in both wells.  From 0 to 65 ft bgs, the wells have steel casings.  The casing is grouted to prevent a possible short circuit from the surface [4].  SVE, using the two extraction wells, was recently conducted for 10 months at the site as an interim remediation measure.
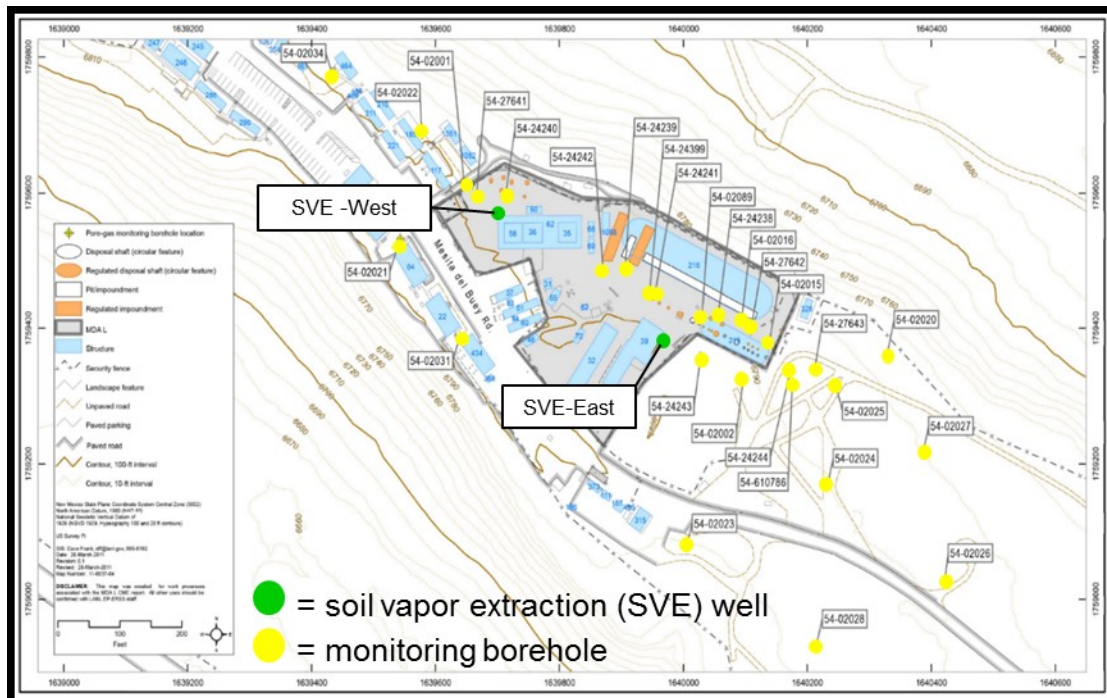


**Figure 1.** Material Disposal Area L with the shaft locations labeled.  Green dots are the extraction wells and the yellow dots indicate the monitoring boreholes.

Volatile organic compounds are slowly leaking from the waste drums into the unsaturated zone to form the observed vapor plumes.  VOCs are sampled at multiple depths within each monitoring borehole.  During SVE, contaminants are extracted from the subsurface vapor plume by suction pumps at the tops of the SVE wells.  VOC concentrations at a subset of 14 monitoring wells within 150 ft of the two extraction wells were sampled quarterly during the SVE operation; all of the 25 monitoring wells were sampled before the SVE interim measure was conducted and then again during the 4th quarter SVE was started. Samples are collected in SUMMA canisters and sent to an analytical laboratory for VOC analysis. The sampling was conducted to understand the changing extent of the plume resulting from the SVE interim measure.

Rebound sampling was also performed following SVE to determine the lasting impacts of the interim measure.  The rebound sampling was conducted by turning on the SVE systems for a short time after a period of being turned off and

measuring extraction concentrations.  A typical rebound response is an increase in concentrations at the extraction well when the well is turned on for sampling after the primary SVE is complete.  As rebound sampling continues, the spike gradually decreases.  This paper presents the results for the removal of VOC mass from the subsurface, the reduction of VOC concentrations throughout the plume all geared toward reducing possible future impacts to groundwater.

**GEOLOGIC SETTING**

MDA L is located on Mesita del Buey, on the Pajarito Plateau where the Laboratory is located [6].  The Pajarito Plateau was created by volcanic eruptions that occurred 1.61 and 1.22 Ma ago.  Five layers make up the Tshirege Member of the Bandelier Tuff (Qbt2 down through Qbtt) [2].  The Bandelier Tuff consists of welded and non-welded rhyolitic ash-flow, as well as, ash-flow tuffs interbedded with pumice layers.  Vertical joints are found throughout the Tshirege Member [6].  The Tsankawi pumice (Qbtt) is the deepest layer of the Bandelier Tuff and has a thickness between 1 and 2 m.  The next layer down is the Cerro Toledo interval.  This layer consists of interbedded volcano-clastic sediments and pyroclastic flows [6].  The sediment size varies greatly in this deposit.  The Otowi Member (Qbo) of the Bandelier Tuff is below the Cerro Toledo interval [2].  This layer consists of non-welded to poorly-welded tuff and a basal layer of Guaje Pumice [6].  The final layer in the unsaturated zone is the Cerros del Rio basalt.  The characteristics of this rock layer can vary substantially in density to porosity to fracturing.  The plume is located almost completely within the tuff units above the basalt. The water table is at a depth of approximately 980 ft [6].
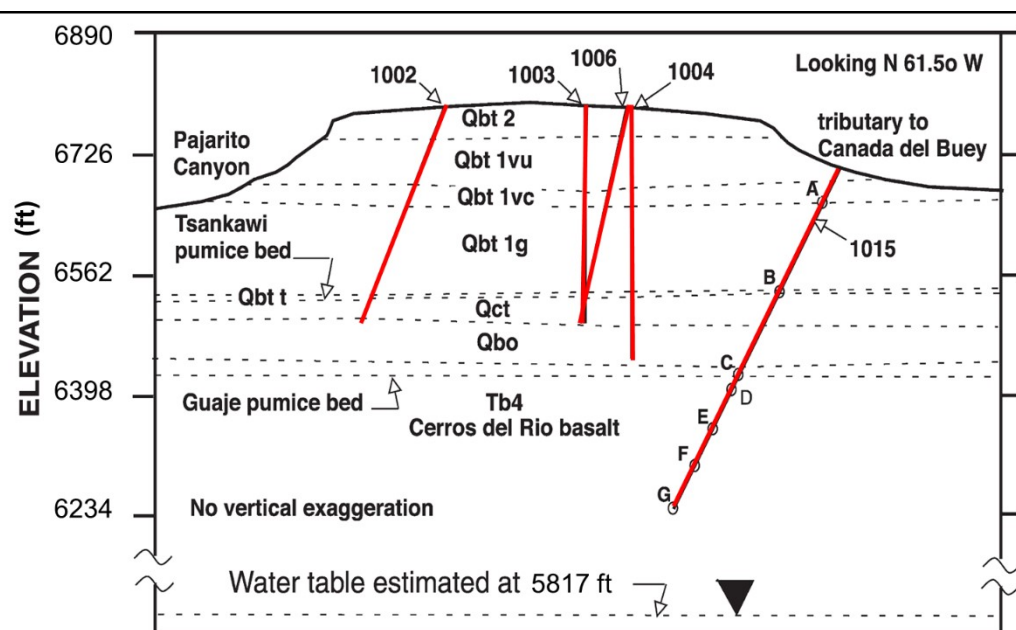


**Figure 2.** A geologic cross section of the study site, MDA L.  The red lines indicate some of the monitoring boreholes at the site and their depths.

## FINITE ELEMENT HEAT AND MASS (FEHM)

A numerical model of the vapor plume at MDA L that honors the pre-SVE vapor concentrations of 1,1,1-trichloroethane (1,1,1-TCA) in the subsurface has been developed.  1,1,1-TCA is the most prevalent contaminant in the vapor plume. This model was used in the current study to predict the extraction concentrations of 1,1,1-TCA from the two SVE wells.  The Finite Element Heat and Mass (FEHM) code is used for the modeling.  FEHM is a multiphase porous flow simulator that can be run in 1, 2, or 3 dimensions.  For this project, a three-dimensional mesh is used with dimensions of 411 m long in the east-west direction by 290 m wide in the north-south direction.  The mesh extends vertically from the ground surface to the water table and has 142,707 nodes [6].  The mesh resolution is 10 m horizontally and 1 to 25 m vertically.  The higher mesh resolution is closer to the ground surface, which is defined by a Digital Elevation Model (DEM) of the site.  Two high-resolution SVE wells are also used [5].  To help accurately model vapor transport, different conceptual features are incorporated.  For FEHM, these features include saturation-dependent vapor diffusion, equilibrium partitioning between 1,1,1-TCA in the liquid and gas phases, topographic boundaries in contact with the atmosphere, asphalt covering which reduces diffusion from the surface, and reduction in diffusion across the land-air interface attributable to boundary layer processes that may impede mass transfer [6].  Under non-pumping conditions, plume size is primarily controlled by diffusion away from the two shaft fields with the atmosphere and pore water acting as sinks. The model was first calibrated using previous monitoring data and a short SVE demonstration.  VOC concentrations throughout the plume were also measured, before the SVE interim measure, in order to determine mass removal.

## METHODS

### Data Collection

Monitoring boreholes located at the MDA L site were sampled before the SVE operation, quarterly during SVE, and then after one year.  Quarterly sampling included monitoring of 14 boreholes within 150 ft of the SVE wells, and pre-SVE and annual sampling involved sampling of all 25 monitoring boreholes found at this site [2].  SUMMA canisters were used to collect the samples, which were then sent for analysis at an analytical laboratory to determine concentrations of the VOCs within the plume.  Suction, flow rate, and effluent concentration data vs. time were also collected for both SVE wells.  After letting the SVE systems extract continuously for 10 months, the operation was switched to a rebound sampling pattern which occurred quarterly [1].
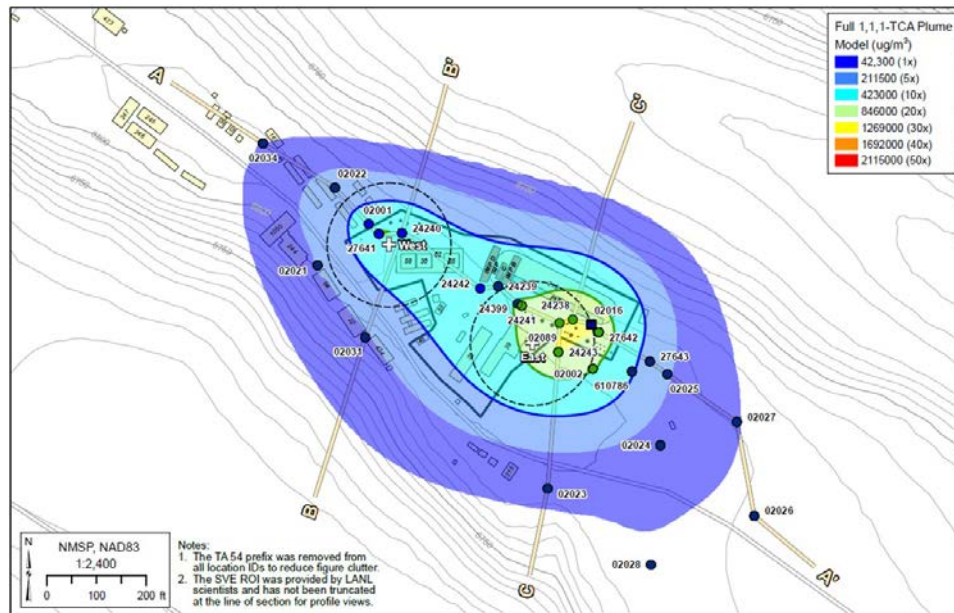
**Figure 3.** Interpolated representation of the 1,1,1-TCA vapor plume concentrations at MDA L for sampling performed before the SVE interim measure was conducted (Sept 2014).
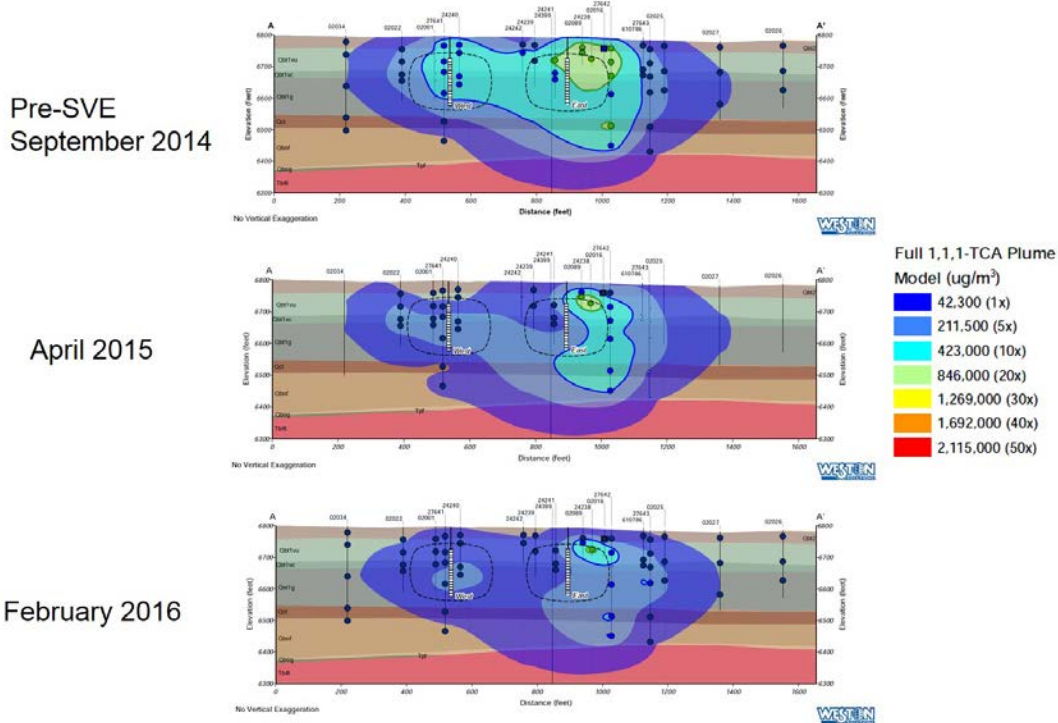


**Figure 4.** Interpolated representations of the 1,1,1-TCA vapor plume concentrations at MDA L for sampling performed before the SVE interim measure was conducted (Sept 2014), during SVE (April, 2015) and following SVE (February, 2016) for cross section A-A' [3]. A geologic cross section is also shown. The lines indicate the monitoring boreholes found at the site with the circles indicating sampling points/concentrations.

**Tracking Plume Size**

Interpolation of the sampling data was conducted to illustrate the plume concentrations and extent before, during, and after the SVE interim measure and to calculate reductions in the plume mass. We present the results for the 1,1,1-TCA concentration data. Figure 3 shows the baseline (pre-SVE) plume from above as a projection of the maximum concentration throughout the plume [7]. Figure 4 shows the interpolated sampling concentration data along the A-A' cross section [3] for the September 2014 (pre-SVE baseline), April 2015 (during SVE), and February 2016 (post-SVE) in order to visually show the reduction of the contaminant plume. The geology of MDA L, as well as, the locations of the SVE wells and monitoring boreholes seen in the cross section are also included [7].

**Concentration Changes over Time and Depth**

Another investigation looked at the vapor concentrations of VOCs over time and at different depths in monitoring wells within 150-ft of the extraction wells to determine the effectiveness of SVE. Concentrations for each of four VOCs (1,1,1-TCA, TCE, PCE, and 1,2-DCA) were graphed individually resulting in four VOC graphs per monitoring borehole. The September 2014 (pre-SVE baseline); April, July, and November 2015 (during SVE); and February, May, and September 2016 (post-SVE) sampling results are compared on each graph. VOC concentrations from 3 monitoring boreholes near SVE-West [5-7] and from 5 monitoring boreholes near SVE-East [8-12] were graphed and compared to each other.

**Modeled vs. Measured Concentration Data**

FEHM was used to create a numerical model of the 1,1,1-TCA vapor plume at MDA L. Three stages from previous studies were used [5]. The first was to simulate waste placement and plume growth until 2006. This first stage is largely diffusion controlled with equilibrium partitioning in the liquid and gas phases. We note that the permeabilities of the tuff layers at the site do not impact the simulations under non-pumping conditions. Secondly, an earlier 2006 SVE pilot test was replicated. The third stage conducted was a blind validation of the model [5] which calculates continued plume growth from 2006 through early 2015 and then the 2015 SVE interim measures. Characteristics from the different rock layers (e.g. permeability) were added to the simulations using site field data. Using this previous model, which was effectively last updated in 2006, an initial plume was created by fixing 300 parts per million volume (ppmv) in the source regions for both shaft fields. The measured and modeled extraction concentrations for 1,1,1-TCA for both SVE wells are compared [13]. The figure shows that predicted extraction concentrations at SVE-West were close to measured concentrations, but predicted concentrations at SVE-East overestimate measured concentrations.

**Rebound**

Recalibration of the 2006 FEHM Model was performed using the observations made during the SVE active phase (Jan 2015 to Nov 2015) to predict rebound of the

plume. The rebound data collected during April and June 2016 from both extraction wells were modeled using the recalibrated FEHM [14].  The recalibrated model modified the initial fixed concentration in the source regions from 300 ppmv to 200 ppmv.  In addition, the permeabilities on both sides were individually changed to best match extraction concentrations observed during the extended SVE period. The simulation was also broken into multiple segments to more accurately match the operating conditions during SVE and the rebound sampling. Segments allow for easier manipulation of SVE-East and SVE-West pumping conditions.  Each well is turned off (no suction) or on (suction) based on its pumping history.  Lastly, the influx of air into the SVE extraction well was accounted for before the SVE well was capped and after it was shut off.  Recalibration significantly improved the predicted extraction concentrations for SVE-East [14]. Predicted rebound concentrations are very close for SVE-West and reasonable for SVE-East.

**Monitoring Wells Modeled vs. Measured Vapor Plume Concentrations**

In Figures 15 and 16, we combine the field data and modeling information to compare concentration vs. time and depth at monitoring wells.  In this case, 1,1,1-TCA concentrations at the monitoring boreholes within the 150 ft radius of each SVE well were analyzed.  The September 2014 (pre-SVE baseline); April, July, and November 2015 (during SVE); and February, May, and September 2016 (post-SVE) sampling results are compared to the modeled results on each graph for each time period that data were collected [15 and 16].

**RESULTS AND DISCUSSION**

**Tracking Plume Size**

Figure 4 pictorially represents the decrease of the plume size from its pre-SVE baseline (September 2014) through the February 2016 post-SVE sampling round. The highest concentration areas (light green (>846,000 $\mu g/m^3$) and teal (>423,000 $\mu g/m^3$) colors) near the shaft fields and the extraction wells decrease as extraction progressed and remain depressed after 3 months of rebound. Based on the interpolated data, the 1,1,1-TCA mass was reduced from 740 kg to 305 kg, a 60% reduction, between the baseline and post-SVE sampling rounds [7]. 1,1,1-TCA is represented in the figures, but the other VOCs found at this site follow similar decreased distributions.

**Concentration Changes over Time and Depth**

The graphs of concentrations vs. both depth and time for the west side [5-7] indicate that the SVE system worked as expected, with reductions in vapor concentration to radial distances of at least 150 ft, the projected radius of influence of the extraction wells, and over the extraction interval of the SVE well (65 ft to 215 ft bgs).  Concentrations drop above the extraction interval as well, probably because fresh air is drawn in from the surface and sweeps the shallow part of the vapor plume toward the extraction interval. On the west side of MDA L, the SVE extraction well is working effectively to remediate the vapor plume. On the east

side, generally most of the boreholes within 150 ft had the same reduction in concentrations through time and at every depth [8-12] as observed for the west side.  However, there were two monitoring wells where this was not the case.  At monitoring wells 54-02089 and 54-24238, the VOC concentrations compared to the baseline actually increase over time [10 and 11].  A possible reason for this phenomenon is that these two wells are located very close to each other and to the disposal shafts on the eastern side. A leak from drums of waste located near these wells or migration of higher concentrations from the north toward the SVE-E extraction well may be impacting the local concentrations more so than is the SVE operation.
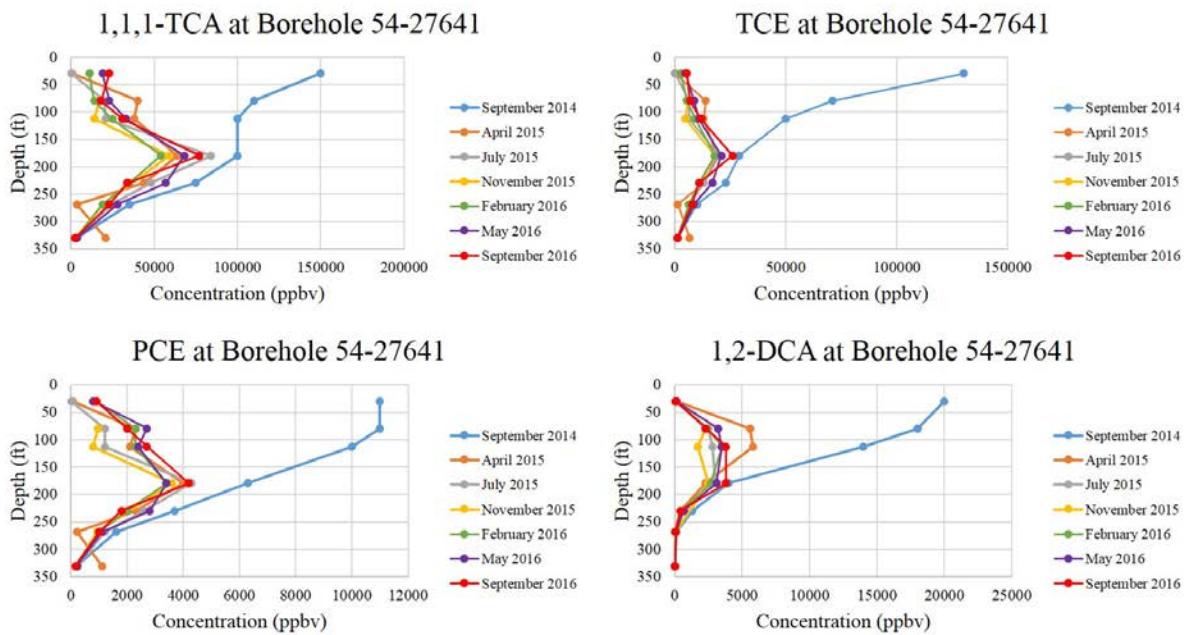
**Figure 5.** Vapor concentrations for 1,1,1-TCA, TCE, PCE and 1,2-DCA at Monitoring Borehole 54-27641 as functions of time and depth near SVE-West.
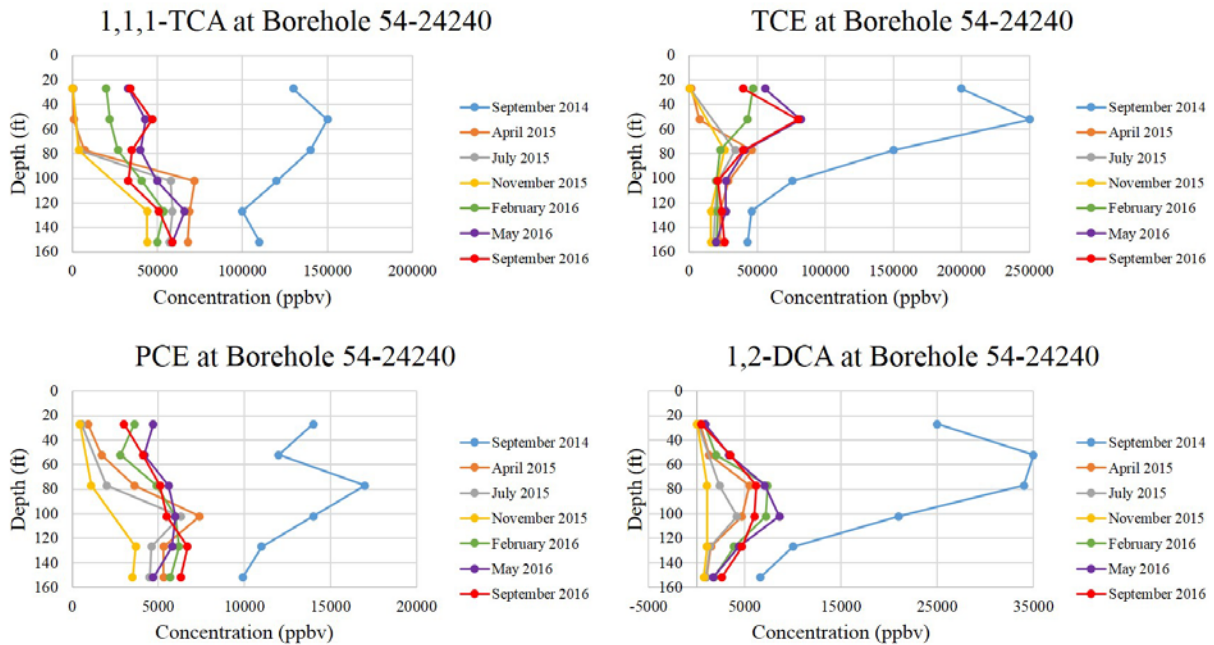
**Figure 6.** Vapor concentrations for 1,1,1-TCA, TCE, PCE and 1,2-DCA at Monitoring Borehole 54-24240 as functions of time and depth near SVE-West.
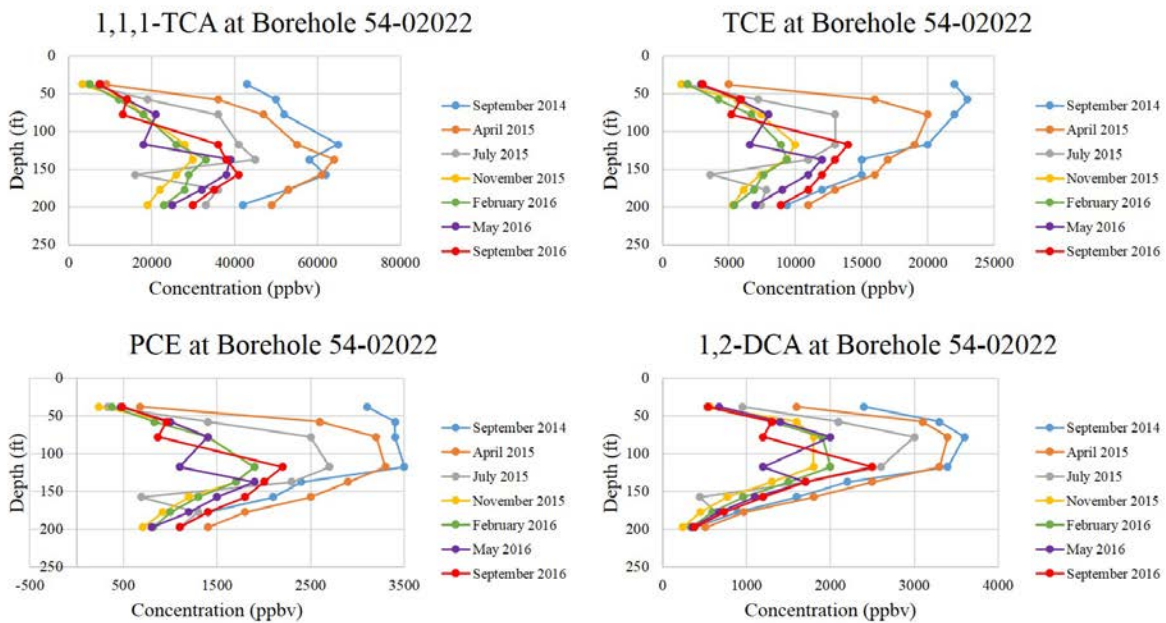
**Figure 7.** Vapor concentrations for 1,1,1-TCA, TCE, PCE and 1,2-DCA at Monitoring Borehole 54-02022 as functions of time and depth near SVE-West.
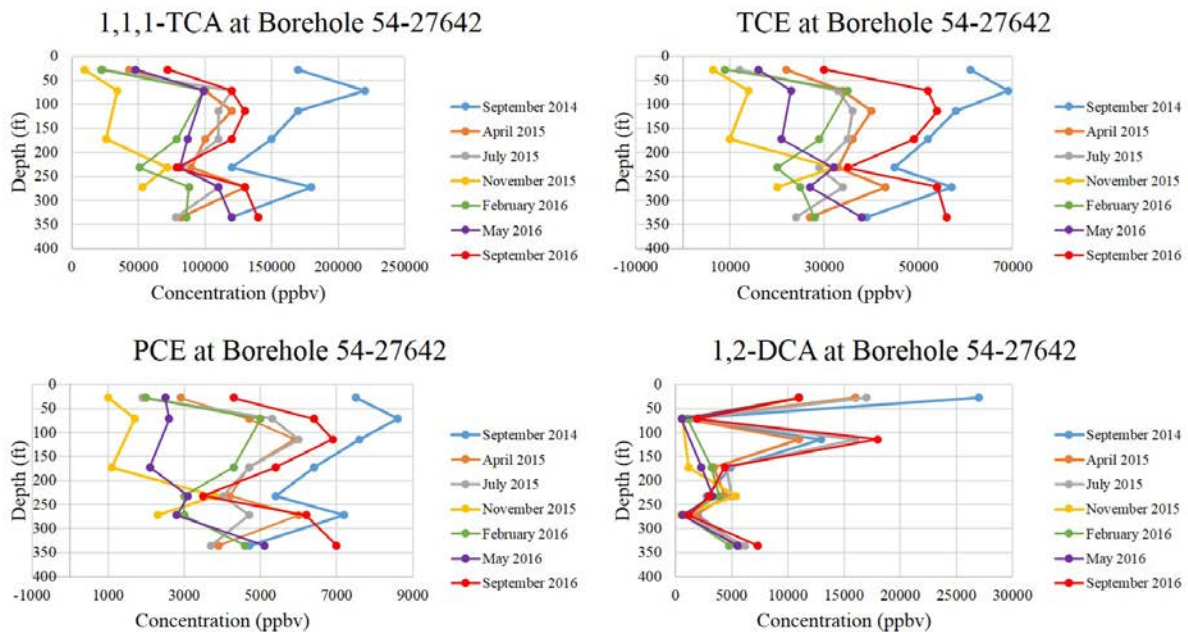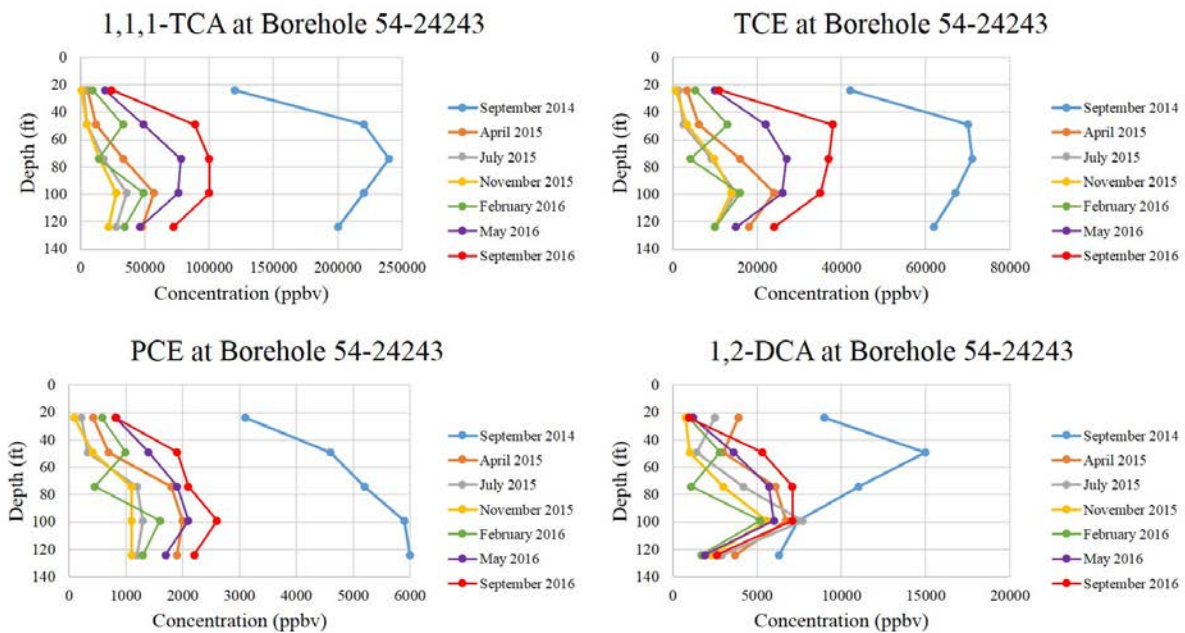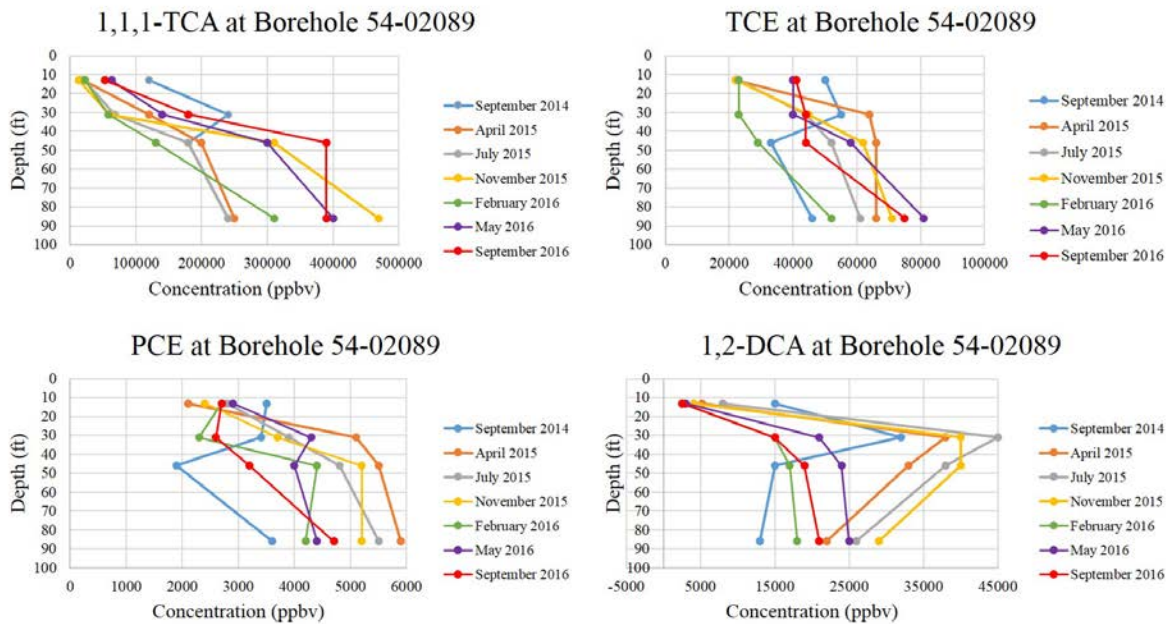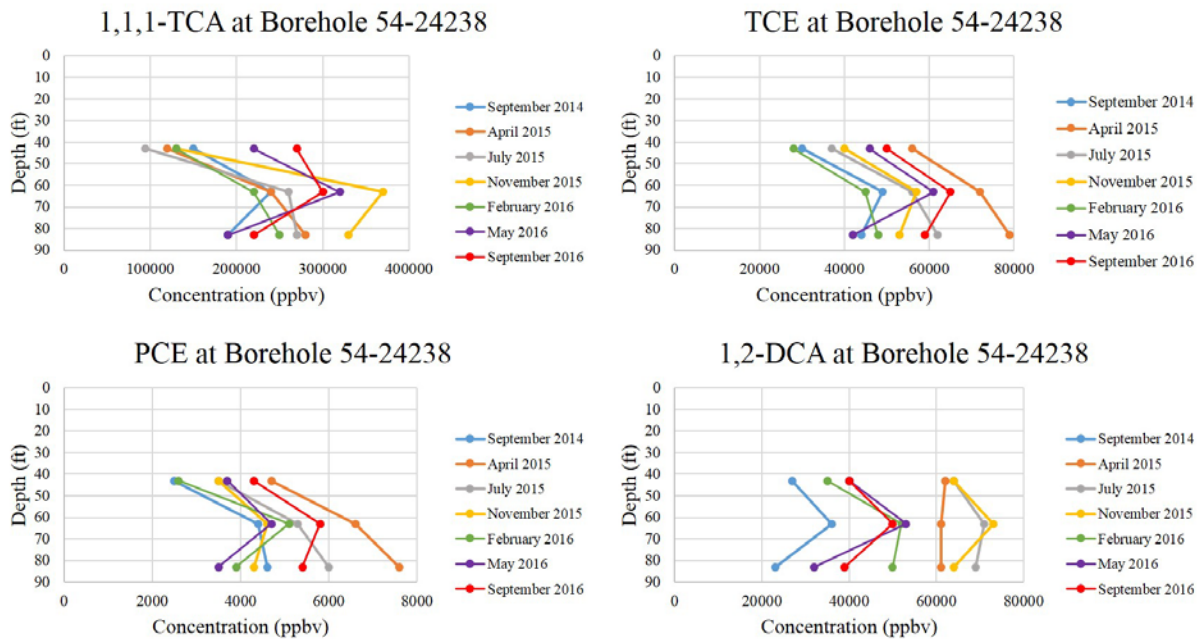
**Figure 8.** Vapor concentrations for 1,1,1-TCA, TCE, PCE and 1,2-DCA at Monitoring Borehole 54-27642 as functions of time and depth near SVE-East.

**Figure 9.** Vapor concentrations for 1,1,1-TCA, TCE, PCE and 1,2-DCA at Monitoring Borehole 54-24243 as functions of time and depth near SVE-East.
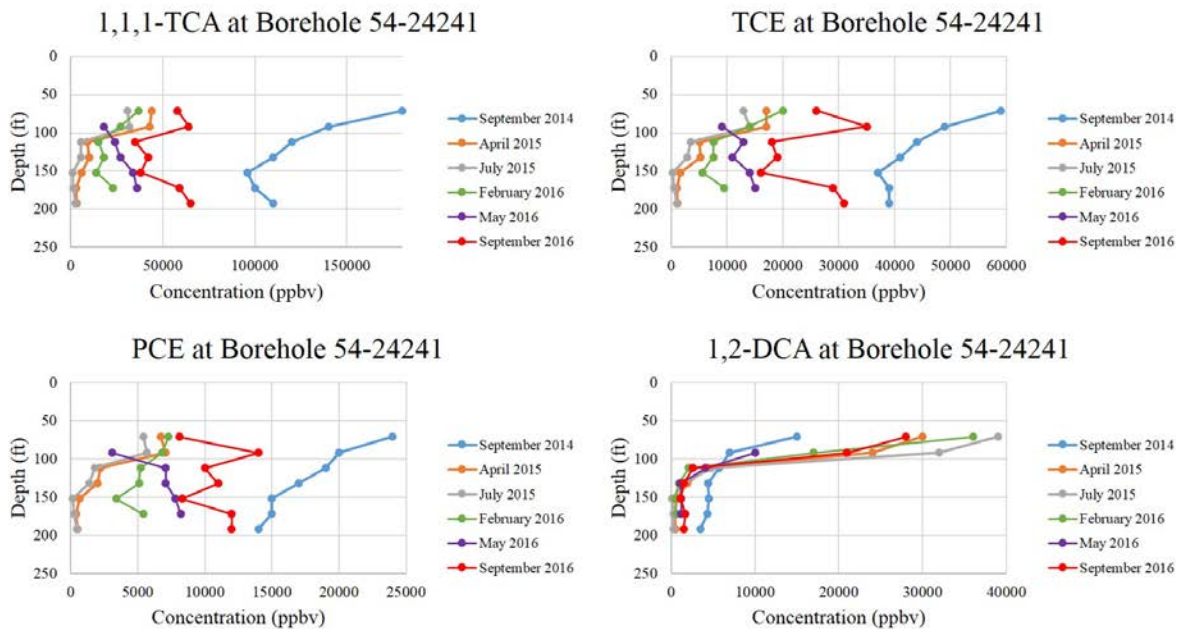
**Figure 10.** Vapor concentrations for 1,1,1-TCA, TCE, PCE and 1,2-DCA at Monitoring Borehole 54-02089 as functions of time and depth near SVE-East.



**Figure 11.** Vapor concentrations for 1,1,1-TCA, TCE, PCE and 1,2-DCA at Monitoring Borehole 54-24238 as functions of time and depth near SVE-East.

**Figure 12.** Vapor concentrations for 1,1,1-TCA, TCE, PCE and 1,2-DCA at Monitoring Borehole 54-24241 as functions of time and depth near SVE-East.

**Predicted Model vs. Measured Data**

Predicted and actual 1,1,1-TCA extraction concentrations using the 2006-era model were compared against each other graphically [13]. On the west side, there was a good fit between the model and data. On the east side, however, the fit was not as good. Recalibrating the model for the eastern side was necessary to improve the fit between the predicted and measured extraction concentrations.
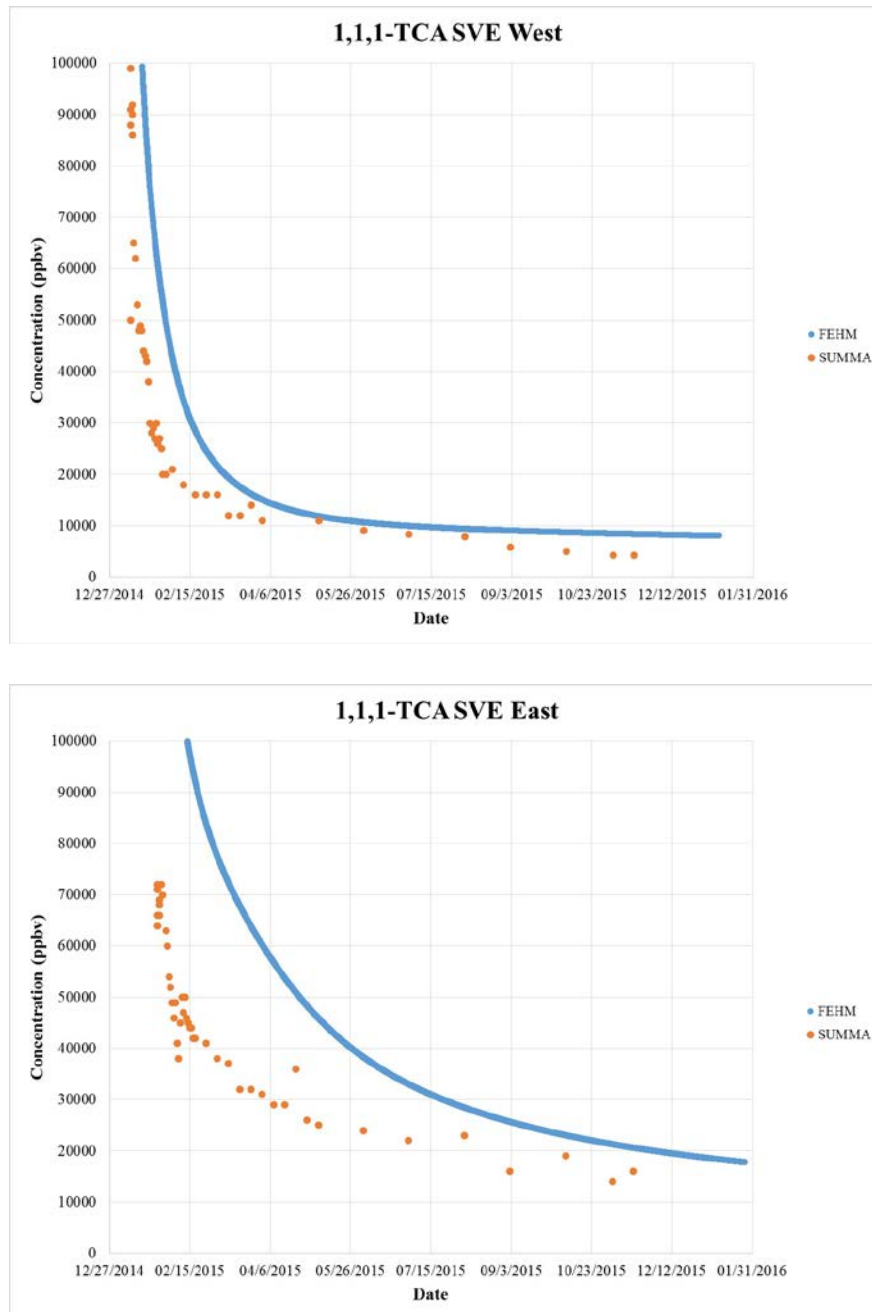
**Figure 13.** Concentrations of 1,1,1-TCA for the two extraction wells comparing analytical data for samples collected in SUMMA canisters (orange) and the FEHM model predictions (blue), using the 2006 FEHM model. **Top:** SVE-West. **Bottom:** SVE-East.

**Rebound**

After recalibrating the model, the model and measured extraction concentrations were again compared. This time the predicted extraction concentrations for both SVE wells compared better to the data. The permeability of the SVE-East well needed significant changes to match both the measured suction and flow rate.

Additionally, by breaking the time into segments and manually changing when and which SVE well was on and off, we achieved a positive effect on the fit of both extraction wells.  Using the recalibrated parameters and correct dates for SVE operations, we were able to obtain a good fit between the simulated rebound and the rebound data from both extraction wells [14].
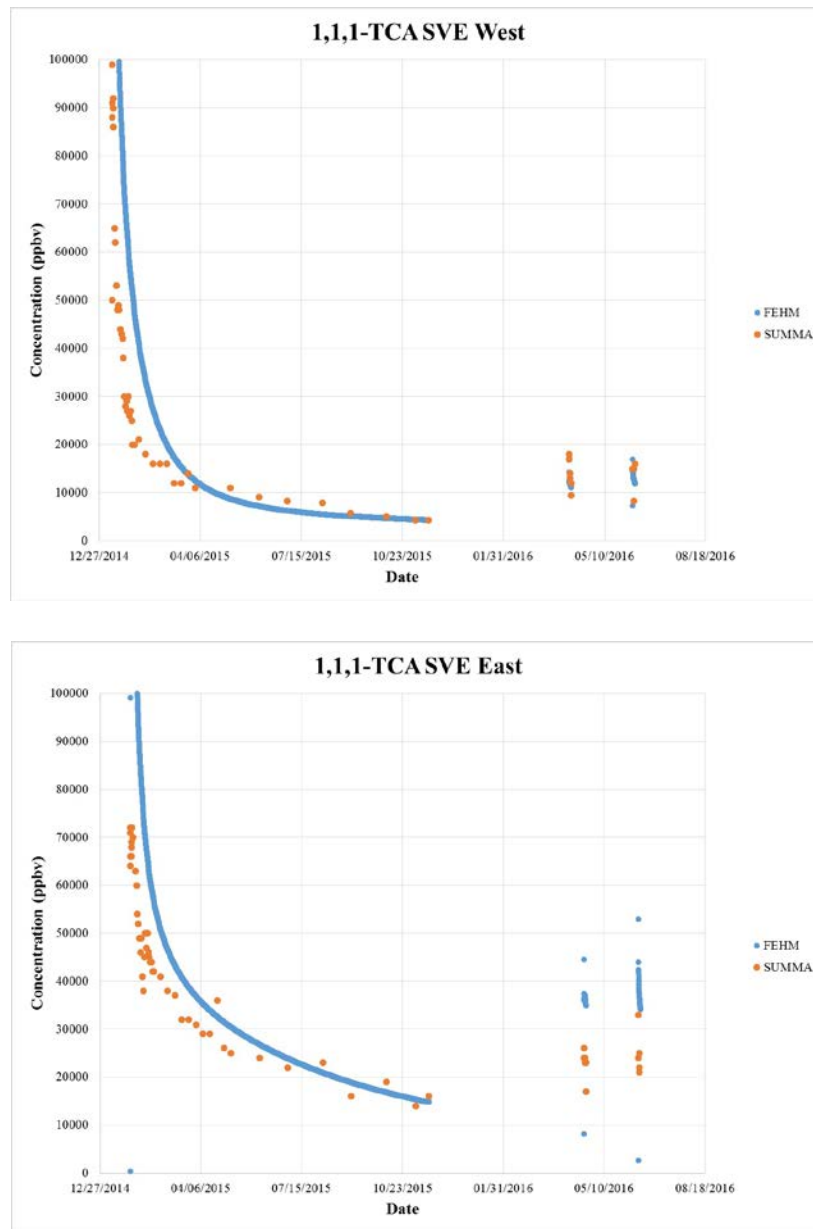


**Figure 14.** Concentrations of 1,1,1-TCA for the two extraction wells comparing analytical data for samples collected in SUMMA canisters (orange) and the FEHM model predictions (blue), using the recalibrated FEHM model. Time period includes active SVE and rebound periods.

## Monitoring Wells Modeled vs. Measured Vapor Plume Concentrations

The predicted modeled concentrations (the darker shade of color) overestimate the measured concentrations (the lighter shade of the same color) at monitoring wells near the extraction wells for most monitoring periods [15 and 16]. The differences between the predicted and the measured concentrations decrease as the concentrations decrease in response to SVE. Further work will be done to lessen the difference between the modeled and measured values.
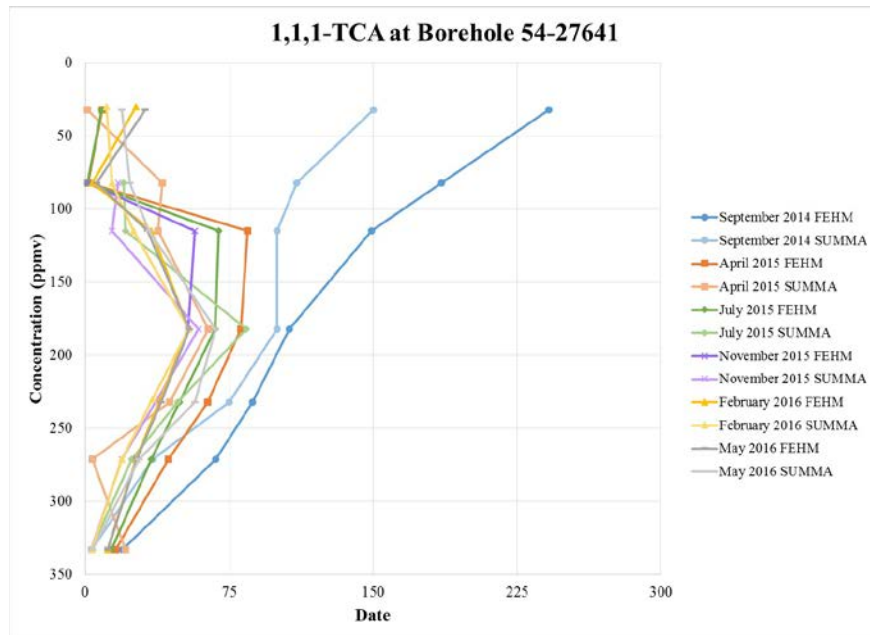


**Figure 15.** Modeled vs. measured concentrations of 1,1,1-TCA at Monitoring Borehole 54-27641 as functions of time and depth near SVE-West. Same sample times are represented by the same color; the darker color represents the FEHM model prediction and the lighter color represents the data for each time period.
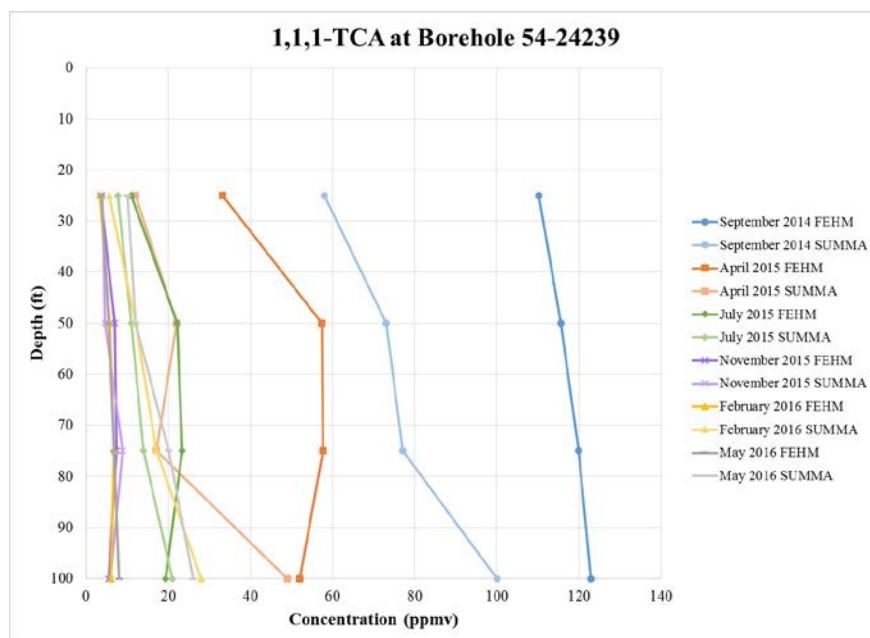
**Figure 16.** Modeled vs. measured concentrations of 1,1,1-TCA at Monitoring Borehole 54-24239 as functions of time and depth near SVE-East. Same sample times are represented by the same color; the darker color represents the FEHM model prediction and the lighter color represents the collected data for each time period.

**CONCLUSION**

Site data presented in this paper consistently show a decrease in concentrations over time, as well as, at every depth for the west side of MDA L. The east side generally shows similar decreases in concentrations over time except at two monitoring wells. Further work will be done to explain these differences, including looking into the release rates from waste drums. SVE has been demonstrated to be an effective remediation technology for the vapor plume at MDA L. After recalibrating the existing model to better fit data for the eastern side of MDA L, the fits between the model and data for both the extraction concentrations and the monitoring data are reasonable, including during the rebound period. When comparing the fit of model to the field data for the monitoring boreholes, the model overestimated the data, but this difference decreased over time. Sampling will continue as we continue to monitor the plume size and ensure the remediation technique is effective.

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