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Report for Supplemental Soil-Vapor Extraction Pilot Test at Material Disposal Area G, Technical Area 54

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EXECUTIVE SUMMARY

From May 15 to May 28, 2010, a supplemental soil-vapor extraction (SVE) pilot test was conducted at Material Disposal Area (MDA) G. The MDA G supplemental SVE pilot test met the objectives of the New Mexico Environment Department–approved work plan and also demonstrated that SVE has the potential to be an effective part of the remediation at MDA G.

Based on the results of this test, a preliminary design was developed to facilitate the review of the corrective measures evaluation (CME) for MDA G. The preliminary design was developed with the following considerations:

- Although dilution-attenuation factors for MDA G were previously estimated in the MDA G CME plan to be on the order of 100, the preliminary SVE design was designed based on volatile organic compound (VOC) contamination exceeding 10 times groundwater screening levels because vapor concentrations at MDA G do not exceed the 100 times threshold.
- The permeability for most stratigraphic units was too low for the 4-h step tests to yield meaningful radius of influence data. As a result, numerical modeling in conjunction with permeability testing was used to predict the vacuum and duration of operation to achieve a target 150-ft radius of influence used in the preliminary design.

The viability of SVE as a technology to address VOC contamination at MDA G is not to be interpreted as suggesting that SVE will be a component of the final remedy at MDA G. Selection of SVE as a component of the final remedy for MDA G requires development of site-specific cleanup levels for VOC vapors and a comparative analysis of technologies/remedies, which will be performed as part of the CME process. Also, although the test results indicate technical feasibility of SVE at MDA G, other factors, including safety considerations, could affect implementability and will need to be addressed during the CME.

In addition, it is recommended that site-specific cleanup levels be developed as part of the CME. These cleanup levels should be protective of groundwater quality and should account for dilution and attenuation effects in the vadose zone and regional aquifer.

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1.0 INTRODUCTION

This report presents the results of the supplemental soil-vapor extraction (SVE) pilot study conducted at Material Disposal Area (MDA) G in Technical Area 54 (TA-54) at Los Alamos National Laboratory (LANL or the Laboratory) (Figure 1.0-1). The New Mexico Environment Department (NMED) required that a second soil-vapor extraction pilot test be conducted, after an initial pilot test in 2008, to evaluate SVE technology in treating the subsurface volatile organic compound (VOC) vapor plumes beneath MDA G (NMED 2009, 107044, p. I-1). The supplemental MDA G SVE pilot study was conducted from May 15 through 28, 2010, in accordance with the NMED-approved work plan (LANL 2010, 108306; NMED 2010, 108679).

The current SVE pilot test is based upon the NMED-approved work plan the Laboratory submitted in January 2010 (LANL 2010, 108306). As directed by NMED, the objectives of the supplemental pilot test are to determine the capabilities and optimal design for a SVE system at MDA G, and to determine whether SVE has the potential to be an effective part of the remediation at MDA G (NMED 2009, 107044). The supplemental pilot test is designed to target the permeable zones identified in the Tshirege Member of the Bandelier Tuff, the contacts between the stratigraphic units, and any permeable layers in the geologic column. It is also designed to assess the ability of major stratigraphic units, such as the Cerro Toledo unit and Otowi Member, to act as either a barrier to contaminant migration or as an effective extraction interval.

Section 2 describes the background of MDA G and previous SVE pilot studies. Section 3 describes the SVE pilot test activities and methodologies used. Section 4 describes the results of the supplemental SVE pilot test. Section 5 provides preliminary design specifications for an SVE system that could be used at MDA G to remediate the VOC contaminant plumes. Section 6 presents conclusions of the supplemental SVE pilot test and recommendations, and section 7 includes references and map data sources for the report.

2.0 BACKGROUND

MDA G is located within Area G, a 63-acre fenced area located in the east-central portion of the Laboratory at TA-54 on Mesita del Buey (Figure 1.0-1). TA-54 has been the main waste storage and disposal facility for the Laboratory since the 1950s. MDA G consists of active and inactive disposal units and contains both surface and subsurface waste management units including 32 pits, 193 shafts, and 4 trenches with depths ranging from 10 ft to 65 ft below the original ground surface (Figure 2.0-1). Historically, MDA G was used for the disposal of low-level radioactive waste (LLW) and transuranic-contaminated (TRU) radioactive waste, certain radioactively contaminated infectious waste, asbestos-contaminated material, organic chemical waste, polychlorinated biphenyls, and the retrievable storage of TRU waste. Disposal of LLW continues at MDA G. The operational history of MDA G is summarized in the Resource Conservation and Recovery Act facility investigation work plan for Operable Unit 1148 (LANL 1992, 007669, pp. 5-179–5-200) and in the approved investigation work plan for MDA G (LANL 2004, 087833, Appendix B).

2.1 Site Description and Geologic Setting

The Laboratory lies between the Jemez Mountains and the Rio Grande on the Pajarito Plateau. The plateau is capped by the Bandelier Tuff, a thick sequence of ash-fall pyroclastics. Erosion of the tuff over time has created a series of canyons separating the narrow, finger-like mesas that compose the Pajarito Plateau.

The pits, trenches, and shafts of MDA G are constructed in unit 2 (caprock) and unit 1 (subsurface) of the Tshirege Member of the Bandelier Tuff (consolidated tuff units). The regional aquifer is estimated to be at an average depth of approximately 930 ft below ground surface (bgs) at MDA G, based on data from wells in the vicinity and the predictions of the hydrogeologic conceptual model for the Pajarito Plateau (LANL 1998, 059599, Appendix H). The topography of Area G is relatively flat. Surface runoff from the site is controlled and discharges into drainages to the north towards Cañada del Buey and to the south towards Pajarito Canyon. Storm water and sediment monitoring stations are distributed throughout the surface of Area G and in drainages leading to the canyons.

The strata below MDA G 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. Figure 2.1-1 provides a schematic of the tuff stratigraphy. The 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 upper portion of Qbt 1v is a distinctive white band of slope-forming tuffs designated as Qbt 1v-u. The lower part of Qbt 1v is a resistant orange-brown colonnade tuff (Qbt 1v-c) that forms a distinctive low cliff characterized by columnar jointing. The lower unit of the Tshirege Member is unit Qbt 1g, which contains the Tsankawi Pumice Bed (Qbtt), which is the basal pumice fallout deposit of the Tshirege Member. The Cerro Toledo interval (Qct) is made up of volcanoclastic sediments interbedded with minor pyroclastic flows. The Otowi Member (Qbo) of the Bandelier Tuff, a nonwelded to poorly welded unit that is not fractured, lies beneath the Cerro Toledo interval and consists of nonwelded to poorly welded tuff with little evidence of fracturing (Reneau and Raymond 1995, 054709). The Cerros del Rio basalt lies beneath the tuff and makes 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, 070225). The saturated zone extends from the lower Cerros del Rio basalt into the underlying Puye Formation basalt. The approved MDA G investigation work plan (LANL 2004, 087624) provides a complete summary of the site geology and geologic properties of Area G.

Bulk permeability can be inferred from data collected in wells at the site (Lowry 1997, 087818). Anemometry measurements from the site made during the mid-1990s show that the Qbt and Qct stratigraphic layers produced three-quarters of the total airflow from the boreholes. Subsequent discrete-point permeability measurements confirmed the Cerro Toledo interval has a higher permeability (3 to 10 darcys) than the other stratigraphic layers (0.2 to 0.9 darcys).

2.2 MDA G Vapor Plumes

VOC vapor plumes have been identified at MDA G. Pore-gas monitoring conducted at MDA G since 1985, and conclusions of the 2005 MDA G investigation report and the 2007 addendum (LANL 2005, 090513; LANL 2007, 096110), indicate the highest VOC concentrations are beneath the eastern portions of MDA G in the vicinity of the shaft field west of pits 2 and 4. The dominant subsurface VOC vapor contaminant is 1,1,1-trichloroethane (TCA) in the eastern and central portion of MDA G, whereas trichloroethene (TCE) is the most dominant VOC in the western portion of MDA G. Recent pore-gas monitoring data were used to estimate the areal and vertical extent of VOC plumes at MDA G. The results of this evaluation are presented in Appendix E. VOC concentrations are highest in the Tshirege Member of the Bandelier Tuff and decrease markedly in the underlying stratigraphic units. The analysis presented in Appendix E shows that 95% of the VOC contaminant mass above action levels is within the Tshirege Member. Concentrations of VOCs are lowest in the deepest unit sampled, the Cerros del Rio basalt. The MDA G investigation report (LANL 2005, 090513) and the addendum to the MDA G investigation report (LANL 2007, 096110) conclude that the nature and extent of the MDA G VOC plumes are defined. The most recent MDA G annual pore-gas monitoring report (LANL 2010, 108496) further indicates that VOCs demonstrate decreasing or stable trends in concentrations at all locations and depths sampled periodically since 1985.

2.3 2008 SVE Pilot Test

The primary goal of the 2008 SVE pilot test was to evaluate the effectiveness and suitability of SVE as a treatment technology for remediating the MDA G vapor plumes (LANL 2009, 105112).

Two boreholes were drilled and configured specifically to be used as vapor-extraction boreholes for the test. The shallow- and deep-extraction boreholes were installed to extract vapor from the Tshirege and Otowi Members of the Bandelier Tuff, respectively. The boreholes were installed at MDA G in the vicinity of the shaft field in the north-central portion of the site.

The shallow-extraction borehole was constructed to evaluate SVE in the Tshirege Member of the Bandelier Tuff. The borehole was cored and logged from the surface to a total depth (TD) of 182.5 ft bgs. The bottom of the shallow-extraction borehole was grouted up to a depth of 145 ft bgs to avoid short-circuiting of airflow through the more permeable Tsankawi Pumice Bed. The top of the borehole was completed with a 10-in.-diameter steel casing from the ground surface to 63 ft bgs, approximately 3 ft into the top of Qbt 1v of the Tshirege Member, resulting in an 82-ft extraction interval within the Tshirege Member from 63 ft to145 ft bgs.

The deep-extraction borehole was constructed to evaluate SVE in the Otowi Member of the Bandelier Tuff. The borehole was drilled to a TD of 185 ft bgs. The bottom of the deep-extraction borehole was grouted up to a depth of 177 ft bgs to ensure the extraction interval would not be affected by the more permeable Guaje Pumice Bed. The top of the borehole was completed with a 10-in.-diameter steel casing from the ground surface to 161 ft bgs, approximately 10 ft into the top of the Otowi Member, resulting in a 16-ft extraction interval within the Otowi Member from 161 ft to 177 ft bgs.

Existing boreholes 54-24878, 54-01116, 54-24388, and 54-01117 were extended and constructed for pore-gas monitoring. The boreholes are located approximately 25 ft, 40 ft, 110 ft, and 125 ft, respectively, from the shallow-extraction borehole and approximately 27 ft, 50 ft, 115 ft, and 135 ft, respectively, from the deep-extraction borehole (Figure 2.2-1).

2.3.1 Shallow-Extraction Pilot Test

Active extraction in the shallow-extraction borehole was conducted for 30 d. The airflow rate for the test was set to approximately 104.9 standard cubic ft per min (scfm); the corresponding vacuum imparted on the extraction borehole was 1.7 in.-Hg (23.1 in.-H_2O). Brüel and Kjær Model 1320 multi-gas analyzer (B&K) and manometer readings were collected from the four pore-gas monitoring boreholes to evaluate the radius of influence of the SVE system and to assess the overall impact of extraction on the VOC plume. During the shallow test, TCA concentrations peaked in the shallow-extraction well at approximately 315 ppmv shortly after the start of the test and decreased to approximately 140 ppmv by the end of the 30-d test. Based on VOC mass-removal calculations using the average airflow and B&K readings, approximately 278 lb of VOCs was removed during the shallow-extraction pilot test.

2.3.2 Deep-Extraction Pilot Test

Active extraction from the deep-extraction borehole was conducted for 30 d. The airflow rate for the deep-extraction test was set to approximately 16.9 scfm; the corresponding vacuum imparted on the extraction borehole was 4.97 in.-Hg (67 in.-H_2O). B&K and manometer readings were collected from the four pore-gas monitoring boreholes to evaluate the radius of influence of the SVE system and to assess the overall impact of extraction on the VOC plume. During the deep test, TCA concentrations in the extraction borehole ranged between approximately 50 and 70 ppmv throughout the 30-d test, with the lowest concentrations in the morning and the highest concentrations in the afternoon. Based on VOC mass-removal calculations using the calculated average airflow and B&K readings, approximately 15 lb of VOCs was removed during the deep-extraction test period.

2.3.3 Passive Venting

Monitoring of passive airflow out of the extraction boreholes was conducted to evaluate the effect of barometric pressure changes on airflow from the subsurface and the potential effectiveness of that airflow for removing vapor-phase VOCs from the subsurface. Passive airflow was monitored from the shallow-extraction borehole and from the deep-extraction borehole for 2 wk at the conclusion of the test.

No measurable airflow from the Otowi Member occurred from the deep-extraction borehole during the passive venting stage of the pilot test. Airflow data for the shallow-extraction borehole, however, indicated the borehole was passively venting air to the atmosphere during late morning and early afternoon. Eight significant airflow events were observed from the shallow-extraction well with maximum airflow rates ranging from 4 to 10 scfm. Each event typically lasted less than 12 h. Based on VOC mass-removal calculations using the variable airflow and B&K readings, approximately 0.7 lb of VOCs was removed from the shallow-extraction borehole during passive venting.

2.3.4 Numerical Analysis

A numerical analysis was conducted in January 2009 using data from the 2008 SVE test to determine the potential extraction radii of influence (ROI), and to further validate that SVE is an effective method for removing subsurface VOCs from MDA G. From this evaluation, the Laboratory determined that with an operational airflow extraction rate of 100 scfm, corresponding to a vacuum imparted on the extraction borehole of 23.1 in.-H_2O, the potential extraction ROI in the Tshirege Member of the Bandelier Tuff was approximately 150 ft (LANL 2009, 105413).

2.3.5 Conclusions

The results of the 2008 MDA G SVE pilot test indicated that SVE is an effective method for extracting vapor-phase VOC contamination from higher-permeability geologic units in the vadose zone beneath MDA G. Approximately 278 lb of VOCs was removed from the shallow-extraction borehole during the 30-d active shallow-extraction phase of the pilot study. Lower airflow was observed in the deep-extraction borehole installed within the Otowi Member. Low airflow, combined with historically lower concentrations of VOCs at this depth, resulted in the removal of approximately 15 lb of VOCs from the deep-extraction borehole during the 30-d active deep-extraction phase of the pilot study. The SVE pilot test also provided data to validate the conceptual model for vapor transport at MDA G. The validated model can be used to aid in the development of a vapor plume treatment strategy for MDA G.

Passive airflow monitoring in the shallow-extraction borehole indicates that changes in barometric pressure can result in airflow out of the Tshirege Member, typically during late morning and early afternoon hours. Monitoring during these times also indicated that VOCs are present in the exhaled air. Approximately 0.7 lb of VOCs was removed during the 14-d passive monitoring period following the 30-d active deep-extraction phase of the pilot study

The 2008 SVE pilot test appears to have had a relatively long-term effect at decreasing concentrations locally within the Tshirege member of the Bandelier Tuff. For example, TCA concentrations at observation borehole 54-01116, located 40 ft from the shallow extraction borehole, ranged from approximately 210 to 300 ppmv in the upper 80 ft before the 2008 shallow extraction test; those concentrations dropped to between 10 and 50 ppmv following the test (Figure 4.2-8 in LANL 2009, 105112). In the most recent vapor sampling (August 2009), concentrations at these same locations ranged from approximately 80 to 150 ppmv (LANL 2010, 108496). This indicates that TCA concentrations rebounded following the shallow extraction test but only returned to about half their pretest values nearly a year after the test. The mass balance estimates presented in Appendix E also indicate the long-term local effect of the first SVE test. Within a 150-ft radius of the shallow extraction borehole, the TCA mass appears to remain reduced by 44% nearly a year after the test.

Based on U.S. Environmental Protection Agency (EPA) guidance (EPA 1996, 103427) regarding site- and chemical-specific parameters for determining the suitability of SVE, the conditions at MDA G met or exceeded the EPA recommendations.

3.0 SVE PILOT-TEST METHODOLOGY

The current SVE pilot test is based upon the NMED-approved work plan the Laboratory submitted in January 2010 (LANL 2010, 108306). The 2010 supplemental SVE pilot-test activities included abandoning the deep-extraction borehole (54-612256), installing a new extraction borehole (54-612255) and a new monitoring borehole (54-612258), and converting the shallow-extraction borehole to a monitoring borehole (54-612257). After establishing the new borehole matrix, permeability and active extraction tests were performed while monitoring pressure responses at six adjacent boreholes. Figure 3.0-1 shows the position of the supplemental SVE pilot-test extraction and monitoring boreholes. The methodology described below addresses the various components associated with this test.

3.1 Well Abandonment

The deep-extraction borehole (54-612256) was not suitable for use in the supplemental SVE pilot test. The Laboratory submitted a work plan to NMED, requesting approval to perform the abandonment (LANL 2010, 109157). NMED approved the work plan on April 19, 2010 (NMED 2010, 109468). The borehole was abandoned on May 5 and 6, 2010. The borehole was abandoned in accordance with section X.D of the Compliance Order on Consent (Consent Order). See Appendix C for well-abandonment details.

3.2 Extraction-Well Installation

The new extraction borehole 54-612255 was completed within the Otowi Member of the Bandelier Tuff to a total depth of 179.4 ft bgs. It was steel-cased from ground surface to a depth of 55 ft bgs. Construction details of the new extraction borehole (54-612255) are shown in Figure 3.2-1 and Appendix B. The open interval from 55 ft bgs to 179.4 ft bgs provides access for a dual packer assembly such that the extraction step tests could be conducted in stratigraphic units and at the targeted unit contacts: Qbt 2/Qbt 1v-u; Qbt 1v-u; Qbt 1v-u/Qbt 1v-c; Qbt 1 v-c; Qbt 1 v-c/Qbt 1g; Qbt 1g/Qbtt; and Qct (Table 3.2-1).

The extraction borehole (Figure 3.2-1) was installed using hollow-stem auger (HSA) drilling methodology. The borehole was logged in accordance with section IX.B.2.c of the Consent Order. Following installation, the extraction borehole was caliper-, camera-, and gamma-logged to ensure borehole integrity and ensure that the packer assembly could achieve an adequate seal during the extraction tests. Results of the borehole logging showed some sloughing in the borehole, which necessitated the use of a solid-stem auger to clean out the debris. Logging of the borehole did not identify any fracture zones or areas of high permeability, which would act as preferential pathways for air movement.

3.3 Monitoring-Well Installation and Conversion

A new pore-gas monitoring borehole (54-612258) was installed within 25 ft of the new extraction borehole (Figure 3.0-1). As with the new extraction borehole, the borehole 54-612258 was installed using HSA drilling methodology. The newly installed monitoring borehole was logged in accordance with section IX.B.2.c of the Consent Order. Logging of the borehole did not identify any fracture zones or areas of high permeability, which would act as preferential pathways for air movement.

The existing shallow-extraction borehole (54-612257) was caliper-, camera-, and gamma-logged to ensure borehole integrity and ensure that the packer assembly could achieve an adequate seal during the permeability tests (Appendix B). Results of the borehole logging showed some sloughing in the borehole, which necessitated the use of a solid-stem auger to clean out the debris. Logging of the borehole did not identify any fracture zones or areas of high permeability, which would act as preferential pathways for air movement.

Borehole 54-612258 and borehole 54-612257 were constructed to evaluate differential pressure responses in the stratigraphic units and at the unit contacts specified in Table 3.3-1.

Borehole 54-612258 was constructed with the following sampling ports:

- Within the Qbt 2 (two sampling ports), Qbt 1g (two sampling ports), and Qbo intervals
- Across the contacts of the Qbt 2/Qbt 1v-u, Qbt 1v-u/Qbt 1v-c, and Qbt 1g/Qbtt units

Borehole 54-612257 was constructed with the following sampling ports:

- Within the Qbt 1v-u and Qbt 1g intervals
- Across the contact of the Qbt 1v-c/Qbt 1g units

The sampling ports consist of 0.5-in.-diameter, 12-in.-long, stainless-steel well screens connected to sampling tubing extending to the ground surface. The sampling tubing is 0.25-in.-diameter stainless-steel tubing connected with Swagelok fittings. The screens are placed in 5-ft sampling intervals filled with 10/20 silica sand. The annular space between the sampling intervals is filled with bentonite chips to isolate the sampling intervals. The bentonite chips are tremied into the borehole and hydrated as they are emplaced. The surface completion of the boreholes is a steel casing with a locking steel cap.

Construction details, including port depths and corresponding stratigraphic units and contacts, for both the new and the existing monitoring boreholes are shown in Figure 3.2-1.

3.4 Permeability Testing

Before conducting extraction step tests, discrete permeability testing was conducted in the new extraction borehole and in the existing shallow-extraction borehole (before conversion to a monitoring borehole). Permeability testing was conducted within the open interval of each borehole at selected intervals. Permeability testing was conducted using a dual packer assembly and a downhole instrument package that measured differential pressure and temperature.

Specific permeability intervals were targeted to correspond with the intervals and contacts that were to be tested in the pilot test. Two intervals were tested in the conversion borehole. Eight intervals, contacts, and the open borehole were tested in extraction borehole. These correspond to the specific pilot-test extraction points (Table 3.4-1).

Within the extraction borehole, a dual packer system was used to segregate extraction intervals within each stratigraphic unit and unit contact of interest. The same packer system was used for both the permeability testing and the extraction testing. The dual-packer system consisted of two inflatable packers, each measuring 3 ft. x 6.25 in. with a 4-in. inner diameter (4-in. I.D.), schedule 40 (Sch 40) steel extraction pipe running through the center of each packer. The packers were connected by a 3-ft length of 4-in. I.D. Sch 40 steel pipe slotted to provide air flow from the formation during extraction. Each slot measured approximately 1.5 ft x 1 in. Once inflated, the effective extraction interval (the distance between the two packers) measured approximately 57 in., or 1.5 m. The inflation pressure of each packer was rated up to approximately 150 psi. The packer assembly was connected to a series of 10-ft x 4-in. threaded Sch 40 steel pipe, raised and lowered from the ground surface by a Central Mine Equipment Company CME-85 drill rig. Individual lengths of pipe were added or removed as needed to achieve the desired depth.

Each permeability test was conducted by placing the center of the packer assembly extraction interval at the desired depth. The packers were then inflated to a pressure of approximately 50 psi to seal the extraction interval from the rest of the borehole. Once an adequate seal was achieved, baseline pressure and temperature conditions were established and recorded using an In-Situ BaroTROLL pressure transducer and temperature probe (Model R71870) affixed to the center of the slotted pipe connecting the two packers. This pressure data was recorded in a portable laptop using In-Situ's Win-Situ data logging software. A low-flow vacuum pump (rated up to 20 L/min) was then used to draw air from the extraction interval. The resulting pressure differential measured at the extraction interval and the corresponding extraction air flow rate were then used to estimate permeability.

Both a homogenous and layered radial numerical model were used to estimate permeability in Appendix H. The homogeneous model recognizes the packer geometry and more realistic radial nature of the SVE flow towards the packed-off extraction intervals, while the layered model allows the added complexity of planar stratigraphy. In conjunction, these numerical models provide bounding conditions with which to validate the spherical analytical model and results obtained from this model. The spherical analytical model is very useful because it allows a range of data to be analyzed and checked quickly without the need for advanced simulation skills. However, there are cases presented where permeability cannot be estimated using the spherical analytical model.

3.5 SVE Systems Operation

A portable, skid-mounted SVE system, provided by Catalytic Combustion, Inc. of Bloomer WI, was used to conduct extraction testing in the new extraction borehole. The SVE system was rated for an air flow rate of 129 scfm at a vacuum of 120 inches of water (120 in. H_2O). The SVE system directed air extracted from the extraction borehole through a liquid/vapor separator, an in-line filter, a positive-displacement vacuum blower, and a heat exchanger. The air discharge from this SVE system was then directed through a high-efficiency particulate air (HEPA) filter to remove any possible radioactive contaminants before being exhausted to the atmosphere. Detailed design specifications and operational instructions for the SVE system are provided in Appendix D.

Extraction testing was conducted in each interval specified using the same dual-packer assembly described in Section 3.4. Active extraction tests were conducted following each permeability test. Following each permeability test, the packers remained inflated to approximately 50 psi and baseline monitoring was conducted to establish downhole static pressure and temperature conditions before active extraction.

During both extraction baseline monitoring and active extraction tests, downhole pressure and temperature were measured using the same In-Situ BaroTROLL pressure transducer and temperature probe (Model R71870) used during the permeability testing. This pressure data was recorded in a portable laptop using In-Situ's Win-Situ data logging software. Differential pressure values were also collected at the wellhead during the tests with a Dwyer Series 475 Mark III digital manometer. Extraction airflows were measured and recorded using a Dwyer orifice-plate flow meter setup using the PE-J-2 orifice plate and a Dwyer magnehelic differential pressure gauge and transmitter, Model 605-20. Extracted air temperature and relative humidity were measured above ground at the extraction borehole wellhead using a Vaisala HMP45AC humidity and temperature probe. Orifice-plate differential pressure, extraction air temperature, and relative humidity parameters at the extraction wellhead were recorded every 15 min using a Campbell Scientific CR-1000 data logger.

Extraction tests were conducted at each extraction interval at six vacuums, or vacuum steps: 15, 30, 50, 70, 90, and 120 in. H_2O. Each extraction vacuum, or step was run for a minimum of 4 h, then increased to the subsequent, higher vacuum level. Vacuum levels were established by increasing the vacuum blower speed and/or closing the air dilution valve on the inlet of the SVE system until a pressure differential corresponding to the desired vacuum level was established at the extraction interval. The pressure differential was continuously measured and verified by the downhole BaroTROLL pressure transducer and temperature probe.

During extraction testing, a B&K photo-acoustic multi-gas analyzer model 1832 was used to monitor concentrations of TCA, perchloroethylene (PCE), TCE, Freon-11, carbon dioxide, oxygen, and water vapor in the extracted air. B&K measurements were recorded using a portable laptop computer at approximately 3-min intervals (Appendix F).

System parameters were also manually monitored and recorded in field logbooks and round sheets (Appendix F).

3.6 Pilot-Test Differential-Pressure Monitoring

Six boreholes in the vicinity of the extraction borehole were monitored for differential pressure during the SVE pilot test. This monitoring was conducted at boreholes 54-01116, 54-01117, 54-24378, 54-24388, 54-612258, and 54-612257. Table 3.3-1 presents borehole port-depth intervals and stratigraphic units. Differential pressure was measured using OMEGA differential pressure sensors (Model PX137-0.3DV), with a range of 0 to 0.3 psi (0 to 2.1 kilopascals [kPa]). The pressure responses measured by the OMEGA pressure sensors were recorded to a Campbell Scientific data logger (Model CR1000). The data loggers were programmed to power and measure the pressure sensors every 15 min. The pressure sensors' output was measured in millivolts, which were converted into kPa. Data recorded by each data logger was manually downloaded approximately on a daily basis.

Barometric pressure readings were collected from the TA-54 weather station during extraction testing every 15 min and are presented in Appendix F.

3.7 Deviations

The following design and operational deviations were observed during the pilot test.

Design Deviations

Investigation-derived waste management: The work plan stated that extracted air would be directed through granular activated carbon (GAC) canisters for treatment. However, after an evaluation of potential VOC concentrations in the off-gas, it was determined that GAC was not required.

Off-gas filtration: A HEPA unit was added to protect against any radioactive material release from vapors being extracted from the test well. Inclusion of the HEPA filter did not adversely affect the operational parameters of the SVE system.

Operational Deviations

Permeability testing: The work plan stated that before conducting extraction step tests, discrete permeability testing of each stratigraphic unit would be conducted in the proposed new extraction borehole and in the existing shallow-extraction borehole (before conversion to a monitoring borehole). However, two additional permeability tests were performed in the extraction borehole: Qbo at 169.4 ft bgs and Qbt 1g at 136.5 ft bgs; and only two permeability tests were performed in the converted borehole (54-612257): Qbt 1g, at 96 ft bgs and 91 ft bgs respectively.

***B&K measurements*:** The work plan stated that TCA, percent oxygen, percent carbon dioxide, and water would be measured at the extraction wellhead every 15 min during the active extraction tests. During the test, concentrations of TCA, PCE, TCE, Freon-11, carbon dioxide, oxygen, and water in the extracted air were monitored approximately every 3 min.

Qbt 1g/Qbtt contact: Target wellhead vacuums of 15, 30, and 50 in. H_2O were attained for the Qbt 1g/Qbtt contact interval. Higher vacuums were not achieved because air flow out of the extraction borehole at vacuums greater than 50 in H_2O exceeded the operational parameters of the SVE system. The pressure transducer for the port set at 132.5 ft bgs malfunctioned during the test, and thus no data were collected.

Qbt 1v-c interval: Test interval for applied vacuum of 70 in. H_2O was cut short by half an hour; only 3.5 h of data collected. No data were collected for 54-01117 at the 15 in. H_2O step because of data logger problems.

Open borehole: Only well head vacuums of 15, 30, and 42 in of water were attained. The higher planned vacuums of 50, 70, 90 and 120 in H_20 were not achieved because air flow out of the extraction borehole at vacuums greater than 42 in H_2O exceeded the operational parameters of the SVE system

4.0 SVE PILOT-TEST RESULTS

Active extraction was conducted in the newly installed extraction borehole location 54-612255 in the following stratigraphic units, moving the straddle packer from the bottom extraction interval within the borehole up through

- Qbo,
- Qct,
- Qbt 1g/Qbtt,
- Qbt 1g,
- Qbt 1v-c/Qbt1g,
- Qbt 1v-c,

- Qbt 1v-u/Qbt 1v-c,
- Qbt 1v-u, and
- Qbt 2/Qbt 1v-u, and
- using the top packer only for the open borehole.

The following is a summary of the permeability- and extraction-test results for each interval. Detailed data sheets are presented in Appendix F.

4.1 Qbo

Permeability testing of the Qbo interval was conducted on May 15, 2010 within the extraction borehole. The resulting permeability was calculated as 1.31 darcys (1.31 E-12 m^2) at a mid-packer depth of 169.4 ft bgs.

No extraction tests were performed in the Qbo interval.

4.2 Qct

Permeability testing of the Qct interval was conducted on May 16, 2010 within the extraction borehole. The resulting permeability was calculated as 11.7 darcys (1.17 E-11 m^2) at a mid-packer depth of 158.5 ft bgs.

Extraction testing of the Qct began on May 18 and was completed on May 19, 2010. The mid-packer depth was 158.5 ft bgs. Target wellhead vacuums of 15, 30, 50, 70, 90 and 120 in. H_2O were attained for the Qct interval.

The results of the test are shown in Figure 4.2-1. The greatest distance for a measureable response was in Borehole 54-01116; 65 ft from the extraction borehole, where a pressure response of 18 in. H_2O was recorded at 151.5 ft bgs.

The largest response was recorded in borehole 54-612258, 25 from the extraction borehole, with a pressure response of approximately 41 in H_2O at 172.5 ft bgs. Also within this borehole, pressure responses greater than 20 in H_2O were recorded for ports at depths of 146.7, 132.5 and 97.5 ft bgs. The shallower ports had responses of less than 5 in H_2O.

At a maximum vacuum of 120 in. H_2O, a maximum flow of 97.1 scfm was achieved. The resulting air flows were achieved at each vacuum:

Qct, 158.5 ft bgs	
Wellhead Vacuum (in. H_2O)	Air Flow (scfm)
15	20.4
30	32.6
50	48.4
70	62.5
90	77.5
120	97.1

4.3 Qbt 1g/Qbtt Contact

Two permeability tests of the Qbt 1g/Qbtt contact interval were conducted on May 16, 2010, and May 17, 2010. The resulting permeability was calculated as 46 darcys (4.6 E-11 m^2) and 33 darcys (3.3 E-11m^2) for each test at a mid-packer depth of 145 ft bgs.

Extraction testing of the Qbt 1g/Qbtt contact interval was performed on May 20, 2010. The mid-packer depth was 146.1 ft bgs. Target wellhead vacuums of 15, 30, and 50 in. H_2O were attained for the Qbt 1g/Qbtt contact interval. Higher vacuums were not achieved because air flow out of the extraction hole at vacuums greater than 50 in H_2O exceeded the operational parameters of the SVE system (i.e., a vacuum of 70 in. H_2O could not be attained).

The results of the Qbt 1g/Qbtt test are shown in Figure 4.3-1. The greatest distance for a measureable pressure response was in borehole 54-01117; 150 ft from the extraction borehole, where a pressure response of 9 in. H_20 was recorded at 159.5 ft bgs.

In borehole 54-01116, 65 ft from the extraction borehole, a pressure response of 34 in. H_2O was measured at 151.5 ft bgs, while ports 82.5 ft bgs and shallower showed responses of less than 5 in. H_2O.

The largest response was recorded in borehole 54-612258; 25 ft from the extraction borehole, where a pressure response of approximately 56 in. H_2O was recorded at 172.5 ft bgs. Also within this borehole, pressure responses greater than 20 in. H_2O were recorded for ports at depths of 146.7 ft bgs and 132.5 ft bgs. Shallower ports exhibited pressure responses of less than 5 in. H_2O.

At a maximum vacuum of 50 in. H_2O, a maximum flow of 121.2 scfm was achieved. The resulting air flows were achieved at each vacuum:

Qbt 1g/Qbtt Contact, 146.1 ft bgs	
Wellhead Vacuum (in. H_2O)	Flow (scfm)
15	39.1
30	73.4
50	121.2

4.4 Qbt 1g

Permeability testing of the Qbt 1g interval was conducted on May 20, 2010 within the extraction borehole. The resulting permeability was calculated as 0.94 darcys (9.4 E-13 m^2) at a mid-packer depth of 136.5 ft bgs. Additionally, permeability testing was performed in borehole 54-612257 before its conversion to a monitoring borehole. The test was performed at mid-packer depths of 96.5 ft bgs and 91 ft bgs, with resulting permeability calculations of 1.3 darcys (1.3 E-12 m^2) and 4.4 darcys (1.3 E-12 m^2), respectively.

No extraction tests were performed in the Qbt 1g interval.

4.5 Qbt 1v-c/Qbt 1g Contact

Permeability testing of the Qbt 1v-c/Qbt 1g contact interval was conducted on May 20, 2010, within the extraction borehole. The resulting permeability was calculated as 2.67 darcys (2.67 E-12 m^2) at a mid-packer depth of 84.5 ft bgs. Additionally, attempts were made to perform permeability testing in borehole 54-612257 at this contact interval. However, severe sloughing of the material from approximately

86 ft bgs to the bottom of the steel casing (63 ft bgs) in this borehole prevented the packer assembly from being able to develop an adequate seal to perform the test.

Extraction testing of the Qbt 1v-c/Qbt 1g contact began on May 20 and was completed on May 22, 2010. The packer depth was 84.5 ft bgs. Target wellhead vacuums of 15, 30, 50, 70, 90 and 120 in. H_2O were attained for the Qbt 1v-c/Qbt 1g contact interval.

The results of the test are shown in Figure 4.5-1. There was minimal pressure response at any of the port depths in any of the wells for any of the applied vacuums. No discernable trend was shown in response to the applied vacuums. The depth response differential exhibited in the pilot test for the deeper extraction intervals (Qct and Qbtt/Qbt 1g) was not present in this test at this depth.

The maximum air flow of 19.5 scfm was observed at 120 in H_2O. The air flows for the applied vacuums are presented below.

Qbt 1v-c/Qbt 1g Contact, 84.5 ft bgs	
Wellhead Vacuum (in. H_2O)	Air Flow (scfm)
15	12.1
30	15.8
50	14.9
70	14.6
90	16.6
120	19.5

4.6 Qbt 1v-c

Permeability testing of the Qbt 1v-c interval was conducted on May 25, 2010, within the extraction borehole. The resulting permeability was calculated as 2.05 darcys (2.05 E-12 m^2) at a mid-packer depth of 77.5 ft bgs. Additionally, attempts were made to perform permeability testing in borehole 54-612257 at this interval. However, severe sloughing of the material from approximately 86 ft bgs to the bottom of the steel casing (63 ft bgs) in this borehole prevented the packer assembly from being able to develop an adequate seal to perform the test.

Extraction testing of the Qbt 1v-c began on May 25 and was completed on May 26, 2010. The packer depth was 77.5 ft bgs. Target wellhead vacuums of 15, 30, 50, 70, 90 and 120 in. H_2O were attained for the Qbt 1v-c interval.

The results of the test are shown in Figure 4.6-1. There was minimal pressure response at any of the port depths in any of the wells for any of the applied vacuums. No discernable trend was shown in response to the applied vacuums. The depth response differential exhibited in the pilot test for the deeper extraction intervals (Qct and Qbtt/Qbt 1g) was not present in this test at this depth. No data were collected for borehole 54-01117 at the 15-in.-H_2O step because of data logger problems. However, since minimal response was observed at higher vacuums, the lack of data in this instance provides little to no impact on the overall results of this test.

The maximum air flow of 18.3 scfm was observed at 120 in. H_2O. The air flows for the applied vacuums are presented below:

Qbt 1v-c, 77.5 ft bgs	
Wellhead Vacuum (in. H_2O)	Air Flow (scfm)
15	15.5
30	15.4
50	13.1
70	13.9
90	16.1
120	18.3

4.7 Qbt 1v-u/Qbt 1v-c Contact

Permeability testing of the Qbt 1v-u/Qbt 1v-c contact interval was conducted on May 24, 2010, within the extraction borehole. The resulting permeability was calculated as 1.79 darcys (1.79 E-12 m^2) at a mid-packer depth of 70 ft bgs. Additionally, attempts were made to perform permeability testing in borehole 54-612257 at this contact interval. However, severe sloughing of the material from approximately 86 ft bgs to the bottom of the steel casing (63 ft bgs) in this borehole prevented the packer assembly from being able to develop an adequate seal to perform the test.

Extraction testing of the Qbt 1v-u/Qbt 1v-c contact interval began May 24 and concluded on May 25, 2010. The mid-packer depth was 70 ft bgs. Target wellhead vacuums of 15, 30, 50, 70, 90 and 120 in. H_2O were attained for the Qbt 1v-u/Qbt 1v-c contact interval.

The results of the test are shown in Figure 4.7-1. There was minimal pressure response at any of the port depths in any of the wells for any of the applied vacuums. No discernable trend was shown in response to the applied vacuums. The depth response differential exhibited in the pilot test for the deeper extraction intervals (Qct and Qbtt/Qbt 1g) was not present in this test at this depth.

The maximum air flow of 17.3 scfm was observed at 120 in. H_2O. The air flows for the applied vacuums are presented below:

Qbt 1v-u/Qbt 1v-c Contact, 70 ft bgs	
Well Head Vacuum (in. H_2O)	Air Flow (scfm)
15	14.2
30	15.1
50	16.1
70	13.2
90	14
120	17.3

4.8 Qbt 1v-u

Permeability testing of the Qbt 1v-u interval was conducted on May 22, 2010, within the extraction borehole. The resulting permeability was calculated as 1.00 darcy (1.00 E-12 m^2) at a mid-packer depth of 65 ft bgs.

Extraction testing of the Qbt 1v-u began on May 22 and concluded on May 23, 2010. The mid-packer depth was 65 ft bgs. Target wellhead vacuums of 15, 30, 50, 70, 90 and 120 in. H_2O were attained for the Qbt 1v-u interval.

The results of the test are shown in Figure 4.8-1. There was minimal pressure response at any of the port depths in any of the wells for any of the applied vacuums. No discernable trend was shown in response to the applied vacuums. The depth response differential exhibited in the pilot test for the deeper extraction intervals (Qct and Qbtt/Qbt 1g) was not present in this test at this depth.

The maximum air flow of 13.8 scfm was observed at 120 in H_2O. The air flows for the applied vacuums are presented below:

Qbt 1v-u, 65 ft bgs	
Wellhead Vacuum (in. H_2O)	Flow (scfm)
15	10.8
30	10.6
50	10.2
70	10.2
90	10.0
120	13.8

4.9 Qbt 2/Qbt 1v-u Contact

Permeability testing of the Qbt 2/Qbt 1v-u contact interval was conducted on May 26, 2010, within the extraction borehole. The resulting permeability was calculated as 1.27 darcys (1.27 E-12 m^2) at a mid-packer depth of 59.5 ft bgs.

Extraction testing of the Qbt 2/Qbt 1v-u contact interval began on May 26 and concluded on May 28, 2010. The mid-packer depth was 59.5 ft bgs. Target wellhead vacuums of 15, 30, 50, 70, 90 and 120 in. H2O were attained for the Qbt 2/Qbt 1v-u contact interval.

The results of the test are shown in Figure 4.9-1. There was minimal pressure response at any of the port depths in any of the wells for any of the applied vacuums. No discernable trend was shown in response to the applied vacuums. The depth response differential exhibited in the pilot test for the deeper extraction intervals (Qct and Qbtt/Qbt 1g) was not present in this test at this depth.

The maximum air flow of 16.7 scfm was observed at 120 in. H_2O. The scfm air flows for the applied vacuums are presented below:

Qbt 2/Qbt 1v-u Contact, 59.5 ft bgs	
Wellhead Vacuum (in. H_2O)	Air Flow (scfm)
15	14.4
30	11.9
50	11.3
70	12.2
90	12.5
120	16.7

4.10 Open Borehole

Extraction testing of the open borehole between 50 to 178 ft bgs was performed on May 28, 2010. Only wellhead vacuums of 15, 30, and 40 in. H_2O were attained. Higher vacuums were not achieved because air flow out of the extraction hole at vacuums greater than 42 in. H_2O exceeded the operational parameters of the SVE system (i.e., a vacuum of 50 in. H_2O could not be attained).

The results of the open borehole test are shown in Figure 4.10-1. The greatest distance for a measureable response was in borehole 54-01116; 65 ft from the extraction borehole. Within this borehole, pressure responses greater than 22 in. H_2O and 11 in. H_2O were recorded for ports at depths of 190 ft bgs and 167.5 ft bgs, respectively. Measured responses in the monitoring ports 132.1 ft bgs and shallower were 5 in. H_2O and less.

The largest response was recorded in borehole 54-612258; 25 ft from the extraction borehole. A pressure response of approximately 56 in. H_2O was recorded at 146.7 ft bgs. Also within this borehole, pressure responses greater than 37 in. H_2O were recorded for ports at depths of 172.5 and 132.5 ft bgs. The monitoring ports 69 ft bgs and shallower exhibited pressure responses of less than 4 in. H_2O.

The largest measured response for borehole 64-612257, 24 ft from the extraction borehole, was approximately 45 in. H_2O at 132.5 ft bgs. The ports shallower than 85 ft bgs recorded pressure differences of less than 4 in. H_2O.

The largest measured response for borehole 64-24378, 39 ft from the extraction borehole, was approximately 40 in. H_2O at 151.5 ft bgs. Also within this borehole, pressure responses of approximately 24 in. H_2O were recorded for ports at depths of 167.5 ft bgs and 132.1 ft bgs. The ports shallower than 82.5 ft bgs recorded pressure differences of less than 4 in H_2O.

At the maximum vacuum of 40 in. H_2O, a maximum air flow of 163.9 scfm was achieved. The air flow exhibited a linear relationship with applied vacuum as shown in Figure 4.10-1. The following air flows were achieved:

Open Borehole, 50 to 178 ft bgs	
Wellhead Vacuum (in. H_2O)	Flow (scfm)
15	69.7
30	124
40	163.9

No permeability test was performed in the open borehole; however, bulk permeability of the open borehole was calculated as 4.5 darcys (4.5 E-12 m^2).

5.0 PRELIMINARY DESIGN

This section presents a preliminary design of an SVE system that could be implemented as part of a corrective measures alternative for MDA G. The purpose of this preliminary design is to specify an SVE system in sufficient detail to include in the corrective measures evaluation (CME) report and support a cost estimate of the accuracy required for a CME. If SVE is included as a component of the corrective measures selected for MDA G, a detailed design would be developed as part of the corrective measures implementation plan.

5.1 Performance Objectives

SVE would be implemented to remove VOCs from the subsurface. The objective of removing VOCs would be to prevent migration to the regional groundwater that could result in groundwater contamination in excess of the cleanup levels or human health risk goals defined in the Consent Order cleanup goals.

The Consent Order does not specify any screening levels or cleanup levels for VOCs in pore gas. In the past, the Laboratory has screened VOC pore-gas data using screening levels based on groundwater cleanup levels and equilibrium vapor-liquid partitioning, as described by Henry's law. Numerically, the screening level for a contaminant is equal to the product of the groundwater cleanup level for that contaminant specified in the Consent Order (i.e., EPA maximum contaminant level [MCL], New Mexico Water Quality Control Commission [NMWQCC] groundwater standard, or NMED tap-water screening level) and the contaminant's dimensionless Henry's law constant. The value of the screening level represents the concentration of VOC in the vapor phase that would be in equilibrium with an aqueous concentration equal to the groundwater cleanup level.

The VOC screening levels described above are very conservative and do not account for transport through the vadose zone to the regional aquifer, aquifer dilution or attenuation, or other mitigating effects in either the vadose zone or the aquifer. Site-specific cleanup levels necessary to protect groundwater at MDA G should be calculated as part of the CME.

Dilution-attenuation factors for the regional aquifer beneath MDA G were calculated and presented in Appendix F of the approved CME plan for MDA G, Revision 2 (LANL 2007, 098608; NMED 2007, 098772). That evaluation conservatively showed that dilution-attenuation factors at MDA G would be on the order of 100 based on representative hydrologic data. The analysis performed in the MDA G CME plan was also conservative in that it did not consider the effects of vadose-zone flux limitations on groundwater concentrations (e.g., Truex et al. 2009, 108331). A dilution-attenuation factor of 100 would mean that VOC vapor concentrations in the subsurface 100 times the Henry's-law-based screening levels would still be protective of groundwater use. Because current VOC concentrations do not exceed 100 times the screening level, a target action level of 10 times the screening level (i.e., an order of magnitude less than the dilution-attenuation factor) was assumed to develop the preliminary design.

5.2 Performance Requirements

Existing VOC data for MDA G were evaluated to determine what areas of the subsurface beneath MDA G would require treatment using SVE based on the assumed target action levels. The contaminants TCA and TCE were selected as the representative contaminants because these are the major constituents present in the vapor plumes at MDA G (see section 2.2). TCA and TCE data from past sampling were used to determine the locations, areas, and volumes of subsurface pore gas exceeding the target action levels, (i.e. ten times the Henry's-law-based screening level), as well as the associated contaminant mass. This evaluation is presented in Appendix E. Specific performance requirements for the SVE system are to

- reduce and maintain subsurface VOC concentrations to levels below target action levels,
- meet regulatory requirements for discharge of extracted pore gas to the atmosphere, and
- not result in adverse impacts to the waste containment features of low-level radioactive waste disposal units within the extraction zone.

5.3 Preliminary Specifications

The following contains preliminary specifications for the SVE system components based on the results of the current pilot test (see Appendix H), as well as previous SVE pilot tests conducted at MDA G (LANL 2008, 103902) and MDA L (LANL 2006, 094152).

5.3.1 Extraction Well Depth, Diameter, and Extraction Interval

Based on the evaluation presented in Appendix E, VOC vapor concentrations greater than target action levels are generally in the Qbt 1v, Qbt 1g, Qbtt, and Qct units, with most of the contaminant mass being in the Qbt 1v and Qbt 1g units. As the results of the current and previous tests show variability in permeability with location, permeability testing will be performed on each borehole before constructing the extraction well. Site-specific permeability data will be used to verify design assumptions. The results from the current test, as well as the previous test at MDA L (LANL 2006, 094152), show that the permeability of the Qbtt and Qct units is much higher than that of the overlying units. If the extraction interval extended into these units, air would be preferentially extracted from these units instead of from the overlying units containing most of the contaminant mass. The results of the previous numerical simulation of SVE at MDA G (LANL 2009, 105413) showed that extraction from the Qbt 1v and Qbt 1g units would still remove contaminants from the Qbtt and Qct units. Therefore, the design extraction interval should be in the Qbt 1v and Qbt 1g units. As the mass of contaminant in the Qbo unit is small and the permeability of this unit is low, the SVE system would not be designed to extract from the Qbo unit.

The depths and thicknesses of the Qbt 1v and Qbt 1g units vary across MDA G. For the purpose of the preliminary design, an extraction interval of 60 ft to 140 ft bgs was assumed. The extraction well would be constructed by drilling with 10-in. outside diameter hollow-stem augers to approximately 3 ft above the base of the Qbt 1g unit. An extraction well consisting of 4-in. polyvinyl chloride (PVC) well screen and casing would then be installed through the auger. The well would consist of slotted well screen from the bottom of the borehole to the top of the Qbt 1v unit and blank casing above this. The borehole annulus outside the well screen would be filled with gravel filter pack to one ft above the top of the screen. Three ft of hydrated bentonite would be emplaced above the filter pack, and the remainder of the annulus would be filled with grout. Specifications for well-screen slot size and filter-pack grain size would be developed during the detailed design.

5.3.2 Number of Extraction Wells

Based on the evaluation of air permeability data collected during the current pilot test, and an evaluation of previous pilot test data (LANL 2009, 105413), extraction wells are expected to have a radius of influence of 150 ft within the extraction interval. This radius is based on an operating vacuum of 70 in. water (see section 5.3.3). Based on the capture area and plume areas estimated in Appendix E, and assuming 20% overlap, approximately 20 extraction wells would be required to treat the plume areas having concentrations greater than target action levels. The areas of the plumes and the associated number of wells are as follows.

- Western TCE/TCA plume – 12.6 acres, 9 wells
- Eastern TCE plume – 9.1 acres, 7 wells
- Eastern TCA plume – 4.2 acres, 3 wells
- Southern TCE plume – 0.9 acres, 1 well

5.3.3 Vacuum and Extraction Rates

The effect of vacuum on extraction radius was previously evaluated using the results of the first SVE pilot test conducted at MDA G (LANL 2009, 105413). Based on that evaluation and the results of the current pilot test (Appendix H), an operating vacuum of 70 in. water was selected. A primary consideration in keeping the vacuum as low as possible was safety concerns associated with impacts to the low-level radioactive waste disposal units within the zone of extraction. Safe operation at this vacuum was demonstrated during the current pilot test at MDA G. It is unknown whether higher vacuums would affect the integrity of buried waste containment features or lead to release of nonvolatile contaminants. It is likely that an unresolved safety question evaluation will be needed before operation to ensure operation at this pressure will be consistent with the safety basis for the site. Keeping the vacuum as low as practicable is also desirable to minimize energy consumption, blower wear, and blower exhaust temperatures. Based on the results of the permeability testing, the flow associated with the vacuum is 90 scfm. The use of higher vacuums and flow rates will be evaluated during the detailed design.

5.3.4 Operating Mode

The operating mode is selected based on the release characteristics of the source. The results of the previous SVE pilot test at MDA G (LANL 2008, 103902), as well as subsequent monitoring (LANL 2010, 108496), show that VOC concentrations were reduced by SVE and are slowly rebounding (section 2.3.5). This behavior indicates a source that is slowly releasing VOCs into the subsurface and/or a plume that is diffusing back to the extraction zone because of concentration gradients. If pore-gas concentrations can be reduced below target action levels during a reasonable extraction period, the most efficient means of operating an SVE system would be intermittent operation with alternating periods of extraction and rebound, rather than continuous operation. This reduces the amount of time the equipment must be operated and increase the contaminant removal rate during operation.

A numerical evaluation of data from the current test showed that operation of an extraction well with the design screened interval at 70 in. vacuum would result in removal of approximately 90% of the contaminant mass within the extraction zone by 180 days. Based on the concentration data presented in Appendix E, concentration reductions of 90% would be more than enough to reach target action levels.

The results of the previous pilot test at MDA G showed slow rebounding of VOC concentrations in the extraction zone. Monitoring wells used in the previous SVE pilot test at MDA G showed VOC concentrations approximately 45% below pretest values 1 yr after the test.

The extraction system would be operated until contaminant concentrations approach an asymptotic value, at which time the extraction system will be turned off and the concentrations allowed to rebound. Based on the results of the previous pilot tests and monitoring, the extraction period is expected to be 180 d and the rebound period 180 d. These annual cycles of operation would continue until concentrations remain below target action levels after rebound.

5.3.5 Off-Gas Treatment

Based on the analysis presented in Appendix E, the total mass of VOCs in the subsurface of the treatment zones is currently estimated to be 200 kg. Extraction to reduce current concentrations by 90% (section 5.3.4) would result in removal of 180 kg VOCs. As described in section 5.3.4, this removal is expected to require approximately 180 d. This would result in an average contaminant removal rate of1.0 kg/d.

5.3.6 System Configuration

As described in section 5.3.4, wells would be operated on a schedule consisting of 180 d of extraction followed by 180 d of rebound. To allow the wells to be extracted continuously if necessary, all wells in each plume area would be manifolded to a central treatment unit for the plume.

Each group of wells will have an associated operating equipment unit consisting of an extraction blower, air-water separator, flow controls, flow measurement devices, vacuum measurement devices, gas sampling devices, and off-gas treatment equipment.

For the purpose of providing a preliminary design to support the CME and associated cost estimate, the following system configuration is assumed.

- Four skid-mounted operating units, one for each plume area as follows.
    - ❖ The units for the western TCE/TCA plume would be sized to treat up to nine wells and would have a 16-horsepower (hp) 220-volt, alternating current (Vac) positive displacement blower with variable frequency drive.
    - ❖ The unit for the eastern TCE plume would be sized to treat seven wells and would have a 12-hp 220-Vac positive-displacement blower with variable frequency drive.
    - ❖ The unit for the eastern TCA plume would be sized to treat three wells and would have a 5-hp 220-Vac positive-displacement blower with variable frequency drive.
    - ❖ The unit for the southern TCE plume would be sized to treat one well and would have a 2-hp 220-Vac positive-displacement blower with variable frequency drive.

- Steel piping, 2-in. diameter, sufficient to connect wells to operating units (4200 ft). Manifold piping would be installed on the surface to avoid impacting the MDA G cover.
- Two GAC adsorbers in series on the blower exhaust side. The adsorbers for the one-well unit would have 400 lb of GAC and the adsorbers for the three-, seven-, and nine-well units would have 1000 lb of GAC. Based on the design vacuum, the temperature rise across the blowers would be less than 50ºF and no heat exchangers would be needed to reduce off-gas temperature to improve adsorption.

5.3.7 Performance Monitoring

Final performance monitoring requirements would be developed during the detailed design process. The monitoring system is expected to include measurement of

- extraction well vacuum using differential pressure manometers or transducers,
- total extracted flow using totalizing flow meters,
- instantaneous flow rates using venturi or orifice plate flow meters,
- blower exhaust temperature using thermometers or thermocouples,
- TCA and TCE concentrations in extracted vapor and GAC exhaust using direct-reading field instruments with confirmatory laboratory analyses of SUMMA canister samples, and
- tritium concentrations in extracted vapor and GAC exhaust using laboratory analysis of samples collected on silica gel.

Performance of the system in meeting target action levels will be monitored by periodic collection of pore-gas samples from selected MDA G vapor monitoring wells.

5.4 Preliminary Cost Estimate

A preliminary cost estimate of the SVE system specified above was developed. The estimated capital cost is $3.5 million, and the annual operation and maintenance cost is $350 thousand. The capital cost estimate is based on unit costs for the following major system components:

- SVE extraction wells and associated manifold piping,
- performance monitoring boreholes with six monitoring ports,
- skid-mounted SVE operating units, and
- installation costs.

The annual operation and maintenance costs consider startup of annual operating cycles, routine maintenance, and monitoring. Waste management and analytical costs are not included.

Additional detail on the preliminary cost estimate is provided in Appendix G.

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Based on the results of the testing described in this report, as well as previous testing at MDA G and MDA L, SVE would be an effective remedial technology if it were necessary to remove subsurface VOCs at MDA G. The permeabilities of the subsurface units measured during the test are within the ranges of values considered feasible for implementation of SVE. Similarly, the pressure responses measured during the step tests indicate a radius of influence large enough for SVE to be implementable and cost effective at the MDA G site based on the assumed target action levels. The tests further show that an effective radius of influence can be achieved using vacuums and air-flow rates achievable with equipment typically used for SVE, although safety considerations associated with use of higher vacuums than previously tested will need to be addressed during this CME.

The permeability values measured during this test are lower than those previously measured at MDA L (LANL 2006, 094152). The distribution of permeability values among stratigraphic units is, however, similar. The permeabilities of most of the units tested were too low for the 4-h step tests to yield meaningful radius of influence data. The variability of permeability with location demonstrates the need to conduct site-specific permeability testing of extraction boreholes during installation to verify design assumptions.

6.2 Recommendations

At present there are no site-specific cleanup levels for VOCs in the subsurface at MDA G. Such cleanup levels would be needed to define the specific objectives of corrective measure alternatives to be evaluated in the CME report. Cleanup levels are necessary to determine the need to implement SVE (i.e., to determine whether VOC concentrations currently exceed cleanup levels) and to identify specific remedial objectives (i.e., the location and extent of contamination exceeding cleanup levels). Site-specific cleanup levels are recommended to be developed as part of the CME. These cleanup levels should be protective of groundwater quality and should account for dilution and attenuation effects in the vadose zone and regional aquifer.

7.0 REFERENCES AND MAP DATA SOURCES

7.1 References

The following list includes all documents cited in this report. Parenthetical information following each reference provides the author(s), publication date, and ER ID. This information is also included in text citations. ER IDs are assigned by the Environmental Programs Directorate’s Records Processing Facility (RPF) and are used to locate the document at the RPF and, where applicable, in the master reference set.

Copies of the master reference set are maintained at the NMED Hazardous Waste Bureau and the Directorate. The set was developed to ensure that the administrative authority has all material needed to review this document, and it is updated with every document submitted to the administrative authority. Documents previously submitted to the administrative authority are not included.

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Turin, H.J., May 1995. "Subsurface Transport Beneath MDA G: A Conceptual Model," Los Alamos National Laboratory document LA-UR-95-1663, Los Alamos, New Mexico. (Turin 1995, 070225)

7.2 Map Data Sources

Data sources used in original figures created for this report are described below and identified by legend title.

Legend Item	Data Source
Disposal pit	Waste Storage Features; LANL, Environment and Remediation Support Services Division, GIS/Geotechnical Services Group, EP2007-0032; 1:2,500 Scale Data; 13 April 2007.
Disposal shaft	Waste Storage Features; LANL, Environment and Remediation Support Services Division, GIS/Geotechnical Services Group, EP2007-0032; 1:2,500 Scale Data; 13 April 2007.
Elevation contour	Hypsography, 10, 20, & 100 Foot Contour Intervals; LANL, ENV Environmental Remediation and Surveillance Program; 1991.
Fence	Security and Industrial Fences and Gates; LANL, KSL Site Support Services, Planning, Locating and Mapping Section; 06 January 2004; as published 10 September 2007.
LANL boundary	LANL Areas Used and Occupied; LANL, Site Planning & Project Initiation Group, Infrastructure Planning Division; 19 October 2008.
MDA	Material Disposal Areas; LANL, ENV Environmental Remediation and Surveillance Program; ER2004-0221; 1:2,500 Scale Data; 23 April 2004.
Paved road	Paved Road Arcs; LANL, KSL Site Support Services, Planning, Locating and Mapping Section; 06 January 2004; as published 10 September 2007.
Structure	Structures; LANL, KSL Site Support Services, Planning, Locating and Mapping Section; 06 January 2004; as published 10 September 2007.
TA boundary	Technical Area Boundaries; LANL, Site Planning & Project Initiation Group, Infrastructure Planning Division; 19 September 2007.
Unpaved road	Dirt Road Arcs; LANL, KSL Site Support Services, Planning, Locating and Mapping Section; 06 January 2004; as published 10 September 2007.
Vapor-monitoring well	Point Feature Locations of the Environmental Restoration Project Database; LANL, Environment and Remediation Support Services Division, EP2007-0754; 30 November 2007.

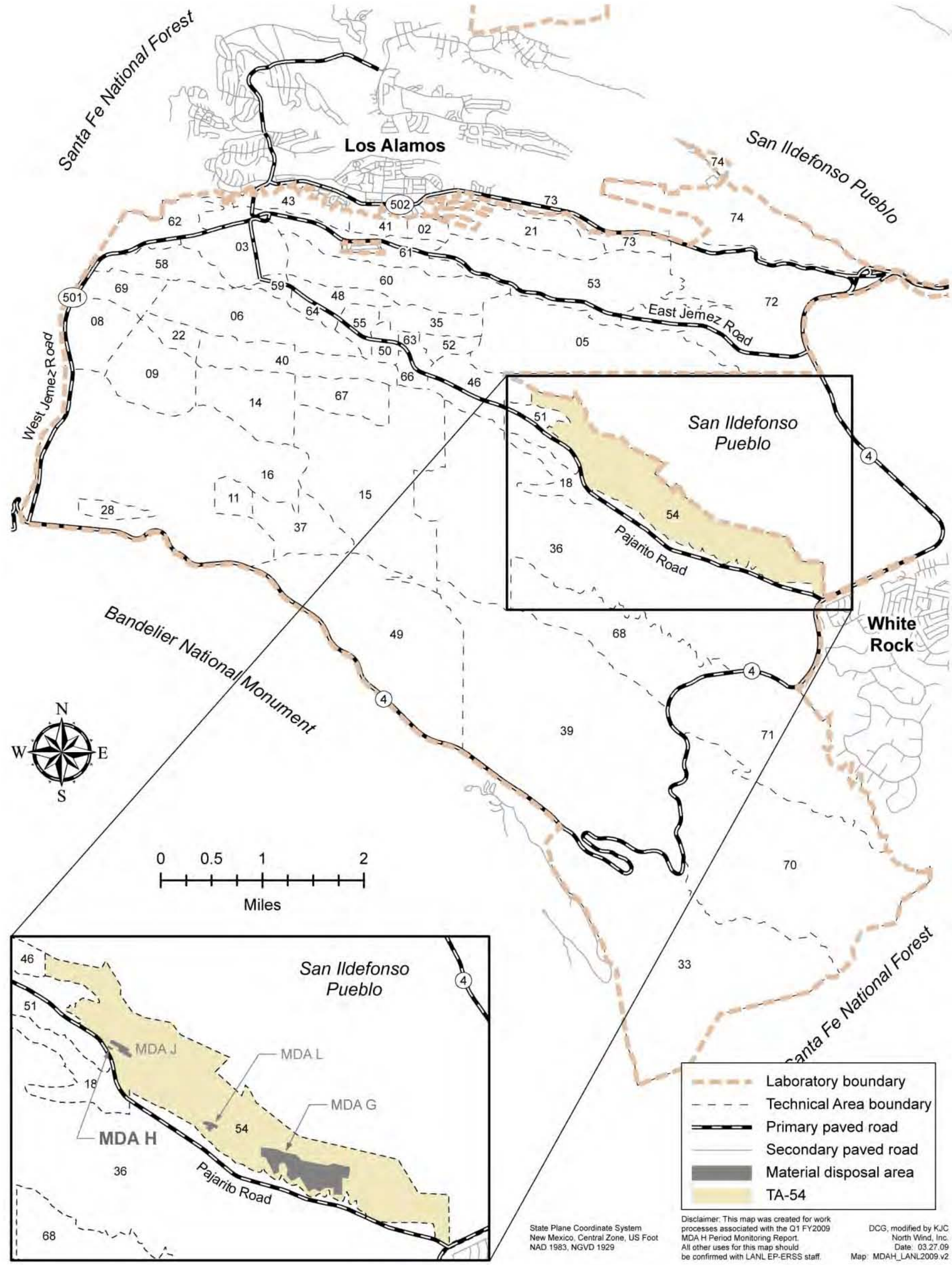

Figure 1.0-1 Location of MDA G with respect to Laboratory TAs and surrounding land holdings

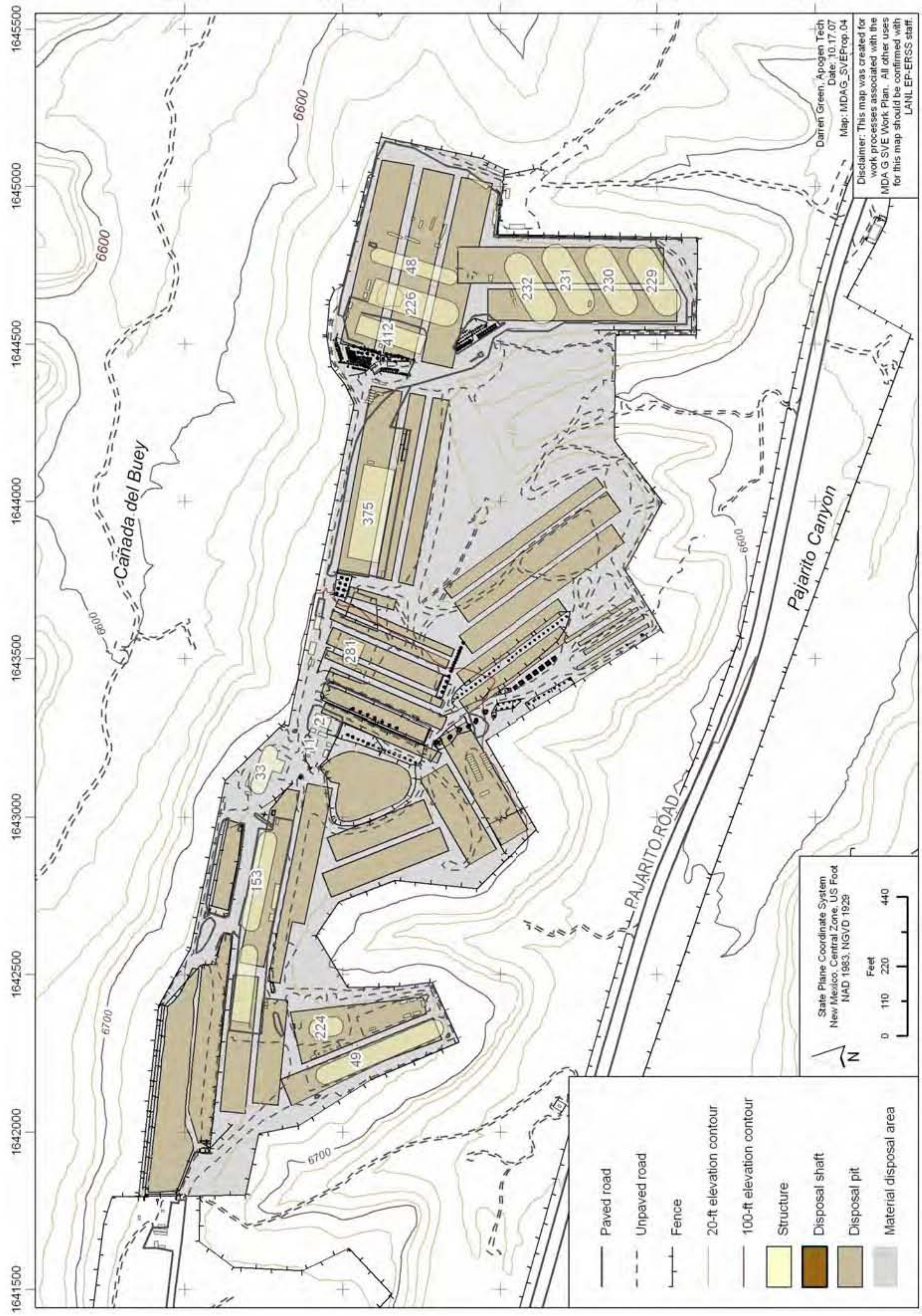

Figure 2.0-1 MDA G site map

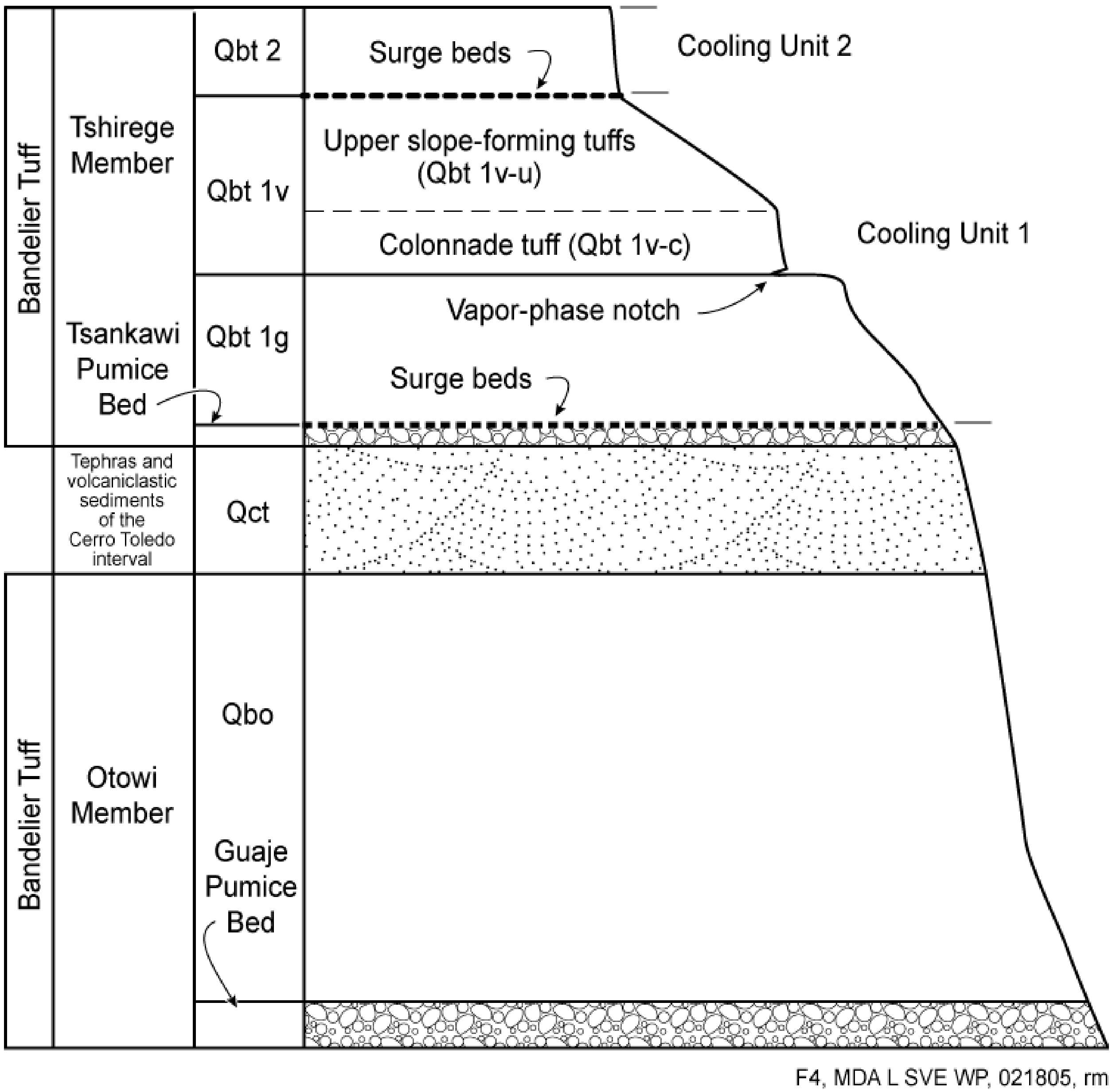

Figure 2.1-1 TA-54 site stratigraphy

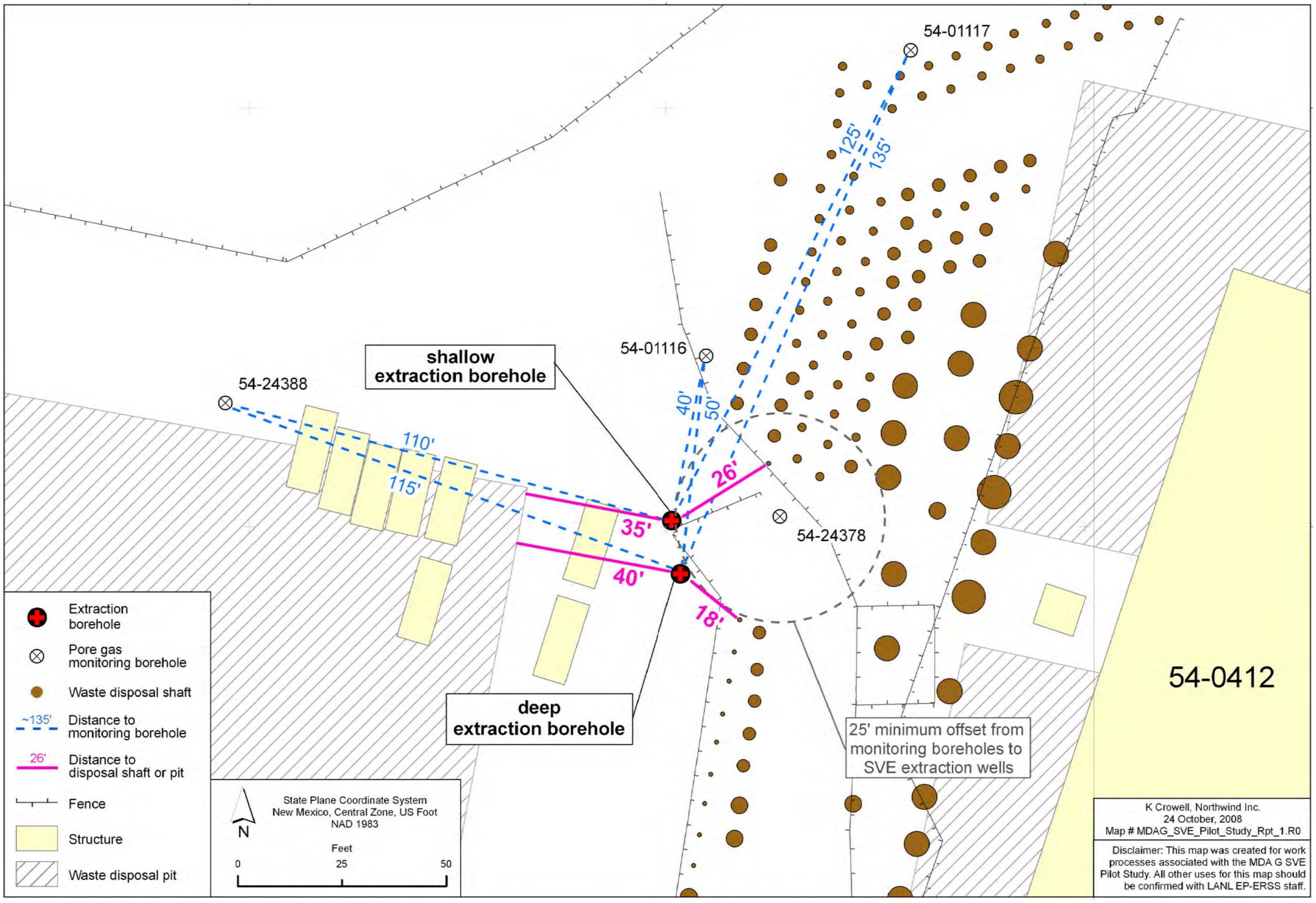

Figure 2.2-1 2008 MDA G SVE pilot-test site plan showing extraction and pore-gas monitoring boreholes

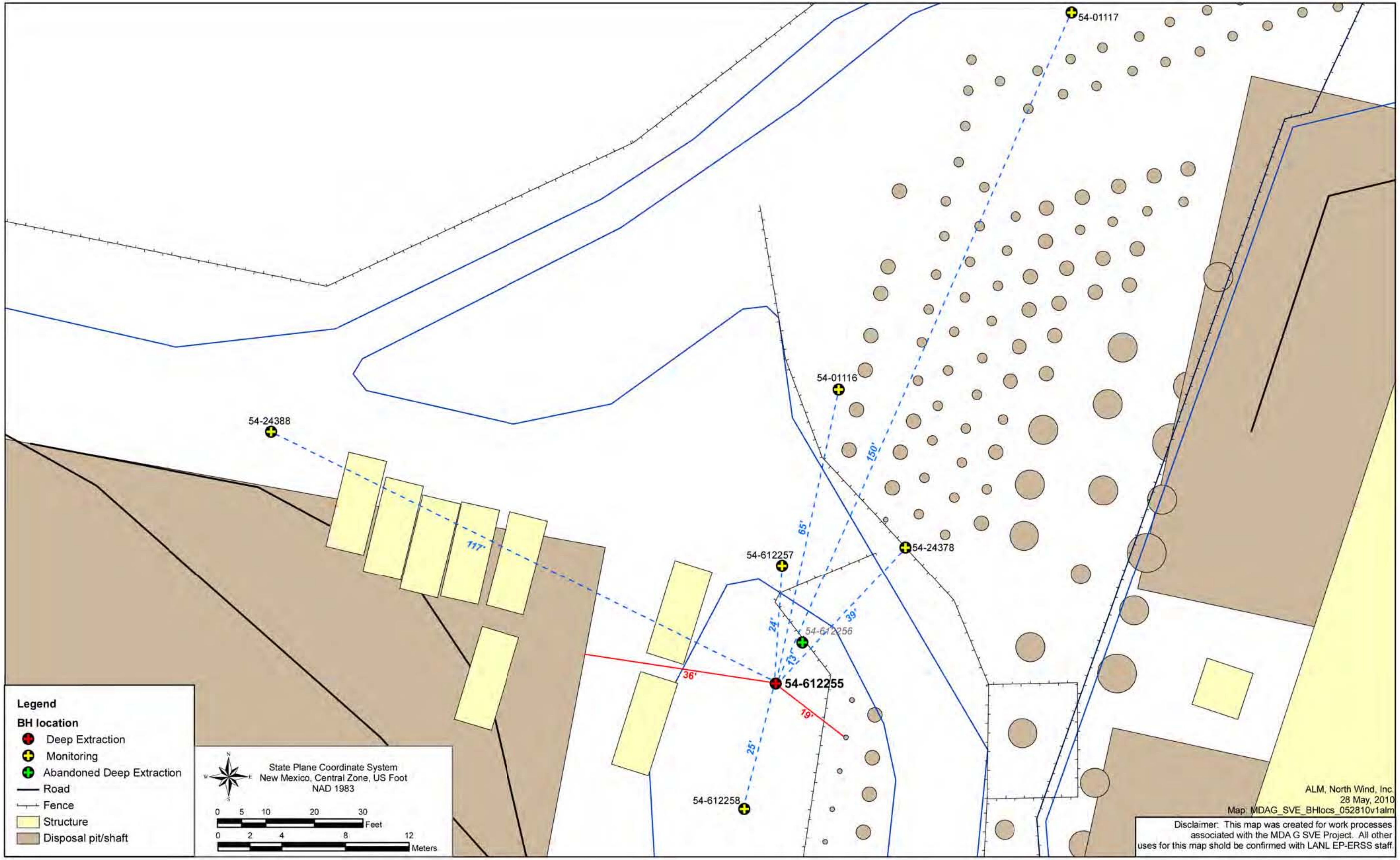

Figure 3.0-1 MDA G supplemental SVE pilot-test site plan showing extraction and pore-gas monitoring boreholes

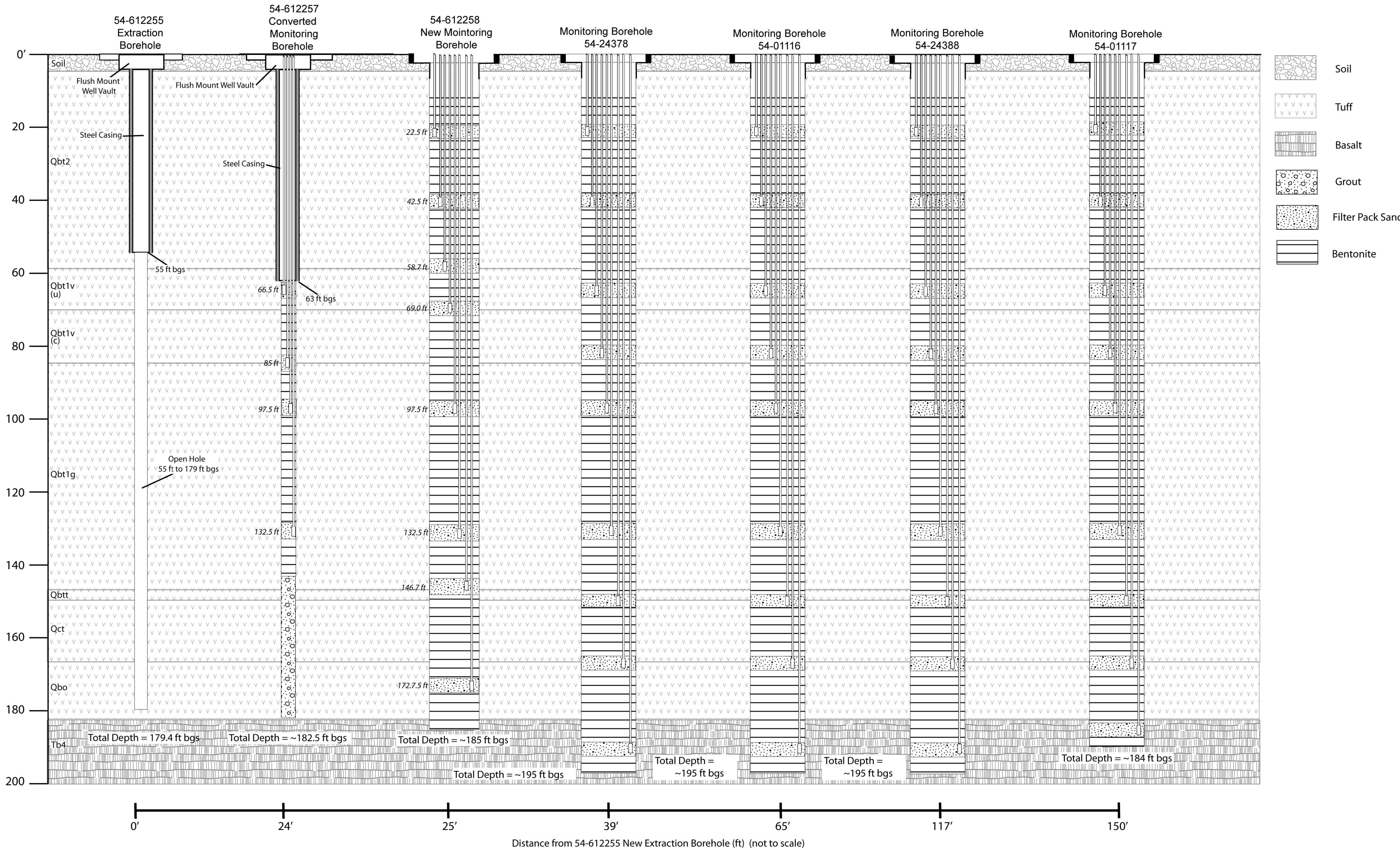

Figure 3.2-1 MDA G supplemental SVE pilot-test extraction and monitoring borehole construction details

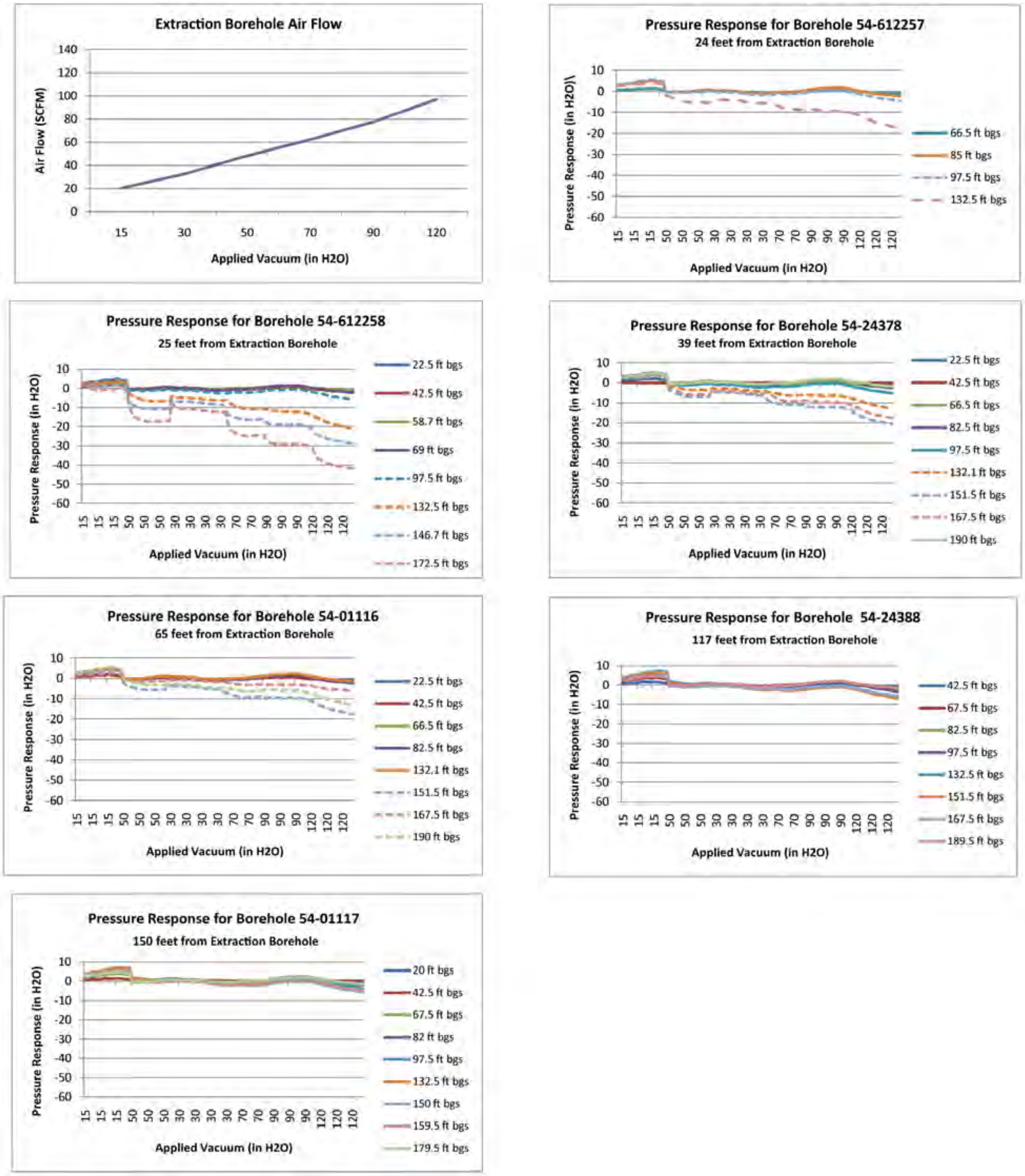

Figure 4.2-1 Results of the Qct pilot test, packer depth of 158.5 ft bgs

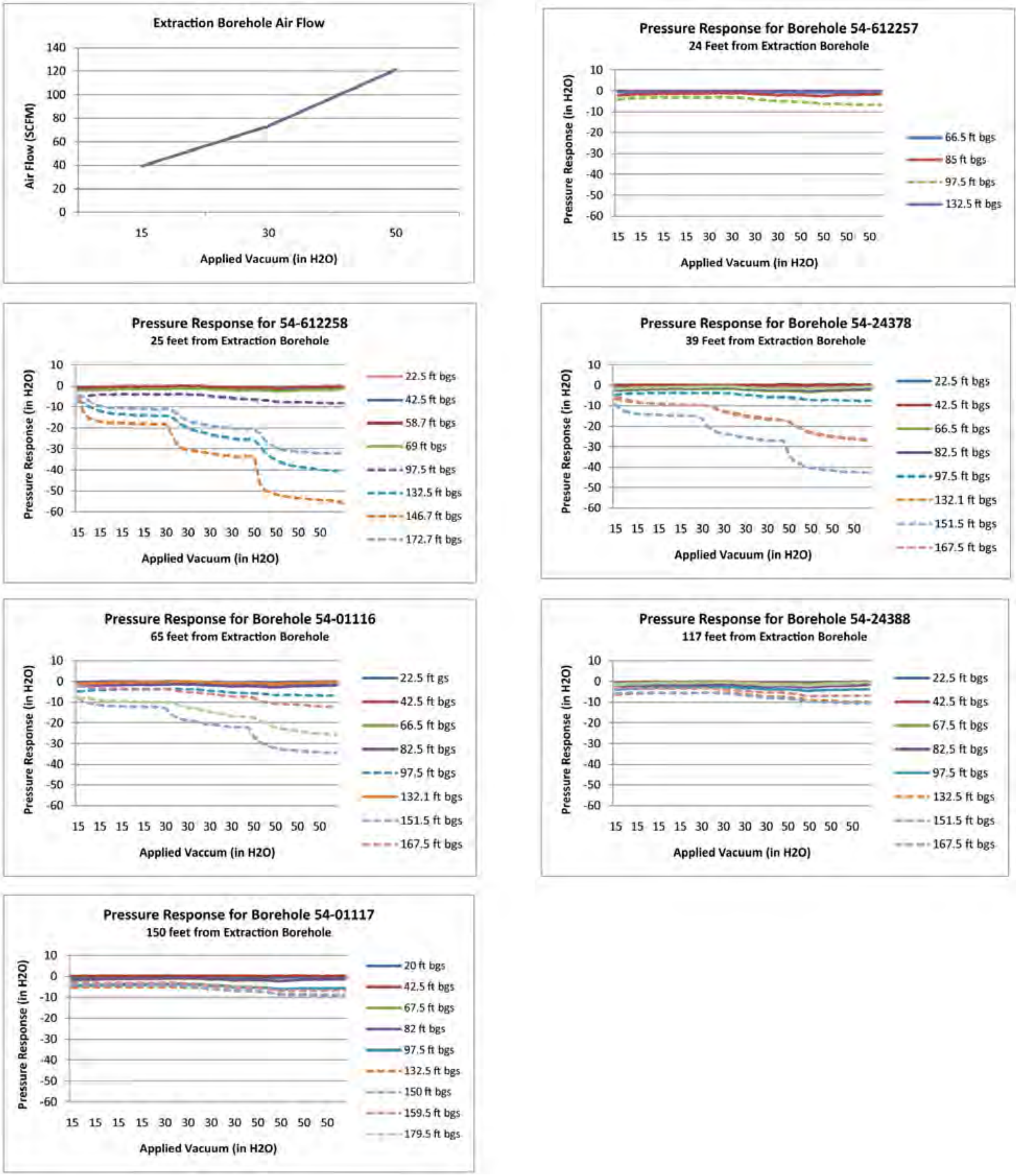

Figure 4.3-1 Results of the Qbtt/Qbt 1g pilot test, packer depth of 146.1 ft bgs

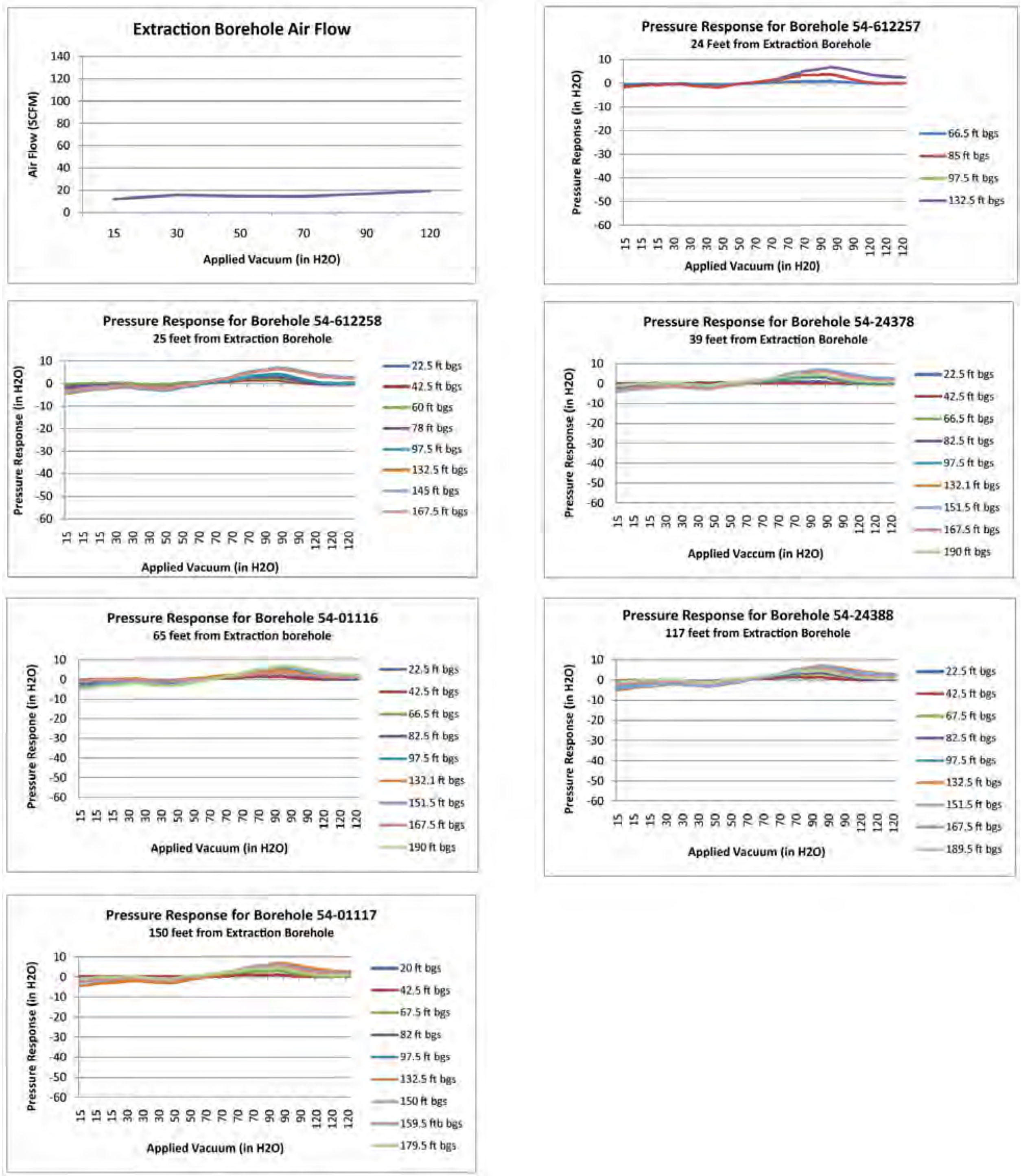

Figure 4.5-1 Results of the Qbt 1v-c/Qbt 1g pilot test, packer depth of 84.5 ft bgs

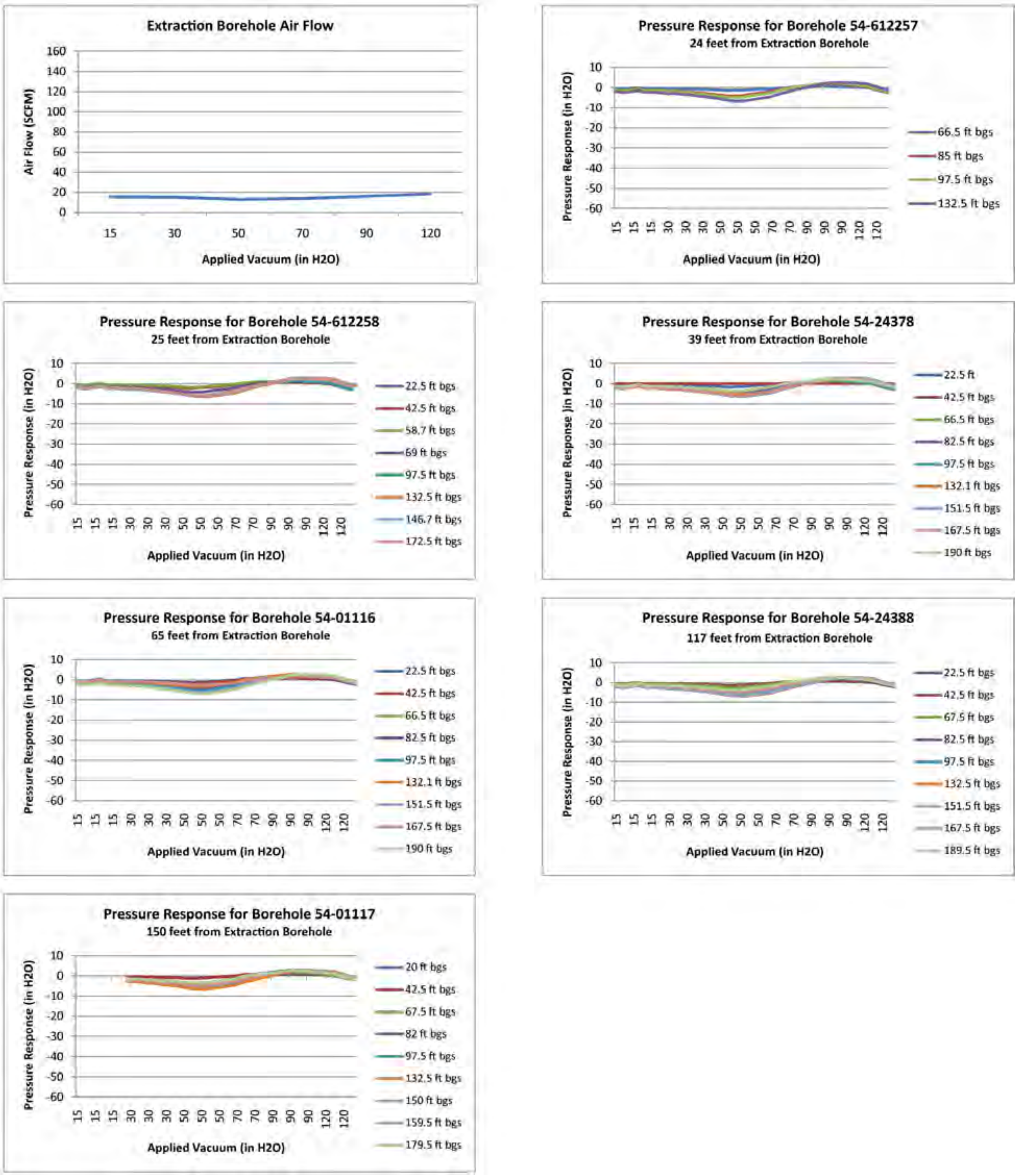

Figure 4.6-1 Results of the Qbt 1v-c pilot test, packer depth of 77.5 ft bgs

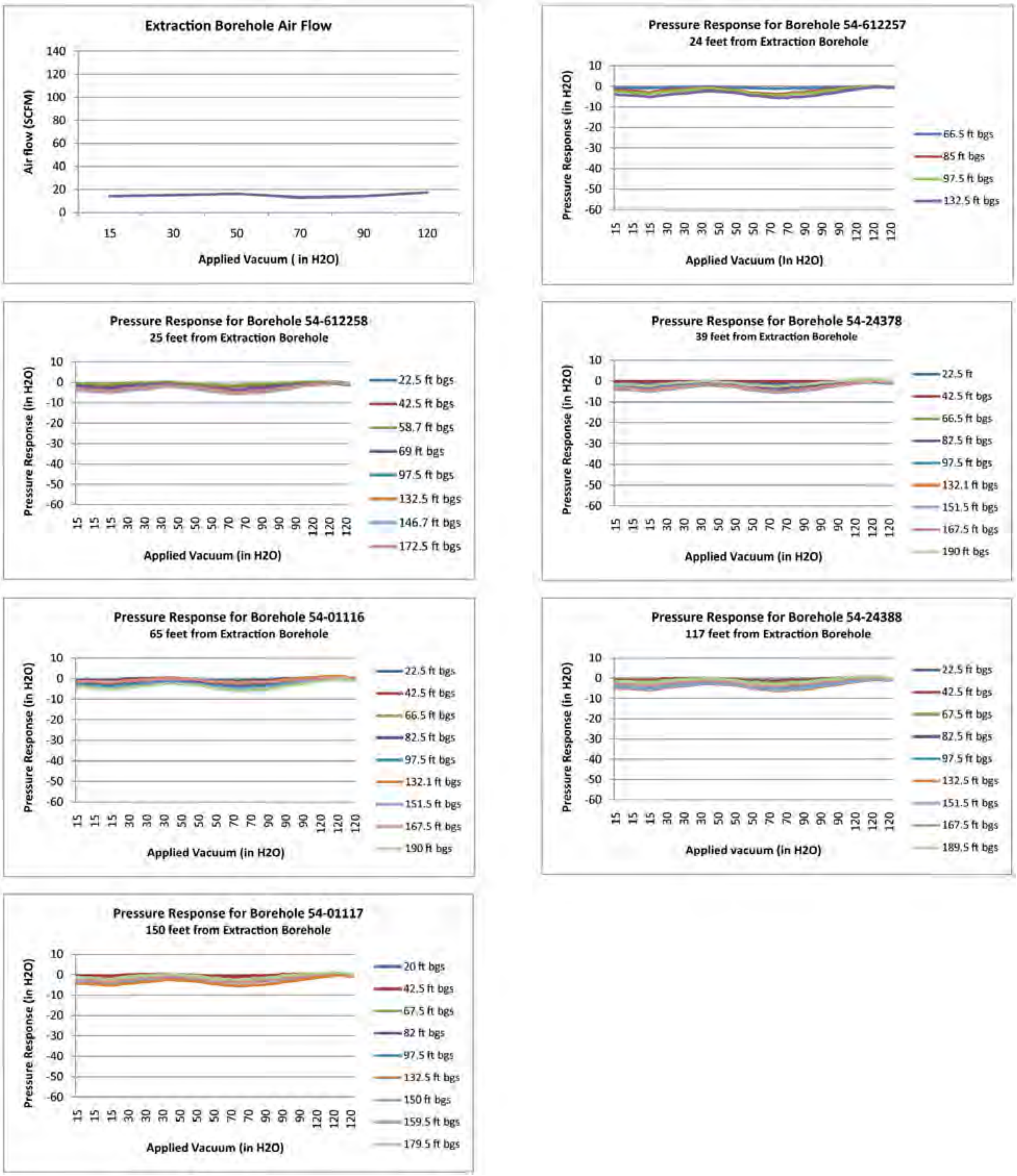

Figure 4.7-1 Results of the Qbt 1v-u/Qbt 1v-c pilot test, packer depth of 70 ft bgs

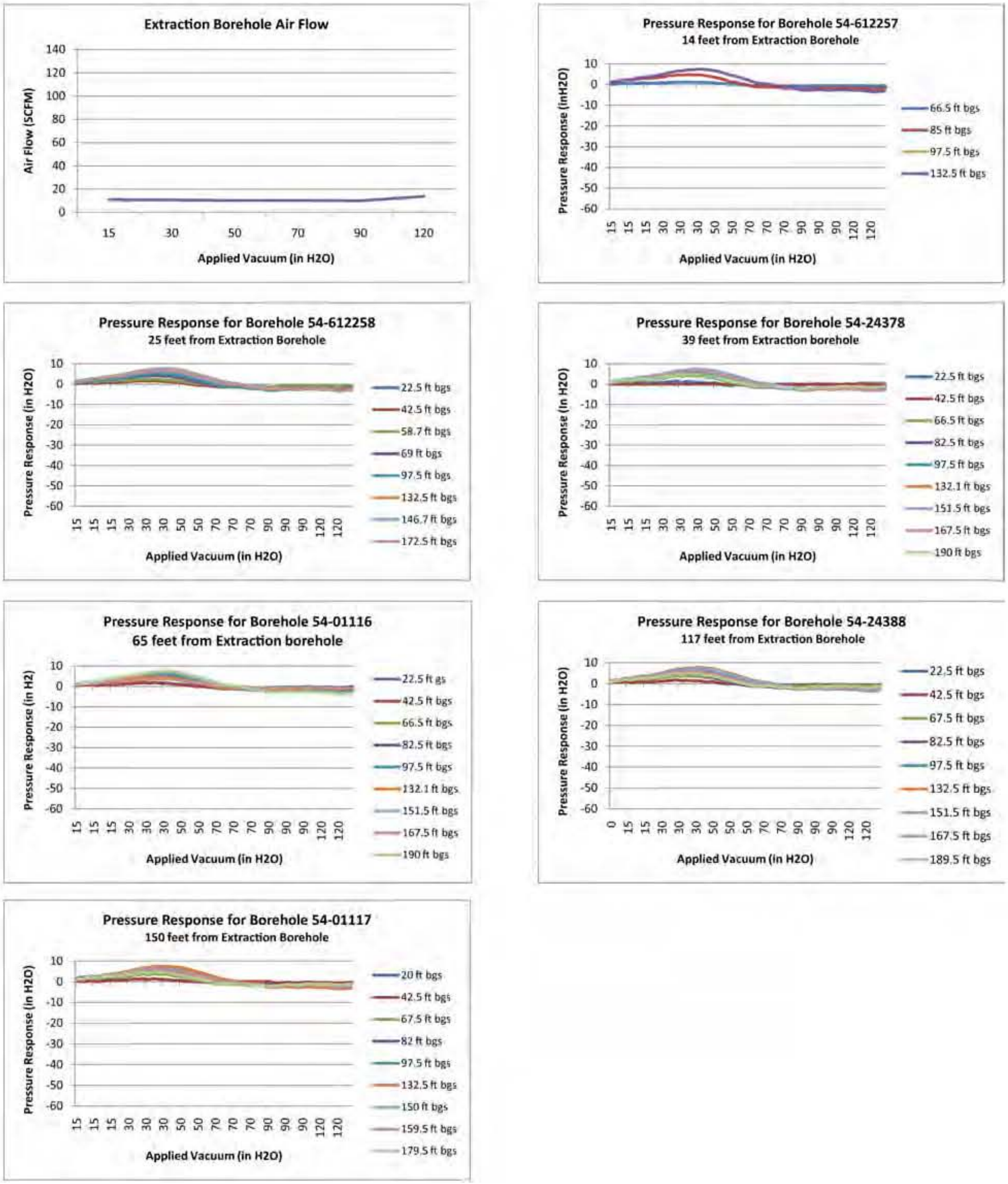

Figure 4.8-1 Results of the Qbt 1v-u pilot test, packer depth of 65 ft bgs

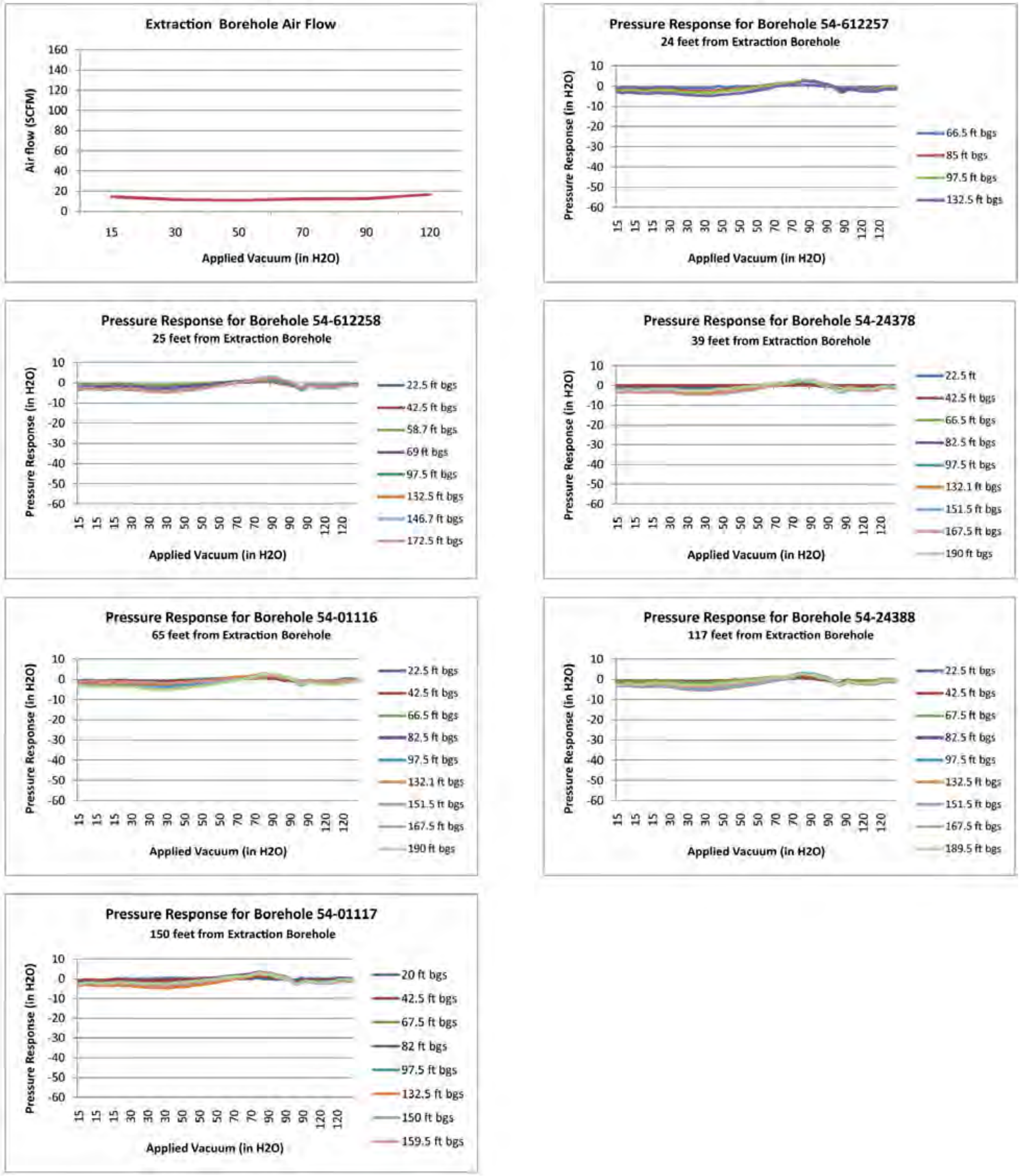

Figure 4.9-1 Results of the Qbt 2/Qbt 1v-c pilot test, packer depth of 59.5 ft bgs

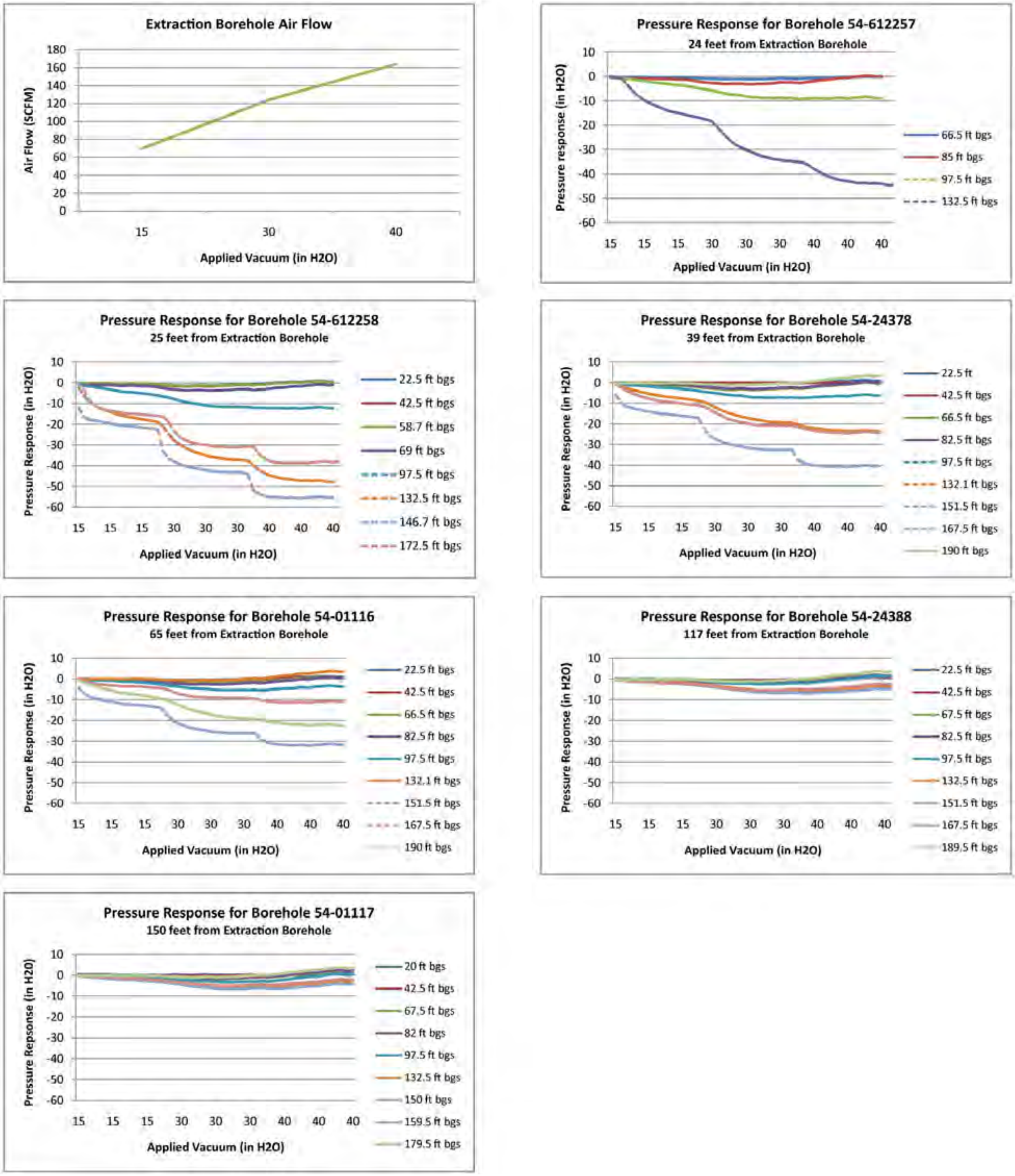

Figure 4.10-1 Results of the open-borehole pilot test, packer depth of 50 to 178 ft bgs

Table 3.2-1
Extraction Borehole Extraction Intervals and Corresponding Stratigraphy

Formation	Member	Unit	New Extraction Borehole 54-612255 Extraction Intervals[a] (ft bgs)
Bandelier Tuff	Tshirege	Qbt 2	53
		Qbt 2	n/a[b]
		Qbt 2/Qbt 1v-u contact	60
		Qbt 1v-u	65
		Qbt 1v-u/Qbt 1v-c contact	70
		Qbt 1v-c	77.5
		Qbt 1v-c/Qbt 1g contact	84.5
		Qbt 1g	136.5
		Qbt 1g	n/a
Bandelier Tuff	Tshirege	Qbt 1g/Qbtt contact	n/a
Cerro Toledo interval		Qct	158.5
Bandelier Tuff	Otowi	Qbo	n/a
Cerros del Rio basalt		Tb4	n/a

[a] Interval depth is the center of the extraction interval.

[b] n/a = Not applicable.

Table 3.3-1
Monitoring Borehole Port Depths and Corresponding Stratigraphy

Formation	Member	Unit	New Monitoring Borehole 54-612258 Port Depth (ft)	Converted Existing Shallow Extraction Borehole 54-612257 Port Depth (ft)	Existing Monitoring Borehole 54-24378 Port Depth (ft)	Existing Monitoring Borehole 54-01116 Port Depth (ft)	Existing Monitoring Borehole 54-27388 Port Depth (ft)	Existing Monitoring Borehole 54-01117 Port Depth (ft)
Bandelier Tuff	Tshirege	Qbt 2	22.5	n/a*	22.5	22.5	22.5	20
		Qbt 2	42.5	n/a	42.5	42.5	42.5	42.5
		Qbt 2/ Qbt 1v-u contact	58.7	n/a	n/a	n/a	n/a	n/a
		Qbt 1v-u	n/a	66.5	66.5	66.5	67.5	67.5
		Qbt 1v-u/ Qbt 1v-c contact	69	n/a	n/a	n/a	n/a	n/a
		Qbt 1v-c	n/a	n/a	82.5	82.5	82.5	82
		Qbt 1v-c/ Qbt 1g contact	n/a	85	n/a	n/a	n/a	n/a
		Qbt 1g	97.5	97.5	97.5	97.5	97.5	97.5
		Qbt 1g	132.5	132.5	132.1	132.5	132.5	132.5
Bandelier Tuff	Tshirege	Qbt 1g/ Qbtt contact	146.7	n/a	n/a	n/a	n/a	n/a
Cerro Toledo interval		Qct	n/a	n/a	151.5	151.5	151.5	150
Bandelier Tuff	Otowi	Qbo	172.7	n/a	167.5	167.5	167.5	159.5
Cerros del Rio basalt		Tb4	n/a	n/a	190	190	189.5	179.5

*n/a = Not applicable.

Table 3.4-1
Permeability Testing Intervals and Corresponding Stratigraphy

Formation	Member	Unit	New Extraction Borehole 54-612255 Testing Interval[a] (ft bgs)	Converted Existing Shallow Extraction Borehole 54-612257 Testing Interval (ft bgs)
Bandelier Tuff	Tshirege	Qbt 2	53	n/a[b]
		Qbt 2/ Qbt 1v-u Contact	60	n/a
		Qbt 1v-u	65	n/a
		Qbt 1v-u/ Qbt 1v-c Contact	70	n/a
		Qbt 1v-c	77.5	n/a
		Qbt 1v-c/ Qbt 1g Contact	84.5	n/a
		Qbt 1g	n/a	91
		Qbt 1g	136.5	96
Bandelier Tuff	Tshirege	Qbt 1g/ Qbtt Contact	146.1	n/a
Cerro Toledo interval		Qct	158.5	n/a
Bandelier Tuff	Otowi	Qbo	169.4	n/a
Cerros del Rio basalt		Tb4	n/a	n/a
Open Borehole		Qbt 2 through Qbo	50 to 179.4	n/a

[a] Interval depth is the center of the testing interval.

[b] n/a = Not applicable.

Appendix A

Acronyms and Abbreviations,
Metric Conversion Table, and Data Qualifier Definitions

A-1.0 ACRONYMS AND ABBREVIATIONS

B&K	Brüel and Kjær
bgs	below ground surface
CME	corrective measures evaluation
Consent Order	Complaince Order on Consent
DOE	Department of Energy (U.S.)
EPA	Environmental Protection Agency (U.S.)
GAC	granular activated carbon
hp	horsepower
HSA	hollow-stem auger
LANL	Los Alamos National Laboratory
LLW	low-level radioactive waste
MDA	material disposal area
NMED	New Mexico Environment Department
PCE	perchloroethylene
ppmv	parts per million by volume
RFI	Resource Conservation and Recovery Act facility investigation
ROI	radii of influence
RPF	Records Processing Facility
scfm	standard cubic feet per minute
SVE	soil-vapor extraction
TA	technical area
TCA	1,1,1-trichloroethane
TCE	trichloroethene
TD	total depth
TRU	transuranic
Vac	volt, alternating current
VOC	volatile organic compound

A-2.0 METRIC CONVERSION TABLE

Multiply SI (Metric) Unit	by	To Obtain U.S. Customary Unit
kilometers (km)	0.622	miles (mi)
kilometers (km)	3281	feet (ft)
meters (m)	3.281	feet (ft)
meters (m)	39.37	inches (in.)
centimeters (cm)	0.03281	feet (ft)
centimeters (cm)	0.394	inches (in.)
millimeters (mm)	0.0394	inches (in.)
micrometers or microns (µm)	0.0000394	inches (in.)
square kilometers (km^2)	0.3861	square miles (mi^2)
hectares (ha)	2.5	acres
square meters (m^2)	10.764	square feet (ft^2)
cubic meters (m^3)	35.31	cubic feet (ft^3)
kilograms (kg)	2.2046	pounds (lb)
grams (g)	0.0353	ounces (oz)
grams per cubic centimeter (g/cm^3)	62.422	pounds per cubic foot (lb/ft^3)
milligrams per kilogram (mg/kg)	1	parts per million (ppm)
micrograms per gram (µg/g)	1	parts per million (ppm)
liters (L)	0.26	gallons (gal.)
milligrams per liter (mg/L)	1	parts per million (ppm)
degrees Celsius (°C)	9/5 + 32	degrees Fahrenheit (°F)

A-3.0 DATA QUALIFIER DEFINITIONS

Data Qualifier	Definition
U	The analyte was analyzed for but not detected.
J	The analyte was positively identified, and the associated numerical value is estimated to be more uncertain than would normally be expected for that analysis.
J+	The analyte was positively identified, and the result is likely to be biased high.
J-	The analyte was positively identified, and the result is likely to be biased low.
UJ	The analyte was not positively identified in the sample, and the associated value is an estimate of the sample-specific detection or quantitation limit.
R	The data are rejected as a result of major problems with quality assurance/quality control (QA/QC) parameters.

Appendix B

Borehole Logs and Diagrams

Included in this appendix are the borehole logs and construction diagrams for extraction borehole 54-612255 (Attachment B-1), monitoring borehole 54-612258 (Attachment B-2), and converted monitoring borehole 54-612258 (Attachment B-3). Attachments B-1 through B-3 are included on CD.

Attachment B-1

Borehole Logs and Diagram for
Extraction Borehole 54-612255
(on CD included with this document)

Attachment B-2

Borehole Log and Diagram for
New Borehole 54-612258
(on CD included with this document)

Attachment B-3

Borehole Logs and Diagram for
Conversion Borehole 54-612257
(on CD included with this document)

Appendix C

Well Abandonment Details

The deep extraction borehole 54-612256 was abandoned on May 5 and 6, 2010, in accordance with section X.D of the Compliance Order on Consent (Consent Order).

Borehole 54-612256 was originally drilled in the fall of 2008 to a total depth of 185 ft below ground surface (bgs). The hole was subsequently cased from the ground surface to a depth of 161 ft bgs using 10-in. steel casing and grouted from 185 ft bgs to 177 ft bgs.

In order to accomplish well abandonment, the borehole was pressure grouted using a mixture of QUIKRETE (Portland Type I/II Cement) (47-lb bags), QUIK-GEL (a high-yield bentonite) (50-lb bags), and water. One-inch polyvinyl chloride tremie pipe was used to seal the borehole from the bottom of the well upward to the surface. Fifty bags of QUIKRETE and 4 bags of QUIK-GEL were mixed with 800 gal. of water for a total of 900 gal. of grout pumped into borehole 54-612256. Abandonment was performed in two phases. The first phase involved placing grout in the open interval from 177 ft bgs to approximately 160 ft bgs. This was done to allow for any settling that might occur. The second phase involved placing grout from the top of the first phase to the top of the casing at ground surface.

Appendix D

Supplemental Soil-Vapor Extraction
Pilot Test System Specifications, Data Logger Programs,
and Standard Operating Procedures

Included in this appendix are the soil-vapor extraction (SVE) system specifications and drawings (Attachment D-1), the programming language for the monitoring system data loggers (Attachment D-2), and the operational procedures used for performing permeability testing and the SVE test (Attachment D-3). Attachments D-1 through D-3 are included on CD.

Attachment D-1

System Specifications
(on CD included with this document)

Attachment D-2

Monitoring System Data Logger Programs
(on CD included with this document)

Attachment D-3

Standard Operating Procedures
(on CD included with this document)

Appendix E

Mass and Distribution of TCA and TCE
in the Subsurface at Material Disposal Area G

E-1.0 INTRODUCTION

This appendix presents estimates for the distributions and masses of trichloroethane[1,1,1-] (TCA) and trichloroethene (TCE) in the subsurface beneath Material Disposal Area G (MDA G). These estimates are based on soil vapor data collected during fourth-quarter (4Q) sampling in fiscal years 2008 (FY08) and 2009 (FY09). Knowing both the distribution and the mass of volatile organic chemicals (VOCs) is important information for designing a potential soil vapor extraction (SVE) system to define the number and placement of wells and to estimate off-gas treatment requirements. The most recent pore-gas sampling data from MDA G (4QFY09) are used to estimate the total masses of TCA and TCE at the site. In addition, data from two time periods are analyzed to provide insight into the rebound of the TCA and TCE vapor plumes following the first SVE test run at MDA G during 2008 (LANL 2009, 105112). The 4QFY08 data were collected just before that test for monitoring locations near the test area; the 4QFY09 data were collected approximately 10 months after the test was completed.

Two different approaches are used for calculating the TCA and TCE masses at MDA G. Both approaches estimate the VOC mass included in pore gas as vapors, dissolved into pore water, and adsorbed onto solid media, as described in Section E-2.0.

1. The first approach calculates the current masses in the MDA G TCA and TCE plumes, based on the most recent vapor monitoring data, in areas where the vapor concentration exceeds 10 times the screening value. The screening value is the equivalent vapor concentration that would be in equilibrium with a water concentration at the maximum contaminant level based on Henry's law partitioning. The screening value comparison is described in detail in the periodic monitoring reports (PMRs) for vapor-sampling activities at the Laboratory (e.g., LANL 2010, 108496). For the purposes of developing site-scale mass estimates, those regions with concentrations exceeding 10 times the screening value are considered. For this demonstration, that mass might be considered as a cleanup goal if SVE were employed. The vapor concentrations that are equivalent to 10 times the screening limits are 423,000 $\mu g/m^3$ for TCA and 20,000 $\mu g/m^3$ for TCE (LANL 2010, 108496).

2. The second approach calculates the total TCA and TCE masses within a 150-ft radius of the shallow extraction borehole, which was the projected radius of influence of the previous (2008) SVE test (LANL 2009, 105413). This estimate does not use 10 times screening value. Rather, it demonstrates the effect that the 2008 extraction test had on the entire masses of TCA and TCE within the radius of influence of the test using data that were collected immediately before the test and approximately 1 yr after the test.

E-2.0 MATHEMATICAL APPROACH

VOCs present in subsurface media will be in pore gas as vapors, dissolved into pore water, and adsorbed onto solid media. Detected concentrations of VOCs in pore gas are orders of magnitude less than the vapor pressures of these chemicals, which is evidence that VOCs are not present as a separate, nonaqueous liquid phase. Several equilibrium partitioning constants describe the relationship between the concentrations of chemicals in these various phases. These constants can be used to develop an expression for the overall concentration of VOC in the bulk medium (i.e., tuff) as a function of the concentration in the vapor phase. Measured vapor phase concentrations can then be used to calculate the bulk concentration in tuff, which can be used to estimate the overall mass of the inventory based on an assumed volume of affected media.

The first partitioning constant used is the Henry's law constant. The dimensionless form of Henry's law constant describes the equilibrium relationship between the volumetric concentrations of chemicals in air and in water:

$$H' = C_{air} / C_{water} ,$$ **Equation E-1**

where H' = the dimensionless form of Henry's law constant,

C_{air} = the volumetric concentration of chemical in air (M/L^3), and

C_{water} = the volumetric concentration of chemical in water (M/L^3).

Rearranging Equation E-1 gives

$$C_{water} = C_{air} / H' .$$ **Equation E-2**

The second partitioning constant used is the distribution coefficient. The distribution coefficient describes the equilibrium relationship between the concentrations of chemicals dissolved in water and adsorbed on solids:

$$K_d = C_{solid} / C_{water} ,$$ **Equation E-3**

where K_d = the distribution coefficient (L^3/M) and

C_{solid} = the mass concentration of contaminant in soil or tuff (M/M).

For organic chemicals, the adsorption of chemicals onto the solid phase is strongly influenced by the amount of organic carbon present in the solid. The distribution coefficient can be estimated from the organic carbon distribution coefficient and the fraction of organic carbon in tuff:

$$K_d = K_{oc} \ f_{oc} ,$$ **Equation E-4**

where K_{oc} is the organic carbon distribution coefficient (L^3/M) and

f_{oc} is the fraction of organic carbon in tuff (M/M).

Rearranging Equation E-3 and substituting Equation E-2 and Equation E-4 gives

$$C_{solid} = K_{oc} \ f_{oc} \ C_{air} / H' .$$ **Equation E-5**

The bulk concentration of chemical in tuff is equal to the total mass of chemical in all three phases per unit mass of tuff:

$$C_{bulk} = \frac{M_{air} + M_{water} + M_{solid}}{M_{soil}} \quad , \qquad \textbf{Equation E-6}$$

where C_{bulk} = the bulk concentration of chemical in tuff (M/M),

M_{air} = the mass of chemical present in the vapor phase in pore gas (M),

M_{water} = the mass of chemical present in the liquid phase in pore water (M),

M_{solid} = the mass of chemical present in the solid phase in tuff (M), and

M_{soil} = the mass of the soil or tuff (M).

The mass of chemical present in the vapor phase in pore gas is equal to the product of the concentration in air and the volume of air. The latter is equal to the product of the volumetric air-filled porosity and the volume of tuff. The mass of contaminant present in the liquid phase in pore water is equal to the product of the concentration in water and the volume of water. The latter is equal to the product of the volumetric water-filled porosity and the volume of tuff. The mass of contaminant present in the solid phase in tuff is equal to the product of the concentration in the solid phase and the mass of tuff. The latter is equal to the product of the volume of tuff and the bulk density of tuff. Using the relationships described above, Equation E-6 can be rewritten as

$$C_{bulk} = \frac{\left(C_{air}\, V_{soil}\, \theta_{air}\right) + \left(C_{air}\, V_{soil}\, \theta_{water} \big/ H'\right) + \left(C_{air}\, K_{oc}\, f_{oc}\, V_{soil}\, \rho_{soil} \big/ H'\right)}{V_{soil}\, \rho_{soil}} \quad , \qquad \textbf{Equation E-7}$$

where V_{soil} = the volume of tuff (L^3),

θ_{air} = the volumetric air-filled porosity (L^3/L^3),

θ_{water} = the volumetric water-filled porosity (L^3/L^3), and

ρ_{soil} = the bulk density of tuff (M/L^3).

Equation E-7 can be simplified to

$$C_{bulk} = \frac{C_{air}\left(\theta_{air} + \theta_{water} \big/ H' + \left(K_{oc}\, f_{oc}\, \rho_{soil}\right) \big/ H'\right)}{\rho_{soil}} \quad . \qquad \textbf{Equation E-8}$$

Equation E-8 gives the bulk concentration of VOC in tuff as a function of the pore-gas concentration and properties of the chemical and tuff. The sources of the data used in Equation E-8 and any associated assumptions are described below.

- C_{air} – The pore-gas monitoring results provide the concentration of a particular VOC measured at each sampling point. In these examples, the concentrations of TCA and TCE measured during 4QFY08 and 4QFY09 vapor sampling at MDA G were used (LANL 2010, 108496). Both analytical data and field-screening data were used, as described in section E-3.0.

- θ_{air} – The volumetric air-filled porosity depends on the total porosity and moisture content of the tuff ($\theta_{air} = porosity - \theta_{water}$), both of which vary depending on geologic unit and depth. The porosity and volumetric moisture content used in this analysis are presented in Table E-1. These values were selected as being representative of tuff at MDA G (Hollis et al. 1997, 063131).
- θ_{water} – The volumetric water content varies depending on the physical properties of the geologic unit (Table E-1).
- H' and K_{oc} – The Henry's law constant and organic carbon distribution coefficient are physical properties of the VOC and were obtained from the New Mexico Environment Department (NMED) soil-screening-level technical background document (NMED 2009, 106420). The values used for H' are 0.705 and 0.4 for TCA and TCE, respectively. The values used for K_{oc} are 48.6 and 107 L/kg for TCA and TCE, respectively.
- f_{oc} – The fraction of organic carbon depends on the amount of organic matter present in the tuff and varies depending on the amount of weathering and biological activity. A single value of 0.0005 (0.05%) was assumed to be representative of tuff in the subsurface beneath MDA G. This value is a factor of 3 less than the representative value for soil presented in NMED (2009, 106420) and reflects the lower organic content of tuff.
- ρ_{soil} – The bulk density depends on the total porosity of the tuff and the density of the solids composing the tuff and varies depending on geologic unit. Table E-1 lists the values used for MDA G (Hollis et al. 1997, 063131).

E-3.0 METHODOLOGY

Pore-gas concentrations are used as input to Equation E-8 to estimate the masses of TCA and TCE at MDA G using the two approaches described in section E-1.0. The following steps and assumptions were used to calculate the estimates:

1. Both analytical data (pore-gas samples collected with SUMMA canisters and analyzed at an analytical laboratory) and field-screening data measured with the Brüel and Kjær (B&K) type 1302 multigas photoacoustic analyzer were combined to obtain the pre- and post- SVE pilot-test data sets. Table E-2 shows the subsurface vapor-sampling locations available at MDA G. Analytical samples were collected at the locations shown in bold text, and field-screening data are available at nearly all locations. Augmenting the analytical data with the field-screening data, therefore, provides a much larger data set. Ports with paired data sets for sampling events from July 2007 through August 2009 were used to develop correlations between screening and analytical data so that screening data could be corrected and used in locations where analytical data were not available. Figures E-1 and E-2 show the correlations developed for TCA and TCE, respectively. The data sets for 4QFY08 and 4QFY09 MDA G SVE data were used to develop the mass estimates presented below; the data CD from the 4QFY09 MDA G vapor PMR (LANL 2010, 108496) was used for this exercise. For those sampling ports where both analytical data (SUMMA samples) and field data are available, the analytical data are considered to be more accurate and are used for the analyses.

2. The combined pore-gas data sets for each time period were imported to the EarthVision software package (Dynamic Graphics, 2009) and interpolated to three-dimensional (3-D) grids representing the subsurface vapor-phase distributions beneath MDA G. Numerous simulations were performed to obtain the optimal set of gridding parameters resulting in plume distributions that best honored the data while providing relatively conservative estimates of plume connectivity

and therefore contaminant mass. The screening data provided such a high density of data down each borehole that not all points could be perfectly honored without imposing a horizontal bias to the plumes that would result in unrealistic lenticular distributions and consequently non-conservative mass estimates. Forty-six simulations were performed for each analyte for one time period to quantify the uncertainty in the mass estimates associated with the uncertainty in plume shape resulting from the different gridding parameters.

3. Finally, the total mass, from all three phases of TCA and TCE, was calculated by intersecting the best estimates of plume distribution with an EarthVision 3-D geologic framework model for MDA G and using the results as input to Equation E-8. Each of the 3-D plumes was discretized into numerous concentration isoshells with geologic zone information attached. The intersections of these plumes with a 150-ft-radius cylinder representing the SVE pilot area were also labeled for the purpose of isolating the impact of the pilot test on plume mass. The volumes of each isoshell were multiplied by the average concentration for that shell, the strata-specific parameters of Table E-1, and the appropriate unit conversion factors to obtain the total mass of each analyte in kg.

E-4.0 RESULTS

This section includes several views of the modeled 3-D vapor-plume distributions for TCA and TCE as well as the mass estimates derived from the combination of those distributions with the overlapping geologic framework. Plan-view and cross-sectional figures illustrating the current lateral and vertical extents of TCA are presented in Figures E-3 and E-4, respectively. Corresponding views of TCE are presented in Figures E-5 and E-6. Only the portion of the plumes exceeding 10 times the Henry's-law-based screening value are depicted in each figure as described above. The concentration contours shown in the plan views define the extents of the TCA and TCE plumes over all depths rather than showing the contours at a given elevation.

Two areas of elevated TCA concentrations were identified; each defined by 1 to 2 boreholes with maximum concentrations of approximately 20 times the screening value of 42,300 µg/m^3. Figure E-3 shows a western lobe of the TCA plume centered over disposal pits 29 and 30. This area of elevated concentration is defined by monitoring well 54-24370 and is constrained to the south and east by three adjacent monitoring wells. The eastern lobe overlaps disposal pits 2, 4, 5, and 6 and is constrained to the north, south, and east. Figure E-4 shows that both plumes are constrained to the upper two-thirds of the Bandelier Tuff beneath MDA G, within the Tshirege Member. The western lobe is defined primarily by a single point at a depth of 72.5 ft. The eastern lobe is based on several points that show a decreasing trend culminating in concentrations less than the screening value by the terminal depth of approximately 200 ft.

Figure E-5 illustrates western and eastern vapor plumes of TCE in the subsurface beneath MDA G that do not appear to be collocated with TCA. The TCE lobes are somewhat larger than those of TCA because of concentrations that are close to 35 times higher than the screening value of 2,000 µg/m^3. An additional area of elevated TCE was identified beneath pit 3 at about two-thirds of the way along horizontal monitoring well 54-22116. The magnitude of this concentration there is roughly the same as for the other two plumes, but the lateral extent is much lower because of the high horizontal data density. Figure E-6 shows that elevated levels of TCE occur to slightly deeper depths but that the plumes are still restricted to the Tshirege member of the Bandelier Tuff, and the concentration gradients still decrease downward and culminate in concentrations less than the screening value by terminal depths of approximately 300 ft.

Figure E-7 provides a view of the overlapping areal extents affected by TCA and TCE concentrations that exceed 10 times the screening value. The area within these contour intervals is equivalent to 27 acres (1.2 x 10^6 ft^2). This information is used in section 5 of the main text to provide a preliminary design for a vapor extraction network.

Mass estimates were calculated for the current (4QFY09 data) plume distributions depicted in Figures E-3 through E-6 and are presented in Table E-3. These estimates account for only the mass within the zones having vapor-phase concentrations of 10 times the screening value or greater and account for all 3 phases (pore gas, pore water, and adsorbed). The estimated subsurface masses are 210 and 79 kg for TCA and TCE, respectively. Despite the greater overall extent of the TCE plumes, the overall mass of TCE is just over one-third of that determined for TCA. The breakdown of mass by geology reiterates that approximately 95% of the mass is within the Tshirege Member of the Bandelier Tuff.

Figures E-8 and E-9 show the vapor-phase distributions of TCA near the extraction area of the 2008 SVE pilot test for data collected pre- and post-test. This figure shows that the maximum concentration within the test area decreased from over 30 times the screening value to between 20 and 25 times the screening value. The estimated masses of TCA both pre- and post-test are presented in Table E-4. TCE was detected at only low levels within the SVE pilot-test area and is therefore not included in the comparison. Table E-4 shows that 10 months after the 2008 SVE pilot test, the TCA mass in the affected area remains reduced by approximately 44% compared with the pretest mass.

Note that there is an uncertainty of ±15% associated with all mass estimates. This value was obtained through analysis of the numerous simulations performed to optimize the gridding parameters mentioned in section E-3.0. The analysis revealed that 80% of the additional TCA mass estimates and 100% of the additional TCE mass estimates fell within 15% of the values presented in Tables E-3 and E-4.

E-5.0 REFERENCES

The following list includes all documents cited in this appendix. Parenthetical information following each reference provides the author(s), publication date, and ER ID. This information is also included in text citations. ER IDs are assigned by the Environmental Programs Directorate's Records Processing Facility (RPF) and are used to locate the document at the RPF and, where applicable, in the master reference set.

Copies of the master reference set are maintained at the NMED Hazardous Waste Bureau and the Directorate. The set was developed to ensure that the administrative authority has all material needed to review this document, and it is updated with every document submitted to the administrative authority. Documents previously submitted to the administrative authority are not included.

Hollis, D., E. Vold, R. Shuman, K.H. Birdsell, K. Bower, W.R. Hansen, D. Krier, P.A. Longmire, B. Newman, D.B. Rogers, and E.P. Springer, March 27, 1997. "Performance Assessment and Composite Analysis for Los Alamos National Laboratory Material Disposal Area G," Rev. 2.1, Los Alamos National Laboratory document LA-UR-97-85, Los Alamos, New Mexico. (Hollis et al. 1997, 063131)

LANL (Los Alamos National Laboratory), January 2009. "Pilot Test Report for Evaluating Soil-Vapor Extraction at Material Disposal Area G at Technical Area 54, Revision 1," Los Alamos National Laboratory document LA-UR-09-0565, Los Alamos, New Mexico. (LANL 2009, 105112)

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NMED (New Mexico Environment Department), August 2009. "Technical Background Document for Development of Soil Screening Levels, Revision 5.0," New Mexico Environment Department, Hazardous Waste Bureau and Ground Water Quality Bureau Voluntary Remediation Program, Santa Fe, New Mexico. (NMED 2009, 106420)

Springer, E.P., 2005. "Statistical Exploration of Matrix Hydrologic Properties for the Bandelier Tuff, Los Alamos, New Mexico," *Vadose Zone Journal,* Vol. 4, pp. 505–521. (Springer 2005, 098534)

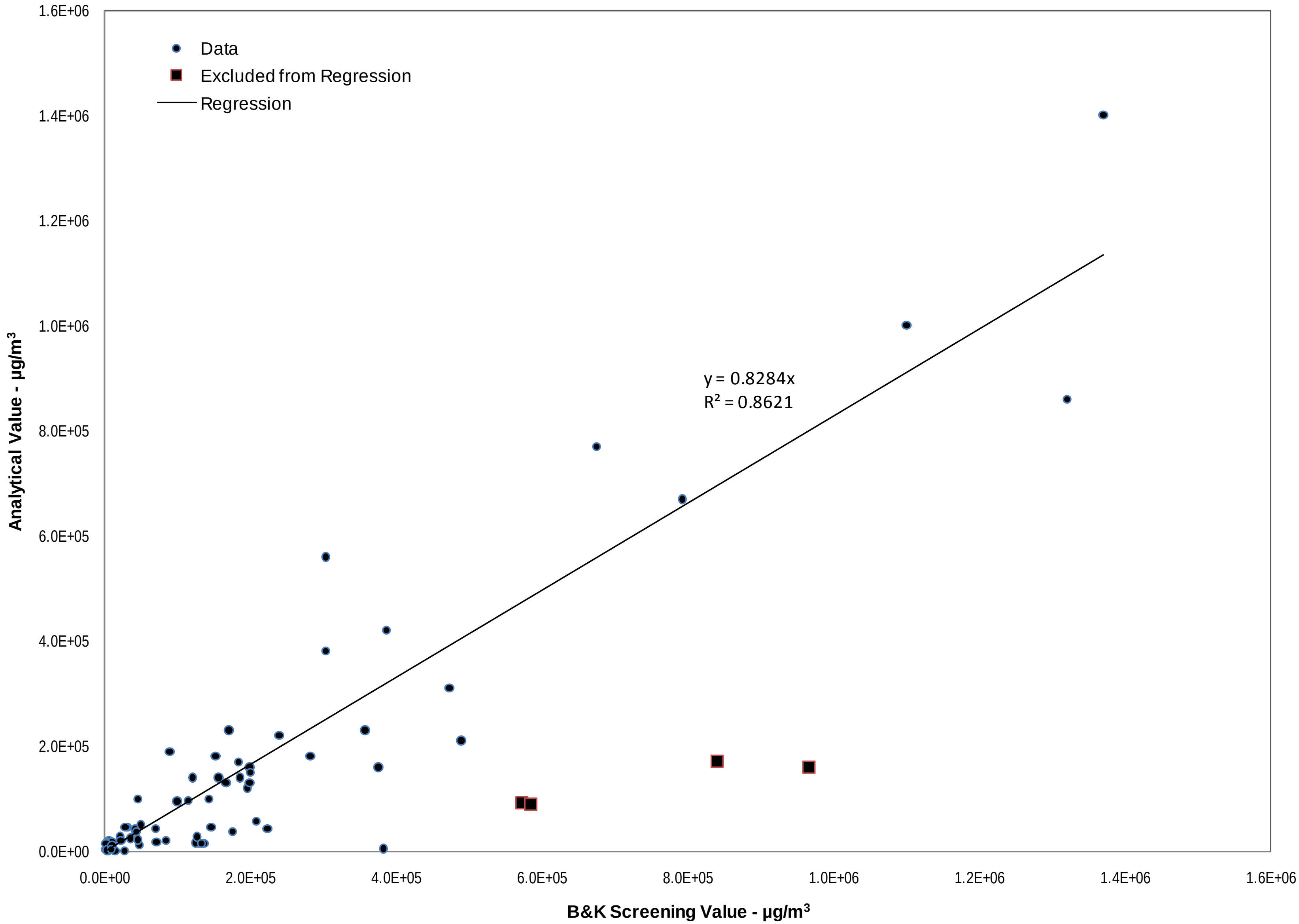


Figure E-1 Correlation between field-screening and analytical data for TCA

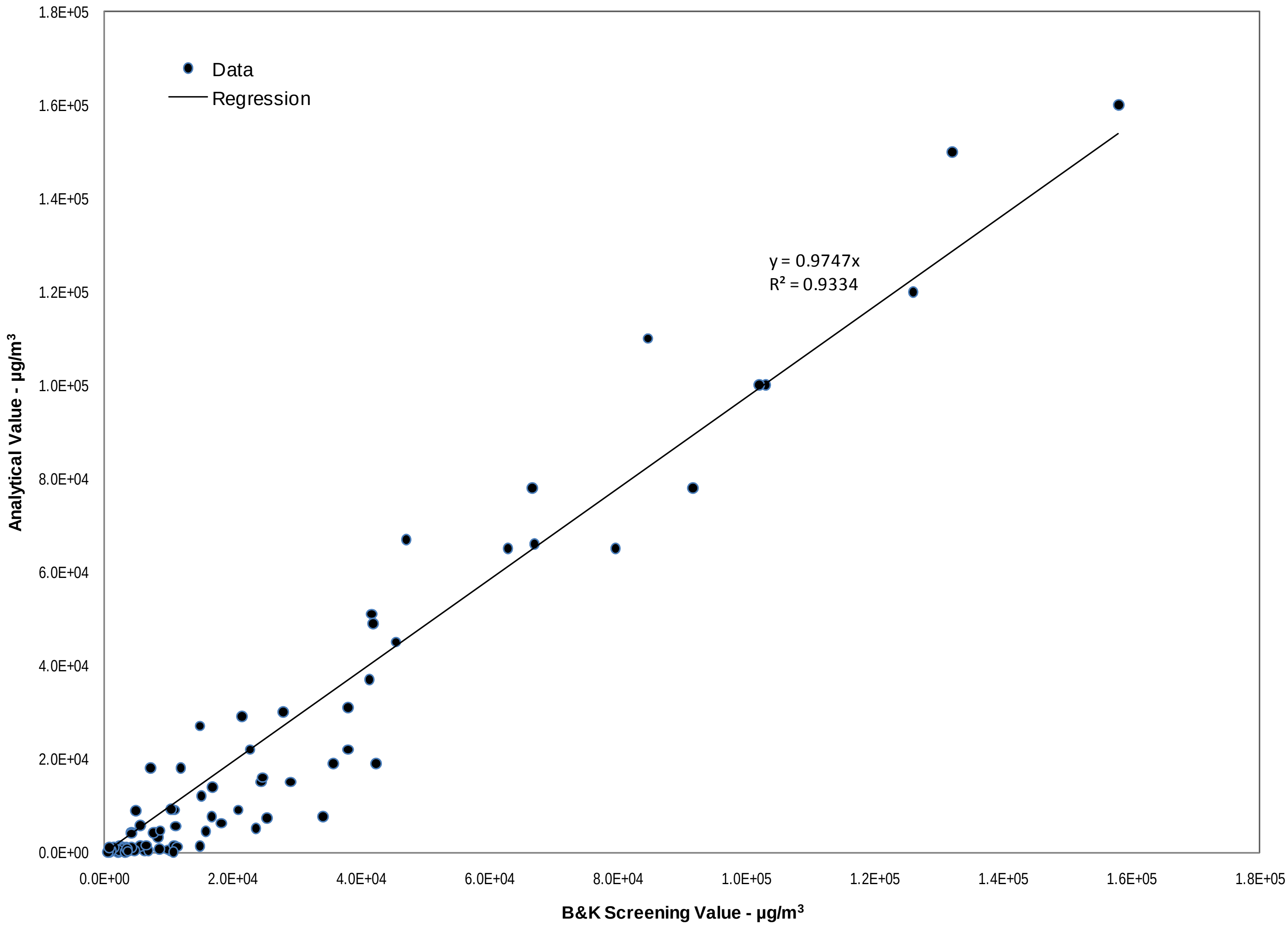


Figure E-2 Correlation between field-screening and analytical data for TCE

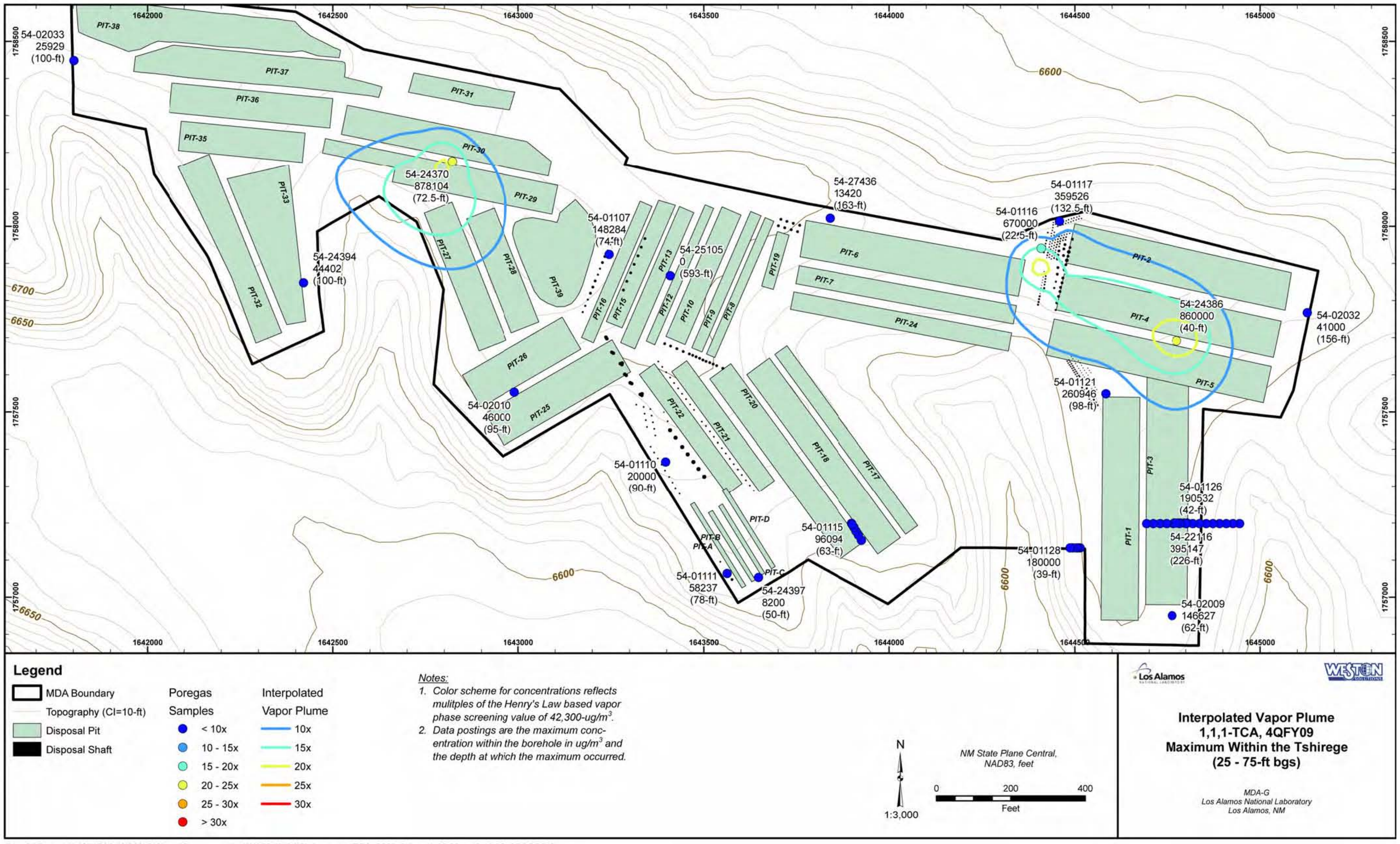


Figure E-3 Interpolated vapor plume for 1,1,1-TCA, 4QFY09, maximum within the Tshirege (25 to 75 ft below ground surface [bgs])

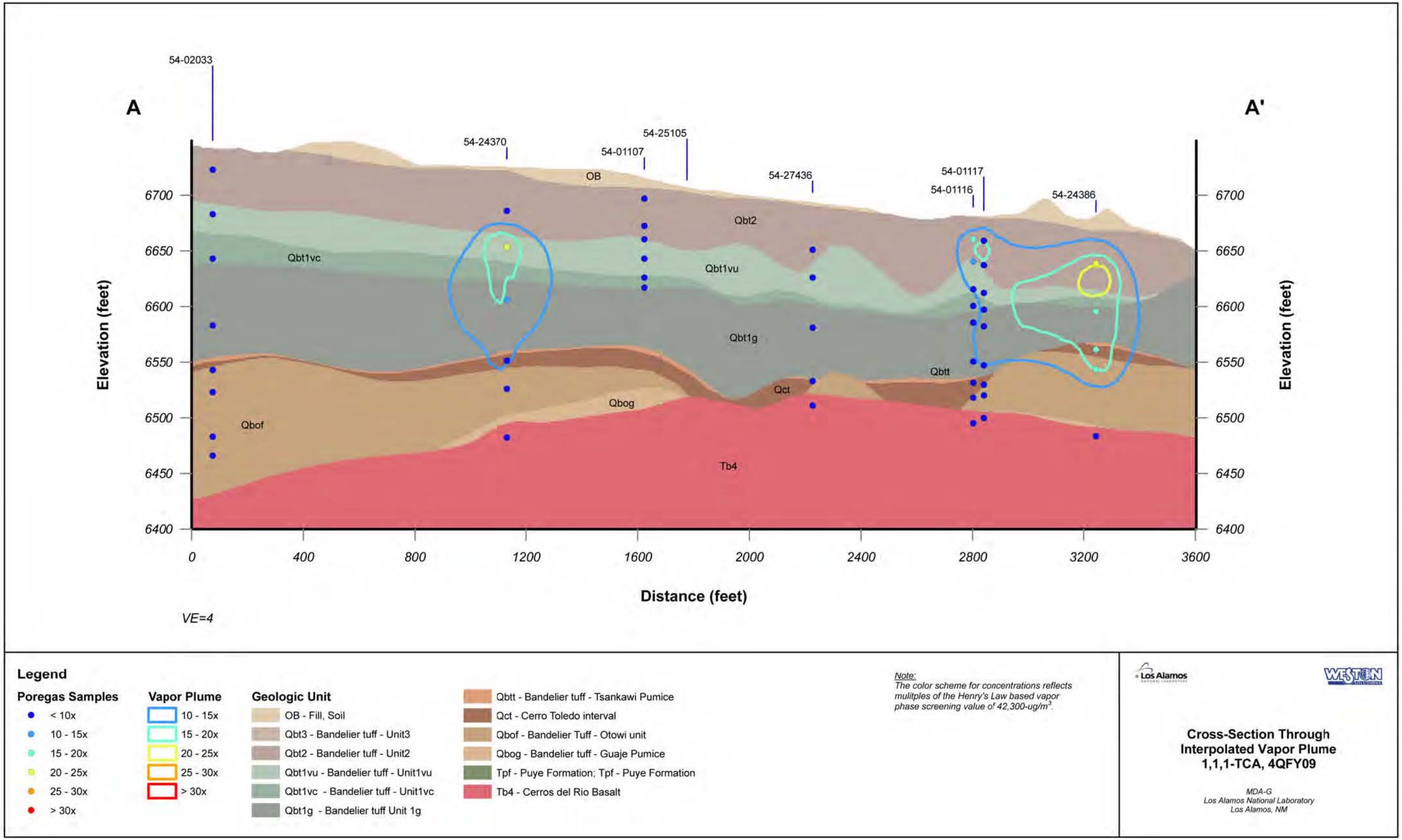


Figure E-4 Cross section through interpolated vapor plume for 1,1,1-TCA, 4QFY09

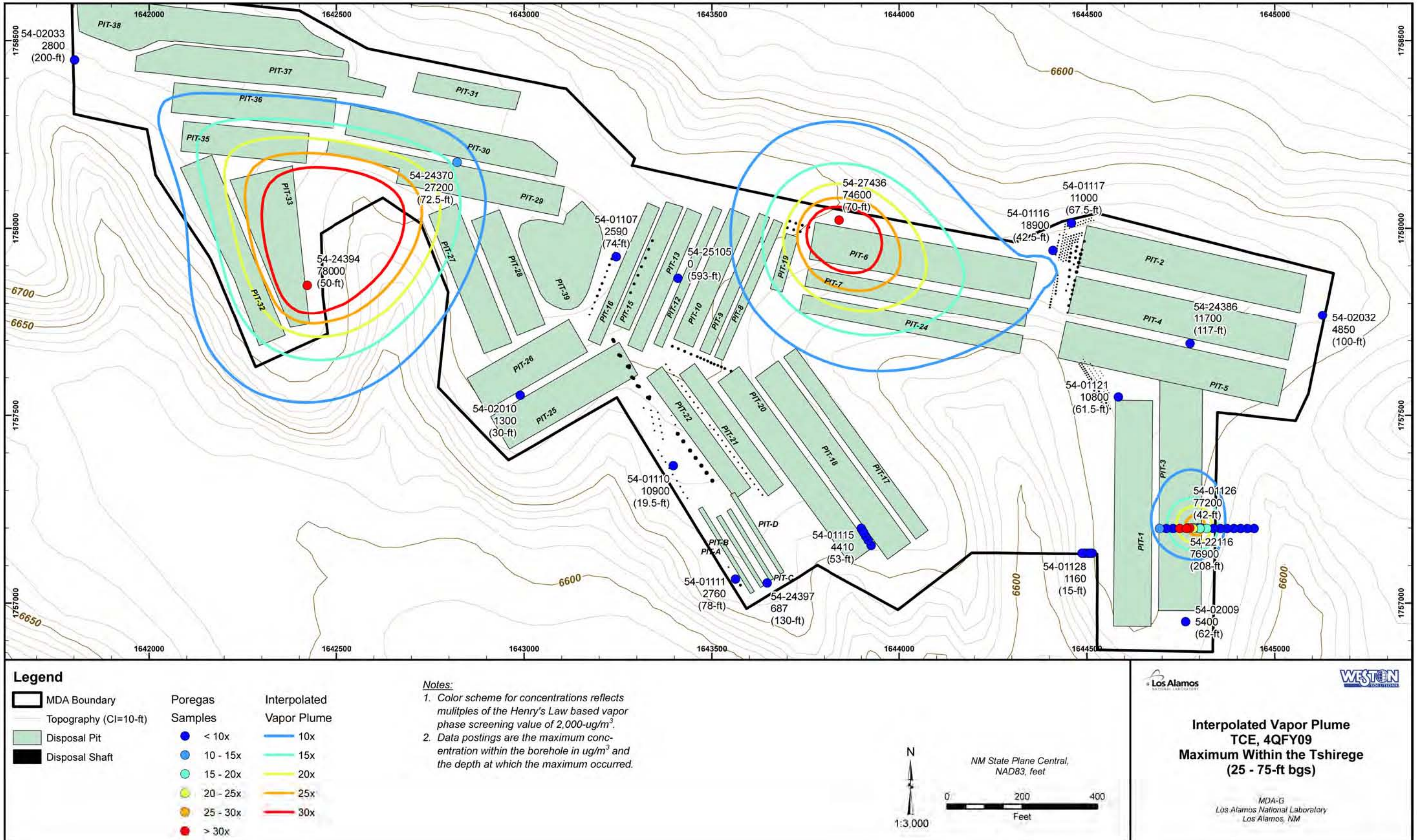


Figure E-5 Interpolated vapor plume for TCE, 4QFY09, maximum within the Tshirege (25 to 75 ft bgs)

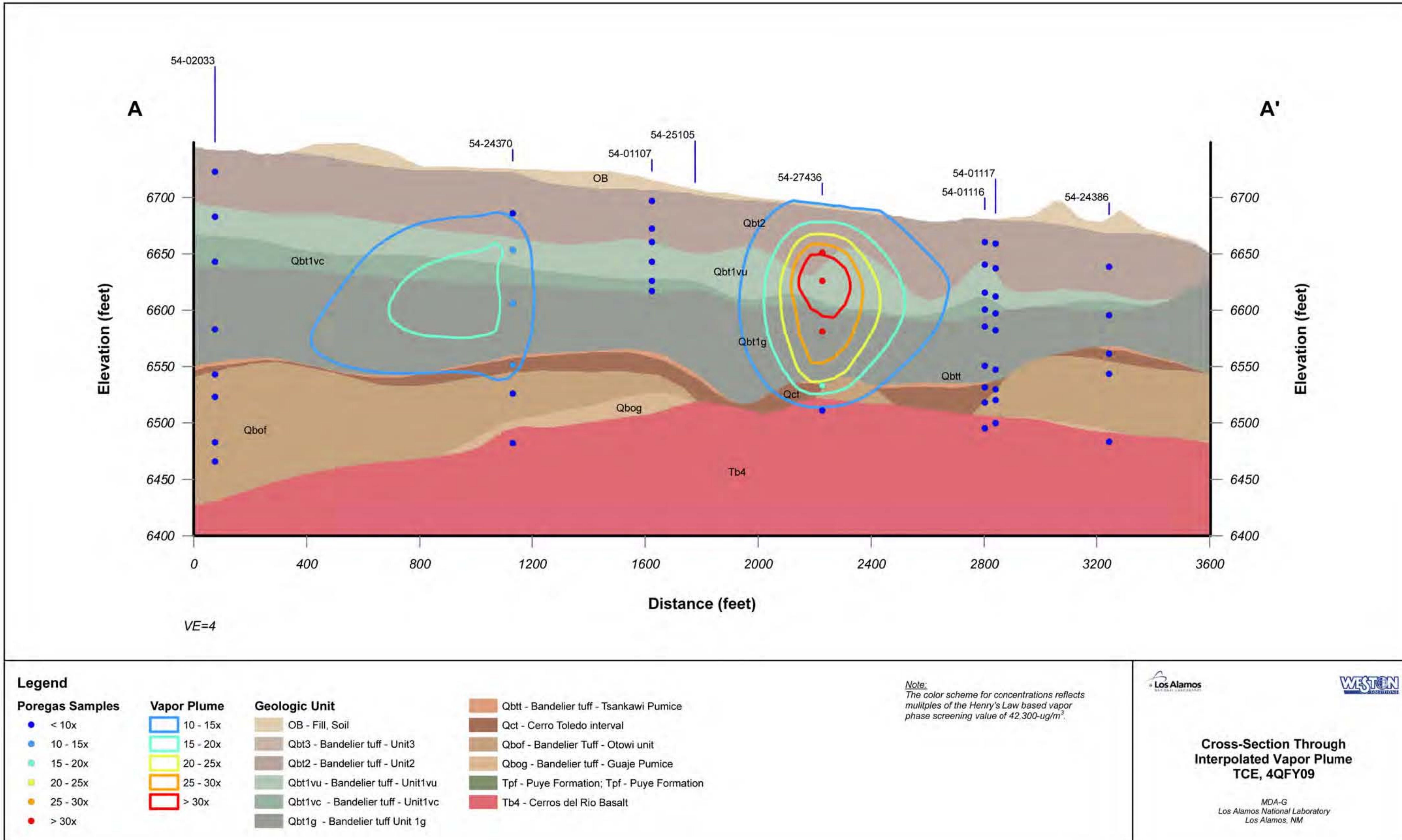


Figure E-6 **Cross section through interpolated vapor plume for TCE, 4QFY09**

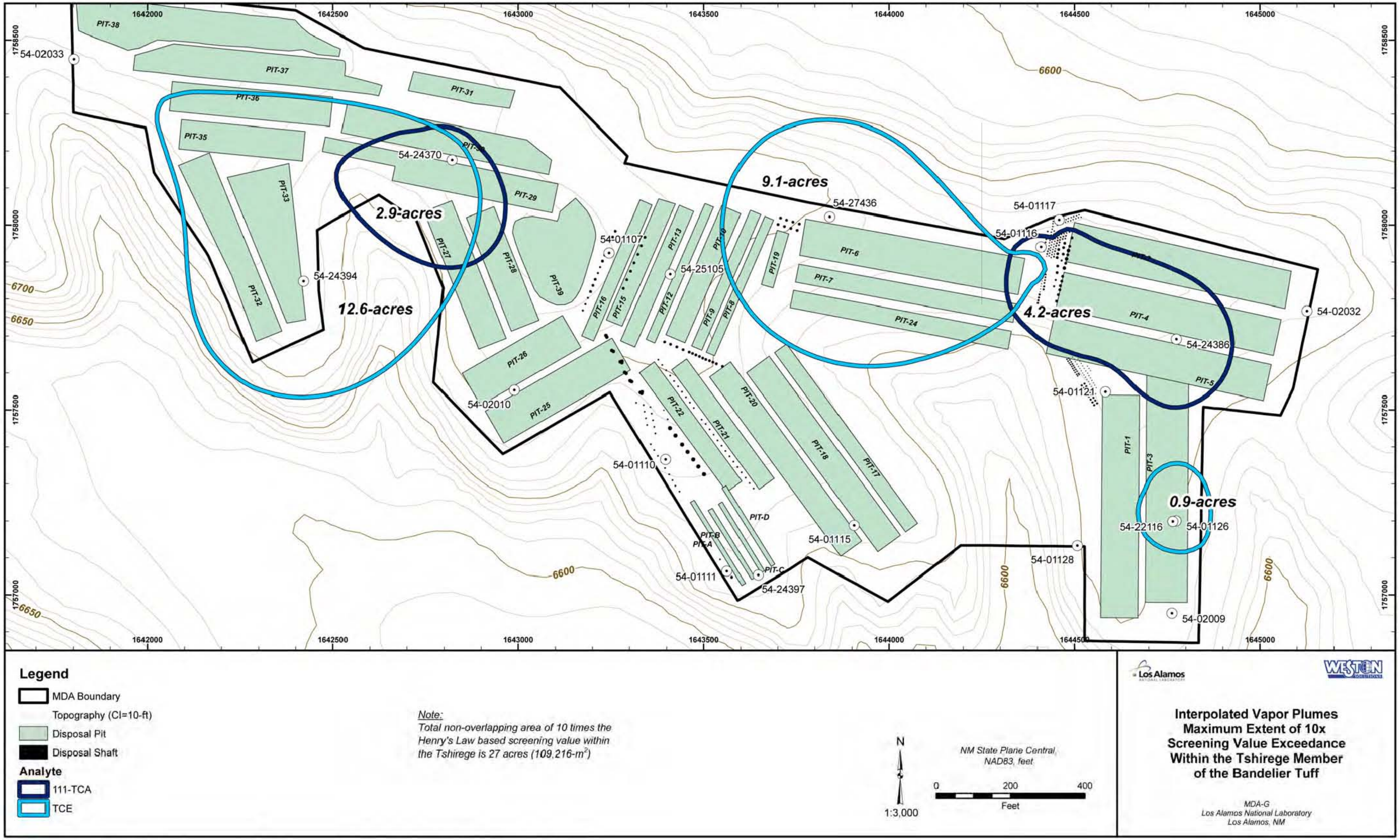


Figure E-7 Overlapping extents of 10 times screening-value contour lines for interpolated vapor plumes for 1,1,1-TCA and TCE, 4QFY09

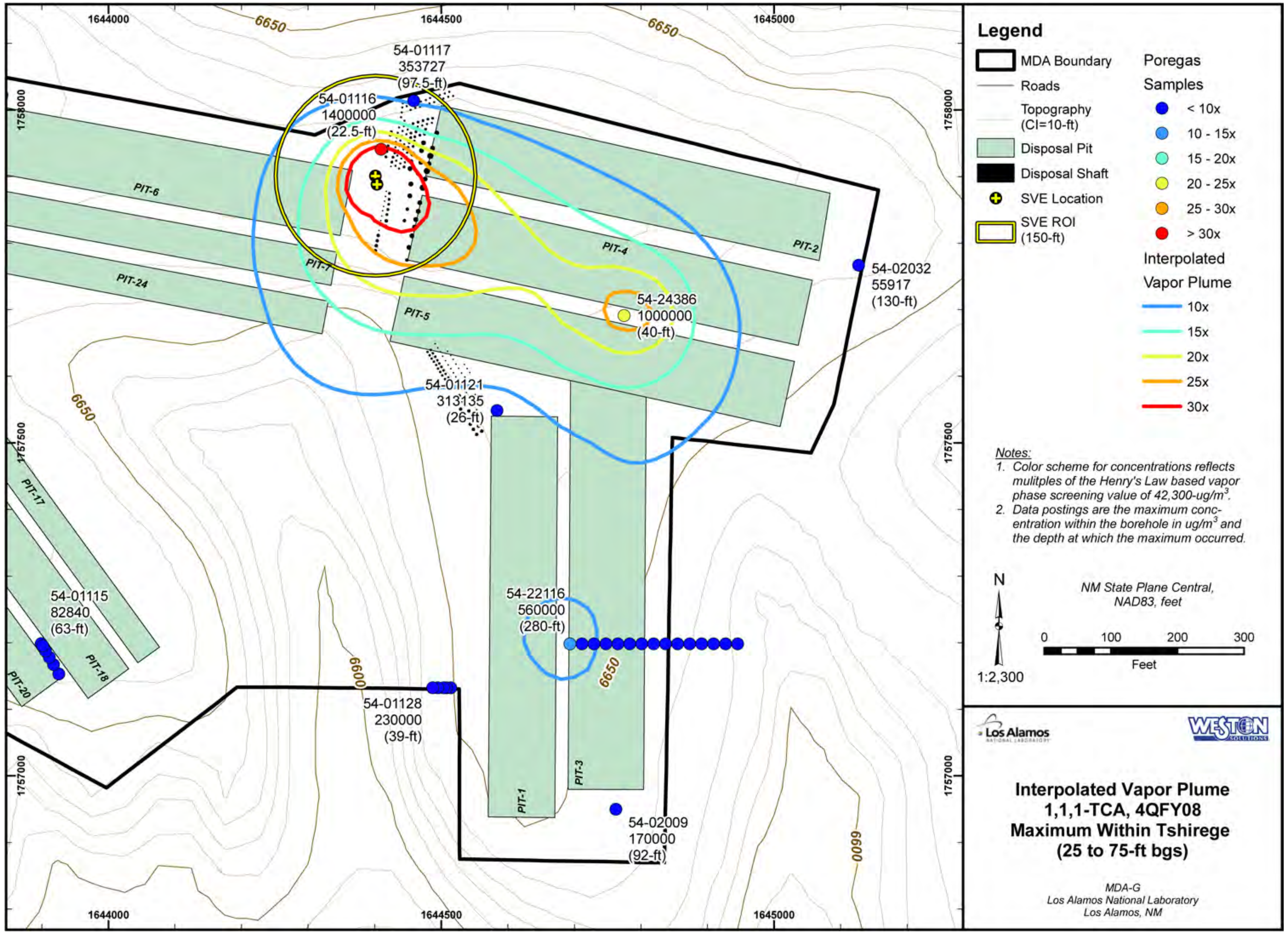


Figure E-8 Interpolated vapor plume for 1,1,1-TCA, 4QFY08, maximum within the Tshirege (25 to 75 ft bgs) near 2008 pilot-test area

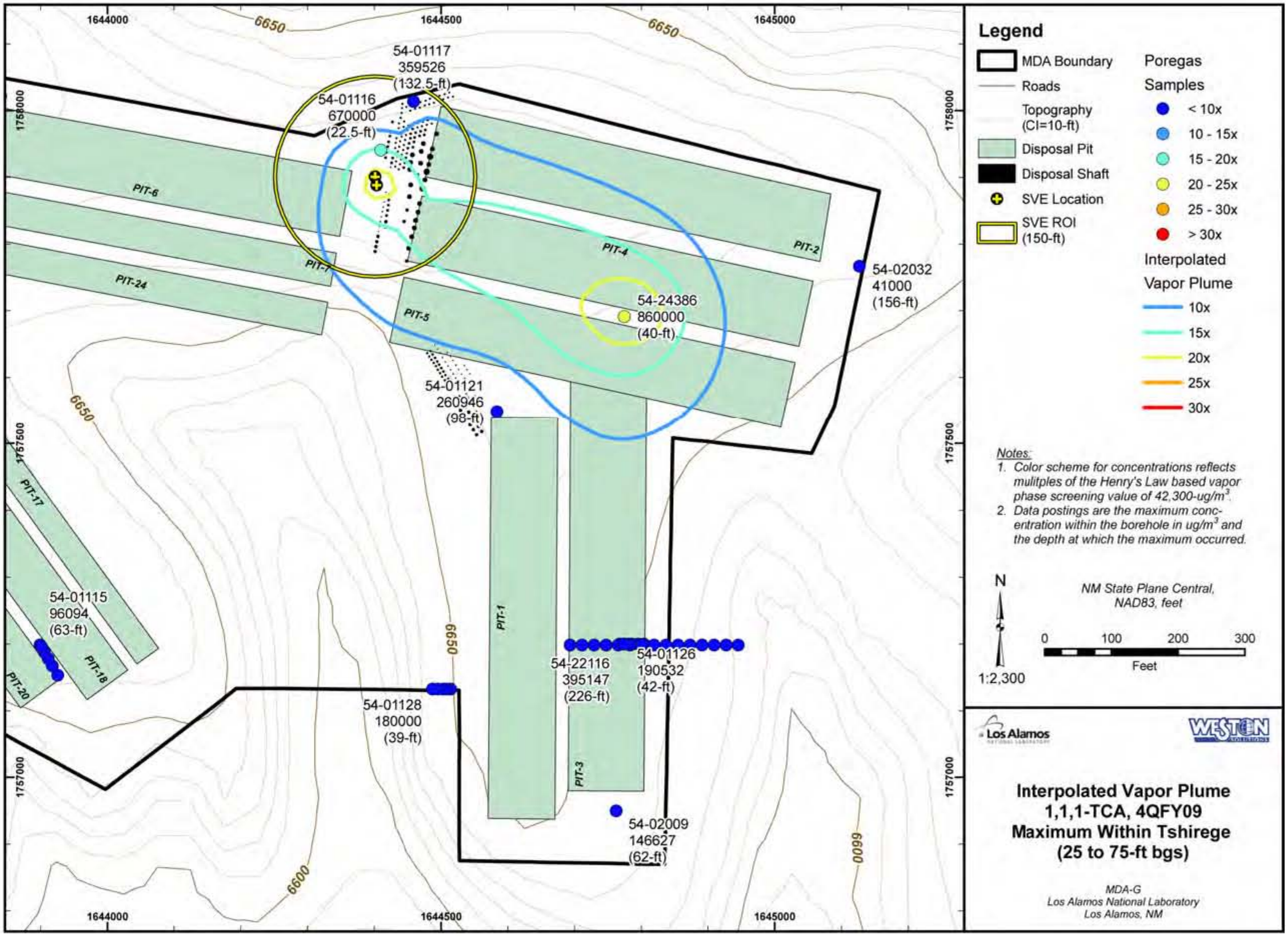


Figure E-9 Interpolated vapor plume for 1,1,1-TCA, 4QFY09, maximum within the Tshirege (25 to 75 ft bgs) near 2008 pilot-test area

Table E-1
MDA G Strata-Specific Properties Affecting Mass Estimates

Geologic Zone	Porosity[a]	Volumetric Water Content[b]	Air-Filled Porosity	Bulk Density[a] (g/cm^3)	Fraction Organic Carbon[c]
Soil	0.4	0.05	0.35	1.5	0.0005
Qbt 2	0.41	0.02	0.39	1.4	0.0005
Qbt 1vu	0.49	0.01	0.48	1.2	0.0005
Qbt 1vc	0.49	0.1	0.39	1.1	0.0005
Qbt 1g	0.46	0.08	0.38	1.2	0.0005
Qct	0.45	0.14	0.31	1.2	0.0005
Qbtt	0.45	0.14	0.31	1.2	0.0005
Qbof	0.44	0.11	0.33	1.2	0.0005
Qbog	0.67	0.2	0.47	0.8	0.0005

[a] Mean values from Springer (2005, 098534).

[b] Mean values from Hollis et al. (1997, 063131).

[c] Estimate.

Table E-2
MDA G Subsurface Vapor-Monitoring Locations

Borehole ID	VOC and Tritium Sampling Port Depths (Intervals) (ft bgs)
54-01107	20 (19–21), 44.5 (43.5–45.5), **56.5 (55.5–57.5)**, 74 (73–75), 91 (90–92), **100 (99–101)**
54-01110	20 (19–20), 48 (47–49), **60 (59–61)**, 70 (69–71), 85 (84–86), **90 (89–91)**
54-01111	**20 (19–21)**, 39.5 (38.5–40.5), 50 (49–51), 70 (69–71), 78 (77–79), 100 (99–101), **139 (138–140)**
54-01115[a]	7 (6–8), 26 (25–27), **40 (39–41)**, 53 (52–54), 63 (62–64), **68 (67–69)**
54-01116	**22.5 (20–25)**, 42.5 (40–45), 67.5 (65–70), 82.5 (80–85), 97.5 (95–100), 132.5 (130–135), 151.5 (149–154), 165 (162.5–167.5), **187.8 (185.3–190.3)**
54-01117[b]	**20 (20),** 31.5 (31.5), 55 (55), 73 (73), 82 (82), **85 (85)**
54-01117[c]	**20 (18.5–22.5)**, 42.5 (40–45), 67.5 (65–70), 82.5 (80–85), 97.5 (95–100), 132.5 (130–135), 150 (147.5–152.5), 159.5 (157–162), **179.8 (177.3–182.3)**
54-01121	**20 (19–21)**, 26 (25–27), 61.5 (60.5–62.5), 70 (69–71), 76 (75–77), 98 (97–99), **121 (120–122)**
54-01126[a]	7 (6–8), 17 (16–18), 28 (27–29), **35 (34–36)**, 42 (41–43), **49 (48–50)**
54-01128[a]	7.5 (6.5–8.5), 15(14–16), **20 (19–21)**, 30 (29–31), **39 (38–40)**
54-02009	**37 (34.5–39.5)**, 62 (59.5–64.5), 79 (76.5–81.5) **92 (89.5–94.5)**
54-02010	**30 (27.5–32.5)**, 53 (51.5–55.5), **95 (92.5–97.5)**
54-02032	**20 (20)**, 60 (60), 100 (100), 130 (130), **156 (156)**
54-02033	20 (20), **60 (60)**, 100 (100), 160 (160), 200 (200), 220 (220), 260 (260), **277 (277)**
54-22116[d]	28 (27–29), 46 (45–47), 64 (63–65), 82 (81–83), 100 (99–101), 118 (117–119), 136 (135–137), 154 (153–155), **172 (171–173), 190 (189–191),** 208 (207–209), 226 (225–227), 244 (243–245), 262 (261–263), **280 (279–281)**
54-24370	**40 (35–45)**, 72.5 (67.5–77.5), 120 (115–125), 174.7 (169.7–179.7), 200 (195–205), **243.7 (238.7–248.7)**
54-24386	**40 (37.5–42.5)**, 83 (80.5–85.5), 117 (114.5–119.5), 135 (132.5–137.5), **195 (192.5–197.5)**
54-24394	**50 (45–55)**, 100 (95–105), 150 (145–155), 192.5 (187.5–197.5), 245.25 (240.25–250.25), **300.5 (295.5–305.5)**
54-24397	**50 (45–55)**, 90 (85–95), 130 (125–135), 165 (160–170), 188 (183–193), **239.75 (234.75–244.3)**
54-25105[e]	**485 (485–701)**
54-27436	**45 (40–50)**, 70 (65–75), 115 (110–120), 163 (158–168), **185 (180–190)**

Note: Depths in bold type denote intervals where VOC and tritium samples are to be collected.

[a] Borehole location is an angled borehole. Port depth and interval is depth below ground surface.

[b] Borehole depth represents old port intervals before redrilling and installation of new depths.

[c] Borehole location redrilled during the reporting time frame (May and June of 2008).

[d] Borehole location is horizontal borehole. Port depths and intervals are length from borehole head.

[e] Open Borehole.

Table E-3
Estimates of TCA and TCE Mass Currently
Exceeding 10 Times the Henry's-Law-Based Screening Value

Analyte	All Layers	Tshirege Only	Below Tshirege
111-TCA	210	195	16
TCE	79	75	4

Note: Units are in kg.

Table E-4
Estimated TCA Mass Reduction within the
2008 Shallow SVE Test Area Based on 4QFY08 and 4QFY09 Data

Time Period	All Layers	Tshirege Only	Below Tshirege
Pre	101	92	9
Post	56	51	6
Difference	45	41	3
% Reduction	**44**	**45**	**35**

Note: Units are in kg.

Appendix F

Soil-Vapor Extraction Pilot Test Field Data
(on CD included with this document)

Appendix G

Soil-Vapor Extraction Cost Estimate

	Units	Unit Price	Total Cost
Capital Costs			
SVE Unit	4	$ 58,889	$ 235,556
Extraction Borehole (assumes installation to 200 ft total depth, with 50 ft steel casing from the surface, and surface completion)	20	$ 24,047	$ 480,940
Monitoring Borehole (assumes installation to 200 ft total depth and surface completion)	60	$ 3,220	$ 193,200
Monitoring Borehole Ports (assumes six monitoring ports per borehole, stainless-steel tubing and monitoring ports, sand pack filter with bentonite between monitoring intervals)	60	$ 23,180	$ 1,390,800
Installation (labor costs associated with the construction of one extraction or one monitoring borehole)	80	$ 15,301	$ 1,224,080
		Total Capital Costs	**$ 3,524,576**
Operations and Maintenance			
Annual Operations (monthly labor costs associated with daily rounds, SVE system disconnects and connects between operational periods, and maintenance)	12	$ 29,296	$ 351,552
		Total Operations and Maintenance Costs	**$ 351,552**

Appendix H

Permeability Test Results

This appendix describes in detail the two methods used to estimate permeability from the data collected during the supplemental soil vapor extraction (SVE) pilot test at Material Disposal Area G (MDA G). Both methods rely primarily on the measured values for (1) flow rate measured at the wellhead using an orifice plate and differential pressure gauge and (2) measured applied vacuum in the test interval.

H-1.0 SPHERICAL APPROXIMATION

The first method uses a spherical approximation of air flow toward a point of vacuum and is described in detail in Wykoff et al. (1998, 098069) (Figure H-1). Using this method, the permeability k can be estimated as

$$k = \frac{\mu R T m}{2\pi (P_o^2 - P^2)} \left(\frac{1}{r_o}\right),$$

where μ = dynamic gas viscosity (Pa s)

R = universal gas constant (J / K mol)

T = absolute temperature (K)

m = gas flow rate into the well (kg/s)

P_o = absolute pressure in the vacuum interval (Pa)

P = background or initial pressure in the vacuum interval (Pa), and

r_o = source radius.

The source radius (r_o) for the packer system is approximated as the radius of the sphere required to yield the same volume as the actual packer system open-interval volume. The packer open interval is 4.75 ft (1.45 m) long and has a diameter of 9.5 in, (0.24 m). For our calculations using this method, r_o is 0.251 m (Table H-1). An assumption in the analytical solution is that the permeability everywhere in the surrounding rocks is uniform. The approximation is more representative of measurements taken in thick units than for measurements taken in thin strata. Table H-2 and Figure H-2 present permeability results for extraction borehole 54-612255, derived from the permeability measurements taken before the SVE test.

H-2.0 PERMEABILITY ESTIMATED FROM A TWO-DIMENSIONAL RADIAL NUMERICAL SOLUTION

This section presents permeability estimated from a two-dimensional (2-D) radial solution for selected intervals from the SVE test. A Laboratory document, Numerical Analysis of the Soil-Vapor Extraction Test at Material Disposal Area G, describes the model (2009, 105413). For this method, very low permeability is assigned to two sections of the borehole that represent the two inflatable packers, and the vacuum is applied to the open interval between the two simulated packers. Figure H-3 shows the numerical domain.

Figure H-4 shows an example of pressure after 4 h for a simulated 120-in. (40-kPa) vacuum test on the Qct. This homogeneous simulation uses the assumption that the entire mesh has the same permeability as the test interval. This is the same assumption that is used in the simple analytical solution. Figure H-5 shows an example of pressure after 4 h for a simulated 120-in. vacuum test on the Qct where the permeability above and below the test interval is much lower than that of the test interval. This shows that with a layered system having lower permeability units bounding the Qct, the pressure drop will propagate to much greater radial distances.

Table H-3 shows permeability values generated using these two methods for a variety of vacuums on the Qct interval. This set of results shows that the homogeneous numerical test is in good agreement with the analytical solution. However, there is a possibility that stratigraphy could impact the estimates, and the in situ permeability of the Qct may be higher by a factor of 4. This effect is likely to be the most pronounced in the highest permeability units and contacts. In the present study, these are limited to the Qct and Qtt intervals. In previous studies of in situ permeability, high permeability horizons were found throughout Qbt 1v, the bottom of Qbt 2, and the top of Qbt 1g.

Another verification of the two methods is to compare the low-flow-rate permeability test data with estimates using the much higher flow rates seen in the SVE test. For the Qct at 70 and 30 in. of water, we found permeability values of 14.8 and 15.6 darcys respectively, compared with 11.7 darcys from the permeability test applying a vacuum of only a few in. of water. One reason that the higher flow rates lead to higher permeability estimates is shown in Figure H-4, where the pressure contours bypass the packers and begin to draw air in from the borehole. This would not be observed with the analytical solution and is a result of studying the numerical results.

H-3.0 ANALYSIS OF DATA FROM QBT 1v-u

The next analysis presented concerns data from the Qbt 1v-u. The SVE test data showed an unlikely trend with no change in flow rate as vacuum was increased from 15 to 90 in. of water, with a small increase when the 120-in. of water vacuum step was applied (Figure H-6). To understand the expected behavior of the data, we used the permeability derived from the permeability test spherical solution in the homogeneous numerical model to create an expected flow rate versus vacuum plot to determine if the SVE data have any validity. Figure H-6 shows that at low flow rates the SVE test was likely giving an incorrect reading for flow rate; however, by the time the vacuum was raised to 90 in., the system began to behave correctly. We hypothesize that the very low flows reported for this interval were below the resolution of the pressure device being used to measure the pressure drop across the orifice plate.

H-4.0 BULK PERMEABILITY ESTIMATED FROM THE OPEN BOREHOLE TEST

We used the 2-D radial model with a homogeneous permeability to determine the bulk permeability of the open borehole. The open borehole test was run at three vacuums: 15, 30, and 40 in. of water (3.75, 7.5, and 10 kPa) yielding three estimates of permeability. Figure H-7 shows the flow rate versus vacuum data from the open borehole test (blue diamonds). The R^2 for the line through these points is 0.998, which shows that we did not exceed the linear response range of the test equipment. The bulk permeability estimates for the three vacuums are shown in Table H-4. These values are approximately 30% lower than the bulk permeability of 6.5 darcys measured during the 2008 pilot test. It is likely that the 2008 test encountered high permeability fractures in the upper section that were not seen in this test. Such variability between boreholes is to be expected from our previous experience with permeability testing at MDA G and MDA L.

H-5.0 ABILITY OF MEASURED PERMEABILITY DATA TO FIT OPEN BOREHOLE FLOW RATE VERSUS VACUUM DATA

We use the permeability estimates from the spherical solution to populate the 2-D radial model and compare the flow rate versus vacuum between model and data. The modeled results are within approximately 10% of the data at all flow rates and show that we have not missed any significant high-permeability pathways (Figure H-7). Because the model and the data are in good agreement, the numerical model can be used to predict mass of contaminants that could potentially be removed from the mesa. Mass removal calculations can then be used to guide our SVE system design for MDA G.

H-6.0 CONCLUSIONS

Permeability values for the geologic units at the pilot site are estimated from the collected flow rate versus vacuum data using two methods. First, a spherical analytical solution to flow is used to estimate permeability from data collected (1) during the permeability testing and (2) for selected step tests. The step test provides a useful double check of the permeability test. Second, because of concerns with using a single analytical model based on spherical geometry to generate the permeability estimates, we also use a 2-D radial numerical model that accounts for a 9.5–in. borehole, a 4.75-ft open section of borehole, two 3-ft-long packers and an approximation of the mesa geometry. The detailed numerical solution provides a more realistic approximation that considers the radial nature of the flow towards the packed off interval and results in a more realistic value for permeability. Results from the numerical method confirm that the analytical method is valid for the assumption of homogeneous permeability. A layered permeability numerical model is needed to propagate a significant pressure drop radially past 60 ft. The 2-D radial model was then used to estimate the bulk permeability of the open borehole test. The bulk permeability of this test is 30% lower than the value obtained from the 2008 test. We used the permeability estimates from the spherical solution to populate the 2-D radial model and compare the flow rate versus vacuum between model and data. The modeled results are within approximately 10% of the data at all flow rates and show that we have not overlooked any significant high-permeability pathways.

H-7.0 REFERENCES

The following list includes all documents cited in this appendix. Parenthetical information following each reference provides the author(s), publication date, and ER ID. This information is also included in text citations. ER IDs are assigned by the Environmental Programs Directorate's Records Processing Facility (RPF) and are used to locate the document at the RPF and, where applicable, in the master reference set.

Copies of the master reference set are maintained at the NMED Hazardous Waste Bureau and the Directorate. The set was developed to ensure that the administrative authority has all material needed to review this document, and it is updated with every document submitted to the administrative authority. Documents previously submitted to the administrative authority are not included.

LANL (Los Alamos National Laboratory), March 2009. "Numerical Analysis of the Soil-Vapor Extraction Test at Material Disposal Area G, Technical Area 54," Los Alamos National Laboratory document LA-UR-09-0995, Los Alamos, New Mexico. (LANL 2009, 105413)

Wykoff, D., J. Stockton, and B. Lowry, February 1998. "Air-Flow Measurements in Los Alamos TA-49-700," Science & Engineering Associates report no. SEASF-TR-97-186, Santa Fe, New Mexico. (Wykoff et al. 1998, 098069)

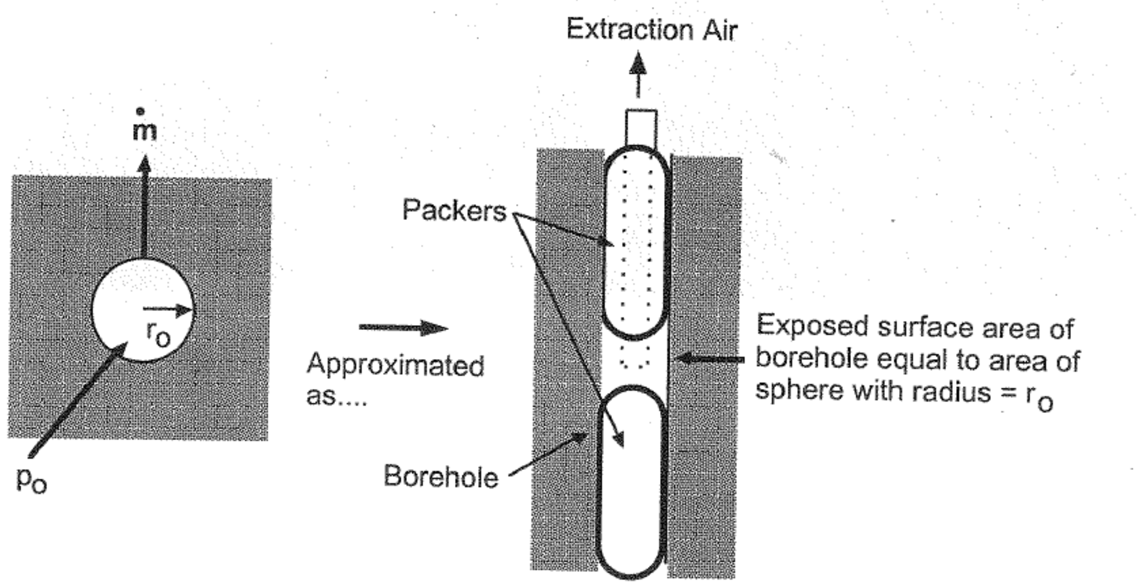


Figure H-1 Approximation of a spherical air-flow geometry with a conventional straddle packer design for in situ soil gas permeability measurements (from Wykoff et al. 1998, 098069)

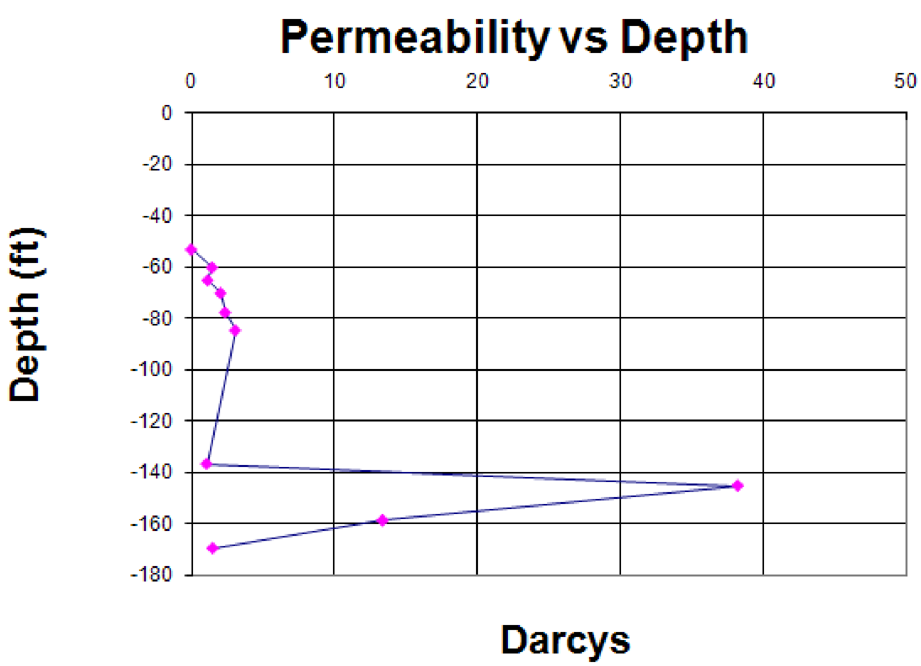


Figure H-2 Spherical-solution permeability values for the permeability test

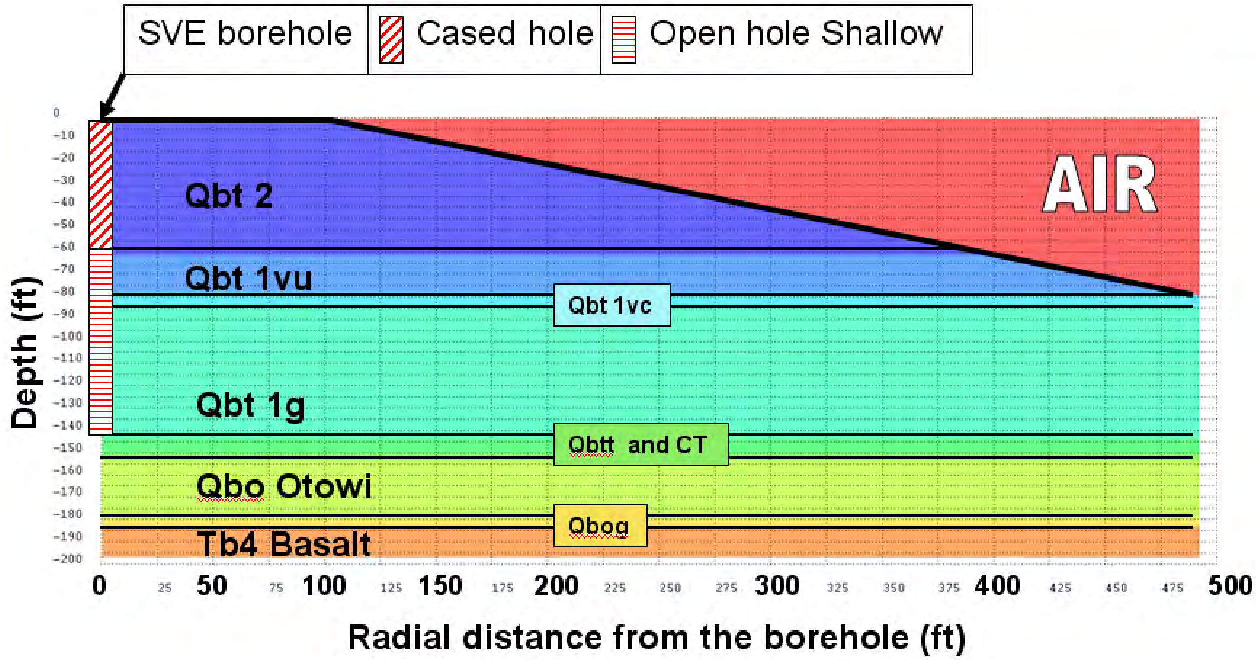
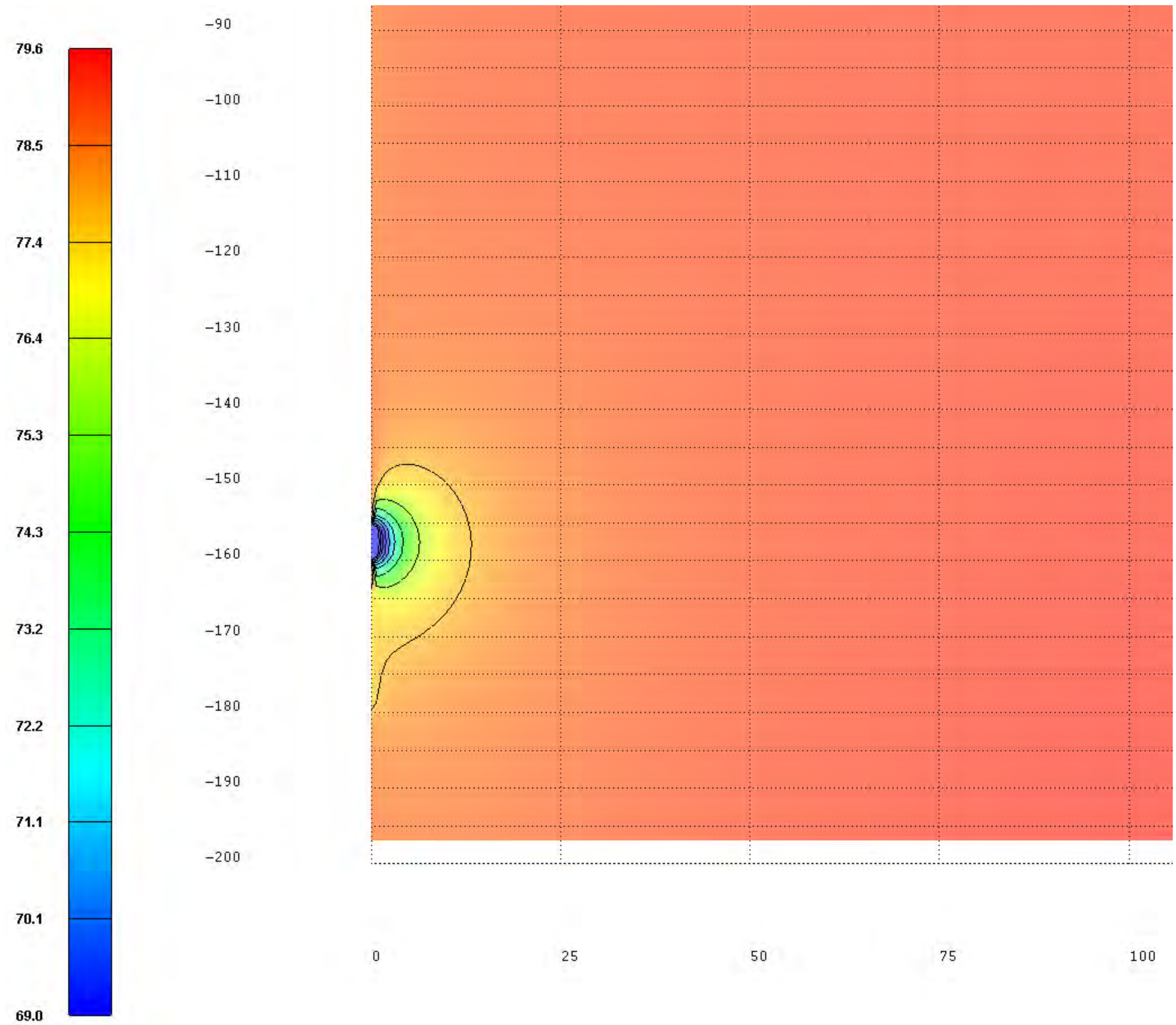
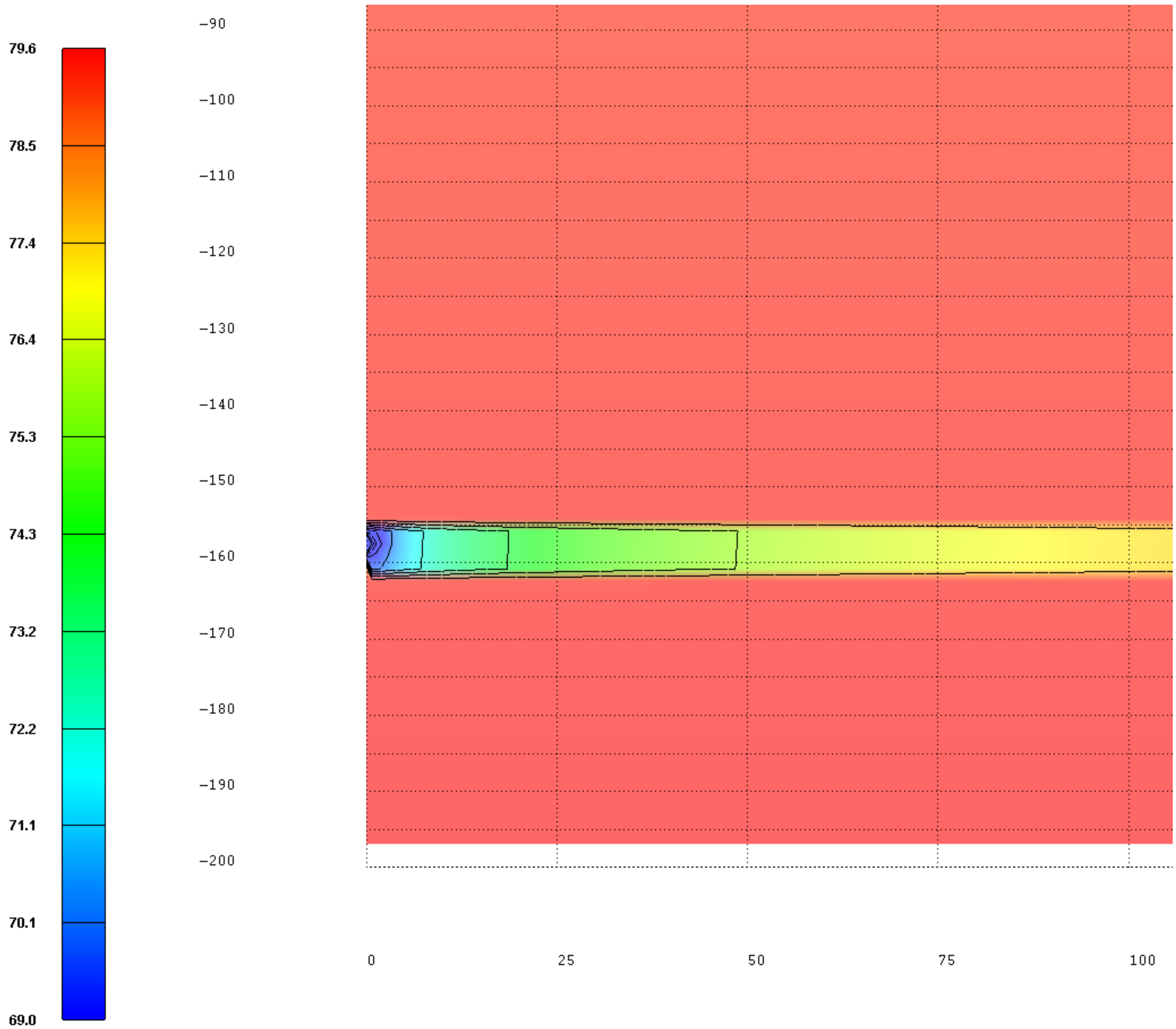


Figure H-3 Simplified stratigraphy and topography used for estimating permeability of the SVE intervals



Note: The vertical axes and horizontal axis are both in feet.

Figure H-4 Example of pressure drawdown after 4 h for a simulated 120-in. (40-kPa) vacuum test on the Qct for a homogeneous system



Note: The vertical axes and horizontal axis are both in feet.

Figure H-5 Example of pressure after 4 h for a simulated 120-in. (40-kPa) vacuum test on the Qct for a strongly layered system

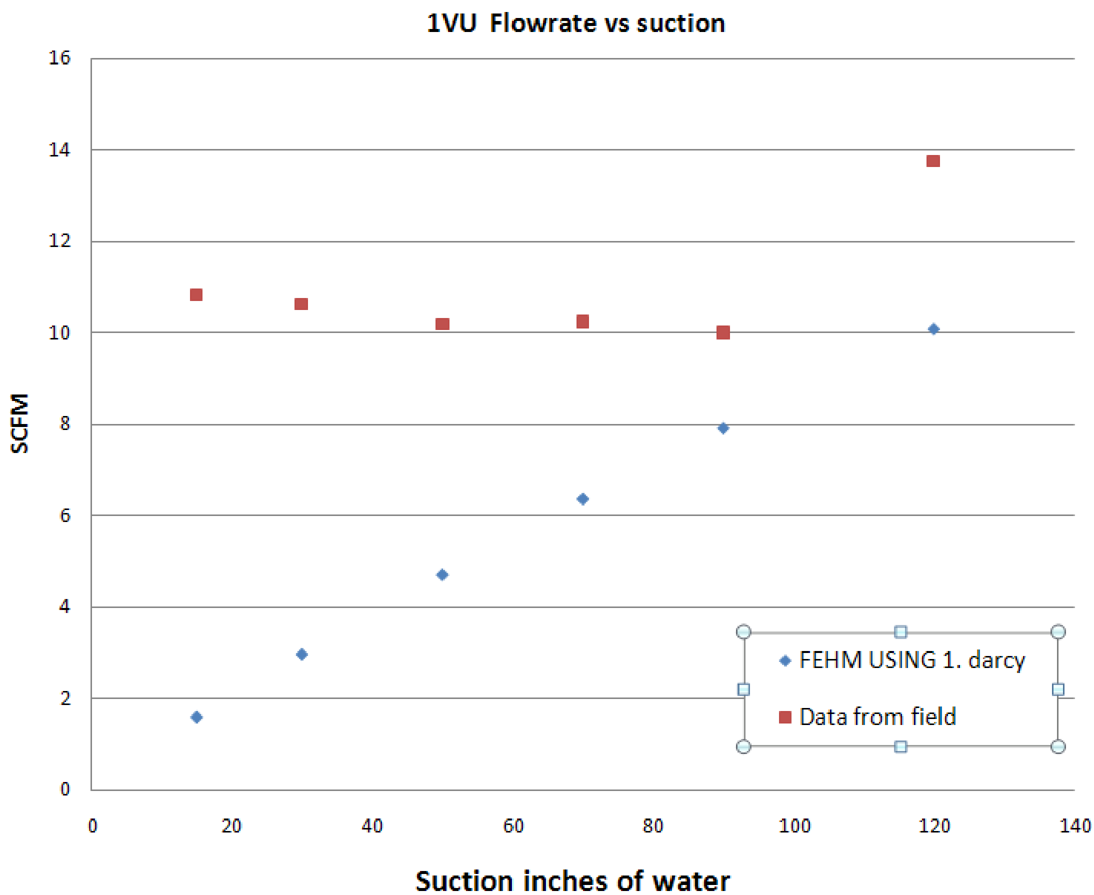


Figure H-6 Comparison of estimated flow rate versus vacuum for a homogenous model using the spherical permeability estimate for Qbt 1v-u and the SVE data

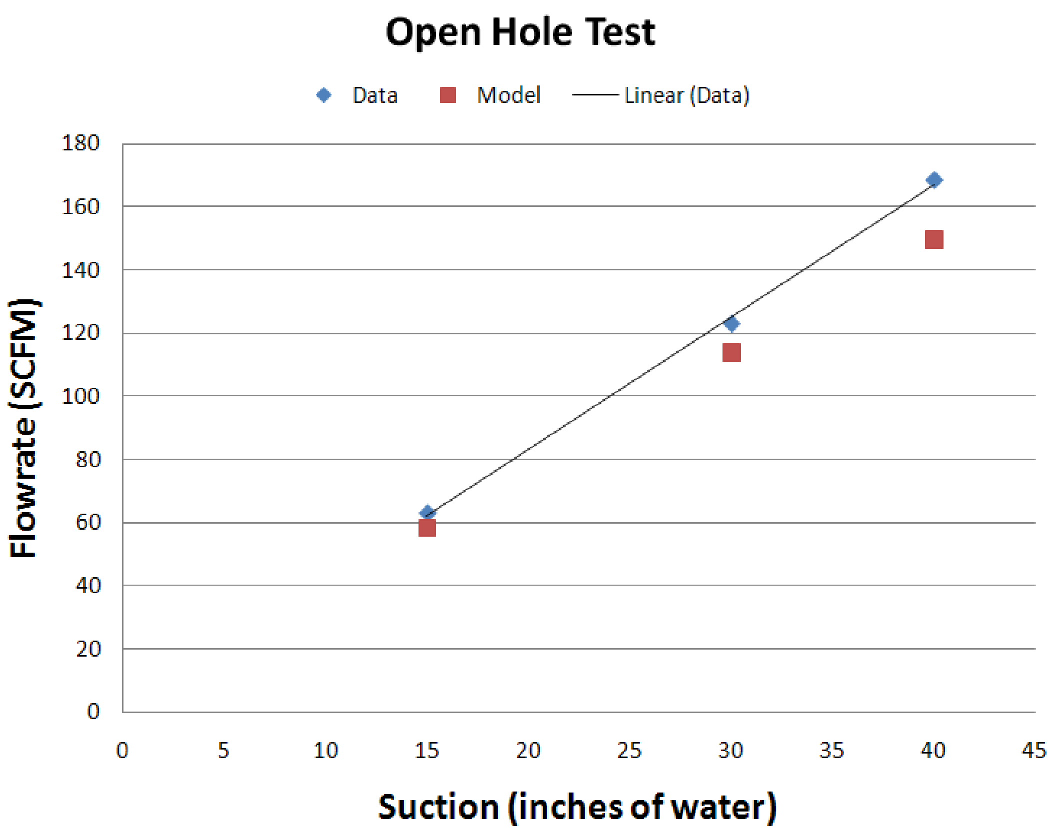


Figure H-7 Flow rate versus vacuum for the open borehole SVE test

Table H-1
Permeability Calculations

Packer Depth (m)	Packer Location (ft)	Atm Pressure (Pa)	Diff. Pressure (Pa)	Flow Rate (Lpm)	R_o	Pa^2-Po^2	Permeability (m^2)	Permeability (darcys)	Interval
-16.2	-53.0	80000	162.0	0.00	0.251	2.59E+07	0.00E+00	0.000	Qbt 2
-18.3	-60.0	80000	1477.0	15.63	0.251	2.34E+08	1.27E-12	1.273	Qbt 2 to Qbt 1v-u
-19.8	-65.0	80000	1821.0	15.14	0.251	2.88E+08	1.00E-12	1.002	Qbt 1v-u
-21.3	-70.0	80000	973.0	14.54	0.251	1.55E+08	1.79E-12	1.792	Qbt 1v-u to Qbt 1v-c, 70 ft
-23.6	-77.5	80000	909.0	15.64	0.251	1.45E+08	2.06E-12	2.063	Qbt 1v-c
-25.8	-84.5	80000	783.0	17.50	0.251	1.25E+08	2.68E-12	2.677	Qbt 1vc to 1g
-41.6	-136.5	80000	2169.0	16.80	0.251	3.42E+08	9.36E-13	0.936	Qbt 1g
-44.2	-145.0	80000	54.2	15.15	0.251	8.67E+06	3.33E-11	33.329	Qbt 1g to Qbtt
-48.3	-158.5	80000	162.0	15.85	0.251	2.59E+07	1.17E-11	11.674	Qct perm. test
-51.6	-169.4	80000	1456.0	15.85	0.251	2.31E+08	1.31E-12	1.309	Otowi
48.3	158.5	80000	17500.0	1939.00	0.251	2.49E+09	1.48E-11	14.829	Qct SVE 70-in. vacuum
48.3	158.5	80000	7500.0	934.00	0.251	1.14E+09	1.56E-11	15.574	Qct SVE 30-in. vacuum

Table H-2
Spherical-Solution Permeability
Derived from the pre-SVE Flow Rate versus Vacuum Measurements

Formation	Member	Unit	Depth (ft)	Permeability (darcys) (1 darcy = 1e-12 m^2)
Bandelier Tuff	Tshirege	Qbt 2 / Qbt 1v-u Contact	60	1.27
		Qbt 1 v-u	65	1.00
		Qbt 1 v-u / Qbt 1 v-c Contact	70	1.79
		Qbt 1 v-c	77.5	2.06
		Qbt 1 v-c / Qbt 1g Contact	84.5	2.67
		Qbt 1g	136.5	0.94
Bandelier Tuff	Tshirege	Qbt 1g / Qbtt Contact	145.0	33.3
Cerro Toledo interval		Qct	158.5	11.7
Bandelier Tuff	Otowi	Qbo	169.4	1.31

Table H-3
Estimated Permeability for the Qct Using the Homogeneous and Layered Numerical Approaches and the Spherical-Solution Results for the Low-Flow Permeability Test and Three Higher-Flow Steps of the SVE Test

Method	120-in. Vacuum	7-in. Vacuum	30-in. Vacuum	Low-Flow Permeability Test
Homogeneous	11.3	13	13	n/a*
Layered	45	53	53	n/a
Spherical	13.4	13.5	15.4	11.7

Note: Units are in darcys.
*n/a = Not applicable.

Table H-4
Bulk Permeability Estimated from the Open Borehole Test

Vacuum (in. of water)	Estimated Open Borehole Bulk Permeability (darcys)
15	4.3
30	4.3
40	4.5