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# Passive Soil Vapor Extraction (PSVE) for VOC Remediation at the Metallurgical Laboratory (MetLab) June 2005 Progress Report

Brian D. Riha

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Westinghouse Savannah River Company, LLC
Savannah River Site
Aiken, SC, 29808

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# Executive Summary

The passive soil vapor extraction (PSVE) system at the MetLab of the Savannah River Site has been operating since May 1998. The concentration trend results to date indicate the technology is performing effectively and is protective of the environment. Well concentrations are decreasing and contour maps of the vadose zone soil gas plume show a decrease in the extent of the plume. In the 7 years of operation approximately 270 pounds of chlorinated organic contaminants have been removed by natural barometric pumping of wells fitted with BaroBall™ valves.

Mass removal during this time frame is primarily attributed to residual contamination in the coarse grained material and contaminant mass transfer from the finer grained zones to coarse zones where the majority of the PSVE flow is achieved. Removal from the fine grained sediments will be limited by the mass transfer from these zones to the coarse grained zones.

The majority of the well concentrations are less than 1 ppmv. Less than 4 lbs PCE and 3 lbs TCE are expected to be removed in calendar year 2005 compared to 65 lbs PCE and 40 lbs TCE removed during the first year of operation. Declining concentrations and mass removal rates indicate PSVE has significantly reduced the solvent source area.

The PSVE system has required minimal operating and maintenance costs and can be expected to operate continuously for the life span of the remediation with little or no intervention.

The PSVE system is performing well in a cost-effective manner. It is recommended that this system be allowed to continue operating to complete the remediation and to continue monitoring activities to verify and monitor the anticipated contaminant removal rates.

# Background

## Site Description

The Metallurgical Laboratory (MetLab) waste unit is located in the A/M areas of the Savannah River Site (SRS). During the 1950's to the early 1980's, solvents were used in MetLab facilities to degrease fuel and target tubes prior to use in other facilities at SRS. The solvents used during this period were primarily trichloroethylene (TCE) and tetrachloroethylene (PCE) with minor amounts of other solvents. Building 717-A is at the center of the soil gas plume and currently houses a machine shop. A site map showing buildings and wells is provided in Figure 1.

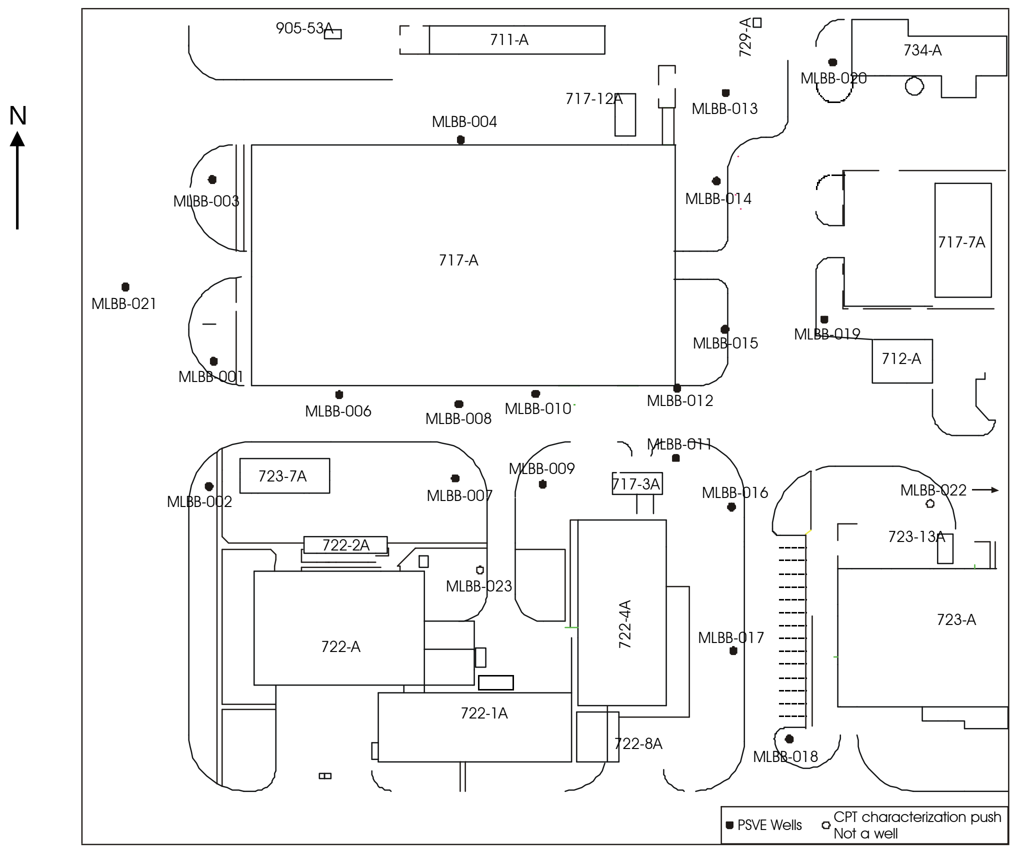


Figure 1 – MetLab Site Map

## Previous Characterization Efforts

The MetLab characterization was initiated to determine the vertical and lateral extent of contaminants in the vadose zone to aid in determining the source of groundwater contamination in the area. MetLab Phase I consisted of installation of seven groundwater monitoring wells and completion of one soil boring near the MetLab Hazardous Waste Management Facility (HWMF). TCE and PCE sediment concentrations in the vadose zone ranged from below detection (<0.001 µg/g) to 0.068 µg/g and 0.025 µg/g respectively (Van Pelt and Dunbar, 1995). MetLab Phase II included six cone penetrometer test (CPT) characterization and soil gas pushes and groundwater sample collection at three locations. TCE and PCE soil gas concentrations ranged from below detection to 15.1 ppmv and 7.2 ppmv respectively (Pemberton et al., 1996).

During MetLab Phase III, soil gas samples were collected at twenty-nine locations using a (CPT) truck around the metallurgical manufacturing facility in M-Area. This work expanded lateral vadose zone characterization north and east of the MetLab HWMF. The highest soil gas concentrations were found in an isolated area near Building 717-A. Concentrations ranged from 88.4 ppmv TCE and 121.6 PCE ppmv near 717-A to non-detect levels at the north end of the characterization area. Other contaminants (e.g. 1,1,1 trichloroethane (TCA), Freon 113, degradation by-products) were also present in the soil gas samples at lower concentrations (Pemberton et al., 1997).

Additional characterization was completed in FY00 to evaluate the concentration of the soil gas plume on the south and west sides of the PSVE well field. One well was installed and two soil gas pushes were completed. The maximum soil gas concentrations observed from both CPT soil gas pushes were 3.0 ppmv PCE, 3.5 ppmv TCE, and 4.5 ppmv Freon 113. Additional wells were not installed due to the low concentrations. Based on the new characterization data and the monitoring results from the existing wells, the current well system adequately bounds the soil gas plume (Riha et al., 2000).

The apparent source term is located on the south side of Building 717-A. The low contaminant concentrations measured in the soil gas (<15 ppmv) at the CPT locations on the north and east side of Building 717-A, indicate that the soil gas plume has probably migrated from the apparent source on the south side of Building 717-A. If other solvent source areas were present near the CPT pushes, much higher soil gas concentrations would be expected. The most likely source of this solvent gas plume is from minor degreasing operations associated with Building 717-A.

## Geology

The SRS is underlain by a thick wedge (approximately 1000 ft) of unconsolidated Tertiary and Cretaceous sediments consisting primarily of sands, clayey sands, and sandy clays. Three fine grain layers in the vadose zone at the MetLab are located at approximately 0-15 ft, 60 ft and 80 ft below ground surface. The upper zone is defined as the ‘upland unit’. This unit is fairly consistent across the SRS A/M Areas and is made up of a very low permeability, high porosity, high water content mix of sand, silt and clay and ranges from 10-50 ft thick at the SRS. Most facilities at the SRS were built on the ‘upland unit’, which has shown to entrap solvent for over 20-30 years (approximate time since releases ceased). The 60 and 80 ft layers are interbedded and range in thickness from approximately 1 to 15 ft. The water table at the site is approximately 140 ft below the ground surface. CPT soil classification logs from two borings (MLBB-022 and MLBB-023) at the MetLab are provided in Figure 2

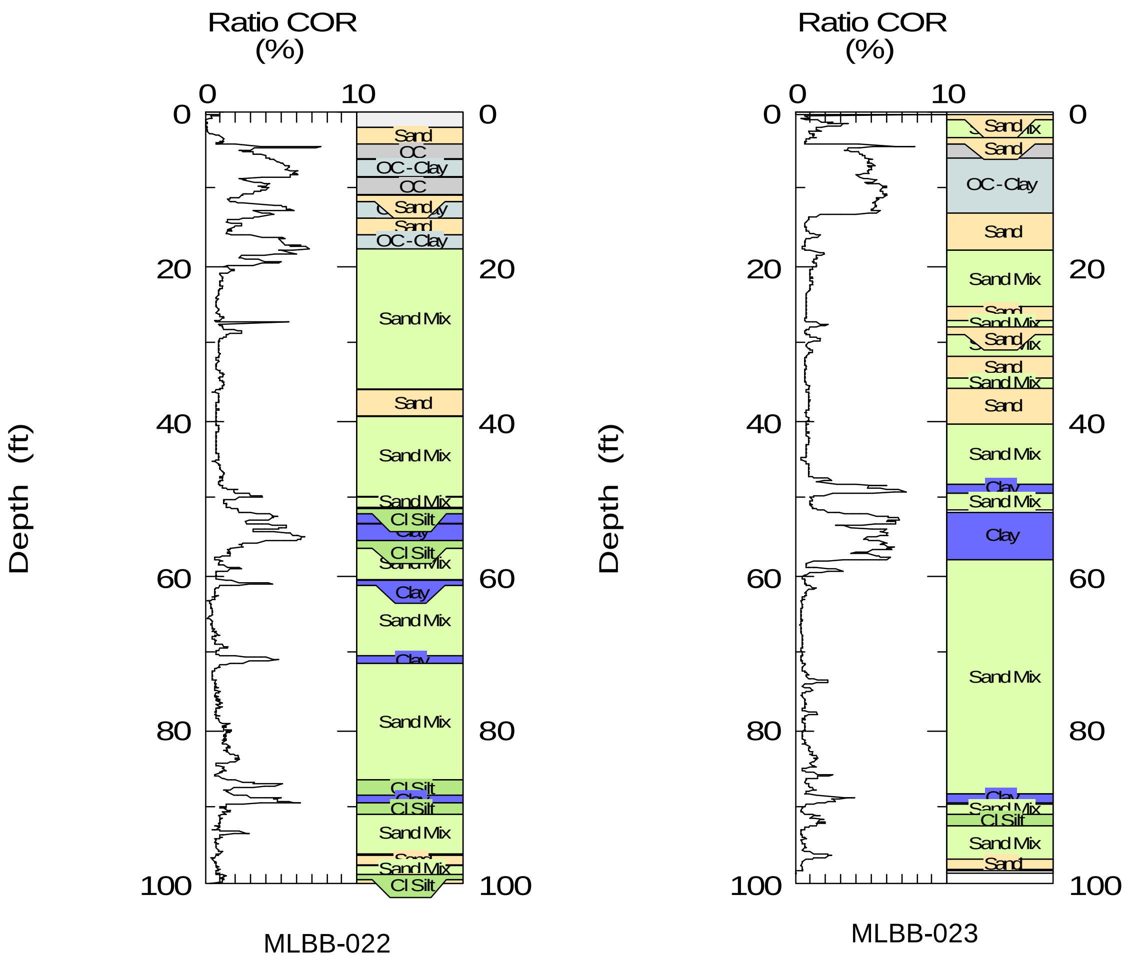


Figure 2 – CPT Soil Classification for MLBB-022 and MLBB-023

## Original PSVE Well Installation

Nineteen vadose zone wells (MLBB-001 to MLBB-004 and MLBB-006 to MLBB-021, see Appendix A) were installed at the MetLab using direct push with a CPT truck after the Phase III characterization. MLBB-005 was not installed due to underground interferences. The wells were installed by threading a steel push tip onto the PVC screen and pushing the tip with the steel CPT rods in the center of the PVC, effectively pulling the PVC well down with the push tip. The CPT rods are removed and the 6 inch long steel push tip and well remain in the ground.

The wells were installed so the formation was compressed against the outer surface of the casing and screen, leaving no annular space. This seal is verified by sustained gas pressure differences between the surface and subsurface. The wells were installed with continuous screens from 20 to 80 feet below surface. Concrete pads were installed around the wells at the surface.

## Technology Description - Barometric Pumping

At numerous sites across the country, wells with open intervals in the unsaturated zone have been observed to "breathe" or to inhale ambient air from the surface and to exhale soil gas to the atmosphere. This process results from the difference in atmospheric pressure and the pressure in the subsurface. Barometric pressure changes, caused by diurnal fluctuations and weather events, are propagated through the subsurface with attenuation and delay induced by stratum permeability changes and depth. For example, low-permeability layers exhibit low gas flow rates and require a longer period of time to equilibrate with a change in atmospheric pressure. This produces the damped and delayed pressure response. At the SRS, the magnitude of the differential pressure increases with depth due to the depositional layering of the sediments. Passive soil vapor extraction (PSVE) enhances and harnesses this natural process as a remediation technique for removing volatile contaminants from the vadose zone.

A plot showing surface and subsurface pressures and the typical diurnal (short) and weather (long) generated differential pressure is shown in Figure 3. Flow is out of the PSVE wells when the subsurface pressure is greater than the atmospheric (surface) pressure and the PSVE flow rate is directly proportional to the magnitude of the differential pressure. By connecting these zones via a vadose zone well, the differential pressure will result in flow either into or out of the well. If the soil gas in the subsurface contains volatile organic compounds (VOCs), flow out of the well will result in the removal of those contaminants from the subsurface without mechanical pumping. The outflow events can be viewed as pulsed soil vapor extraction events.

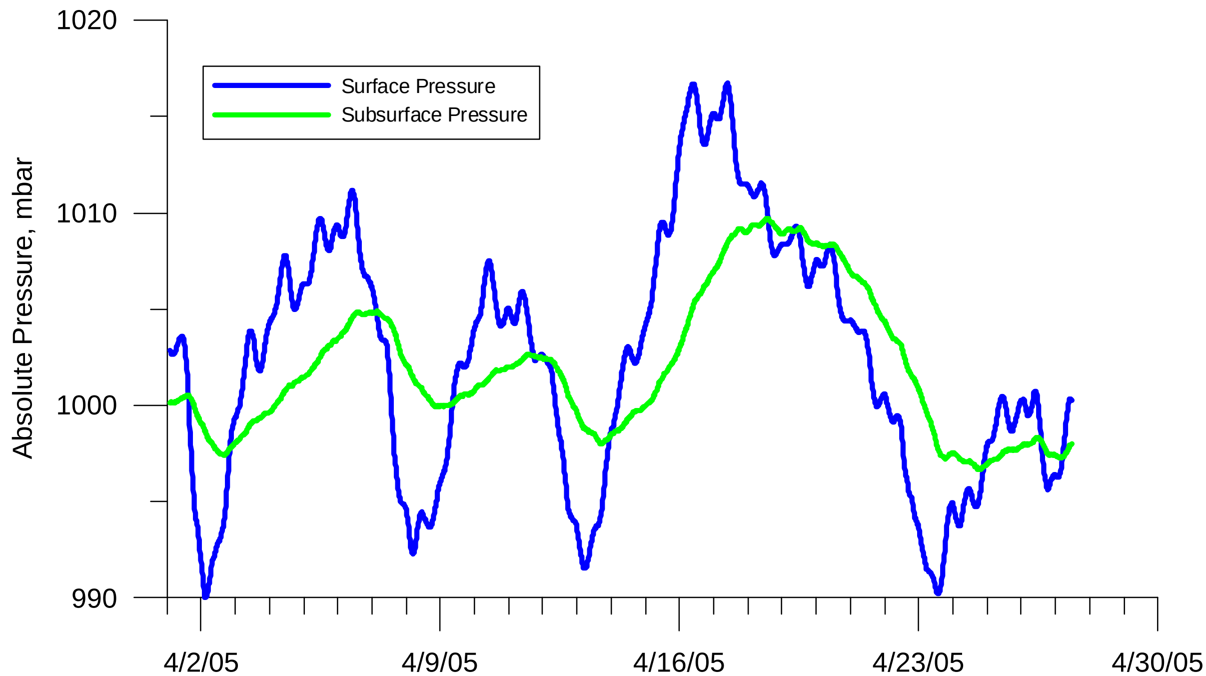


Figure 3 – Atmospheric and Subsurface Pressure Relation at Well MLBB-021

This phenomena has been observed for more than a century; the first reference in the literature is an article in Science (Fairbanks, 1896). The duration of flow events (either flow into the well or flow out of the well) can be several days continuously but, as expected by mass balance considerations, the average time of flow in is equal to the average time of flow out. The flow rates for a typical well are generally low compared to active soil vapor extraction (ASVE0. Mass removal can be enhanced with installation of one way mechanical valves to prevent spread and movement of contaminated soil gas away from the well during inflow and provide a stepped or pulsed removal of vapor from the subsurface.

The BaroBall™ (U.S. Patent #5,641,245) is a device developed and patented by WSRC specifically for barometric pumping applications. It uses a lightweight ball in a conical seat to permit gas flow in one direction with a minimal pressure requirement (approximately 1 mbar), but effectively prevents gas flow in the reverse direction. The BaroBall device is attached directly to the top of the well casing at the surface.

The PSVE approach directly addresses three critical components of the VOC contaminated soil problem:

1. Containment: Soil vapor extraction can directly address the source term at contaminated sites. Decreasing the source term decreases the potential for contaminant transport, which contains the plume. In addition, advective flow will move the vapor to the well and then the surface when controlling flow with one-way valves. The density driven component of gas flow is dominated by the advective component in these situations. Finally, by decreasing the contaminant vapor concentration near the vent well, diffusive flow will move the contaminant toward the well rather than toward the groundwater.
2. Primary Removal: In a situation where a very high removal rate is not required, interim action is required, vapor concentrations are low, or in locations away from the center of the plume, passively vented wells may be a cost-effective alternative to ASVE (mechanical pumping).
3. Long-Term Stewardship: After an initial large mass removal, continuing the pumping of an ASVE system at a rate faster than the contaminant's kinetic mass transfer rate into the vapor phase will result in decreased concentrations in the vented flow. At this point, passive venting is likely to be much more cost-effective than an active system per kilogram of contaminant vapor removed.

Application of this technology is directed to any site where volatile substances (chlorinated solvents, petroleum products, etc.) have contaminated the vadose zone. Natural pressure fluctuations and their damped and delayed transmission through the subsurface occur in all environments, but are particularly well-suited to sites with large vadose zones or substantial low permeability layers that increase the damping and delay of the atmospheric pressure signal.

Field scale studies have been ongoing at SRS, the Hanford site and the Idaho National Environmental Engineering Lab for approximately six years, and a field scale implementation of the technology for control of subsurface methane migration using a combination of passive injection and extraction was installed at a landfill in Richmond County, Georgia. In addition several other contaminated sites, both public and private, have implemented barometric pumping remediation programs with the BaroBall. The 1996 start of PSVE at the SRS Miscellaneous Chemical Basin was the first implementation to directly target the removal of the vadose zone source term.

# Methods

## Well Vapor Sampling and Analysis Methods

Soil vapor samples were collected at MetLab during barometric pumping outflow events. Three methods were used for gas sampling and were performed in accordance with work instruction WI-ERTS-0013 'Sampling Passive Soil Vapor Extraction (PSVE) Wells for VOC Analysis'. The sampling methods in the work instruction are briefly described below.

1. **Well vapor sampling using Tedlar gas sample bags –** This method collects gas samples in Tedlar bags by placing a cap with a tube fitting on the venting well head and filling the bag. This method is primarily used as confirmation sampling for the other two methods.
2. **Well vapor sampling using an Infrared Photo-Acoustic Spectroscopy (IRPAS) Field Screening Instrument –** This method uses a field screening instrument to directly sample and analyze soil gas from the venting well head.
3. **Well vapor sampling using glass vials –** This method collects gas samples in 20 ml glass vials by placing a cap with a tube on the venting well and filling the glass vial inside a thin walled plastic bag, sealing the bag and then crimping the vial closed.

<u>VOC Analysis of Soil Vapor Samples</u>

Tedlar bag laboratory analyses were performed in accordance with WSRC Manual L14.1 Procedure 2-106, "Procedure for the Operation and Calibration of Gas Chromatographs Used for the Analysis of Gas Phase Samples". The IRPAS field analyzer provides screening level data for TCE, PCE and carbon dioxide ($CO_2$). The instrument is operated according to the manufacturer's operational manual and an operation check is done according WI-ERTS-0013. Glass vial laboratory analysis was performed in accordance with WSRC Manual L14.1, Procedure 2-143 'Procedure for the Calibration and Sample Analysis of Agilent Gas Chromatographic Systems with the Automatic Sampler'. The analysis results from the different methods are comparable based on the data objectives of evaluating concentration trends of variable data.

<u>Data Quality Objectives</u>

Generally, the screening data obtained must support the evaluation of remediation effectiveness. Soil gas sample analysis was performed in accordance with WSRC

Manual L14.1 Procedure 2-106, “Procedure for the Operation and Calibration of Gas Chromatographs Used for the Analysis of Gas Phase Samples” and WSRC Manual L14.1, Procedure 2-143 ‘Procedure for the Calibration and Sample Analysis of Agilent Gas Chromatographic Systems with the Automatic Sampler’. Minimum detection limits (MDL) and minimum quantification limits (MQL) for the Savannah River National Laboratory (SRNL) for the methods are provided in Table 1 and Table 2. The detection limits for the IRPAS field analyzer is approximately 1 ppmv for PCE and TCE. Data from the gas analysis were reviewed for completeness and accuracy using professional judgment and previous experience at the MetLab. Results were compared to prior gas samples at the MetLab, results from confirmation samples (Tedlar bag method), and calibration standards.

Table 1 – Gas Analysis Limits for Tedlar Bag Method (L14.1, Procedure 2-106)

| **Compound** | **MDL (ppmv)** | **MQL (ppmv)** |
|---|---|---|
| 1,1 DCE | 0.071 | 0.119 |
| Carbon Tetrachloride ($CCl_4$) | 0.001 | 0.002 |
| Choloroform | 0.010 | 0.017 |
| cis-DCE | 0.919 | 1.532 |
| Freon-11 | 0.001 | 0.001 |
| Freon-113 | 0.004 | 0.007 |
| PCE | 0.002 | 0.003 |
| 1,1,1 Trichloroethane (TCA) | 0.004 | 0.006 |
| TCE | 0.008 | 0.013 |
| Toluene | 0.488 | 0.813 |
| trans-DCE | 0.609 | 1.015 |
| Vinyl Chloride | 0.736 | 1.227 |

Table 2 – Gas Analysis Limits for Gas Vial Method (L14.1, Procedure 2-143)

| **Compound** | **MDL (ppmv)** | **MQL (ppmv)** |
|---|---|---|
| Benzene | 0.2 | 0.3 |
| Carbon Tetrachloride ($CCl_4$) | 0.0005 | 0.001 |
| Chloroform | 0.005 | 0.009 |
| cis-DCE | 0.4 | 0.6 |
| Freon-11 | 0.0005 | 0.001 |
| Freon-113 | 0.003 | 0.01 |
| Methylene Chloride | 0.4 | 0.7 |
| PCE | 0.0006 | 0.001 |
| TCA | 0.002 | 0.003 |
| TCE | 0.004 | 0.006 |
| Toluene | 0.1 | 0.2 |
| trans-DCE | 0.4 | 0.7 |

# Results and Discussion

## PSVE Well Vapor Concentration Trends

Well vapor concentration measurements show mass removal and a concentration decrease in the vadose zone at the MetLab. Wellhead samples were collected during outflow events using the methods described above. Although IRPAS data was collected at times, the data was not used for concentration trend evaluations due to the precision of the measurements. The precision of the instrument was decreased due to measurement interference caused by Freon-113 and the low concentrations encountered with time. The IRPAS detection limit for PCE and TCE is approximately 1 ppmv without interference with Freon-113 and concentrations have decreased significantly over time. Comparison with the two gas chromatograph (GC) methods showed the IRPAS results overestimated the PCE and TCE concentrations with a dependence on the Freon-113 concentrations. Only the two GC methods were used for reporting purposes for this progress report.

Soil gas concentrations measured over this seven year time period show an exponentially declining concentration as is expected based on a conceptual model of mass transfer from the liquid or aqueous phase in the fine grained zones to the gas phase in the coarse grain sediments. The GC data during this time period were exponential fitted to determine a concentration decay constant (*k*) and temporal concentrations were estimated using the following equation.

$$C_{vt} = C_{v0}e^{-kt}$$

where
$C_{vt}$ = PSVE well vapor concentration at time t (ppmv)
$C_{v0}$ = initial PSVE well concentration on 1-Jun-98 (ppmv)
$k$ = fitted exponential decay constant (day$^{-1}$)
t = time in days

Selected concentration data along with the fitted equation and correlation coefficient (quality of fit) from several wells are shown in Figure 4 and Figure 5. Plots of the concentration data and exponential fitted lines for each PSVE well are provided in Appendix B. The variability of individual well vapor concentration measurements may be caused by several factors including extended rainfall (change in permeability and migration), duration of no flow events, duration and intensity of outflow events, and time of sample collection during the outflow event (mass transfer effects).

Since the IRPAS data were not as accurate as desired, the fitted equations were projected back to the start of the PSVE (June 1998) to estimate size and concentration of the soil gas plume and mass removal. The parameters for the exponential concentration decline equations and the yearly PSVE well concentration from the equations are provided in Table 3 and Table 4. The GC data are provided in Appendix C.

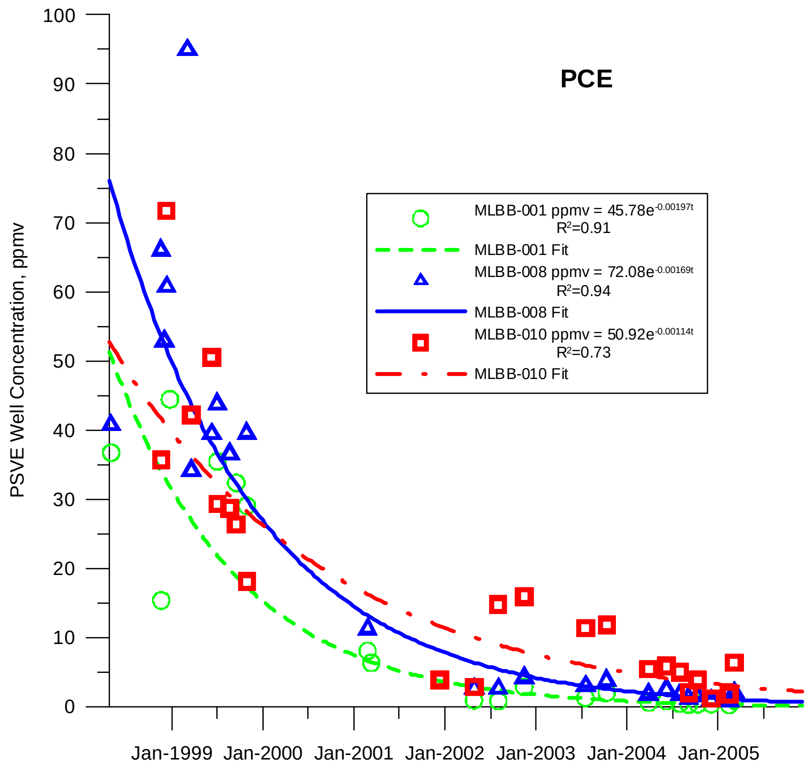


Figure 4 – PCE Well Vapor Concentration Trends for MetLab Vadose Zone Plume

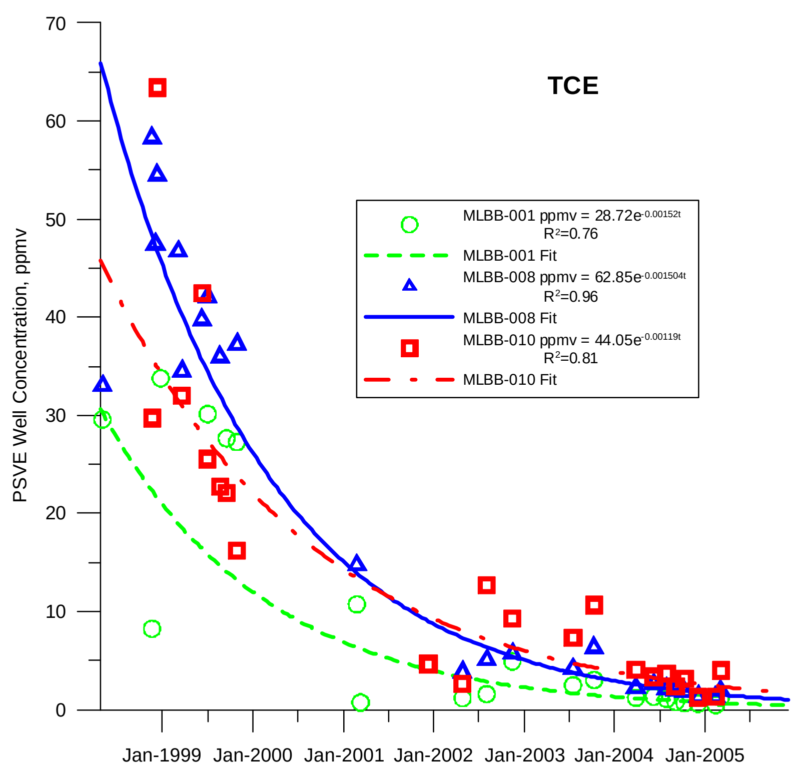


Figure 5 – TCE Well Vapor Concentration Trends for MetLab Vadose Zone Plume

Table 3 – Fitted PCE Concentration Data by Well for the MetLab Vadose Zone Plume

| Well ID | Decay Constant $k$ | PCE Well Vapor Concentration, ppmv | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 1-Jun-98 | 1-Jun-99 | 1-Jun-00 | 1-Jun-01 | 1-Jun-02 | 1-Jun-03 | 1-Jun-04 | 1-Jun-05 |
| MLBB-001 | -1.965E-03 | 45.78 | 22.35 | 10.89 | 5.31 | 2.59 | 1.27 | 0.62 | 0.30 |
| MLBB-002 | -1.269E-03 | 13.20 | 8.31 | 5.22 | 3.29 | 2.07 | 1.30 | 0.82 | 0.51 |
| MLBB-003 | -1.743E-03 | 7.48 | 3.96 | 2.09 | 1.11 | 0.59 | 0.31 | 0.16 | 0.09 |
| MLBB-004 | -1.641E-03 | 15.33 | 8.42 | 4.62 | 2.54 | 1.40 | 0.77 | 0.42 | 0.23 |
| MLBB-006 | -1.574E-03 | 41.67 | 23.46 | 13.19 | 7.42 | 4.18 | 2.35 | 1.32 | 0.74 |
| MLBB-007 | -1.387E-03 | 17.87 | 10.77 | 6.48 | 3.91 | 2.36 | 1.42 | 0.85 | 0.52 |
| MLBB-008 | -1.690E-03 | 72.08 | 38.90 | 20.95 | 11.31 | 6.10 | 3.29 | 1.77 | 0.96 |
| MLBB-009 | -1.558E-03 | 27.50 | 15.57 | 8.81 | 4.99 | 2.83 | 1.60 | 0.90 | 0.51 |
| MLBB-010 | -1.135E-03 | 50.92 | 33.65 | 22.21 | 14.68 | 9.70 | 6.41 | 4.23 | 2.80 |
| MLBB-011 | -1.648E-03 | 11.78 | 6.46 | 3.53 | 1.94 | 1.06 | 0.58 | 0.32 | 0.17 |
| MLBB-012 | -8.349E-04 | 44.92 | 33.12 | 24.40 | 17.99 | 13.26 | 9.78 | 7.20 | 5.31 |
| MLBB-013 | -7.972E-04 | 1.09 | 0.81 | 0.61 | 0.45 | 0.34 | 0.25 | 0.19 | 0.14 |
| MLBB-014 | -9.573E-04 | 3.22 | 2.27 | 1.60 | 1.13 | 0.79 | 0.56 | 0.39 | 0.28 |
| MLBB-015 | -8.604E-04 | 15.09 | 11.02 | 8.05 | 5.88 | 4.29 | 3.14 | 2.29 | 1.67 |
| MLBB-016 | -1.150E-03 | 3.55 | 2.33 | 1.53 | 1.01 | 0.66 | 0.43 | 0.29 | 0.19 |
| MLBB-017 | -8.422E-04 | 2.92 | 2.15 | 1.58 | 1.16 | 0.85 | 0.63 | 0.46 | 0.34 |
| MLBB-018 | -6.247E-04 | 0.86 | 0.68 | 0.54 | 0.43 | 0.35 | 0.27 | 0.22 | 0.17 |
| MLBB-019 | -1.423E-03 | 5.54 | 3.30 | 1.96 | 1.16 | 0.69 | 0.41 | 0.24 | 0.15 |
| MLBB-020 | -1.142E-03 | 2.14 | 1.41 | 0.93 | 0.61 | 0.40 | 0.27 | 0.18 | 0.12 |

$C_{vt}$ (ppmv) = $C_{v0}e^{(-kt)}$ where $C_{v0}$ is the concentration on 1-Jun-98 and t is time in days

Table 4 – Fitted TCE Concentration Data by Well for the MetLab Vadose Zone Plume

| Well ID | Decay Constant *k* | Well Vapor TCE Concentration, ppmv | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 1-Jun-98 | 1-Jun-99 | 1-Jun-00 | 1-Jun-01 | 1-Jun-02 | 1-Jun-03 | 1-Jun-04 | 1-Jun-05 |
| MLBB-001 | -1.516E-03 | 28.72 | 16.51 | 9.48 | 5.45 | 3.13 | 1.80 | 1.03 | 0.59 |
| MLBB-002 | -9.707E-04 | 9.38 | 6.58 | 4.61 | 3.24 | 2.27 | 1.59 | 1.12 | 0.78 |
| MLBB-003 | -1.491E-03 | 5.79 | 3.36 | 1.95 | 1.13 | 0.66 | 0.38 | 0.22 | 0.13 |
| MLBB-004 | -1.594E-03 | 3.53 | 1.97 | 1.10 | 0.61 | 0.34 | 0.19 | 0.11 | 0.06 |
| MLBB-006 | -1.153E-03 | 30.89 | 20.28 | 13.30 | 8.73 | 5.73 | 3.76 | 2.47 | 1.62 |
| MLBB-007 | -1.119E-03 | 13.53 | 9.00 | 5.97 | 3.97 | 2.64 | 1.75 | 1.16 | 0.77 |
| MLBB-008 | -1.504E-03 | 62.85 | 36.30 | 20.93 | 12.09 | 6.98 | 4.03 | 2.32 | 1.34 |
| MLBB-009 | -1.341E-03 | 27.68 | 16.97 | 10.38 | 6.36 | 3.90 | 2.39 | 1.46 | 0.90 |
| MLBB-010 | -1.189E-03 | 44.05 | 28.55 | 18.48 | 11.97 | 7.76 | 5.03 | 3.25 | 2.11 |
| MLBB-011 | -1.077E-03 | 8.55 | 5.77 | 3.89 | 2.63 | 1.77 | 1.20 | 0.81 | 0.55 |
| MLBB-012 | -1.315E-03 | 32.98 | 20.41 | 12.62 | 7.81 | 4.83 | 2.99 | 1.85 | 1.14 |
| MLBB-013 | -7.763E-04 | 0.88 | 0.66 | 0.50 | 0.37 | 0.28 | 0.21 | 0.16 | 0.12 |
| MLBB-014 | -8.747E-04 | 1.87 | 1.36 | 0.98 | 0.72 | 0.52 | 0.38 | 0.27 | 0.20 |
| MLBB-015 | -1.327E-03 | 9.82 | 6.05 | 3.72 | 2.29 | 1.41 | 0.87 | 0.54 | 0.33 |
| MLBB-016 | -7.005E-04 | 3.63 | 2.81 | 2.18 | 1.68 | 1.30 | 1.01 | 0.78 | 0.61 |
| MLBB-017 | -3.955E-04 | 2.93 | 2.54 | 2.20 | 1.90 | 1.64 | 1.42 | 1.23 | 1.07 |
| MLBB-018 | -5.786E-04 | 0.30 | 0.24 | 0.20 | 0.16 | 0.13 | 0.10 | 0.08 | 0.07 |
| MLBB-019 | -1.166E-03 | 3.41 | 2.23 | 1.46 | 0.95 | 0.62 | 0.41 | 0.27 | 0.17 |
| MLBB-020 | -1.164E-03 | 1.27 | 0.83 | 0.54 | 0.35 | 0.23 | 0.15 | 0.10 | 0.06 |

$C_{vt}$ (ppmv) = $C_{v0}e^{(-kt)}$ where $C_{v0}$ is the concentration on 1-Jun-98 and t is time in days

Yearly concentration contour plots of TCE and PCE well concentrations from 6/98 to 6/05 are provided in Figure 6, Figure 7, Figure 8, and Figure 9. The wells have long screens (60 ft) so these plots show a general representation of the soil gas plume at the unit. Over the 7 years of PSVE with Baroball flow enhancement, the soil gas plume has decreased in concentration and size. The contours were created using the fitted exponential equations. These contour plots show the PSVE is decreasing the size and mass of the plume and is adequately covering the soil gas plume.

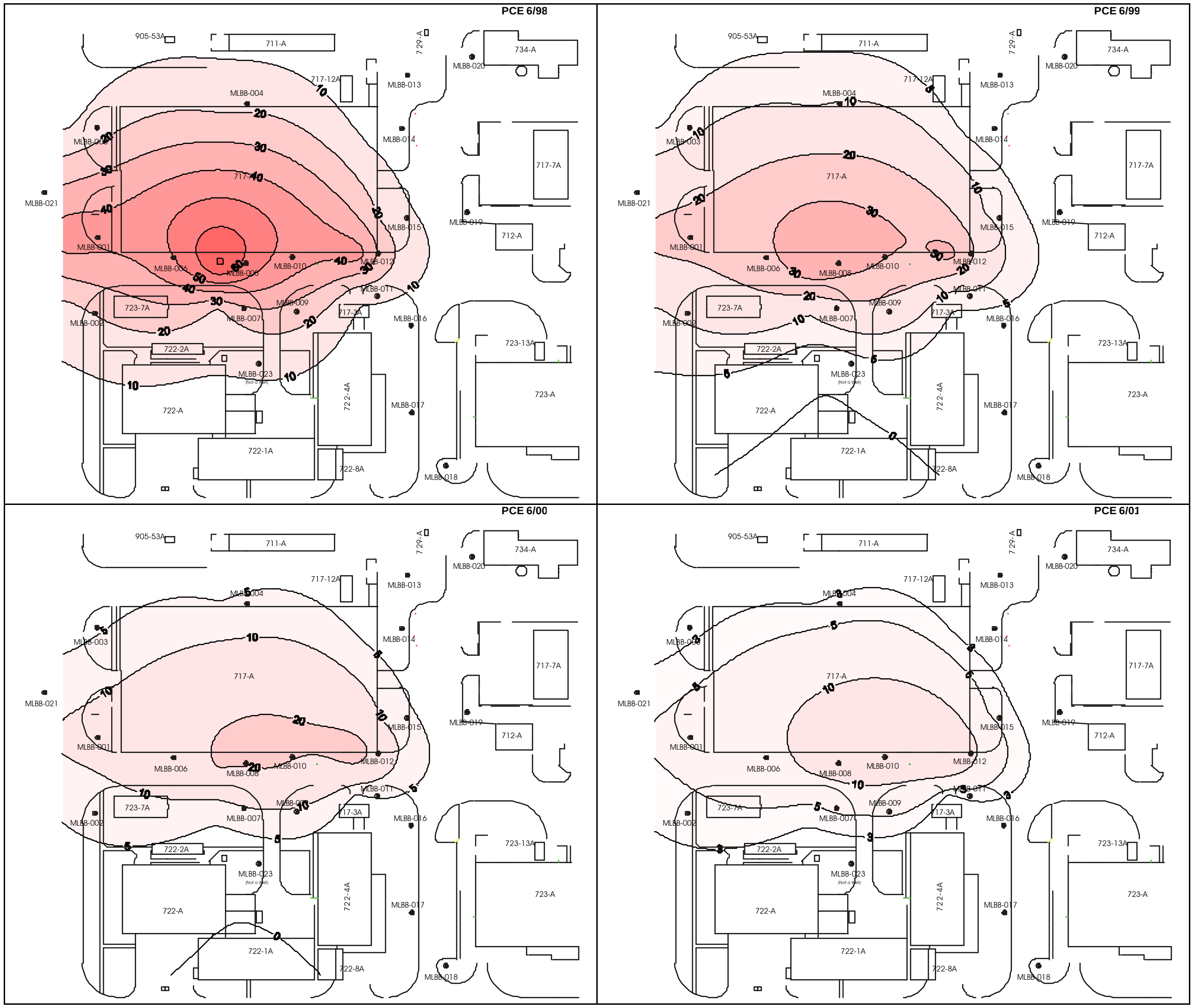


Figure 6 – PCE Contour Plots in ppmv (1998-2001)

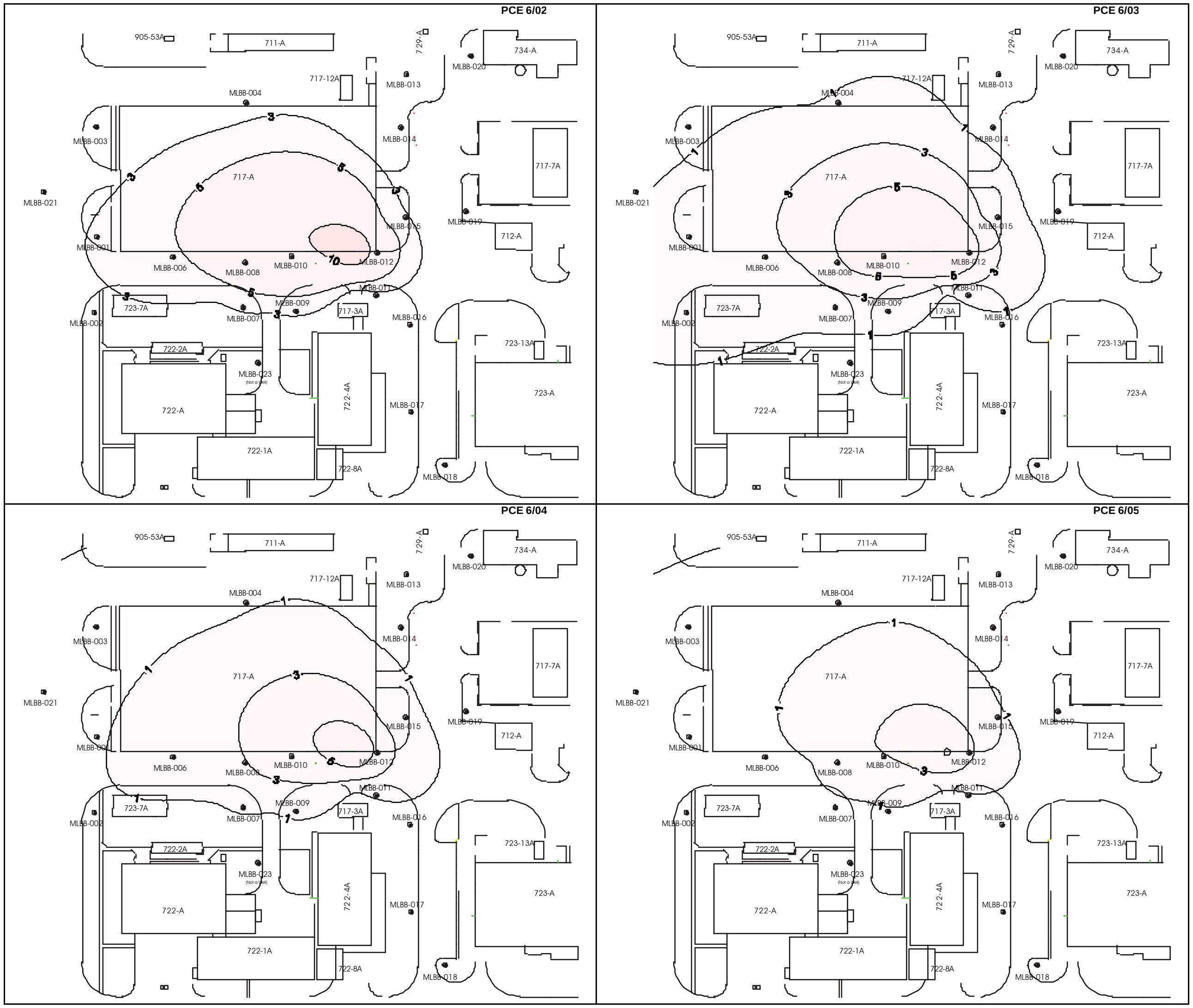


Figure 7 – PCE Contour Plots in ppmv (2002-2005)

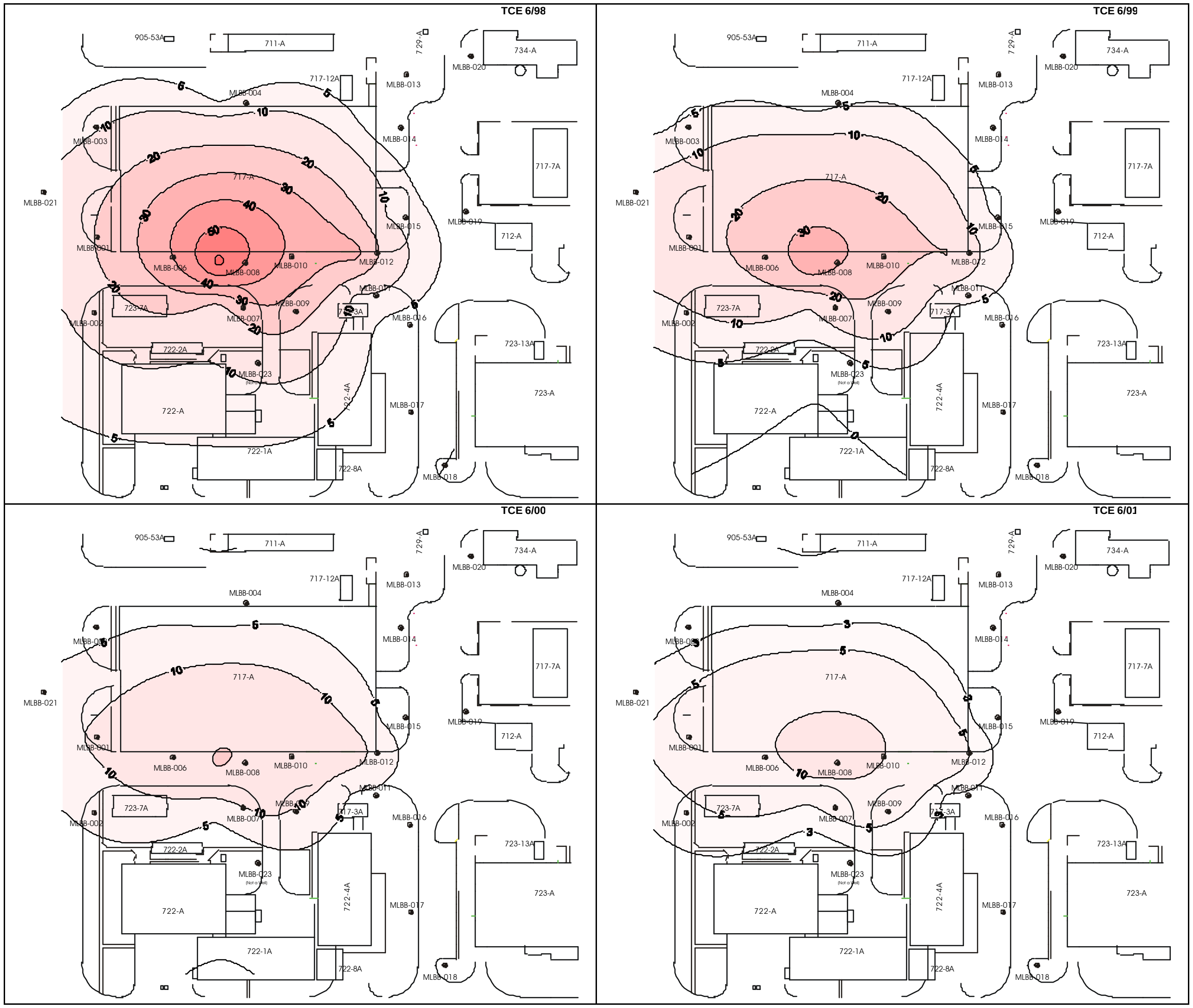


Figure 8 – TCE Contour Plots in ppmv (1998-2001)

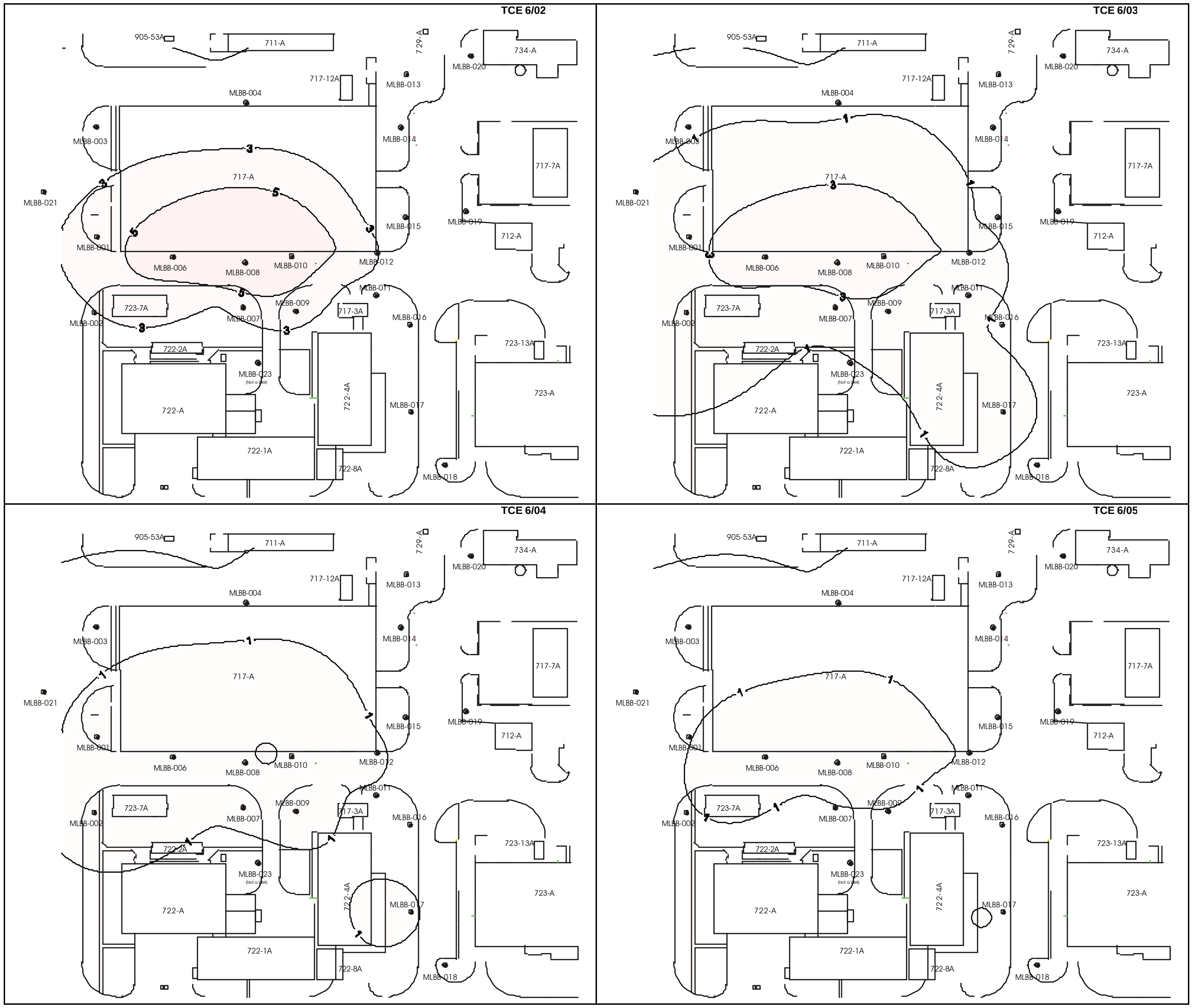


Figure 9 – TCE Contour Plots in ppmv (2002-2005)

## Mass Removal Estimation

Based on the concentration curves for the19 wells installed at MetLab, the mass of contaminants removed can be estimated. The assumptions include a uniform average flow rate of 1 cfm ($ft^3$/min) out of all of the wells based on measured flow from other PSVE wells, initial concentrations estimated from the concentration trends on 6/1/98 and final concentration projected using the rate constants from approximately 7 years of monitoring. Physically observed vapor flow and concentration measurements indicate mass removal from the vadose zone at the MetLab.

Well flow rates have not been measured at the MetLab so PSVE flow rates from nearby wells are used for estimating the mass removal. The average flow measured from 2 inch diameter PSVE wells at the Miscellaneous Chemical Basin and near the M-Area Basin is approximately 2 cfm during outflow events. Since soil gas is removed 50% of the time with barometric pumping, the continuous average flow out of the wells is 1 cfm. The area under the removal curves is calculated and multiplied by the flow rate to obtain the mass of contaminant removed. Mass removal was calculated monthly. The total mass removed at the MetLab for a given time period is the sum of the mass removed from the individual wells.

The cumulative calculated mass removal for each well and the total system by year is presented in Table 5 and Table 6. Graphs showing the monthly mass removal and cumulative mass removed since the inception of PSVE at the MetLab are presented in Figure 10. The data tables and graphs clearly show the decline in the rate of mass removal as the source term is diminished. Based on these analyses it is estimated that less than 3 lbs TCE and 4 lbs PCE will be removed in calendar year 2005.

After 7 years of PSVE approximately 100 lbs TCE and 160 lbs PCE have been removed by the natural barometric pumping of wells fitted with BaroBall valves. The mass removal estimates are approximate since the flow rates are estimated and the concentration data are based on exponential fits of the data set.

## Table 5 – Cumulative PCE Mass Removed by Well

| | Cumulative PCE Mass Removed, lbs | | | | | | |
|---|---|---|---|---|---|---|---|
| Well ID | 1-Jun-99 | 1-Jun-00 | 1-Jun-01 | 1-Jun-02 | 1-Jun-03 | 1-Jun-04 | 1-Jun-05 |
| MLBB-001 | 7.05 | 10.50 | 12.18 | 13.00 | 13.40 | 13.59 | 13.69 |
| MLBB-002 | 2.31 | 3.76 | 4.67 | 5.24 | 5.61 | 5.83 | 5.98 |
| MLBB-003 | 1.20 | 1.83 | 2.17 | 2.35 | 2.44 | 2.49 | 2.52 |
| MLBB-004 | 2.50 | 3.88 | 4.63 | 5.05 | 5.28 | 5.40 | 5.47 |
| MLBB-006 | 6.88 | 10.76 | 12.94 | 14.17 | 14.86 | 15.25 | 15.46 |
| MLBB-007 | 3.05 | 4.90 | 6.01 | 6.67 | 7.08 | 7.32 | 7.46 |
| MLBB-008 | 11.66 | 17.96 | 21.35 | 23.18 | 24.17 | 24.70 | 24.99 |
| MLBB-009 | 4.55 | 7.14 | 8.60 | 9.43 | 9.89 | 10.16 | 10.31 |
| MLBB-010 | 9.11 | 15.15 | 19.12 | 21.75 | 23.49 | 24.64 | 25.40 |
| MLBB-011 | 1.92 | 2.97 | 3.55 | 3.86 | 4.04 | 4.13 | 4.18 |
| MLBB-012 | 8.50 | 14.79 | 19.40 | 22.81 | 25.32 | 27.18 | 28.54 |
| MLBB-013 | 0.21 | 0.36 | 0.48 | 0.57 | 0.63 | 0.68 | 0.72 |
| MLBB-014 | 0.59 | 1.02 | 1.31 | 1.52 | 1.67 | 1.77 | 1.84 |
| MLBB-015 | 2.84 | 4.92 | 6.44 | 7.55 | 8.36 | 8.95 | 9.38 |
| MLBB-016 | 0.63 | 1.05 | 1.32 | 1.50 | 1.62 | 1.70 | 1.75 |
| MLBB-017 | 0.55 | 0.96 | 1.26 | 1.48 | 1.64 | 1.76 | 1.84 |
| MLBB-018 | 0.17 | 0.30 | 0.41 | 0.50 | 0.57 | 0.62 | 0.66 |
| MLBB-019 | 0.94 | 1.50 | 1.83 | 2.03 | 2.15 | 2.22 | 2.26 |
| MLBB-020 | 0.38 | 0.64 | 0.80 | 0.91 | 0.98 | 1.03 | 1.06 |
| Total PCE Removed, lbs | 65.06 | 104.40 | 128.48 | 143.56 | 153.16 | 159.41 | 163.51 |

## Table 6 – Cumulative TCE Mass Removed by Well

| | Cumulative TCE Mass Removed, lbs | | | | | | |
|---|---|---|---|---|---|---|---|
| Well ID | 1-Jun-99 | 1-Jun-00 | 1-Jun-01 | 1-Jun-02 | 1-Jun-03 | 1-Jun-04 | 1-Jun-05 |
| MLBB-001 | 3.80 | 5.99 | 7.24 | 7.96 | 8.37 | 8.61 | 8.75 |
| MLBB-002 | 1.37 | 2.34 | 3.01 | 3.48 | 3.81 | 4.05 | 4.21 |
| MLBB-003 | 0.77 | 1.22 | 1.48 | 1.63 | 1.71 | 1.76 | 1.79 |
| MLBB-004 | 0.46 | 0.72 | 0.86 | 0.94 | 0.99 | 1.01 | 1.02 |
| MLBB-006 | 4.37 | 7.24 | 9.12 | 10.35 | 11.16 | 11.69 | 12.04 |
| MLBB-007 | 1.92 | 3.21 | 4.06 | 4.62 | 5.00 | 5.25 | 5.41 |
| MLBB-008 | 8.33 | 13.15 | 15.92 | 17.52 | 18.45 | 18.98 | 19.29 |
| MLBB-009 | 3.78 | 6.10 | 7.52 | 8.39 | 8.92 | 9.24 | 9.44 |
| MLBB-010 | 6.18 | 10.20 | 12.79 | 14.47 | 15.56 | 16.27 | 16.73 |
| MLBB-011 | 1.23 | 2.06 | 2.61 | 2.99 | 3.24 | 3.42 | 3.53 |
| MLBB-012 | 4.52 | 7.33 | 9.06 | 10.13 | 10.79 | 11.20 | 11.46 |
| MLBB-013 | 0.13 | 0.23 | 0.31 | 0.37 | 0.41 | 0.44 | 0.46 |
| MLBB-014 | 0.28 | 0.48 | 0.63 | 0.73 | 0.81 | 0.87 | 0.91 |
| MLBB-015 | 1.34 | 2.17 | 2.68 | 3.00 | 3.19 | 3.31 | 3.38 |
| MLBB-016 | 0.56 | 0.99 | 1.33 | 1.59 | 1.79 | 1.94 | 2.06 |
| MLBB-017 | 0.48 | 0.89 | 1.25 | 1.56 | 1.83 | 2.06 | 2.26 |
| MLBB-018 | 0.05 | 0.09 | 0.12 | 0.14 | 0.16 | 0.18 | 0.19 |
| MLBB-019 | 0.48 | 0.80 | 1.00 | 1.14 | 1.22 | 1.28 | 1.32 |
| MLBB-020 | 0.18 | 0.30 | 0.37 | 0.42 | 0.46 | 0.48 | 0.49 |
| Total TCE Removed, lbs | 40.23 | 65.48 | 81.35 | 91.43 | 97.88 | 102.05 | 104.77 |

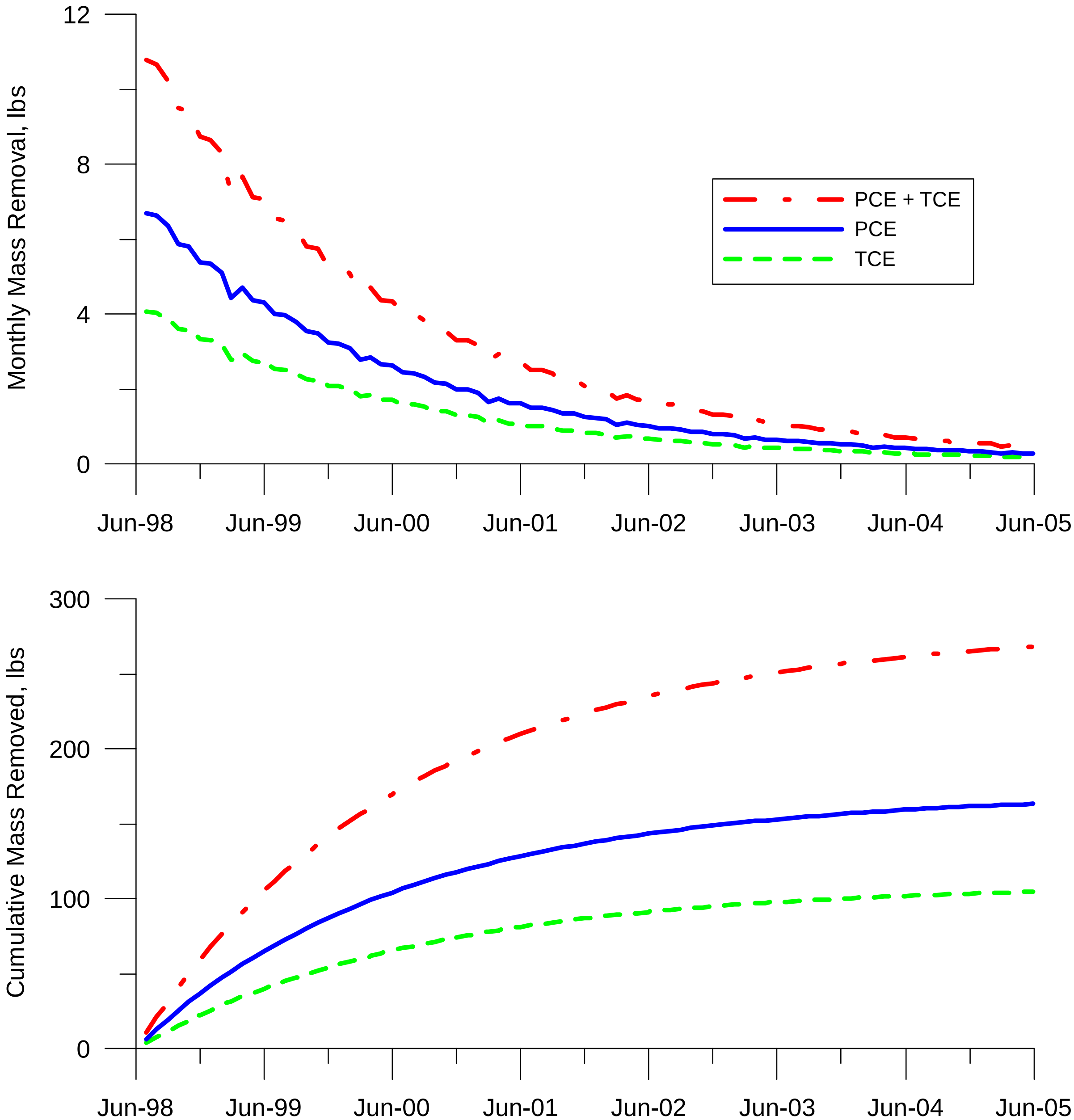


Figure 10 – Monthly and Cumulative Mass Removed for the MetLab Vadose Zone Plume

### Performance Metric for PSVE

An indicator that PSVE is preventing VOC migration to the water table is evidence that the mass in the vadose zone is decreasing. At the SRS PSVE sites, the primary hypothesis for PSVE effectiveness is declining PSVE concentrations. Thus, the metric uses indirect evidence that the PSVE is removing VOCs as fast as they are released by diffusion and before they migrate to the water table.

The easiest and best way to validate PSVE as effective is to verify stable or declining concentration trends from the PSVE wells. At the MetLab these trends indicate the attenuation capacity of PSVE equals or exceeds the contaminant loading and minimizes the impact to the groundwater. The author believes that once these conditions are met, the remediation will progress and minimal monitoring and maintenance will be required.

## Conclusions

The analyses of the PSVE system at the MetLab of the SRS indicate the technology is performing effectively. Well concentrations are decreasing and contour maps of the vadose zone soil gas plume show a decrease in the extent of the plume. In the 7 years of operation approximately 270 pounds of chlorinated organic contaminants have been removed by natural barometric pumping of wells fitted with BaroBall valves.

The majority of the well concentrations are less than 1 ppmv. Less than 4 lbs PCE and 3 lbs TCE are expected to be removed in calendar year 2005 compared to 65 lbs PCE and 40 lbs TCE removed during the first year of operation. Declining concentrations and mass removal rates indicate PSVE has significantly reduced the solvent source area.

The PSVE system has required minimal operating and maintenance costs and can be expected to operate continuously with little intervention.

## Recommendations

The PSVE system is performing well in a cost-effective manner. The system should continue operating to complete the remediation.

Quarterly PSVE well monitoring is recommended due to the variability of individual point measurements.

# References

Fairbanks, H. A. 1896. "Notes on a Breathing Gas Well." Science **3**: 693.

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Pemberton, B. E., J. Rossabi and B. D. Riha. 1997. MetLab Phase III Characterization Report. Westinghouse Savannah River Company. Aiken, SC. WSRC-RP-97-4.

Riha, B. D., J. Rossabi and W. K. Hyde. 2000. Metallurgical Laboratory (MetLab) Treatability Study: An Analysis of Passive Soil Vapor Extraction Wells (PSVE), June 2000 Update. Westinghouse Savannah River Company. Aiken, SC. WSRC-TR-2000-00182.

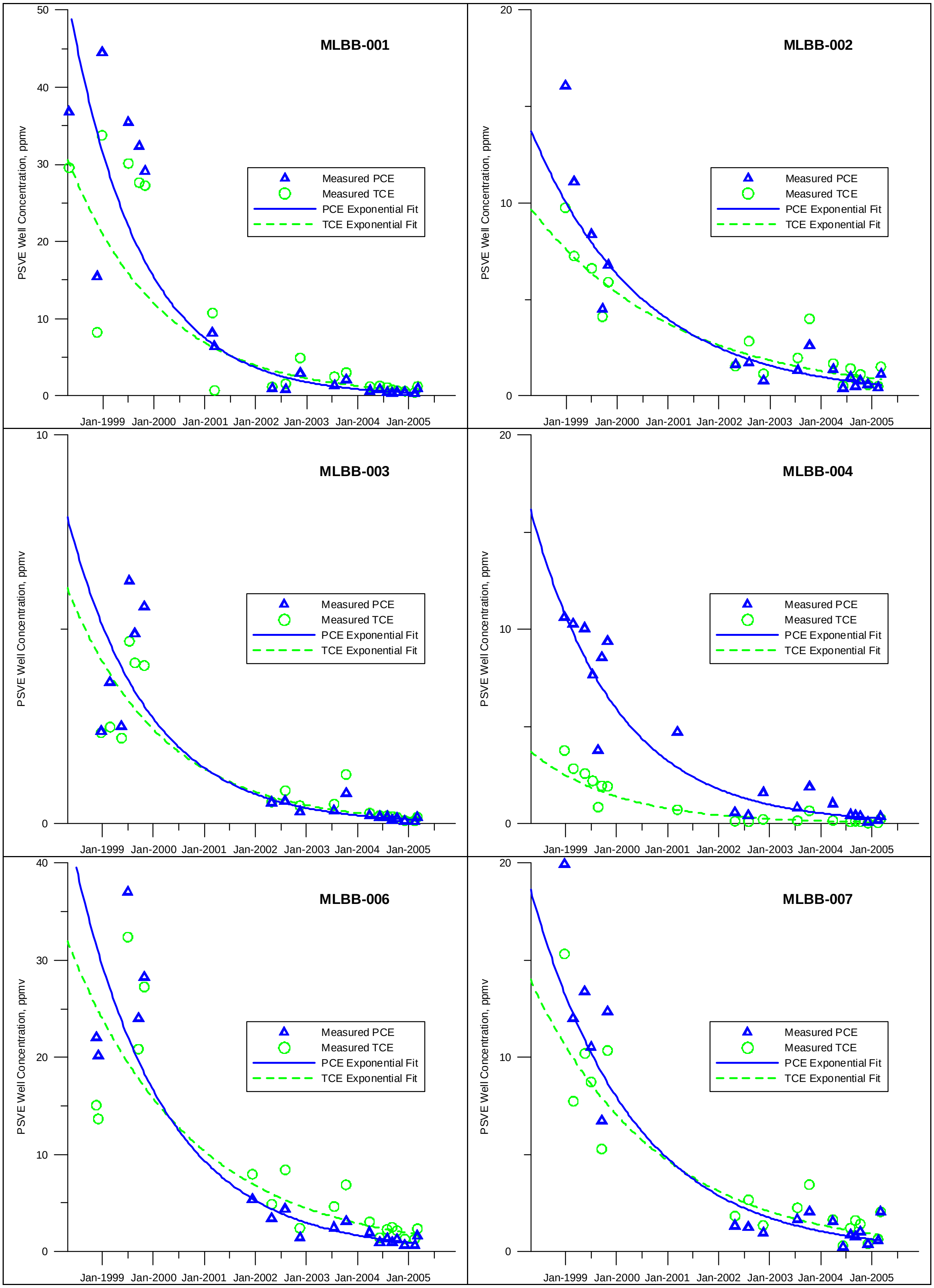
Van Pelt, R. S. and T. Dunbar. 1995. A/M Area Metallurgical Laboratory: Summary of Phase I Characterization - Well Installation, Cone Penetrometer Testing, and Soil Core for Headspace Analysis. Westinghouse Savannah River Company. Aiken, SC. WSRC-RP-95-1553.

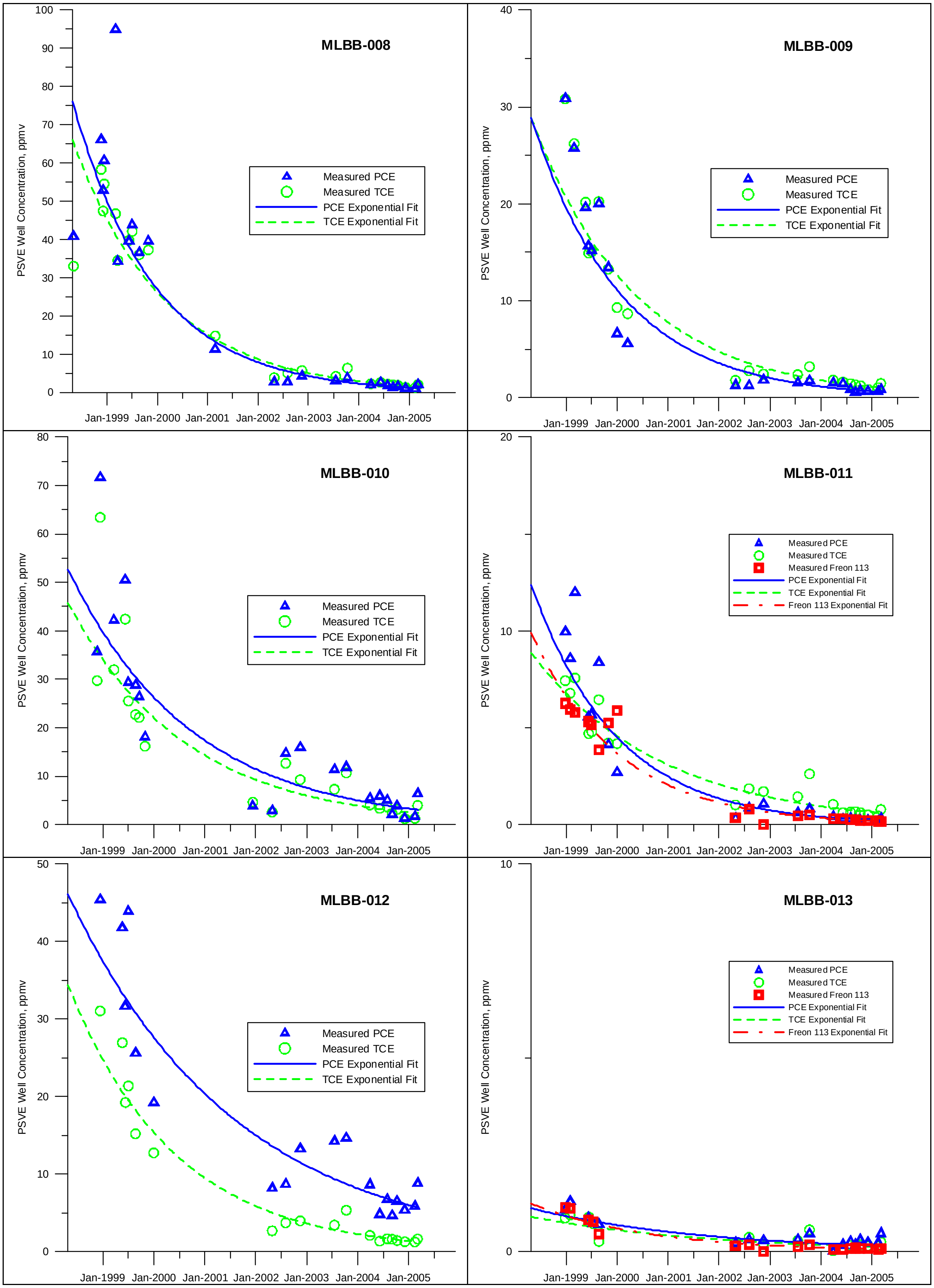
# APPENDIX A – Well and CPT Boring Coordinates

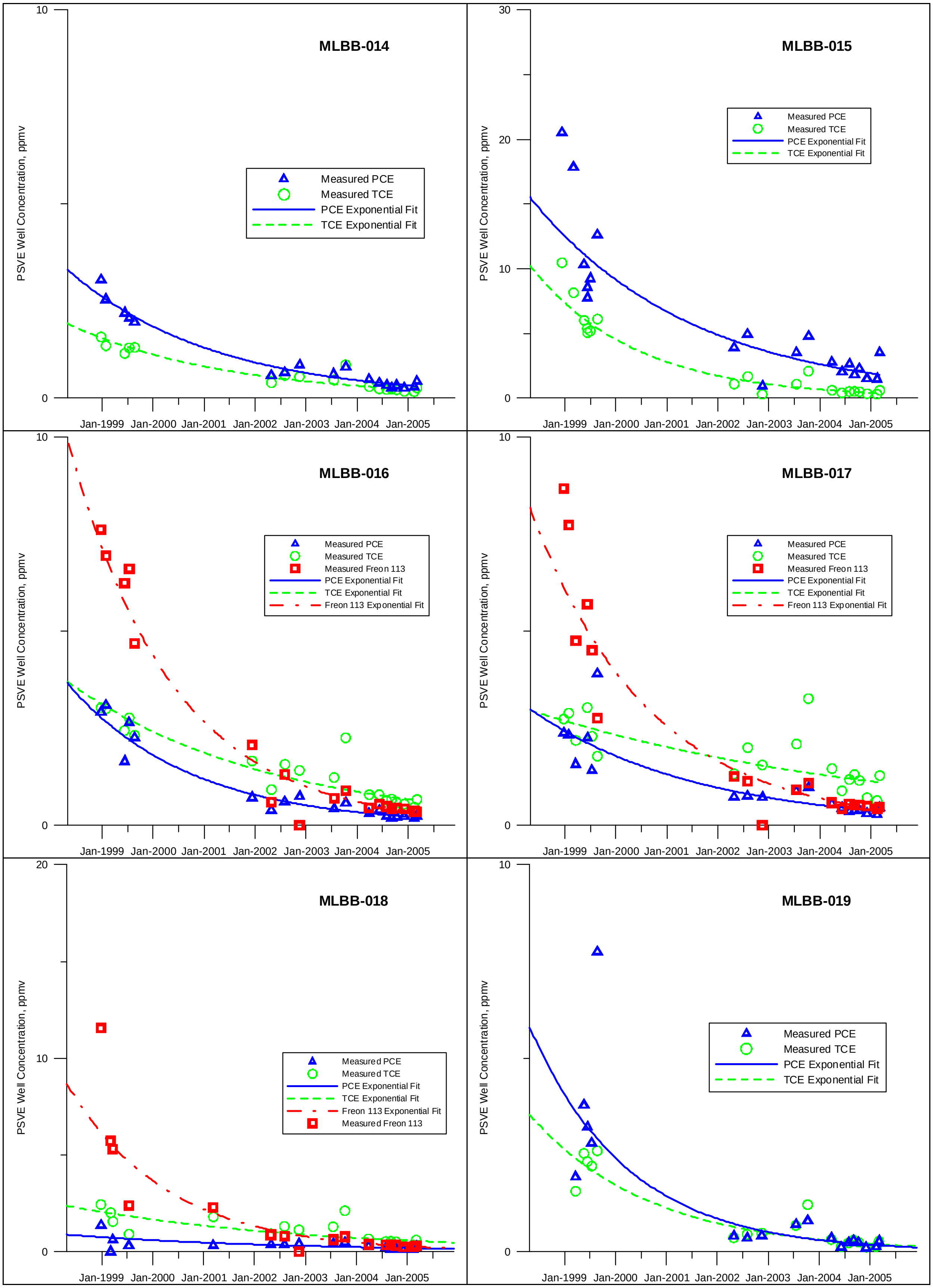
| Well ID | Easting | Northing |
|---|---|---|
| MLBB-001 | 50675 | 104777 |
| MLBB-002 | 50671.75 | 104687.5 |
| MLBB-003 | 50674 | 104907 |
| MLBB-004 | 50851.39 | 104935.4 |
| MLBB-006 | 50764.68 | 104753.1 |
| MLBB-007 | 50847.57 | 104693.3 |
| MLBB-008 | 50850.04 | 104746.6 |
| MLBB-009 | 50910 | 104689 |
| MLBB-010 | 50904.78 | 104753.9 |
| MLBB-011 | 51005 | 104708 |
| MLBB-012 | 51006 | 104758 |
| MLBB-013 | 51040.5 | 104969.1 |
| MLBB-014 | 51034 | 104906 |
| MLBB-015 | 51040 | 104800 |
| MLBB-016 | 51044.75 | 104673 |
| MLBB-017 | 51046 | 104570 |
| MLBB-018 | 51086 | 104507 |
| MLBB-019 | 51111 | 104807 |
| MLBB-020 | 51117 | 104991 |
| MLBB-021 | 50613.6 | 104817.3 |
| MLBB-022* | 51290.7 | 104680.2 |
| MLBB-023* | 50866.6 | 104629.6 |

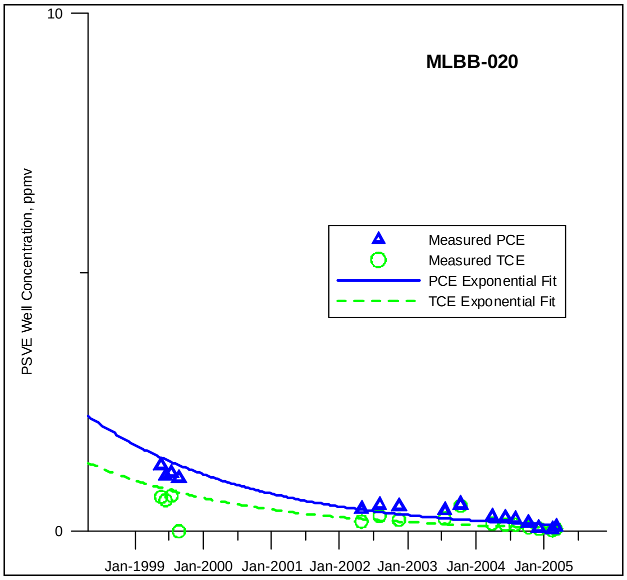
*CPT Borings – not wells

# APPENDIX B – PSVE Well Concentration Trends


MLBB-001
MLBB-002
MLBB-003
MLBB-004
MLBB-006
MLBB-007
Measured PCE
Measured TCE
PCE Exponential Fit
TCE Exponential Fit
PSVE Well Concentration, ppmv
Jan-1999 Jan-2000 Jan-2001 Jan-2002 Jan-2003 Jan-2004 Jan-2005
0
10
20
30
40
50


MLBB-008
MLBB-009
MLBB-010
MLBB-011
MLBB-012
MLBB-013
PSVE Well Concentration, ppmv
Measured PCE
Measured TCE
Measured Freon 113
PCE Exponential Fit
TCE Exponential Fit
Freon 113 Exponential Fit
Jan-1999 Jan-2000 Jan-2001 Jan-2002 Jan-2003 Jan-2004 Jan-2005
0
10
20
30
40
50
60
70
80
90
100


MLBB-014
Measured PCE
Measured TCE
PCE Exponential Fit
TCE Exponential Fit
PSVE Well Concentration, ppmv
MLBB-015
MLBB-016
Measured Freon 113
Freon 113 Exponential Fit
MLBB-017
MLBB-018
MLBB-019
Jan-1999 Jan-2000 Jan-2001 Jan-2002 Jan-2003 Jan-2004 Jan-2005


MLBB-020
PSVE Well Concentration, ppmv
10
0
Measured PCE
Measured TCE
PCE Exponential Fit
TCE Exponential Fit
Jan-1999
Jan-2000
Jan-2001
Jan-2002
Jan-2003
Jan-2004
Jan-2005

# APPENDIX C – Well Vapor Concentrations

| Well ID | Sample Date | Freon 113 ppmv | PCE ppmv | TCE ppmv |
|---|---|---|---|---|
| MLBB-001 | 10/14/1997 | 0.38 | 55.41 | 38.19 |
| | 5/8/1998 | 0.16 | 36.75 | 29.56 |
| | 11/24/1998 | 0.08 | 15.41 | 8.23 |
| | 12/29/1998 | 0.25 | 44.47 | 33.75 |
| | 7/7/1999 | 0.57 | 35.48 | 30.12 |
| | 9/21/1999 | 0.48 | 32.38 | 27.64 |
| | 11/2/1999 | 0.36 | 29.10 | 27.26 |
| | 2/28/2001 | 0.24 | 8.11 | 10.73 |
| | 3/15/2001 | 0.41 | 6.38 | 0.72 |
| | 5/1/2002 | 0.05 | 0.99 | 1.16 |
| | 8/6/2002 | 0.04 | 0.87 | 1.57 |
| | 11/18/2002 | 0.00 | 2.89 | 4.91 |
| | 7/21/2003 | 0.06 | 1.34 | 2.48 |
| | 10/14/2003 | 0.04 | 2.10 | 3.01 |
| | 3/31/2004 | 0.05 | 0.64 | 1.21 |
| | 6/10/2004 | 0.02 | 0.85 | 1.30 |
| | 8/2/2004 | 0.05 | 0.50 | 1.08 |
| | 9/7/2004 | 0.04 | 0.33 | 0.79 |
| | 10/13/2004 | 0.04 | 0.43 | 0.65 |
| | 12/7/2004 | 0.05 | 0.43 | 0.60 |
| | 2/16/2005 | 0.04 | 0.29 | 0.45 |
| | 3/8/2005 | 0.04 | 0.93 | 1.22 |
| MLBB-002 | 12/29/1998 | 0.64 | 16.06 | 9.75 |
| | 3/3/1999 | 0.75 | 11.09 | 7.24 |
| | 7/7/1999 | 1.04 | 8.36 | 6.61 |
| | 9/21/1999 | 0.57 | 4.50 | 4.11 |
| | 11/2/1999 | 0.69 | 6.76 | 5.89 |
| | 5/1/2002 | 0.09 | 1.62 | 1.54 |
| | 8/6/2002 | 0.10 | 1.74 | 2.83 |
| | 11/18/2002 | 0.00 | 0.78 | 1.15 |
| | 7/21/2003 | 0.07 | 1.30 | 1.96 |
| | 10/14/2003 | 0.09 | 2.60 | 3.99 |
| | 3/31/2004 | 0.08 | 1.37 | 1.68 |
| | 6/10/2004 | 0.06 | 0.41 | 0.52 |
| | 8/2/2004 | 0.09 | 0.96 | 1.42 |
| | 9/7/2004 | 0.07 | 0.51 | 0.87 |
| | 10/13/2004 | 0.07 | 0.77 | 1.11 |
| | 12/7/2004 | 0.07 | 0.58 | 0.57 |
| | 2/16/2005 | 0.06 | 0.42 | 0.49 |
| | 3/8/2005 | 0.07 | 1.13 | 1.51 |

| Well ID | Sample Date | Freon 113 ppmv | PCE ppmv | TCE ppmv |
|---|---|---|---|---|
| MLBB-003 | 12/29/1998 | 0.05 | 2.37 | 2.34 |
| | 3/3/1999 | 0.10 | 3.64 | 2.48 |
| | 5/24/1999 | 0.10 | 2.51 | 2.20 |
| | 7/19/1999 | 0.27 | 6.25 | 4.69 |
| | 8/27/1999 | 0.05 | 4.88 | 4.14 |
| | 11/2/1999 | 0.16 | 5.58 | 4.07 |
| | 5/1/2002 | 0.06 | 0.54 | 0.56 |
| | 8/6/2002 | 0.05 | 0.57 | 0.85 |
| | 11/18/2002 | 0.00 | 0.30 | 0.46 |
| | 7/21/2003 | 0.04 | 0.33 | 0.50 |
| | 10/14/2003 | 0.05 | 0.78 | 1.26 |
| | 3/31/2004 | 0.03 | 0.21 | 0.27 |
| | 6/10/2004 | 0.03 | 0.17 | 0.20 |
| | 8/2/2004 | 0.03 | 0.17 | 0.20 |
| | 9/7/2004 | 0.03 | 0.09 | 0.18 |
| | 10/13/2004 | 0.03 | 0.13 | 0.16 |
| | 12/7/2004 | 0.02 | 0.06 | 0.08 |
| | 2/16/2005 | 0.02 | 0.05 | 0.07 |
| | 3/8/2005 | 0.02 | 0.16 | 0.17 |
| MLBB-004 | 12/29/1998 | 1.27 | 10.64 | 3.76 |
| | 3/3/1999 | 1.37 | 10.28 | 2.84 |
| | 5/24/1999 | 1.42 | 10.05 | 2.58 |
| | 7/19/1999 | 0.94 | 7.64 | 2.20 |
| | 8/27/1999 | 0.07 | 3.77 | 0.85 |
| | 9/21/1999 | 0.95 | 8.56 | 1.95 |
| | 11/2/1999 | 0.90 | 9.37 | 1.92 |
| | 3/15/2001 | 0.42 | 4.71 | 0.72 |
| | 5/1/2002 | 0.89 | 0.57 | 0.12 |
| | 8/6/2002 | 0.04 | 0.41 | 0.10 |
| | 11/18/2002 | 0.00 | 1.58 | 0.22 |
| | 7/21/2003 | 0.01 | 0.81 | 0.14 |
| | 10/14/2003 | 0.09 | 1.88 | 0.66 |
| | 3/31/2004 | 0.05 | 1.03 | 0.16 |
| | 8/2/2004 | 0.04 | 0.44 | 0.10 |
| | 9/7/2004 | 0.05 | 0.40 | 0.12 |
| | 10/13/2004 | 0.04 | 0.38 | 0.10 |
| | 12/7/2004 | 0.01 | 0.09 | 0.03 |
| | 2/16/2005 | 0.01 | 0.19 | 0.04 |
| | 3/8/2005 | 0.06 | 0.38 | 0.25 |

| Well ID | Sample Date | Freon 113 ppmv | PCE ppmv | TCE ppmv |
|---|---|---|---|---|
| MLBB-006 | 11/24/1998 | 0.11 | 22.02 | 15.06 |
| | 12/8/1998 | 0.10 | 20.18 | 13.66 |
| | 7/7/1999 | 0.34 | 37.02 | 32.38 |
| | 9/21/1999 | 0.36 | 24.03 | 20.85 |
| | 11/2/1999 | 0.33 | 28.23 | 27.25 |
| | 12/14/2001 | 0.17 | 5.33 | 7.95 |
| | 5/1/2002 | 0.13 | 3.43 | 4.87 |
| | 8/6/2002 | 0.10 | 4.36 | 8.41 |
| | 11/18/2002 | 0.00 | 1.43 | 2.41 |
| | 7/21/2003 | 0.08 | 2.46 | 4.63 |
| | 10/14/2003 | 0.10 | 3.14 | 6.87 |
| | 3/31/2004 | 0.07 | 1.97 | 3.06 |
| | 6/10/2004 | 0.04 | 0.90 | 1.43 |
| | 8/2/2004 | 0.07 | 1.34 | 2.28 |
| | 9/7/2004 | 0.07 | 0.97 | 2.50 |
| | 10/13/2004 | 0.06 | 1.24 | 2.14 |
| | 12/7/2004 | 0.05 | 0.64 | 1.29 |
| | 2/16/2005 | 0.05 | 0.65 | 1.28 |
| | 3/8/2005 | 0.06 | 1.59 | 2.35 |
| MLBB-007 | 12/29/1998 | 2.29 | 19.94 | 15.32 |
| | 3/3/1999 | 1.60 | 11.99 | 7.73 |
| | 5/24/1999 | 2.78 | 13.38 | 10.20 |
| | 7/7/1999 | 2.31 | 10.52 | 8.73 |
| | 9/21/1999 | 1.08 | 6.72 | 5.28 |
| | 11/2/1999 | 2.24 | 12.36 | 10.35 |
| | 5/1/2002 | 0.34 | 1.33 | 1.83 |
| | 8/6/2002 | 0.26 | 1.24 | 2.66 |
| | 11/18/2002 | 0.00 | 0.98 | 1.35 |
| | 7/21/2003 | 0.19 | 1.66 | 2.25 |
| | 10/14/2003 | 0.24 | 2.05 | 3.44 |
| | 3/31/2004 | 0.14 | 1.55 | 1.64 |
| | 6/10/2004 | 0.04 | 0.23 | 0.30 |
| | 8/2/2004 | 0.12 | 0.85 | 1.20 |
| | 9/7/2004 | 0.14 | 0.78 | 1.60 |
| | 10/13/2004 | 0.13 | 1.01 | 1.42 |
| | 12/7/2004 | 0.05 | 0.38 | 0.41 |
| | 2/16/2005 | 0.07 | 0.57 | 0.63 |
| | 3/8/2005 | 0.13 | 2.04 | 2.05 |

| Well ID | Sample Date | Freon 113 ppmv | PCE ppmv | TCE ppmv |
|---|---|---|---|---|
| MLBB-008 | 5/8/1998 | 0.47 | 40.75 | 33.01 |
| | 11/24/1998 | 0.83 | 66.03 | 58.27 |
| | 12/8/1998 | 0.64 | 52.90 | 47.43 |
| | 12/16/1998 | 0.75 | 60.70 | 54.49 |
| | 3/9/1999 | 1.00 | 94.95 | 46.71 |
| | 3/25/1999 | 0.70 | 34.19 | 34.49 |
| | 6/14/1999 | 0.51 | 39.50 | 39.75 |
| | 7/7/1999 | 1.26 | 43.78 | 42.06 |
| | 8/26/1999 | 0.74 | 36.60 | 35.96 |
| | 11/2/1999 | 1.17 | 39.60 | 37.23 |
| | 2/28/2001 | 0.39 | 11.31 | 14.73 |
| | 5/1/2002 | 0.25 | 2.69 | 3.82 |
| | 8/6/2002 | 0.12 | 2.66 | 5.06 |
| | 11/18/2002 | 0.00 | 4.29 | 5.71 |
| | 7/21/2003 | 0.15 | 3.01 | 4.18 |
| | 10/14/2003 | 0.20 | 3.83 | 6.33 |
| | 3/31/2004 | 0.10 | 1.88 | 2.21 |
| | 6/10/2004 | 0.09 | 2.55 | 2.58 |
| | 8/2/2004 | 0.10 | 1.74 | 2.12 |
| | 9/7/2004 | 0.10 | 1.33 | 2.00 |
| | 10/13/2004 | 0.09 | 1.62 | 1.81 |
| | 12/7/2004 | 0.09 | 1.01 | 1.32 |
| | 2/16/2005 | 0.07 | 0.92 | 1.26 |
| | 3/8/2005 | 0.08 | 2.10 | 1.97 |
| MLBB-009 | 12/29/1998 | 4.89 | 30.84 | 30.82 |
| | 3/3/1999 | 4.85 | 25.73 | 26.21 |
| | 5/24/1999 | 4.64 | 19.61 | 20.16 |
| | 6/15/1999 | 4.43 | 15.63 | 14.90 |
| | 7/7/1999 | 5.01 | 15.22 | 15.05 |
| | 8/26/1999 | 2.13 | 20.01 | 20.23 |
| | 11/2/1999 | 3.77 | 13.44 | 13.26 |
| | 1/4/2000 | 4.07 | 6.62 | 9.29 |
| | 3/20/2000 | 3.05 | 5.56 | 8.66 |
| | 5/1/2002 | 0.46 | 1.29 | 1.79 |
| | 8/6/2002 | 0.37 | 1.24 | 2.78 |
| | 7/21/2003 | 0.27 | 1.57 | 2.37 |
| | 10/14/2003 | 0.28 | 1.75 | 3.21 |
| | 3/31/2004 | 0.16 | 1.52 | 1.81 |
| | 6/10/2004 | 0.14 | 1.43 | 1.61 |
| | 8/2/2004 | 0.16 | 0.85 | 1.44 |
| | 9/7/2004 | 0.14 | 0.56 | 1.32 |
| | 10/13/2004 | 0.14 | 0.70 | 1.24 |
| | 12/7/2004 | 0.14 | 0.64 | 0.85 |
| | 2/16/2005 | 0.11 | 0.65 | 1.04 |
| | 3/8/2005 | 0.13 | 0.85 | 1.46 |

| Well ID | Sample Date | Freon 113 ppmv | PCE ppmv | TCE ppmv |
|---|---|---|---|---|
| MLBB-010 | 11/24/1998 | 1.72 | 35.68 | 29.72 |
| | 12/16/1998 | 0.99 | 71.69 | 63.39 |
| | 3/25/1999 | 0.07 | 42.20 | 31.96 |
| | 6/14/1999 | 0.42 | 50.53 | 42.41 |
| | 7/7/1999 | 2.24 | 29.39 | 25.52 |
| | 8/26/1999 | 0.44 | 28.73 | 22.73 |
| | 9/21/1999 | 2.04 | 26.35 | 22.11 |
| | 11/2/1999 | 2.36 | 18.12 | 16.19 |
| | 12/14/2001 | 0.62 | 3.95 | 4.62 |
| | 5/1/2002 | 0.28 | 2.91 | 2.59 |
| | 8/6/2002 | 0.28 | 14.80 | 12.66 |
| | 11/18/2002 | 0.00 | 15.99 | 9.28 |
| | 7/21/2003 | 0.17 | 11.43 | 7.29 |
| | 10/14/2003 | 0.22 | 11.86 | 10.64 |
| | 3/31/2004 | 0.11 | 5.46 | 4.04 |
| | 6/10/2004 | 0.05 | 5.93 | 3.31 |
| | 8/2/2004 | 0.11 | 5.07 | 3.65 |
| | 9/7/2004 | 0.10 | 2.12 | 2.33 |
| | 10/13/2004 | 0.10 | 3.92 | 3.14 |
| | 12/7/2004 | 0.08 | 1.28 | 1.23 |
| | 2/16/2005 | 0.06 | 1.77 | 1.28 |
| | 3/8/2005 | 0.09 | 6.38 | 3.97 |
| MLBB-011 | 12/29/1998 | 6.26 | 9.94 | 7.43 |
| | 2/2/1999 | 5.95 | 8.59 | 6.78 |
| | 3/9/1999 | 5.78 | 12.00 | 7.56 |
| | 6/15/1999 | 5.32 | 5.57 | 4.69 |
| | 7/7/1999 | 5.15 | 5.68 | 4.79 |
| | 8/26/1999 | 3.86 | 8.36 | 6.44 |
| | 11/2/1999 | 5.23 | 4.14 | 4.20 |
| | 1/4/2000 | 5.88 | 2.71 | 4.18 |
| | 5/1/2002 | 0.38 | 0.33 | 1.02 |
| | 8/6/2002 | 0.78 | 0.86 | 1.86 |
| | 11/18/2002 | 0.00 | 1.07 | 1.71 |
| | 7/21/2003 | 0.47 | 0.64 | 1.44 |
| | 10/14/2003 | 0.50 | 0.80 | 2.62 |
| | 3/31/2004 | 0.31 | 0.43 | 1.05 |
| | 6/10/2004 | 0.29 | 0.28 | 0.62 |
| | 8/2/2004 | 0.26 | 0.31 | 0.65 |
| | 9/7/2004 | 0.25 | 0.20 | 0.67 |
| | 10/13/2004 | 0.21 | 0.23 | 0.61 |
| | 12/7/2004 | 0.23 | 0.21 | 0.51 |
| | 2/16/2005 | 0.19 | 0.19 | 0.45 |
| | 3/8/2005 | 0.18 | 0.31 | 0.78 |

| Well ID | Sample Date | Freon 113 ppmv | PCE ppmv | TCE ppmv |
|---|---|---|---|---|
| MLBB-012 | 12/16/1998 | 0.64 | 45.41 | 31.04 |
| | 5/24/1999 | 0.95 | 41.77 | 26.95 |
| | 6/15/1999 | 0.85 | 31.63 | 19.24 |
| | 7/7/1999 | 0.99 | 43.93 | 21.38 |
| | 8/26/1999 | 0.76 | 25.59 | 15.19 |
| | 1/4/2000 | 1.05 | 19.20 | 12.74 |
| | 5/1/2002 | 0.45 | 8.19 | 2.68 |
| | 8/6/2002 | 0.33 | 8.69 | 3.72 |
| | 11/18/2002 | 0.00 | 13.23 | 3.97 |
| | 7/21/2003 | 0.41 | 14.24 | 3.42 |
| | 10/14/2003 | 0.53 | 14.62 | 5.34 |
| | 3/31/2004 | 0.30 | 8.65 | 2.08 |
| | 6/10/2004 | 0.26 | 4.82 | 1.36 |
| | 8/2/2004 | 0.29 | 6.74 | 1.65 |
| | 9/7/2004 | 0.27 | 4.65 | 1.59 |
| | 10/13/2004 | 0.27 | 6.50 | 1.44 |
| | 12/7/2004 | 0.27 | 5.36 | 1.27 |
| | 2/16/2005 | 0.23 | 5.84 | 1.25 |
| | 3/8/2005 | 0.26 | 8.78 | 1.63 |
| MLBB-013 | 12/29/1998 | 1.14 | 1.09 | 0.87 |
| | 2/2/1999 | 1.11 | 1.29 | 0.95 |
| | 6/16/1999 | 0.81 | 0.87 | 0.89 |
| | 7/19/1999 | 0.78 | 0.74 | 0.72 |
| | 8/27/1999 | 0.46 | 0.70 | 0.26 |
| | 5/1/2002 | 0.16 | 0.22 | 0.23 |
| | 8/6/2002 | 0.18 | 0.32 | 0.37 |
| | 11/18/2002 | 0.00 | 0.29 | 0.21 |
| | 7/21/2003 | 0.13 | 0.32 | 0.29 |
| | 10/14/2003 | 0.17 | 0.46 | 0.56 |
| | 3/31/2004 | 0.06 | 0.01 | 0.02 |
| | 6/10/2004 | 0.06 | 0.17 | 0.10 |
| | 8/2/2004 | 0.09 | 0.26 | 0.16 |
| | 9/7/2004 | 0.09 | 0.18 | 0.17 |
| | 10/13/2004 | 0.09 | 0.30 | 0.18 |
| | 12/7/2004 | 0.08 | 0.23 | 0.15 |
| | 2/16/2005 | 0.06 | 0.23 | 0.14 |
| | 3/8/2005 | 0.08 | 0.47 | 0.25 |

| Well ID | Sample Date | Freon 113 ppmv | PCE ppmv | TCE ppmv |
|---|---|---|---|---|
| MLBB-014 | 12/29/1998 | 0.85 | 3.04 | 1.57 |
| | 2/2/1999 | 0.72 | 2.54 | 1.35 |
| | 6/16/1999 | 0.70 | 2.19 | 1.15 |
| | 7/19/1999 | 0.60 | 2.06 | 1.30 |
| | 8/27/1999 | 0.53 | 1.96 | 1.30 |
| | 5/1/2002 | 0.17 | 0.57 | 0.39 |
| | 8/6/2002 | 0.16 | 0.65 | 0.58 |
| | 11/18/2002 | 0.00 | 0.85 | 0.55 |
| | 7/21/2003 | 0.12 | 0.61 | 0.46 |
| | 10/14/2003 | 0.16 | 0.80 | 0.85 |
| | 3/31/2004 | 0.09 | 0.49 | 0.29 |
| | 6/10/2004 | 0.08 | 0.39 | 0.23 |
| | 8/2/2004 | 0.09 | 0.33 | 0.22 |
| | 9/7/2004 | 0.08 | 0.26 | 0.23 |
| | 10/13/2004 | 0.08 | 0.32 | 0.21 |
| | 12/7/2004 | 0.08 | 0.25 | 0.17 |
| | 2/16/2005 | 0.07 | 0.29 | 0.16 |
| | 3/8/2005 | 0.08 | 0.43 | 0.26 |
| MLBB-015 | 12/16/1998 | 1.81 | 20.53 | 10.46 |
| | 3/9/1999 | 2.06 | 17.83 | 8.13 |
| | 5/24/1999 | 2.29 | 10.31 | 5.99 |
| | 6/15/1999 | 2.58 | 8.57 | 5.38 |
| | 6/16/1999 | 2.61 | 7.75 | 5.05 |
| | 7/7/1999 | 2.37 | 9.24 | 5.18 |
| | 8/27/1999 | 1.44 | 12.63 | 6.10 |
| | 5/1/2002 | 0.42 | 3.90 | 1.08 |
| | 8/6/2002 | 0.41 | 4.92 | 1.66 |
| | 11/18/2002 | 0.00 | 0.92 | 0.29 |
| | 7/21/2003 | 0.22 | 3.52 | 1.07 |
| | 10/14/2003 | 0.29 | 4.77 | 2.07 |
| | 3/31/2004 | 0.15 | 2.76 | 0.60 |
| | 6/10/2004 | 0.10 | 2.01 | 0.39 |
| | 8/2/2004 | 0.13 | 2.64 | 0.50 |
| | 9/7/2004 | 0.13 | 1.80 | 0.50 |
| | 10/13/2004 | 0.12 | 2.26 | 0.48 |
| | 12/7/2004 | 0.10 | 1.48 | 0.34 |
| | 2/16/2005 | 0.09 | 1.47 | 0.29 |
| | 3/8/2005 | 0.11 | 3.51 | 0.59 |

| Well ID | Sample Date | Freon 113 ppmv | PCE ppmv | TCE ppmv |
|---|---|---|---|---|
| MLBB-016 | 12/29/1998 | 7.62 | 2.92 | 3.03 |
| | 2/2/1999 | 6.95 | 3.10 | 3.00 |
| | 6/15/1999 | 6.24 | 1.65 | 2.44 |
| | 7/19/1999 | 6.61 | 2.65 | 2.77 |
| | 8/26/1999 | 4.69 | 2.26 | 2.32 |
| | 12/14/2001 | 2.07 | 0.71 | 1.66 |
| | 5/1/2002 | 0.60 | 0.38 | 0.92 |
| | 8/6/2002 | 1.31 | 0.60 | 1.57 |
| | 11/18/2002 | 0.00 | 0.74 | 1.42 |
| | 7/23/2003 | 0.70 | 0.42 | 1.23 |
| | 10/14/2003 | 0.89 | 0.57 | 2.25 |
| | 3/31/2004 | 0.45 | 0.32 | 0.79 |
| | 6/10/2004 | 0.54 | 0.39 | 0.79 |
| | 8/2/2004 | 0.48 | 0.24 | 0.64 |
| | 9/7/2004 | 0.42 | 0.19 | 0.67 |
| | 10/13/2004 | 0.44 | 0.21 | 0.58 |
| | 12/7/2004 | 0.42 | 0.23 | 0.54 |
| | 2/16/2005 | 0.36 | 0.18 | 0.46 |
| | 3/8/2005 | 0.35 | 0.25 | 0.66 |
| MLBB-017 | 12/29/1998 | 8.68 | 2.38 | 2.74 |
| | 2/2/1999 | 7.73 | 2.33 | 2.89 |
| | 3/25/1999 | 4.76 | 1.58 | 2.19 |
| | 6/15/1999 | 5.70 | 2.26 | 3.04 |
| | 7/19/1999 | 4.51 | 1.42 | 2.30 |
| | 8/26/1999 | 2.76 | 3.91 | 1.78 |
| | 5/1/2002 | 1.26 | 0.73 | 1.33 |
| | 8/6/2002 | 1.13 | 0.76 | 2.00 |
| | 11/18/2002 | 0.00 | 0.72 | 1.56 |
| | 7/21/2003 | 0.92 | 0.88 | 2.09 |
| | 10/14/2003 | 1.08 | 0.97 | 3.27 |
| | 3/31/2004 | 0.58 | 0.56 | 1.46 |
| | 6/10/2004 | 0.42 | 0.44 | 0.89 |
| | 8/2/2004 | 0.55 | 0.37 | 1.18 |
| | 9/7/2004 | 0.53 | 0.37 | 1.31 |
| | 10/13/2004 | 0.52 | 0.38 | 1.16 |
| | 12/7/2004 | 0.49 | 0.30 | 0.71 |
| | 2/16/2005 | 0.43 | 0.28 | 0.64 |
| | 3/8/2005 | 0.47 | 0.45 | 1.28 |

| Well ID | Sample Date | Freon 113 ppmv | PCE ppmv | TCE ppmv |
|---|---|---|---|---|
| MLBB-018 | 12/29/1998 | 11.56 | 1.37 | 2.44 |
| | 3/9/1999 | 5.74 | 0.00 | 2.02 |
| | 3/25/1999 | 5.31 | 0.64 | 1.56 |
| | 7/19/1999 | 2.39 | 0.31 | 0.91 |
| | 3/15/2001 | 2.29 | 0.33 | 1.80 |
| | 5/1/2002 | 0.87 | 0.38 | 0.93 |
| | 8/6/2002 | 0.82 | 0.36 | 1.31 |
| | 11/18/2002 | 0.00 | 0.40 | 1.13 |
| | 7/21/2003 | 0.63 | 0.44 | 1.29 |
| | 10/14/2003 | 0.78 | 0.48 | 2.12 |
| | 3/31/2004 | 0.38 | 0.29 | 0.67 |
| | 8/2/2004 | 0.36 | 0.21 | 0.53 |
| | 9/7/2004 | 0.34 | 0.14 | 0.54 |
| | 10/13/2004 | 0.33 | 0.20 | 0.52 |
| | 12/7/2004 | 0.24 | 0.11 | 0.32 |
| | 2/16/2005 | 0.25 | 0.11 | 0.33 |
| | 3/8/2005 | 0.32 | 0.25 | 0.61 |
| MLBB-019 | 3/25/1999 | 0.78 | 1.93 | 1.56 |
| | 5/24/1999 | 1.19 | 3.79 | 2.54 |
| | 6/17/1999 | 1.21 | 3.22 | 2.33 |
| | 7/19/1999 | 1.33 | 2.81 | 2.21 |
| | 8/27/1999 | 1.74 | 7.74 | 2.61 |
| | 5/1/2002 | 0.34 | 0.40 | 0.36 |
| | 8/6/2002 | 0.28 | 0.35 | 0.45 |
| | 11/18/2002 | 0.00 | 0.42 | 0.48 |
| | 7/21/2003 | 0.25 | 0.70 | 0.68 |
| | 10/14/2003 | 0.29 | 0.79 | 1.21 |
| | 3/31/2004 | 0.12 | 0.35 | 0.32 |
| | 6/10/2004 | 0.05 | 0.11 | 0.13 |
| | 8/2/2004 | 0.10 | 0.23 | 0.23 |
| | 9/7/2004 | 0.00 | 0.28 | 0.30 |
| | 10/13/2004 | 0.10 | 0.24 | 0.25 |
| | 12/7/2004 | 0.05 | 0.10 | 0.12 |
| | 2/16/2005 | 0.06 | 0.13 | 0.13 |
| | 3/8/2005 | 0.09 | 0.27 | 0.27 |

| Well ID | Sample Date | Freon 113 ppmv | PCE ppmv | TCE ppmv |
|---|---|---|---|---|
| MLBB-020 | 5/24/1999 | 1.16 | 1.27 | 0.66 |
| | 6/17/1999 | 1.00 | 1.08 | 0.60 |
| | 7/19/1999 | 1.24 | 1.13 | 0.69 |
| | 8/27/1999 | 0.00 | 1.03 | 0.00 |
| | 5/1/2002 | 0.20 | 0.43 | 0.19 |
| | 8/6/2002 | 0.20 | 0.51 | 0.30 |
| | 11/18/2002 | 0.00 | 0.49 | 0.22 |
| | 7/21/2003 | 0.14 | 0.40 | 0.25 |
| | 10/14/2003 | 0.18 | 0.52 | 0.49 |
| | 3/31/2004 | 0.11 | 0.29 | 0.15 |
| | 6/10/2004 | 0.09 | 0.26 | 0.13 |
| | 8/2/2004 | 0.10 | 0.23 | 0.13 |
| | 10/13/2004 | 0.09 | 0.16 | 0.08 |
| | 12/7/2004 | 0.05 | 0.07 | 0.05 |
| | 2/16/2005 | 0.01 | 0.03 | 0.02 |
| | 3/8/2005 | 0.03 | 0.09 | 0.05 |