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Work Plan for the Implementation of an In Situ Soil Vapor Extraction Pilot Study at Technical Area 54, Material Disposal Area L, Los Alamos National Laboratory

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EST. 1943

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Prepared by
Environmental Stewardship–Environmental Remediation and Surveillance Program

EXECUTIVE SUMMARY

Material Disposal Area (MDA) L was used as a nonradioactive liquid chemical waste subsurface disposal site from the early 1960s until 1985. The surface of the site is currently used for Resource Conservation and Recovery Act-permitted chemical waste storage and for mixed waste storage under interim status authority. Today, the major contaminant release at the site is a subsurface organic solvent vapor-phase plume. Under Los Alamos National Laboratory's Environmental Stewardship–Environmental Remediation and Surveillance Program, extensive sampling and analysis have been conducted to determine the nature and extent of the plume, and a conceptual model to characterize the subsurface plume has been developed. An analysis of collected data has shown that the site does not currently pose a potential unacceptable risk to human health or the environment. The Laboratory proposes to conduct a pilot study to determine whether a soil vapor extraction system can effectively remove VOC contamination from the subsurface vapor-phase plume at MDA L.

Previous investigations conducted at MDA L on plume remediation include a Pilot Extraction Study Plan (PESP) and an independent Technical Advisory Group (TAG) study to evaluate potential plume treatment alternatives. Included in the PESP was a Pilot Vapor Extraction Test (PVET), in which a soil vapor extraction (SVE) system was constructed and operated near the outer boundary of the plume. The results of this test demonstrated the potential effectiveness of SVE at MDA L. In addition, the TAG concluded that SVE may be a potentially effective method for removing volatile organic compounds at the site.

The proposed pilot study entails installation of an active soil vapor extraction system to evaluate the rate of reduction of the contaminant concentrations immediately around the source terms. Active extraction will be conducted over an approximately four-month period. Continued subsurface monitoring of the vapor contaminant concentrations will capture soil vapor concentration rebound and will determine when or if additional extraction should take place. Rebound analysis will also provide valuable information on the nature of the source. Should future monitoring indicate an increase in the soil vapor concentrations, the emplaced extraction system may be used to remove and treat contaminants, ensuring that the subsurface plume size does not increase. Continuous monitoring of the off-gas will be conducted to ensure that all regulatory requirements are met. Data from the pilot study will be used in the corrective measure evaluation for MDA L to assess the effectiveness of SVE as a remedy for remediation of the subsurface vapor-phase plume at MDA L.

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Acronyms

bgs	below ground surface
CME	corrective measures evaluation
DOE	Department of Energy
ENV-ERS	Environmental Stewardship–Environmental Remediation and Surveillance Program
EPA	Environmental Protection Agency
ITRD	Innovative Treatment and Remediation Demonstration
LANL	Los Alamos National Laboratory
MDA	material disposal area
NMED	New Mexico Environment Department
NMEID	New Mexico Environmental Improvement Division
PCE	tetrachloroethene
PESP	Pilot Extraction Study Plan
ppmv	parts per million by volume
PVET	Pilot Vapor Extraction Test
RCRA	Resource Conservation and Recovery Act
RFI	RCRA facility investigation
scfm	standard cubic feet per minute
SVE	soil-vapor extraction
TA	technical area
TAG	Technical Advisory Group
TCA	1,1,1-tricholorethane
TCE	tricholorethylene
UC	University of California
VOC	volatile organic compound

1.0 INTRODUCTION

Los Alamos National Laboratory (LANL or Laboratory) is a multidisciplinary research facility owned by the U.S. Department of Energy (DOE) and managed by the University of California (UC). The Laboratory's Environmental Stewardship–Environmental Remediation and Surveillance (ENV-ERS) Program is charged with investigating sites contaminated or potentially contaminated by past Laboratory operations. The nature and extent of contaminant releases are determined in accordance with the 2005 Compliance Order on Consent (the Order). Work plans are prepared to present recommendations for activities required to complete the site characterization.

One site that ENV-ERS is currently investigating is Material Disposal Area L (MDA L) at Technical Area 54 (TA-54) at Los Alamos National Laboratory (the Laboratory). MDA L, approximately 2.5 acres, was used for subsurface disposal of Laboratory-generated nonradiological liquid chemical waste. Characterization of the site began in 1985. The major contaminant release at the site is a subsurface organic solvent vapor-phase plume. Since 1997, the Laboratory has conducted quarterly sampling of volatile organic compound (VOC) pore gas throughout the subsurface area. This monitoring and completion of activities defined in the MDA L investigation work plan (LANL 2004, 87624) have provided sufficient data to estimate the nature and extent of the VOC vapor-phase plume. Extraction data from a previous soil vapor extraction (SVE) pilot study carried out between 1994 and 1997 (discussed further in Section 2.3.1) showed that the contaminant movement through the media was not retarded. This finding, coupled with the fact that rock samples from boreholes as deep as 300 ft showed no condensed liquid VOC or sorption of organic compounds on the matrix, indicates that no free-liquid form of the contaminant is present. This observation is consistent with the absence of organic carbon, low moisture content, and low specific surface area of the media. Based on these observations, the conceptual model of the site assumes that organic liquids leak slowly from the buried containers and volatilize rapidly and that the VOC vapor-phase plume is at near steady state.

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

This document describes a pilot study which implements in situ SVE technology at MDA L. The study will support the MDA L corrective measures evaluation (CME) by evaluating SVE technology as a method for removing organic vapor from the subsurface and as a potential method to minimize the growth of the plume in the event that the source term changes substantially (e.g., one or more containers holding the liquid waste fails). The results of the pilot test will be used to evaluate the potential effectiveness of SVE for treating the vapor plume at MDA L and to determine the SVE treatment system design criteria.

2.0 BACKGROUND

2.1 Site History

From the early 1960s until 1985, MDA L was used as a subsurface nonradiological liquid, chemical-waste disposal facility. Both containerized and uncontainerized liquid chemical wastes, including chlorinated solvents, were disposed of at the site. The MDA L disposal facilities consist of 3 surface impoundments, 1 pit, and 34 vertical shafts, as shown in Figure 1. None of the disposal areas were lined.

Pit A operated between 1964 and 1978, during which time uncontainerized bulk quantities of treated aqueous waste were disposed of directly into the pit and left to pool and evaporate. Disposal records indicate 38,333 gal. of waste were disposed of during the life of the pit. When the pit was decommissioned in 1978, it was covered with crushed tuff. The waste was not reported to contain VOCs; thus, Pit A is not considered to be a source of the subsurface VOC contamination.

The surface impoundments (B, C, and D) operated from 1969 to 1986. Impoundment B operated between 1969 and 1985, Impoundment C operated between 1972 and 1986, and Impoundment D operated between 1972 and 1974. Surface Impoundments B and C were used as evaporative lagoons for treated salt solutions such as ammonium bifluoride and electroplating wastes, which are sources of copper, barium, chromium, and zinc. Impoundment D was used exclusively for treating small-batch quantities of lithium hydride by reaction with water and allowing the neutralized solutions to evaporate. After decommissioning, the impoundments were covered with a minimum of three ft of crushed tuff. Most wastes disposed of in the surface impoundments were inorganic chemicals; therefore, Impoundments B, C, and D are not considered to be sources of the subsurface VOC vapor contamination.

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

After subsurface disposal activities at the site ended, most of the surface was covered with asphalt and/or chemical waste storage structures. Area L is used for Resource Conservation and Recovery Act (RCRA)-permitted chemical waste storage and treatment and for mixed-waste storage under interim status authority.

2.2 Site Conditions

The Laboratory lies on the Pajarito Plateau between the Jemez Mountains and the Rio Grande. Bandelier Tuff, a thick sequence of ash-fall pyroclastics, caps the plateau. Erosion of the tuff over time has created a series of canyons separating the narrow, finger-like mesas that comprise Pajarito Plateau. MDA L is situated atop one such mesa, Mesita del Buey. Figure 2 shows the stratigraphy beneath the mesa.

The strata below MDA L are composed of nonwelded to moderately welded rhyolitic ash-flow and ash-fall tuffs interbedded within pumice beds. The rhyolitic units overlie a thick basalt unit, which, in turn, overlies a conglomerate formation. Canyons on either side of MDA L (Cañada del Buey to the north and Pajarito Canyon to the south) lie approximately 100 ft below the steep-sided mesa (Figure 3). The regional aquifer is located approximately 985 ft below the disposal pits. No perched aquifers are known to occur below the mesa (LANL 1998, 59599).

Figure 4 provides a schematic of the tuff stratigraphy. The Bandelier Tuff is the upper most formation and consists of the Tshirege and Otowi Members separated by the Cerro Toledo. Three upper units make up the Tshirege Member of the Bandelier Tuff. Unit 2 (Qbt 2) and the upper portion of unit 1v (Qbt 1v) are fractured, and the fractures are often filled with calcite and/or clay. The Cerro Toledo stratum (Qct) is made up of volcanoclastic sediments interbedded with minor pyroclastic flows. The Otowi Member (Qbo) underlies the Cerro Toledo interval and consists of nonwelded to poorly welded tuff containing little evidence of fracturing (Vaniman and Chipera 1995, 54709).

The Cerros del Rio basalts lie beneath the tuffs and make up roughly 35% of the vadose zone. Characteristics of this unit vary widely, ranging from extremely dense with no effective porosity to highly fractured to very vesicular so as to appear foamy (Turin 1995, 70225). The Puye Formation is a conglomerate deposit that underlies the Cerros del Rio basalts. The water table occurs within the Puye Formation beneath TA-54. A summary of the site geology and geologic properties can be found in the MDA L investigation work plan (LANL 2004, 87624).

Table 1 summarizes the geohydrologic and hydraulic properties for the stratigraphic layers and provides the bulk density, porosity, in situ permeability, moisture content by volume, percent saturation, saturated hydraulic conductivity, and degree of induration and fracturing of the various formations. The bulk permeability of the media can be inferred from data collected in boreholes at the site (SEA 1997, 87818). Anemometry measurements from boreholes at the site provide information on the bulk flow within the media. These data indicated that in the upper 300 ft of strata, air flows primarily through the Cerro Toledo. Subsequent discrete point permeability measurements confirmed the Cerro Toledo has a higher permeability than the other stratigraphic layers (3–10 darcies compared to 0.2–0.9 darcies). Figure 5 shows both the anemometry and discrete-point permeability measurements from borehole 54-01018. The variability in the anemometry readings in the Qbt 1g unit resulted from measurement variability; however, the general trend of the data is consistent with the permeability results.

2.3 Results of Previous Investigations

In 1985, the Laboratory received a compliance order from the New Mexico Environmental Improvement Division (NMEID, now the New Mexico Environment Department [NMED]) addressing numerous waste issues (NMEID 1985, 75885). The order specified six tasks involving site investigation activities in and around MDA L. These tasks required measuring specific soil characteristics at the site, including intrinsic permeability, soil-moisture characteristic curves, and unsaturated hydraulic conductivity; analyzing the infiltration and redistribution of meteoric water into the site soil; characterizing the core and pore gas in the vadose zone; and analyzing the potential presence of perched water. In 1987, the Laboratory provided the results of work performed to complete those tasks (LANL 1987, 76068). Implementation of quarterly pore-gas monitoring at MDA L began in 1990. Phase I of the RCRA facility investigation (RFI) for MDA L began in 1993 and was completed in 2001. Analysis of core and pore-gas samples collected at the site during the Phase I RFI and quarterly monitoring has led to the following conclusions:

- The 34 disposal shafts, grouped at the east and west ends of the site, are considered to be the source of the VOCs.
- The primary constituents of the plume are 1,1,1-trichloroethane ([TCA] 75%); trichloroethene ([TCE] 12.5%); and Freon (11%).
- Free organic liquid has not been detected below the shafts.
- Sorbed organic chemicals have not been detected below the shafts.
- Pore gases are contaminated with VOCs.
- The VOC vapor plume has migrated over 330 ft laterally along the long axis of the mesa from the shafts; the depth of the10 ppmv TCA contour is approximately 300 ft bgs.
- The total mass of VOCs in the plume is at least 2200 lbs.

In 1993 and 1994, the surface flux of VOCs and tritium was measured (Quadrel 1993, 63868; Quadrel 1994, 63869; Eklund 1995, 56033; Trujillo et al. 1998, 58242), and core samples were collected (LANL 1994, 76071). In 1994, channel sediments from tributaries of Cañada del Buey were analyzed (LANL 1996, 54462), and ambient-air samples were collected. Between 1994 and 1997, the PESP was carried out to determine whether SVE is an effective method for removing VOCs beneath the site. Soil matric potential, in situ soil permeability, and borehole anemometry measurements were made, and pore-gas pressures and chemical constituents were recorded at several boreholes. In 1996, the VOC vapor plume at the site was modeled using T2VOC, and a tracer gas injection/monitoring system was used to evaluate the disturbance of pore gas by air-rotary drilling. In 1997 and 1998, the effectiveness of passive vapor extraction of subsurface vapor-phase VOCs was studied. In 2001, the impact of a single drum failure on the VOC plume extent was evaluated (Stauffer et al. 2002, 88400). The results of these previous investigations are summarized in Appendix B of the MDA L investigation work plan (LANL 2004, 87624).

In 2004 and 2005, ENV-ERS completed field work to finalize the characterization of the nature and extent of contamination at MDA L as specified in the investigation work plan for MDA L (LANL 2004, 87624). Seven boreholes were drilled in 2004 and 2005 to supplement the data from the 1995 investigation at MDA L (LANL 2004, 87624, Appendix B). Pore-gas samples were collected from each of the seven boreholes and analyzed for VOCs.

2.3.1 Results of Previous Studies

Of particular interest for the proposed pilot study are the PESP carried out between 1994 and 1997 and the independent review of potential remedial technologies conducted by the TAG in mid-2001. The PESP provided a broad study of vapor extraction specific to the site, while the TAG reviewed the conclusions of the PESP and evaluated remedial technologies. The results from each study are summarized below.

2.3.1.1 Pilot Extraction Study

The PESP proposed a strategy for remediating the VOC vapor plume at MDA L using a process of active SVE to retract the plume to the vicinity of the source, followed by using passive extraction techniques over the long-term to maintain the plume in its contracted state. Various tests conducted by the Laboratory helped to define the process of vapor venting in the Bandelier Tuff.

SVE is an in situ technology to remediate soil in the unsaturated (vadose) zone whereby a vacuum is applied to the soil to induce the controlled flow of air resulting in removing volatile and some semivolatile contaminants from the soil. The gas leaving the soil may be treated to recover or destroy the contaminants, depending on local and state air discharge regulations. Vertical extraction vents are typically used at depths of 5 ft or greater and have been successfully applied as deep as 300 ft. In VOC-contaminated soils with appropriate physical and chemical properties, SVE is a relatively inexpensive and efficient technology that can remove up to 99% of the VOC contaminants. This technology was shown to be effective at the Laboratory and at DOE's Hanford Site in Washington. Over a period of 20 months, the Laboratory's SVE system removed a total of 16,000 pounds of light-end hydrocarbons from the Knights of Columbus site in Los Alamos County. Over a period of nine years, the Hanford SVE system extracted a total of 170,000 lbs of carbon tetrachloride (CCl_4) from the vadose zone. Over this period, CCl_4 concentrations decreased from initial concentrations of 30,000 parts per million by volume (ppmv) to 40 ppmv.

The PVET was performed over a 34-day period between September and October 1995 at the edge of the VOC vapor plume (Figure 6). Borehole 54-01017 was completed as the extraction borehole for the test.

Steel surface casing (8 in. in diameter) extended to a total depth of 75 ft, and the open borehole (9 in. in diameter) extended to a total depth of 150 ft below ground surface (bgs). A 5hp, 208V regenerative blower capable of up to 203 ft^3 per min and a maximum vacuum of 88 in. of water column were used to extract the soil gas. Given the low contaminant concentration of the soil gas in this area, no vapor treatment system was required. The extraction process, including the total flow from the borehole, borehole vacuum, extraction air temperature, and atmospheric pressure, soil-gas pressure, and soil-gas contaminant concentrations, was measured during the test (ERM/Golder 1997, 70334). No known open boreholes or holes were detected within the extraction zone during the PVET.

During the test, the PVET system extracted approximately 25 standard cubic feet per minute (scfm) of air. The extraction rates of the contaminants monitored during the PVET are shown in Table 2. Analysis of the data showed that the influence of the extraction system extended approximately 140 ft horizontally from the extraction interval. It was determined that this radius of influence may be great enough that the plume at MDA L could be remediated and/or controlled with an SVE system.

Little change was seen in the soil-vapor contaminant concentrations or the measured pressures below the extraction interval. Fresh air from the surface was drawn down to the high-permeability region of the Qbt stratigraphic layer (starting approximately 120 ft bgs), particularly the Qbt 1v(c) layer, and then moved laterally through this layer to the extraction borehole. Hence, these layers, which coincided with the highest contaminant concentration levels, provided a large percentage of the total extracted flow. Data analysis using a pure resistive/capacitive circuit model estimated that up to 99% of the contaminants in the existing the plume could be removed in 90 to 175 days.

The test demonstrated that organic vapors in the tuff media beneath MDA L move readily toward an extraction borehole with little or no sorption, making this technology well-suited for plume control and/or remediation. Further, a comparison of the measured data with pre-test modeling results showed that standard numerical and analytical modeling techniques may be used to predict air flow within the media. The strong correlation between the model and the measured data confirmed that discrete near-field permeability measurements were adequate in representing bulk flow in the media.

The main conclusions of PESP activities may be summarized as follows.

- During active vapor extraction, the vapor moved at the same velocity as the pore gas. By tracking the concentration at several depth intervals in several boreholes, it was concluded that the contaminant movement through the media was not retarded. This conclusion was further supported by the lack of a restart spike in the active extraction borehole.
- The Laboratory measured both the in situ horizontal permeability as a function of depth in several boreholes and the gross borehole flow using an anemometer. Pressure data from the active and passive extraction tests indicated that the vertical permeability was different from the measured horizontal permeability at some locations. The Laboratory also measured the flow in open boreholes induced by variations in barometric pressure. Close agreement of the data with modeling efforts indicated that the flow into and out of a borehole is governed by the horizontal permeability and is reduced by the vertical penetration of barometric pressure variations into the earth from ground surface. In addition, the passive tests showed air flow rates at most locations across the mesa will be fairly similar, although occasionally a borehole will hit a cavity or fracture that alters the flow.
- Measured penetration of barometric pressure variations within the Bandelier Tuff and the underlying Cerros del Rio basalt showed that air flow in Qbt 1v(c) is dominated by fractures and vertical flow.

- Based on induced subsurface vacuum pressure at steady state, the radius of influence of the PVET was approximately 140 ft. The test also indicated that the depth of influence was equivalent to the depth of the extraction borehole.
- Air velocities of the plume within the Qbt 1v(c) (colonnade) averaged approximately 1.6 ft per day.
- The PVET effect on TCA concentrations and negative-pressure propagation was different in various subunits of the Bandelier Tuff.
- The greatest change in TCA concentrations and air flow caused by the PVET occurred in Qbt 1v(c). This subunit demonstrates geohydrologic characteristics that are conducive to enhanced air flow, including induration-supporting fractures, fine-grain size that enhances porosity, and overall higher permeability than the units above and below it.

2.3.1.2 Results of Technical Advisory Group Evaluation

In mid-2001, a TAG was formed by DOE's Innovative Treatment and Remediation Demonstration (ITRD) Group to provide technical assistance in evaluating remedial technologies for the vapor-phase plume at MDA L (LANL 2004, 87624, Appendix H). The specific goals of the TAG were to evaluate the site and to assess passive and active venting versus other applicable technologies in order to remediate the vapor-phase plume. The TAG used a remediation technologies screening matrix that was originally developed by the U.S. Environmental Protection Agency (EPA) and the U.S. Air Force (EPA/542/B-93/005). The screening matrix identifies processes used to remediate contaminated soil and groundwater with some degree of success. In situ biological treatment, in situ physical/chemical treatment, in situ thermal treatment, ex situ biological treatment, ex situ physical/chemical treatment, ex situ thermal treatment, containment, and other treatment processes were considered. After reviewing the data, the TAG concluded that vapor extraction and natural attenuation were viable remediation technologies. In addition, the TAG concluded that because waste in the 34 disposal shafts constitutes a VOC vapor source term that will probably continue to release contaminants into the formation, vapor extraction was deemed more feasible than natural attenuation. The TAG report (LANL 2004, 87624, Appendix H) listed the following as primary factors favoring vapor extraction:

- the absence of phase separated liquid (free product),
- a large depth to the bottom of the plume (10 ppmv TCA at approximately 300 ft bgs),
- very low organic carbon in tuff that resulted in easy desorption of adsorbed VOCs,
- the presence of the contaminant only in unsaturated medium,
- reasonable soil flow characteristics, and
- high volatility and low sorption of the halogenated VOCs.

The combination of these factors led the TAG to conclude that contaminant removal rates by vapor extraction would be very high and that the vapor-phase plume at the site could be remediated by SVE.

2.3.2 Characterization of the Vapor Plume

A review of analytical results for pore gas samples collected from boreholes at MDA L between 1988 and 1992 is presented in a report entitled "Pilot Extraction Study Plan for the Organic Vapor Plume at MDA L" (LANL 1993, 22430), which states,

> the principal vapor phase organic compounds, listed in descending order of concentration, were TCA, trichloroethene (TCE), carbon tetrachloride, chloroform, tetrachloroethene (PCE), toluene, and benzene. Other contaminants that have been detected, but at much lower concentrations, include chlorobenzene, xylenes, and 1,2,4-trimethylbenzene. TCA was found in the greatest concentration, and it also exhibits the greatest lateral and vertical extent in the organic vapor plume. The measured concentrations of TCA are almost an order of magnitude greater than values measured for TCE, the contaminant of second highest concentration.

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

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

An evaluation of preliminary vapor data collected from seven boreholes completed as part of site characterization activities in 2004 and 2005 indicates that the results are consistent with data collected during the RFI and during quarterly monitoring. Vapor concentrations are highest close to the source area and decrease with lateral distance and depth. Furthermore, these results do not indicate the presence of a free product release. Final results of this testing will be presented in an investigation report later this year.

VOC concentrations have remained relatively constant or have decreased slightly over time. Therefore, it the plume appears to be in a near steady state. Stauffer et al. (2002, 88400) modeled the plume evolution using a three-dimensional finite element program. The model assumed vapor diffusion emanating from two source areas located at the two shaft fields at MDA L. The model was calibrated using the quarterly pore-gas monitoring data. The resulting modeled plume closely matches the shape, concentration gradients, and extent of the plume as measured. The model also predicted that the plume should be at or near steady state. This modeling supported the conclusion that the VOC plume exists predominantly in the vapor phase, that the VOCs move by diffusion, and that the plume is stable. Stauffer et al. (2002, 88400) also predicted the plume’s evolution over time and concluded that if the assumed source remains constant, the plume will continue to grow slowly. The model fit was improved by allowing for the partitioning of VOC into pore water. If a constant source was removed in the simulations, the plume decreased in mass as VOC is lost to the atmospheric boundary, with the 10 ppmv contour contracting back toward the source region.

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

To date, the major findings of plume characterization activities include the following.

- Releases from disposal units at MDA L resulted in a subsurface vapor-phase VOC plume extending beneath the site and beyond the boundary of MDA L.
- Vertically, the 10 ppmv TCA contour is approximately 300 ft bgs; VOCs have not been detected in vapor samples from the basalt or below.
- The long-axis extent of the plume along the length of the mesa, as defined by the 10 ppmv TCA contour, has fluctuated between 700 and 1000 ft. The short-axis extent is defined by the width of the mesa (approximately 450 ft across).
- VOCs are transported from the source areas in the vapor phase.
- TCA is the primary constituent of the VOC plume.
- TCA concentrations vary across the plume.
- The plume has changed very little in area or contaminant concentrations since 1999.
- Uncertainties associated with potential increases in the source term from container failure in the future are significant.

3.0 METHODOLOGY OF THE PILOT STUDY

The results of the PVET performed during the PESP indicate that an SVE system may be used effectively to extract VOCs from the subsurface vapor plume at MDA L. Additional data on the effectiveness of SVE in the two source areas are needed to support evaluation of this technology as part of the corrective measures evaluation (CME) for MDA L.

The PVET provided important data for the design of the SVE. However, the design will differ from the PVET in several ways. First, the design of the extraction boreholes places them closer to the source areas, and the highest plume concentrations are located directly beneath the asphalt pad at MDA L. Locating extraction boreholes beneath or near this cover will reduce the amount of surface air pulled into the extraction interval, potentially increasing the radial influence of the extraction system. Secondly, because the PVET extraction borehole was located on the outer edge of the contaminant plume, contaminants upgradient of the borehole were pulled towards the plume boundary, causing concentrations to increase over time. Concentrations of the contaminants decreased over time downgradient of the extraction borehole. The mass removal rate measured in the PVET remained fairly constant over time. Locating the extraction interval nearer to the contaminant plume will result in a decrease in concentrations of the soil gas over time at all distances from the extraction borehole. Similarly, the mass removal rate will be highest in the beginning and will decrease with time. Near the source, contaminant concentrations are higher both near the surface and at greater depths than was seen in the area where the PVET was installed. Using measured removal rates from the PVET for predicting the mass removal rates from the pilot study extraction borehole(s) provides only an estimate of the actual mass removal rate.

3.1 SVE Pilot Study Scope

This pilot study will involve the following activities.

- Two boreholes will be drilled and configured specifically to be used as vapor extraction boreholes for this project. One borehole will be located in the immediate vicinity of each of the two source zones (Figure 7). The borehole diameters will be 9 in., the same as those used in the PVET.
- The boreholes will be drilled to a depth of 215 ft and cased to a depth of 65 ft.
- Existing boreholes will be instrumented to allow for pore-gas sampling and pressure monitoring. The total flow from the borehole, borehole vacuum, extraction air temperature, and atmospheric pressure, will be measured at regular intervals during the extraction process.
- Line power from the facility will be used to power the SVE system.
- SVE cycling will be performed to further characterize the source zones by providing rebound data and to increase the overall rate of VOC removal.
- Catalytic oxidation will be used to treat the VOCs removed from the plume. Other treatment methods will be considered as deemed necessary.
- Once initial extraction is completed, ongoing pore-gas monitoring at MDA L from surrounding boreholes will be modified as necessary to assess the effects of the SVE project.

The results of the pilot study data analysis will determine the appropriate extraction rate for reducing the extent of the plume. In addition, the study will assess the ability of an SVE system to respond to potential releases from the inventory resulting from possible container failure in the future.

3.2 SVE Pilot Study System

The primary goal of the pilot test is to provide information critical to designing an SVE system capable of achieving the following objectives:

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

Based on the PESP results, two extraction boreholes will be installed with an extraction interval starting at 65 ft bgs. The upper 65 ft will be cased and the casing grouted in place; a basal grout plug will be emplaced to eliminate the potential for short circuiting. Surface casing will be set in concrete. Because the plume is deep, extending to depths as great as 300 ft bgs, the extraction interval will be extended to a depth of 215 ft to allow control of a large portion of the plume without penetrating the higher permeability Cerro Toledo. Penetrating the Cerro Toledo will reduce the removal efficiency in the upper portions of the Bandelier Tuff. Figure 7 shows the placement of the proposed extraction boreholes, including the minimum anticipated radius of influence.

Extraction boreholes drilled for the pilot study will be logged to provide information on subsurface geology. Drill cuttings and camera logs of the boreholes will provide the actual locations of the various stratigraphic layers. A gamma log of the borehole will locate the surge bed/vapor phase notch. Discrete soil-vapor gas samples will provide a near-source concentration profile of the contaminants and more accurate estimates of contaminant removal rates. Permeability measurements will confirm measured values from the PVET borehole and will be used to further analyze the SVE results. A 5-ft core will be collected from an interval approximately 5 to 10 ft below the deepest of the nearby shafts to analyze for free liquid contaminants. If field screening indicates the presence of VOCs, one sample will be collected for laboratory analysis.

Measurements of the extraction process (including the total flow from the borehole, borehole vacuum, extraction air temperature, and atmospheric pressure) and soil gas contaminant concentrations will be collected during the test. Existing boreholes will be used to monitor the contaminant concentrations and evaluate the radius of influence of the extraction system.

The anticipated operating sequence of the SVE pilot study includes a short extraction and rebound interval at the two extraction boreholes, followed by longer duration extraction and rebound periods. Initial short extraction times will confirm the absence of a free-liquid source and minimize gross scale movement of the plume. The SVE system will be connected to each of the new extraction boreholes and run for a short period (on the order of days or weeks, depending on how quickly the monitoring port concentrations respond with a reduction in measured values). The system will be operated until the change in contaminant concentrations reaches steady state and a trend is confirmed, after which the system will be turned off and the concentration rebound will be monitored. The rate of increase in VOC concentrations will be used to evaluate the potential presence of sorbed contaminants, the fracture vapor flow from the source zone, and the contribution of pore water phase contamination. For example, a rapid increase of concentrations at the ports nearest the source may indicate the presence of contaminants in the sorbed phase. An attenuated response at the nearest ports to the source resulting in measurements that are lower than initial peak value may indicate a free-liquid source is not present (Figure 8).

Once the short duration periods are completed, longer duration extraction tests will be performed. Extraction at each of the boreholes will be conducted until measured concentrations within the area of influence have been significantly reduced. Layers of higher permeability will dominate the flow. In time, concentrations in these layers may decrease enough relative to other depths; thus, it may be necessary to extract selectively from above or below these zones using an air-packer system.

Once active extraction is stopped, soil-gas monitoring will continue to show near-field rebound; data outside the zone of influence will be used to evaluate the natural decay in concentrations due to diffusion.

3.3 Technologies for Treatment of Exhaust Gas from SVE Systems

Several treatment technologies are available for treating exhaust gas extracted vapor from SVE systems: activated carbon, thermal oxidation, and catalytic oxidation. Based on VOC concentrations in the extraction interval, the technology most suitable for exhaust gas treatment at MDA L is catalytic oxidation. Catalytic oxidation equipment is used to destroy contaminants in the exhaust gas from SVE systems. A catalyst is used to accelerate the rate of oxidation by adsorbing the oxygen and the contaminant on the catalyst surface, where they react to form carbon dioxide, water, and hydrogen chloride gas. This technology has several advantages:

- A contaminant destruction efficiency of 97% to 99% may be achieved.
- The catalyst enables oxidation reaction to occur at much lower temperatures than required by thermal oxidation, resulting in lower fuel use and cost.
- The equipment used in the extraction process is portable and is usually mounted on a trailer.

The technology also has limitations: influent gas concentrations must be maintained below the 25% lower explosive limit, which may require dilution with outside air.

During the early stages of the pilot test, the expected extraction rate for MDA L is estimated to be less than 200 lb of VOCs per day, which is within the ideal range of operation for catalytic oxidation systems. As the initial pore volume is extracted, the amount of contaminant extracted will decrease. Activated carbon adsorption, which is less expensive than catalytic oxidation, or the suspension of treatment will be evaluated as vapor concentrations in SVE off-gas decrease.

On December 20, 2004, the Laboratory submitted a “Notice of Intent Application for the TA-54 MDA L Soil Vapor Extraction Project” to the New Source Review, Air Quality Bureau, NMED (LANL 2004, 88401). On January 5, 2005, NMED acknowledged receipt of the application and stated that the New Source Performance Standards or National Emission Standards for Hazardous Air Pollutants do not apply to this facility (NMED 2005, 88402).

4.0 MONITORING AND SAMPLING PROGRAM

An automatic monitoring system will be used to monitor the extraction system while soil gas contaminant concentration samples will be collected manually. The extraction system monitoring will include extraction air flow, temperature, contaminant concentration measurements, and borehole vacuum measurements. Baseline data will be collected for two weeks before the test starts and at a minimum of four times per day during the test period.

Distances between the available monitoring boreholes and the extraction borehole (hundreds of feet) prevent a single centralized collection system; therefore, samples from pilot test monitoring boreholes will be collected manually using Tedlar bags. Samples will be analyzed with an Innova (formerly Brüel & Kjaer) photoacoustic analyzer. The detector will be calibrated for TCA and TCE, the two most prevalent contaminants in the plume. Other filters may be used to monitor trichlorofluoromethane (Freon 11), tetrachloroethene, or other plume constituents. The sensor will measure carbon dioxide to ensure that samples are not diluted with atmospheric air and will monitor water vapor.

Currently, 32 pore-gas monitoring boreholes have been installed at MDA L. Borehole coordinates and port depths are shown in Table 3. Figure 9 plots the monitoring boreholes, along with the proposed extraction boreholes, over a topographic map of Area L. All monitoring ports are currently scheduled to be sampled each quarter. This sampling frequency is sufficient to determine the long-term effects of the SVE system, including how quickly the plume boundary, determined by the 10 ppmv contour of TCA, retracts once the source term is depleted.

To determine the near source effects on the extraction system, selected ports in existing vapor monitoring boreholes will be sampled immediately before, during, and after extraction. Boreholes within a 200 ft radius of the extraction boreholes have been selected for pore-gas sampling to evaluate the radius of influence of the SVE systems. Most of the ports sampled will be within the extraction interval. In addition, samples will be collected from intervals above and below the extraction interval to determine the vertical influence of the SVE system. Data for the monitoring boreholes within a 200-ft radius of the east and west extraction boreholes are listed in Tables 4 and 5, respectively. The tables also show whether the ports are above, within, or below the extraction interval. All sampling ports on boreholes F, G, D, E, B, A, 54-02016, and 54-02002 will be sampled while the east extraction borehole is operating. All sample ports on boreholes C, 54-02021, 54-02031, 54-02022, and 54-02001 will be sampled while the west borehole is operating.

4.1 Data Analysis and Final Report

Data from the pilot test will be used to evaluate the potential of SVE for remediating the current MDA L vapor plume and for controlling future releases from the vertical shaft source zone. In addition to providing critical lessons learned, these data will be used to assess the following SVE system design criteria:

- the vacuum pressure needed to induce adequate airflow and radius of influence;
- the airflow rates required to achieve maximum contaminant mass removal;
- large-scale SVE system component and equipment requirements;
- the number and configuration of extraction boreholes necessary to remediate the current VOC plume;
- the number and configuration of extraction boreholes necessary to control future potential releases from the source area;
- borehole screen position for maximum contaminant removal;
- the potential value of strategic passive borehole installation;
- confirmation of off-gas treatment technology performance;
- operation and maintenance and remote monitoring alternatives; and
- the management of SVE system closure.

This information will be presented in a pilot study report that will determine the effectiveness of the technology in remediating the plume at MDA L. The information will also be included in the CME.

5.0 SCHEDULE

The pilot SVE tests are scheduled to be completed by the end of March 2006 to allow for

- providing input to the CME, which is scheduled to start in April 2006,
- understanding the influence of the asphalt cap on potential remediation actions, and
- characterizing the source term further and gaining a better understanding of natural attenuation at the site.

To meet the April 2006 deadline for initiating work on the CME, the subcontractor must perform the following activities on or before the following dates:

July 2005:	Submit final system specifications and configuration
October 2005:	Drill and characterize extraction boreholes
October 2005:	Install and test extraction equipment
September–October 2005:	Collect background data at ports near the east extraction borehole
October–November 2005:	Conduct short extraction test at east borehole
November 2005:	Collect data near east extraction borehole to determine source term rebound
November–December 2005:	Conduct longer extraction test at east borehole

December–January 2005:	Collect post-test data near east borehole
December 2005:	Relocate equipment to west borehole
December 2005:	Collect background data at ports near the west extraction borehole
January 2006:	Conduct short extraction test at west borehole
January 2006:	Collect data near west extraction borehole to determine source term rebound
January–February 2006:	Conduct longer extraction test at west borehole
February–March 2006:	Collect post-test data near west borehole
April 2006:	Deliver peer review draft of report

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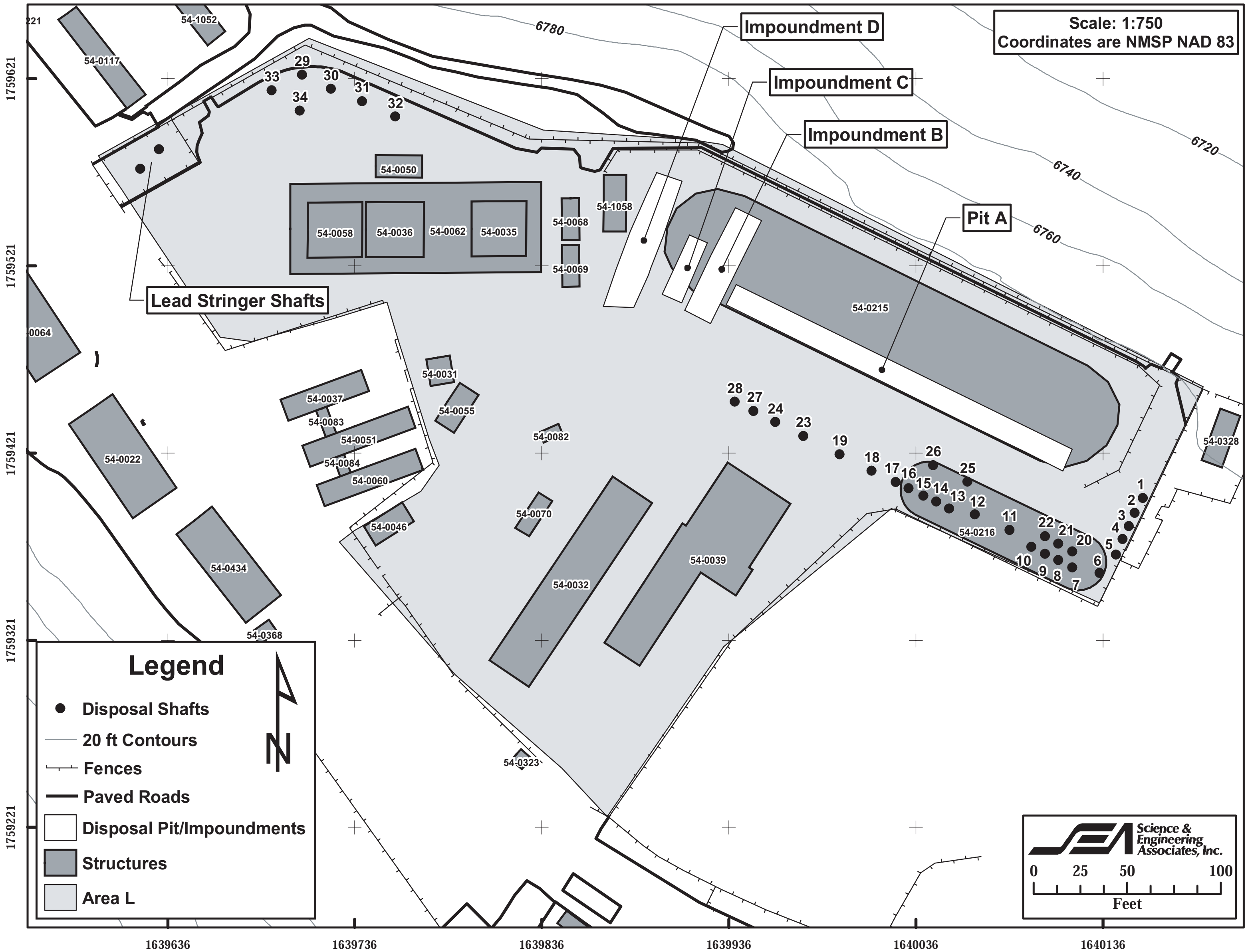


Figure 1. Detailed map of MDA L showing disposal pits and shafts

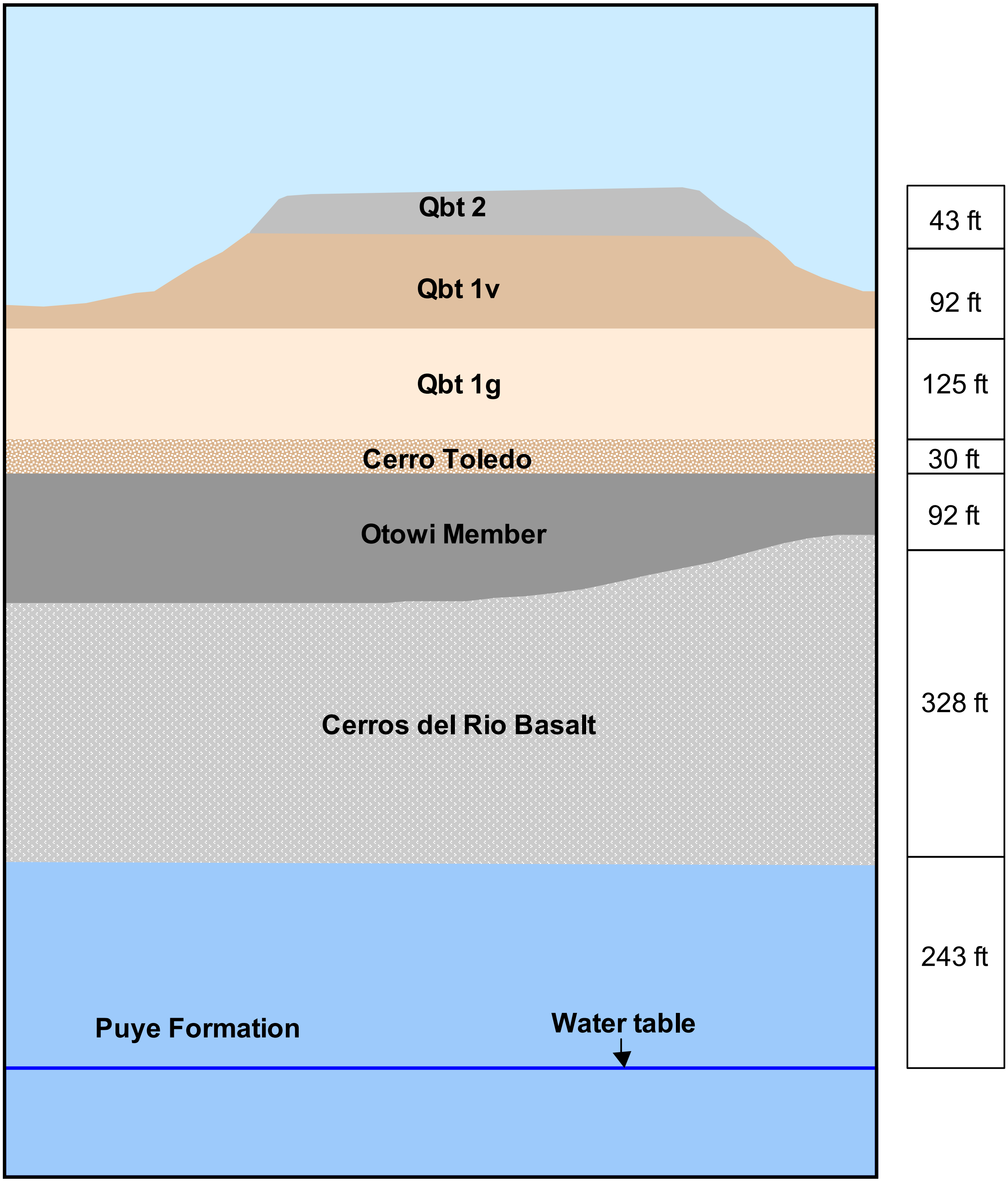


Figure 2. Generalized cross-sectional view of Mesita del Buey

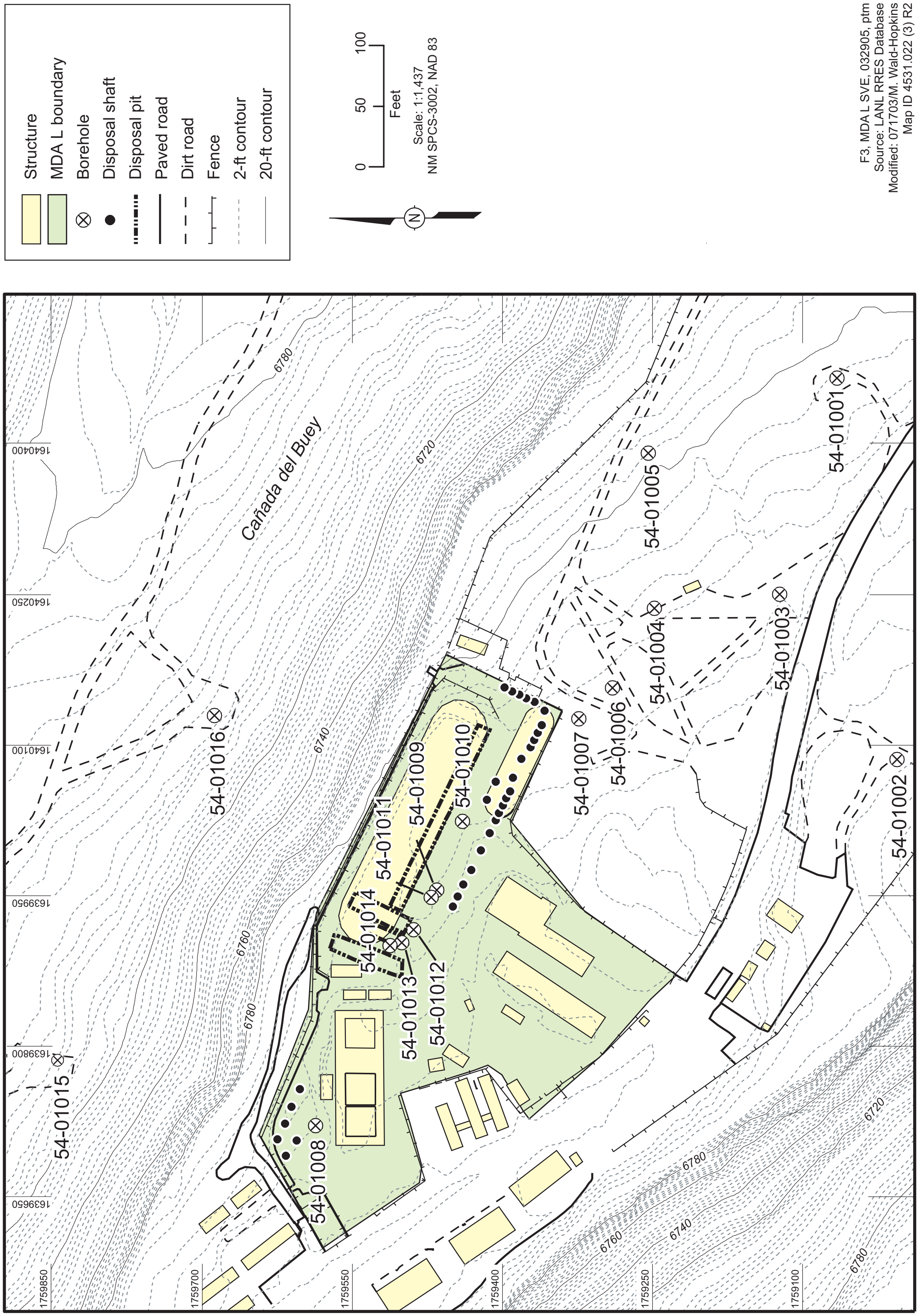


Figure 3. Topographic map of MDA L and the surrounding area

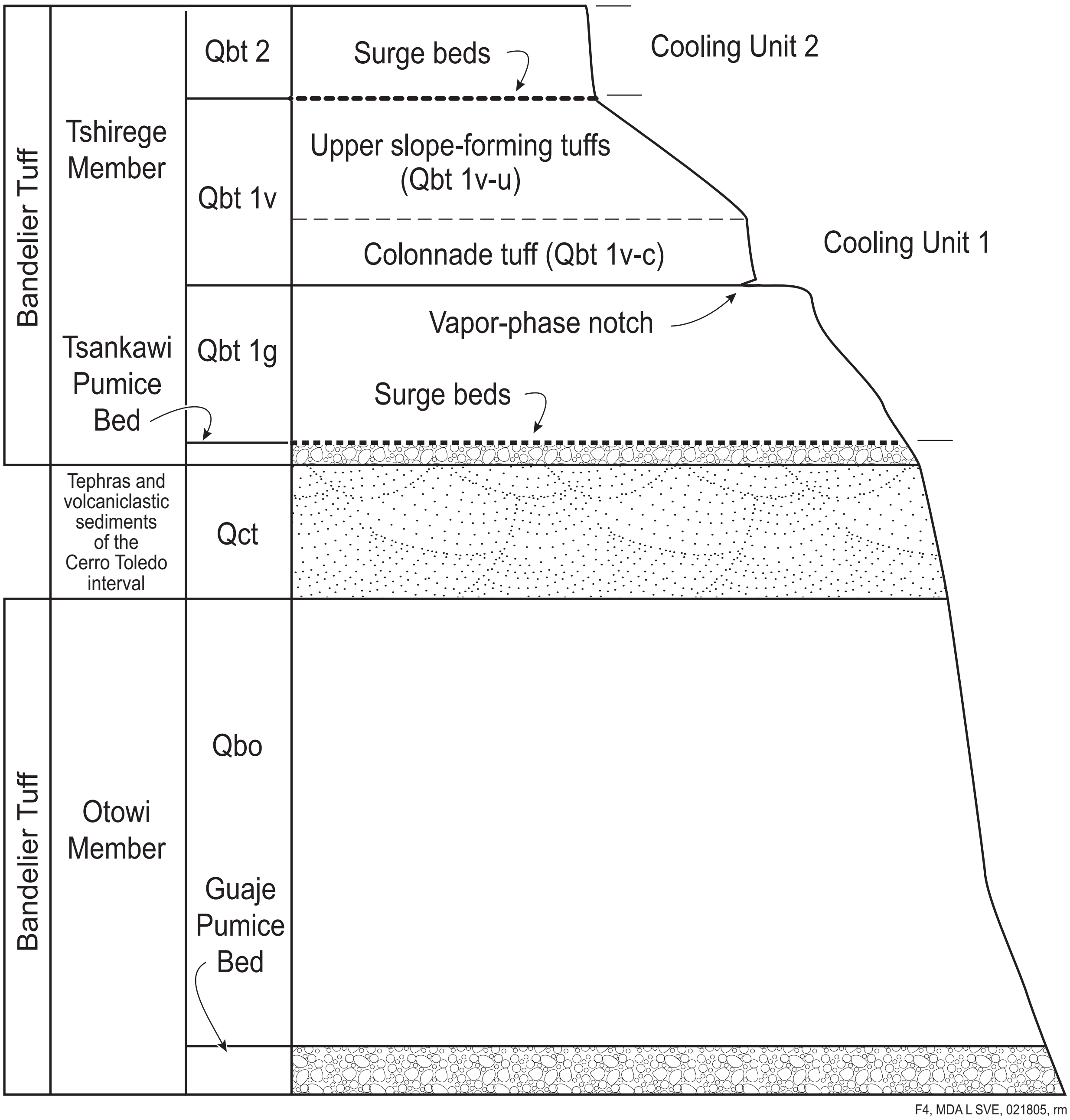
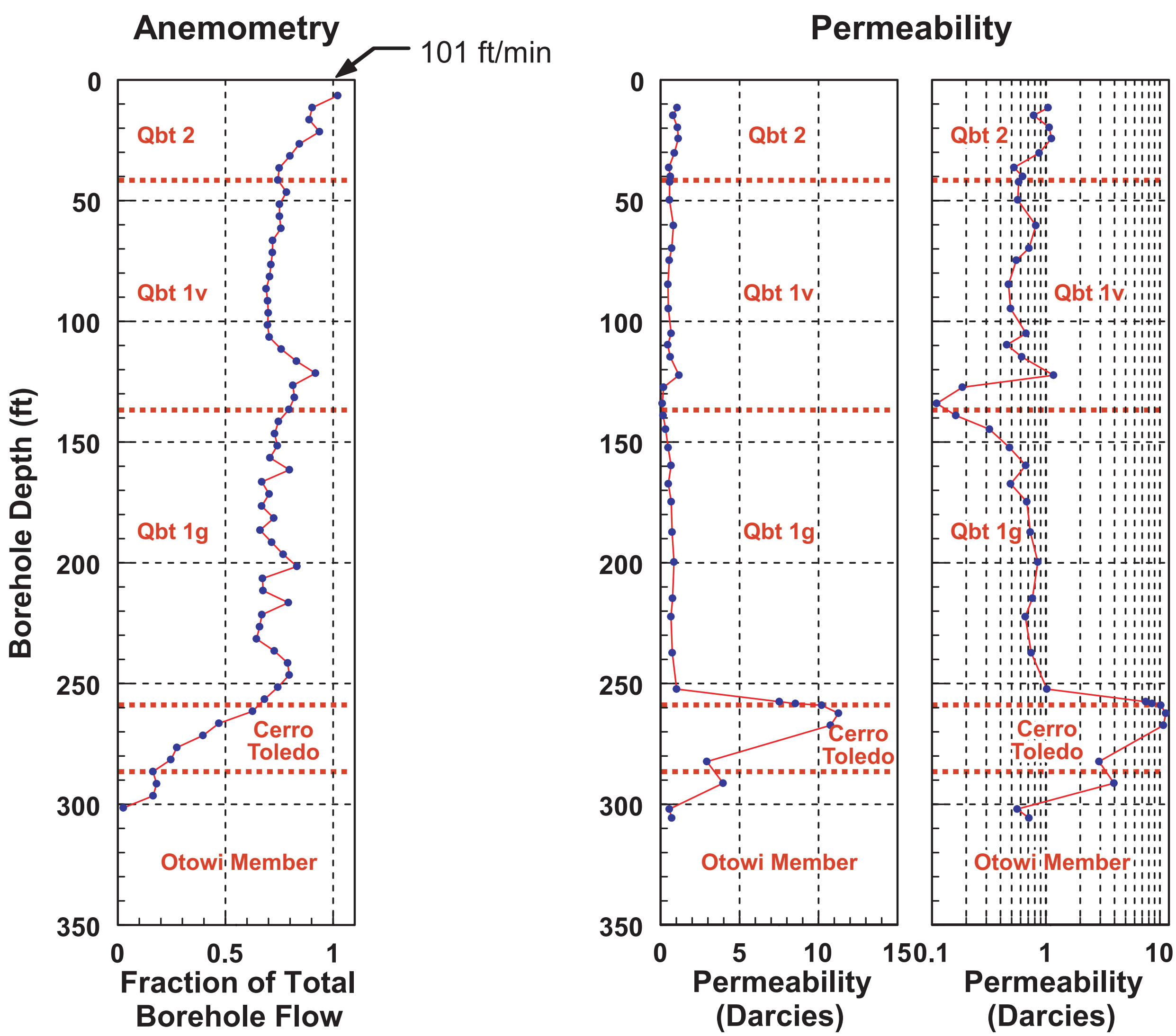


Figure 4. Simplified site stratigraphy



Note: Permeability is depicted on both linear and log scales

Figure 5. Open borehole anemometry and straddle packer permeability results for borehole 54-01018

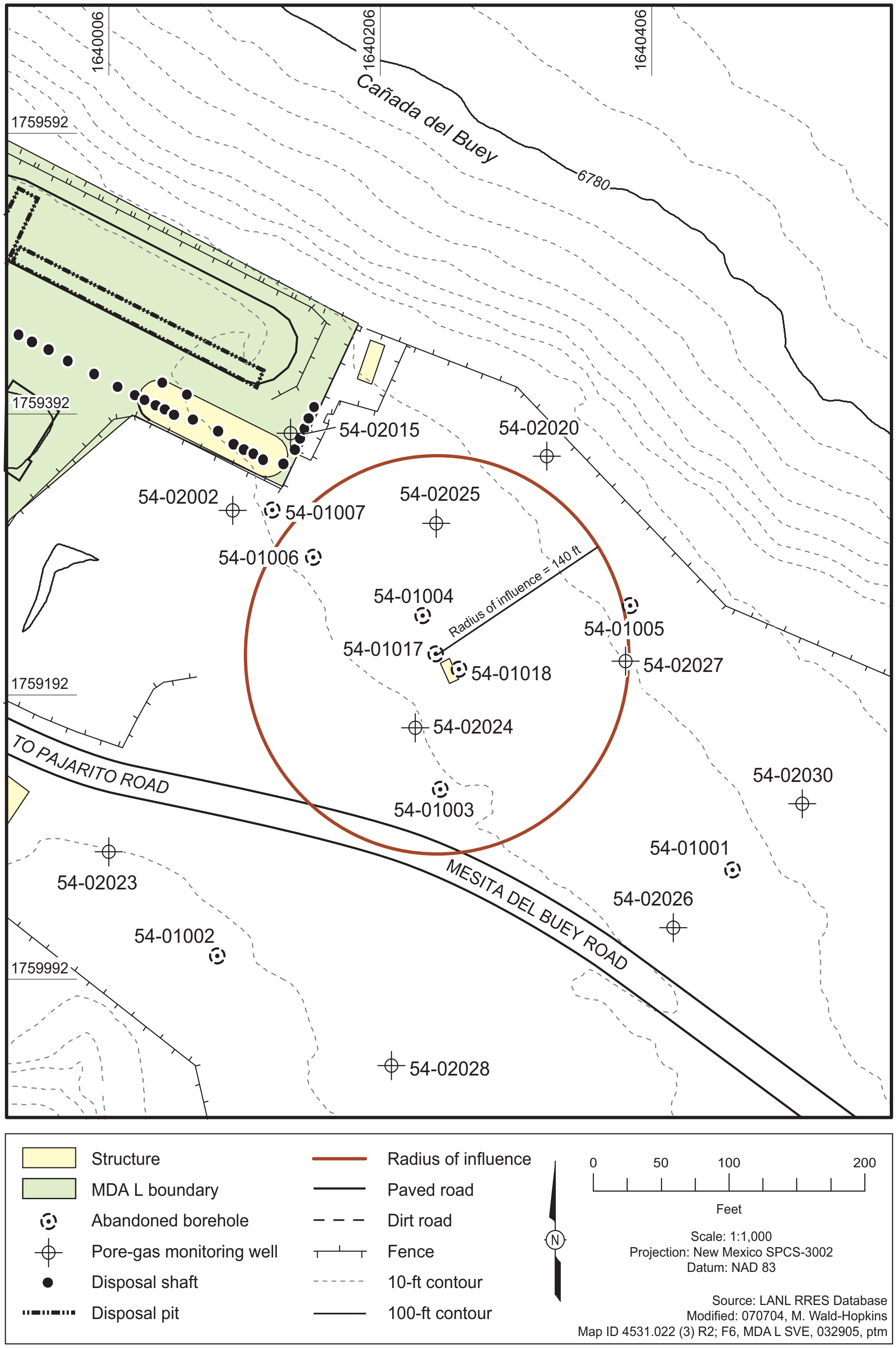
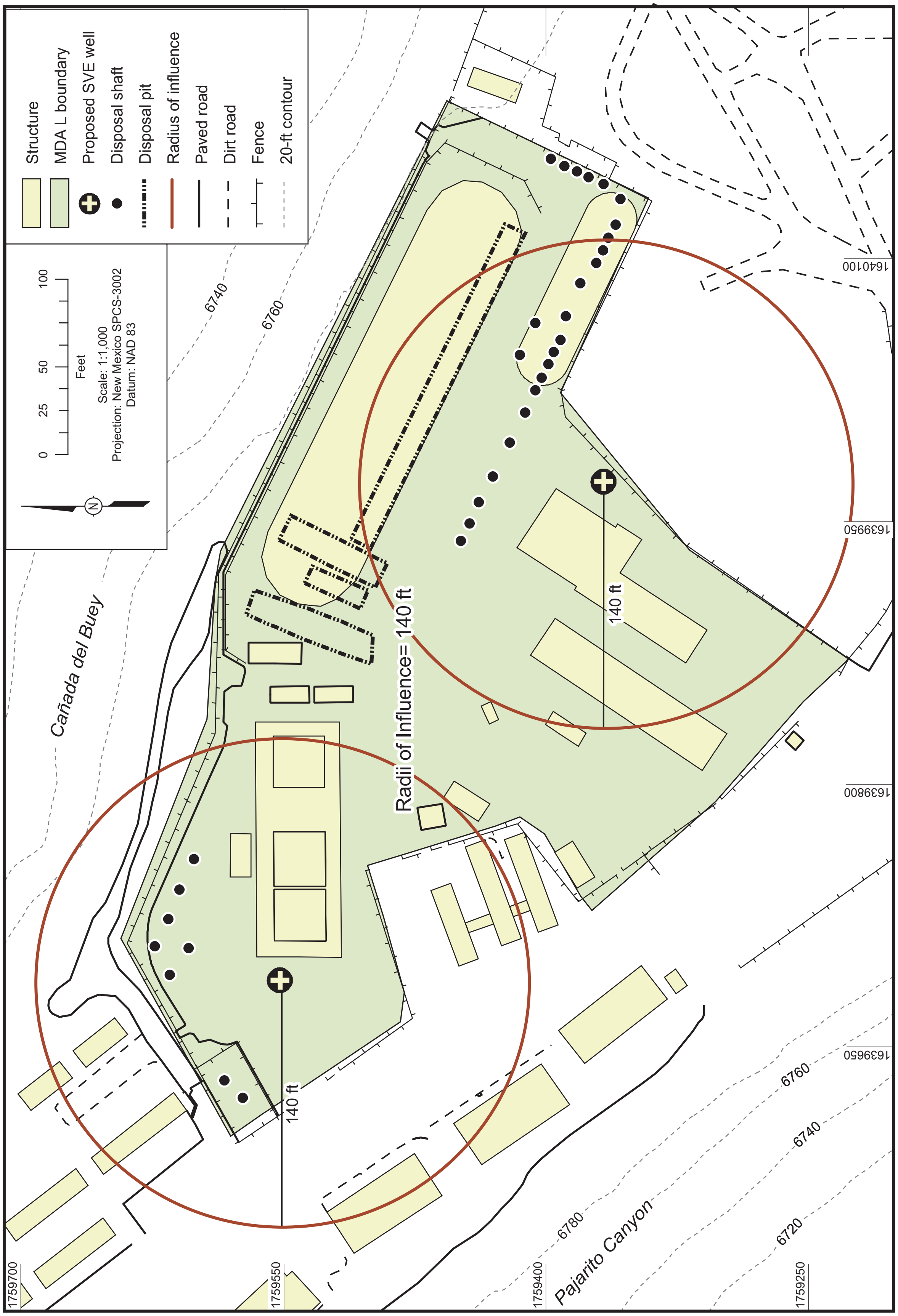


Figure 6. Locations of PVET monitoring wells east of MDA L (near the edge of the vapor plume) and the interpolated radius of influence of the test



Source: LANL RRES Database; Modified: 070704, M. Wald-Hopkins, Map ID 4531.022 (3) R2; F7, MDA L SVE, 032905, ptm

Figure 7. Proposed locations of SVE extraction wells and radii of influence

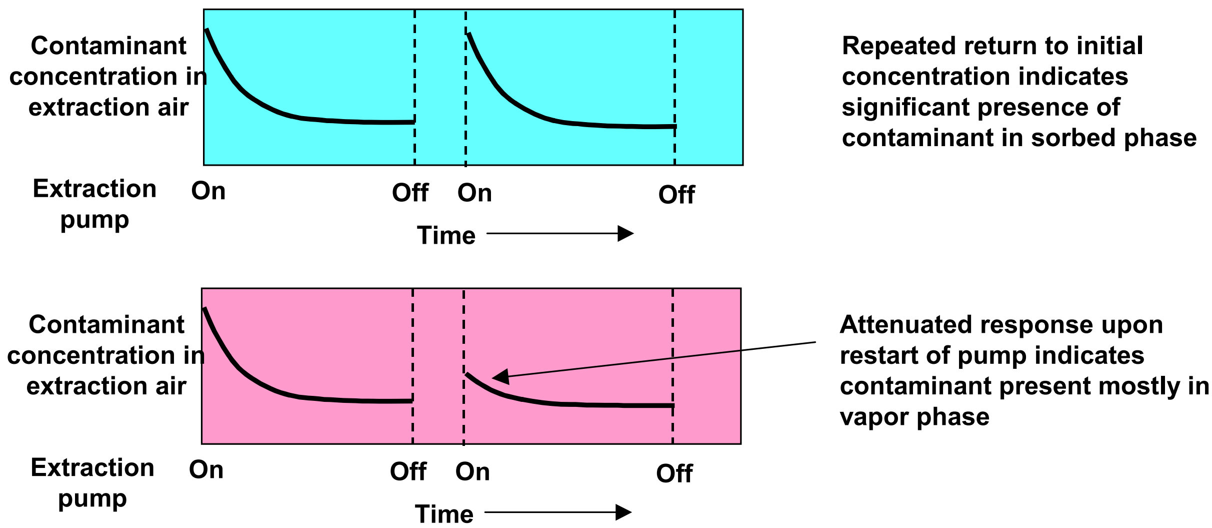


Figure 8. Schematic of rebound profiles after extraction

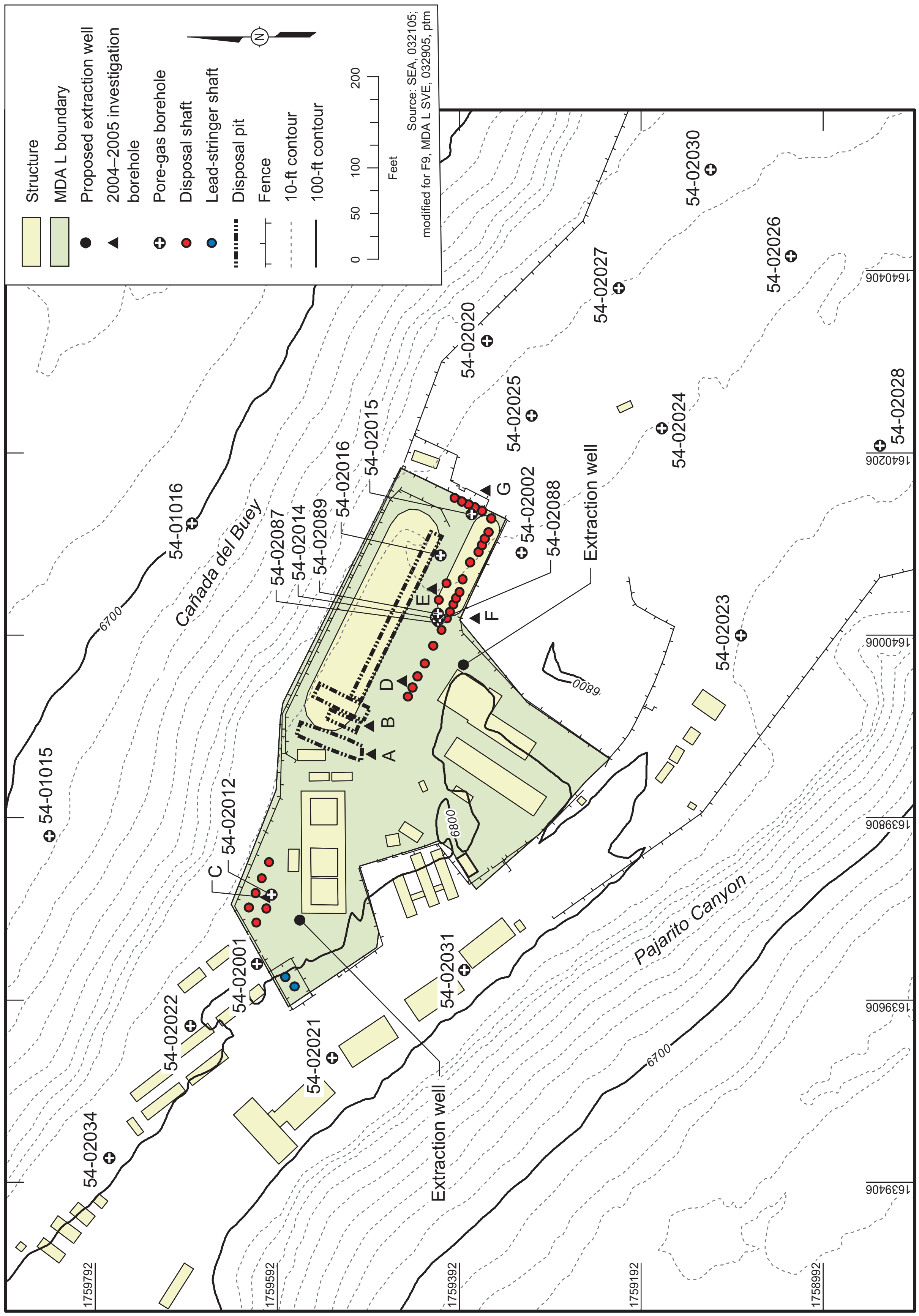


Figure 9. Existing and proposed MDA L monitoring well locations and proposed SVE pilot test extraction wells

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Table 1
Geohydrologic and Hydraulic Properties for Stratigraphic Layers

Stratigraphic Units/Subunits		Hydraulic Properties[a]						Geohydrologic Characteristics[b]		
Unit	Subunit	Bulk Density (lb/in.^{3})	Porosity (%)	In Situ Permeability (darcies)[c]	Volumetric Moisture Content	Saturation (%)	Saturated Hydraulic Conductivity (ft/day)	Gravimetric Moisture Content (%)	Induration[d]	Fractures[e]
2	2(u)	0.0495	45.7	0.5–1	2.57	5.7	1.24	2.12	Mod	Many
	2(l)							1.24	Strong	Many
1v(u)	1v(u_2)	0.0448	48.7	0.4–0.9	1.89	3.7	0.42	1.03	Slight	Mod
	1v(u_1)							1.79	Non	None
1v(c)	1v(c)	0.0426	49.3	0.1–1.2	10.88	21.3	0.47	5.11	Mod	Mod
1g	1g(u)	0.0415	46.2	0.5–1	8.94	16.9	0.53	5.77	Mod	Mod
	1g							5.83	Non	None
Tsankawi/ Cerro Toledo		0.0404	47.3	7–10	14	30.3	2.43	10.8	Mod	Rare
								8.49	Slight	Rare

[a] From Table 2-1, “Pilot Vapor Extraction Test at TA-54” (ERM/Golder 1997, 70334), values converted to English units.

[b] From MDA L and MDA G RFI boreholes.

[c] Straddle packer permeability results for borehole 54-01018, data measured from 10–310 ft bgs (SEA 1997, 87818).

[d] Qualitative induration (hardness) scale is non = nonindurated; slight = slightly indurated; mod = moderately indurated; strong = strongly indurated.

[e] Qualitative fracture scale is none = not present; rare = few present; mod = some present; many = fractures abundant.

Table 2
Resulting Extraction Rates of
Monitored Contaminants during the PVET

Analyte	PPM	lb/day
1,1,1-Tricholorethane	113	1.15
Tricholorethylene	24.2	0.24
Freon 11	1.79	0.02
Freon 113	24.3	0.35
Total		**1.76**

Table 3
Coordinates and Port Depths of Soil Vapor Monitoring Ports in Area L

	Surface Coordinates			
Borehole	x	y	z	Port Depth(s)
54-01015	1639786	1759843	6708	0
	1639780	1759822	6669	45
	1639761	1759757	6544	187
	1639739	1759683	6401	350
	1639734	1759666	6370	385
	1639727	1759644	6326	435
	1639721	1759621	6282	485
	1639715	1759602	6247	525
54-01016	1640129	1759686	6700	0
	1640124	1759668	6669	36
	1640114	1759632	6606	109
	1640104	1759593	6538	188
	1640086	1759528	6426	318
	1640076	1759492	6364	390
	1640064	1759447	6286	481
	1640064	1759447	6286	533
	1640057	1759421	6241	601
54-01018	1640262	1759209	6790	21.7, 39.2, 50.6, 70.7, 111.2, 123.7, 141.4, 181.1, 228.5, 254.7, 263.3, 306
54-02001	1639646	1759615	6798	20, 40, 60, 80, 100, 120, 140, 160, 180, 200
54-02002	1640097	1759324	6792	20, 40, 60, 80, 100, 120, 140, 160, 180, 200
54-02012	1639722	1759599	6795	7, 27, 42
54-02014	1640026	1759418	6792	13, 31, 48, 86
54-02015	1640139	1759379	6789	8, 31, 82
54-02016	1640094	1759413	6789	7, 8, 31, 82

Table 3 (continued)

Borehole	Surface Coordinates			Port Depth(s)
	x	y	z	
54-02020	1640329	1759362	6776	20, 40, 60, 80, 100, 120, 140, 160, 180, 200
54-02021	1639543	1759532	6803	20, 40, 60, 80, 100, 120, 140, 160, 180, 200
54-02022	1639578	1759388	6796	20, 40, 60, 80, 100, 120, 140, 160, 180, 197
54-02023	1640006	1759083	6790	20, 40, 60, 80, 100, 120, 140, 160, 180, 200
54-02024	1640233	1759170	6790	20, 40, 60, 80, 100, 120, 140, 160, 180, 200
54-02025	1640247	1759313	6786	20, 60, 100, 160, 190
54-02026	1640422	1759028	6786	20, 60, 100, 160, 200, 215
54-02027	1640387	1759217	6782	20, 60, 100, 160, 200, 220, 250
54-02028	1640214	1758930	6793	20, 60, 100, 160, 200, 220, 250
54-02029	1640276	1758823	6791	20, 60, 100, 160, 200, 220, 260, 288
54-02030	1640517	1759116	6779	20, 60, 100, 160, 200, 220, 243
54-02031	1639639	1759387	6803	20, 60, 100, 160, 200, 220, 260
54-02034	1639433	1759777	6799	60, 100, 160, 200, 220, 260, 300
54-02087	1640022	1759416	6792	13, 31, 46, 86
54-02088	1640026	1759414	6792	13, 31, 46, 86
54-02089	1640030	1759416	6792	13, 31, 46, 86
A	1639876	1759490	6790	20, 40, 60, 80, 100, 120, 140, 150
B	1639907	1759492	6790	20, 40, 60, 80, 100, 120, 140, 150
C	1639719	1759606	6790	40, 80, 120, 160, 200, 240, 280, 300
D	1639956	1759456	6790	100, 200, 300, 400, 500, 600, 700
E	1640057	1759423	6790	20, 40, 60, 80, 100, 120, 140, 150
F	1640025	1759376	6790	20, 40, 60, 80, 100, 120, 140, 150
G	1640165	1759364	6790	20, 40, 60, 80, 100, 120, 140, 150

Table 4
Data for Ports within 200 ft of the Proposed East Extraction Borehole

Borehole	x	y	z	Depth bgs (ft)	Horizontal Distribution to East Extraction Borehole (ft)	Is the Port Within the Extraction Interval?
F	1640025	1759376	6770	20	52.7	45 ft higher
F	1640025	1759376	6750	40	52.7	25 ft higher
F	1640025	1759376	6730	60	52.7	5 ft higher
F	1640025	1759376	6710	80	52.7	Within interval
F	1640025	1759376	6690	100	52.7	Within interval
F	1640025	1759376	6670	120	52.7	Within interval
F	1640025	1759376	6650	140	52.7	Within interval
F	1640025	1759376	6640	150	52.7	Within interval
54-02087	1640022	1759416	6779	13	55.3	54 ft higher
54-02087	1640022	1759416	6761	31	55.3	36 ft higher
54-02087	1640022	1759416	6746	46	55.3	21 ft higher
54-02087	1640022	1759416	6692	86	55.3	Within interval
54-02089	1640030	1759416	6779	13	57.7	54 ft higher
54-02089	1640030	1759416	6761	31	57.7	36 ft higher
54-02089	1640030	1759416	6747	46	57.7	21 ft higher
54-02089	1640030	1759416	6706	86	57.7	Within interval
54-02014	1640026	1759418	6779	13	60.0	54 ft higher
54-02014	1640026	1759418	6761	31	60.0	36 ft higher
54-02014	1640026	1759418	6746	46	60.0	21 ft higher
54-02014	1640026	1759418	6706	86	60.0	Within interval
54-02088	1640026	1759414	6779	13	62.7	54 ft higher
54-02088	1640026	1759414	6761	31	62.7	36 ft higher
54-02088	1640026	1759414	6747	46	62.7	22 ft higher
54-02088	1640026	1759414	6706	86	62.7	Within interval
D	1639956	1759456	6683	100	69.8	Within interval
D	1639956	1759456	6583	200	69.8	Within interval
D	1639956	1759456	6483	300	69.8	92 ft deeper
D	1639956	1759456	6383	400	69.8	192 ft deeper
D	1639956	1759456	6283	500	69.8	292 ft deeper
D	1639956	1759456	6183	600	69.8	392 ft deeper
D	1639956	1759456	6083	700	69.8	492 ft deeper
54-01016	1640057	1759421	6241	601	89.4	334 ft deeper
E	1640057	1759423	6770	20	90.1	45 ft higher
E	1640057	1759423	6750	40	90.1	25 ft higher
E	1640057	1759423	6730	60	90.1	5 ft higher

Table 4 (continued)

Borehole	x	y	z	Depth bgs (ft)	Horizontal Distribution to East Extraction Borehole (ft)	Is the Port Within the Extraction Interval?
E	1640057	1759423	6710	80	90.1	Within interval
E	1640057	1759423	6690	100	90.1	Within interval
E	1640057	1759423	6670	120	90.1	Within interval
E	1640057	1759423	6650	140	90.1	Within interval
E	1640057	1759423	6640	150	90.1	Within interval
54-01016	1640064	1759447	6286	533	107.6	289 ft deeper
54-01016	1640064	1759447	6286	481	107.6	289 ft deeper
B	1639907	1759492	6770	20	123.7	45 ft higher
B	1639907	1759492	6750	40	123.7	25 ft higher
B	1639907	1759492	6730	60	123.7	5 ft higher
B	1639907	1759492	6710	80	123.7	Within interval
B	1639907	1759492	6690	100	123.7	Within interval
B	1639907	1759492	6670	120	123.7	Within interval
B	1639907	1759492	6650	140	123.7	Within interval
B	1639907	1759492	6640	150	123.7	Within interval
54-02002	1640097	1759324	6772	20	138.7	47 ft higher
54-02002	1640097	1759324	6752	40	138.7	27 ft higher
54-02002	1640097	1759324	6732	60	138.7	7 ft higher
54-02002	1640097	1759324	6712	80	138.7	Within interval
54-02002	1640097	1759324	6692	100	138.7	Within interval
54-02002	1640097	1759324	6672	120	138.7	Within interval
54-02002	1640097	1759324	6652	140	138.7	Within interval
54-02002	1640097	1759324	6635	157	138.7	Within interval
54-02002	1640097	1759324	6612	180	138.7	Within interval
54-02002	1640097	1759324	6592	200	138.7	Within interval
A	1639876	1759490	6770	20	141.9	45 ft higher
A	1639876	1759490	6750	40	141.9	25 ft higher
A	1639876	1759490	6730	60	141.9	5 ft higher
A	1639876	1759490	6710	80	141.9	Within interval
A	1639876	1759490	6690	100	141.9	Within interval
A	1639876	1759490	6670	120	141.9	Within interval
A	1639876	1759490	6650	140	141.9	Within interval
A	1639876	1759490	6640	150	141.9	Within interval
54-01016	1640076	1759492	6364	390	146.0	211 ft deeper
54-02016	1640139	1759413	6771	18	166.9	46 ft higher
54-02016	1640139	1759413	6769	20	166.9	44 ft higher
54-02016	1640139	1759413	6758	31	166.9	33 ft higher

Table 4 (continued)

Borehole	x	y	z	Depth bgs (ft)	Horizontal Distribution to East Extraction Borehole (ft)	Is the Port Within the Extraction Interval?
54-02016	1640139	1759413	6749	40	166.9	24 ft higher
54-02016	1640139	1759413	6707	82	166.9	Within interval
54-01016	1640086	1759528	6426	318	179.2	149 ft deeper
G	1640165	1759364	6770	20	192.3	45 ft higher
G	1640165	1759364	6750	40	192.3	25 ft higher
G	1640165	1759364	6730	60	192.3	5 ft higher
G	1640165	1759364	6710	80	192.3	Within interval
G	1640165	1759364	6690	100	192.3	Within interval
G	1640165	1759364	6670	120	192.3	Within interval
G	1640165	1759364	6650	140	192.3	Within interval
G	1640165	1759364	6640	150	192.3	Within interval

Table 5
Data for Ports within 200 ft of the Proposed West Extraction Borehole

Borehole	x	y	z	Depth bgs (ft)	Horizontal Distribution to West Extraction Borehole (ft)	Is the Port Within the Extraction Interval?
54-01015	1639715	1759602	6247	525	40.4	328 ft deeper
54-02012	1639722	1759599	6768	28	41.3	43 ft higher
C	1639719	1759606	6750	40	45.3	25.1522 ft higher
C	1639719	1759606	6710	80	45.3	within interval
C	1639719	1759606	6670	120	45.3	within interval
C	1639719	1759606	6631	159	45.3	within interval
C	1639719	1759606	6591	199	45.3	within interval
C	1639719	1759606	6551	239	45.3	24.0867 ft deeper
C	1639719	1759606	6511	279	45.3	63.9345 ft deeper
C	1639719	1759606	6491	299	45.3	83.8584 ft deeper
54-01015	1639721	1759621	6282	485	59.1	293 ft deeper
54-01015	1639727	1759644	6326	435	82.6	249 ft deeper
54-01015	1639734	1759666	6370	385	106.3	205 ft deeper
54-01015	1639739	1759683	6401	350	123.0	174 ft deeper
54-02021	1639543	1759532	6783	20	155.1	58 ft higher
54-02021	1639543	1759532	6763	40	155.1	38 ft higher
54-02021	1639543	1759532	6743	60	155.1	18 ft higher
54-02021	1639543	1759532	6723	80	155.1	within interval
54-02021	1639543	1759532	6703	100	155.1	within interval
54-02021	1639543	1759532	6683	120	155.1	within interval
54-02021	1639543	1759532	6663	140	155.1	within interval
54-02021	1639543	1759532	6643	160	155.1	within interval
54-02021	1639543	1759532	6623	180	155.1	within interval
54-02021	1639543	1759532	6603	200	155.1	within interval
54-02031	1639639	1759387	6783	20	189.3	58 ft higher
54-02031	1639639	1759387	6743	60	189.3	18 ft higher
54-02031	1639639	1759387	6703	100	189.3	within interval
54-02031	1639639	1759387	6643	160	189.3	within interval
54-02031	1639639	1759387	6603	200	189.3	within interval
54-02031	1639639	1759387	6583	220	189.3	within interval
54-02031	1639639	1759387	6543	260	189.3	32 ft deeper
54-01015	1639761	1759757	6544	187	200.6	31 ft deeper

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