Work Plan for Direct Current Resistivity Profiling in Cañon de Valle

Introduction	Major uncertainties in the site conceptual model for Technical Area 16 (TA-16) at Los Alamos National Laboratory include recharge pathways for high explosives– (HE-) contaminated groundwater through the vadose zone and the areal extent of deep-perched groundwater near Cañon de Valle (LANL 2011, 207069; LANL 2012, 213573). This work plan describes direct current (DC) resistivity profiling intended to address these uncertainties. The proposed work supports the corrective measures evaluation for Consolidated Unit 16-021(c)-99 by further constraining the nature and extent of contaminated deep-perched groundwater.
Background	Consolidated Unit 16-021(c)-99 (aka the 260 Outfall) is the primary contaminant source with high potential to impact groundwater at TA-16 (Figure 1). It received large quantities of contaminants, particularly RDX (hexahydro-1,3,5-trinitro-1,3,5-triazine), at high concentrations and large volumes of water that provided a significant hydrologic driving force for infiltration of contaminants (LANL 2011, 207069; LANL 2012, 213573). Much of the contamination released from the 260 Outfall was transported to Cañon de Valle by surface-water flow. Based on the extent of perennial surface water and alluvial groundwater, the main infiltration pathway for contaminated water in Cañon de Valle is located downcanyon of the 260 Outfall and extends east to the vicinity of Material Disposal Area P (LANL 2011, 207069). Infiltration of surface water and alluvial groundwater into bedrock units results in the vertical transport of contaminants into the bedrock units of the vadose zone. Transport of contaminants to these deeper zones is generally limited to soluble constituents such as RDX, other HE components, boron, and other organic compounds (LANL 2011, 207069). Water percolation into bedrock is assumed to be greater beneath the canyon floors than on the mesa tops because surface flow and alluvial groundwater provide hydrologic drivers for infiltration. However, mesas have local areas of increased infiltration where sufficient hydrologic drivers exist, such as beneath ponds (e.g., the 260 Outfall pond) or beneath tributary drainages that flow during snowmelt and storm events or that received effluent in the past (LANL 2011, 207069; LANL 2012, 213573). The relative importance of these infiltration pathways will be assessed by comparing DC resistivity profiles for mesa tops and canyon bottoms. The two deep-perched groundwater zones beneath middle Cañon de Valle near well R-25 are the most important in terms of contaminant pathways and are possible sources of contaminated recharge to the regional aquifer (Figure 2) (LANL 2011, 207069; LANL 2012, 213573). Existing wells penetrating these deep-perched groundwater zones are either located in Cañon de Valle or on the mesa south of the canyon (Figure 1). Because of local recharge along Cañon de Valle, groundwater mounding is likely beneath Cañon de Valle, and deep-perched groundwater may be distributed symmetrically about the axis of the canyon. Consequently, contaminated deep-perched groundwater may extend north of Cañon de Valle and is a potential secondary source for increasing RDX concentrations detected in the regional aquifer at well R-18 (LANL 2011, 207069). Mounding can significantly influence local groundwater flow directions and may affect the optimal placement of monitoring wells. Further refinement of the nature and extent of HE-contaminated deep-perched groundwater is important to assessing potential remedial alternatives for protection of the regional aquifer.
Technical Approach	Two shallow DC resistivity surveys conducted in Cañon de Valle in 1999 and 2001 were successful in delineating the extent of the alluvial aquifer and mapped the electrical structure of bedrock tuffs to a depth of about 50 ft (LANL 2003, 077965). In 2011, a DC resistivity survey mapped the electrical structure of bedrock to a depth of about 900 ft beneath the Sandia Canyon wetland (Crook et al. 2011, 210306). The geophysical survey proposed herein is similar in methodology to the two earlier surveys, but the profile line lengths will be increased to provide greater depth of penetration of the electrical signals. Additionally, updated data-processing techniques, similar to those used by hydroGEOPHYSICS (Crook et al. 2011, 210306) in the Sandia wetland, will be applied to generate the resistivity profiles. Consequently, the proposed DC resistivity profiles will have a depth of investigation of approximately 1000 ft, which is sufficient to map the electrical structure of the vadose zone at depths where deep-perched groundwater is known to occur. Recharge pathways through the

	vadose zone may be identified as zones of higher electrical conductivity that correspond to increased moisture content or alteration of bedrock to clay minerals. Similarly, the areal extent of deep-perched groundwater will be mapped by identifying rocks that have higher electrical conductivity, corresponding to increased moisture content or clay- and silt-rich beds that act as perching horizons. The acquisition of electrical resistivity data will involve injecting current into the ground between two electrodes and measuring the electrical potential between two other electrodes, repeated for multiple combinations of electrodes. Data will be collected using a multichannel electrical resistivity system and associated cables, electrodes, and battery power supply. Stainless-steel electrodes will be laid out along profiles with constant electrode spacing. Data collected will be analyzed using inverse modeling to produce a smooth model of the subsurface electrical resistivity. Where possible, data from previous hydroGEOPHYSICS surveys will be included with that from the proposed surveys for processing. The subcontractor awarded this work will recommend appropriate field equipment, data collection techniques, and data processing. The final study design elements will be provided by the geophysical subcontractor. Figure 1 shows the locations of the six proposed resistivity profiles, and Table 1 presents the rationale for each line. Three of the proposed resistivity profiles (numbers 1, 2, and 3) cross Cañon de Valle at a high angle to provide a cross-sectional view of electrical conductivity in the subsurface. Three other resistivity profiles (numbers 4, 5, and 6) are subparallel to Cañon de Valle, with lines located along the canyon axis and on the north and south rims. An important design criterion for these lines is to encompass areas with good subsurface control because wells south of Cañon de Valle are closely spaced. This coverage will allow validation of observed resistivity signals against known zones of deep-perched water and other hydrogeologic features. The distribution of utilities corridors at TA-16 (e.g., electrical lines) constrains the direction and length of some profiles. To reach depths of 1000 ft, cables on the surface must be at least 3300 ft long. Five of the six profiles are longer than 3300 ft, but profile 1 is only 2450 ft long because it is in an area surrounded by utility lines that could interfere with the resistivity profile. The total length of proposed resistivity profiles, as shown in Figure 1, is approximately 24,265 ft (Table 1). Measurement results will be modeled as 2½ dimensions wherever possible and will be presented as color-contoured profiles. Interpretation of the modeling results will include a comparison of the resistivity profiles with hydrogeologic and geophysical information from existing wells and with geologic data (e.g., faults) depicted in detailed geologic maps of the area. Interpreted DC resistivity data will be used in conjunction with other site data to determine the location of a new deep-perched zone well that is proposed for siting north of Cañon de Valle (LANL 2012, 213573).
Schedule	The DC resistivity survey will be completed by December 31, 2012.

REFERENCES

The following list includes all documents cited in this plan. 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 New Mexico Environment Department 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.

Crook, N., B. Cubbage, G. Noonan, and M. McNeill, October 17, 2011. "Final Report, Geophysical Survey of the Wetland Area of Upper Sandia Canyon," report prepared for TerranearPMC by hydroGEOPHYSICS, Tucson, Arizona. (Crook et al. 2011, 210306)

LANL (Los Alamos National Laboratory), September 2003. "Phase III RFI Report for Solid Waste Management Unit 16-021(c)-99," Los Alamos National Laboratory document LA-UR-03-5248, Los Alamos, New Mexico. (LANL 2003, 077965)

LANL (Los Alamos National Laboratory), September 2011. "Investigation Report for Water Canyon/Cañon de Valle," Los Alamos National Laboratory document LA-UR-11-5478, Los Alamos, New Mexico. (LANL 2011, 207069)

LANL (Los Alamos National Laboratory), March 2012. "Technical Area 16 Well Network Evaluation and Recommendations," Los Alamos National Laboratory document LA-UR-12-1082, Los Alamos, New Mexico. (LANL 2012, 213573)

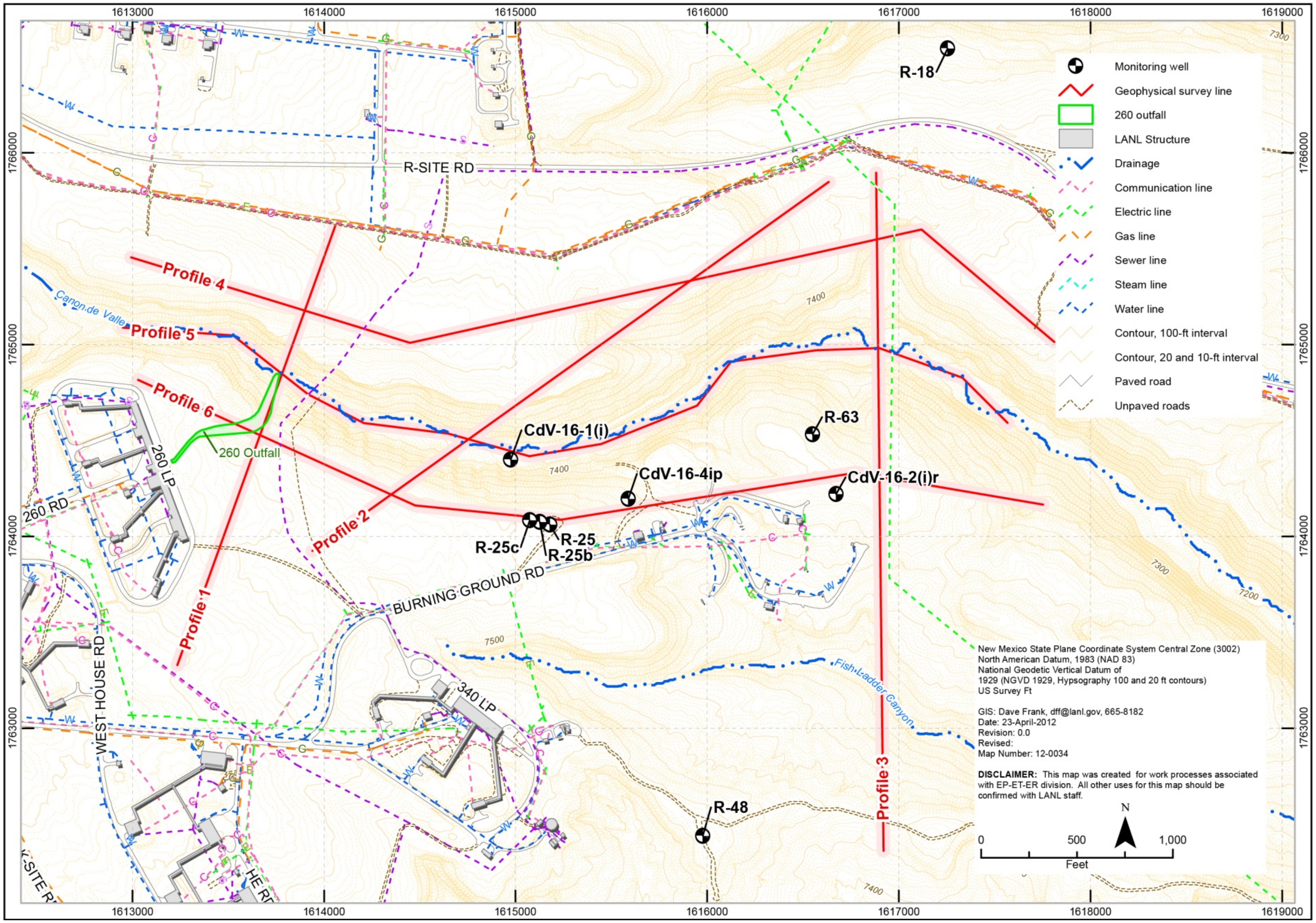

Figure 1 Map showing proposed geophysical DC resistivity profiles 1 through 6, mesa and canyon shaded relief, and utility corridors

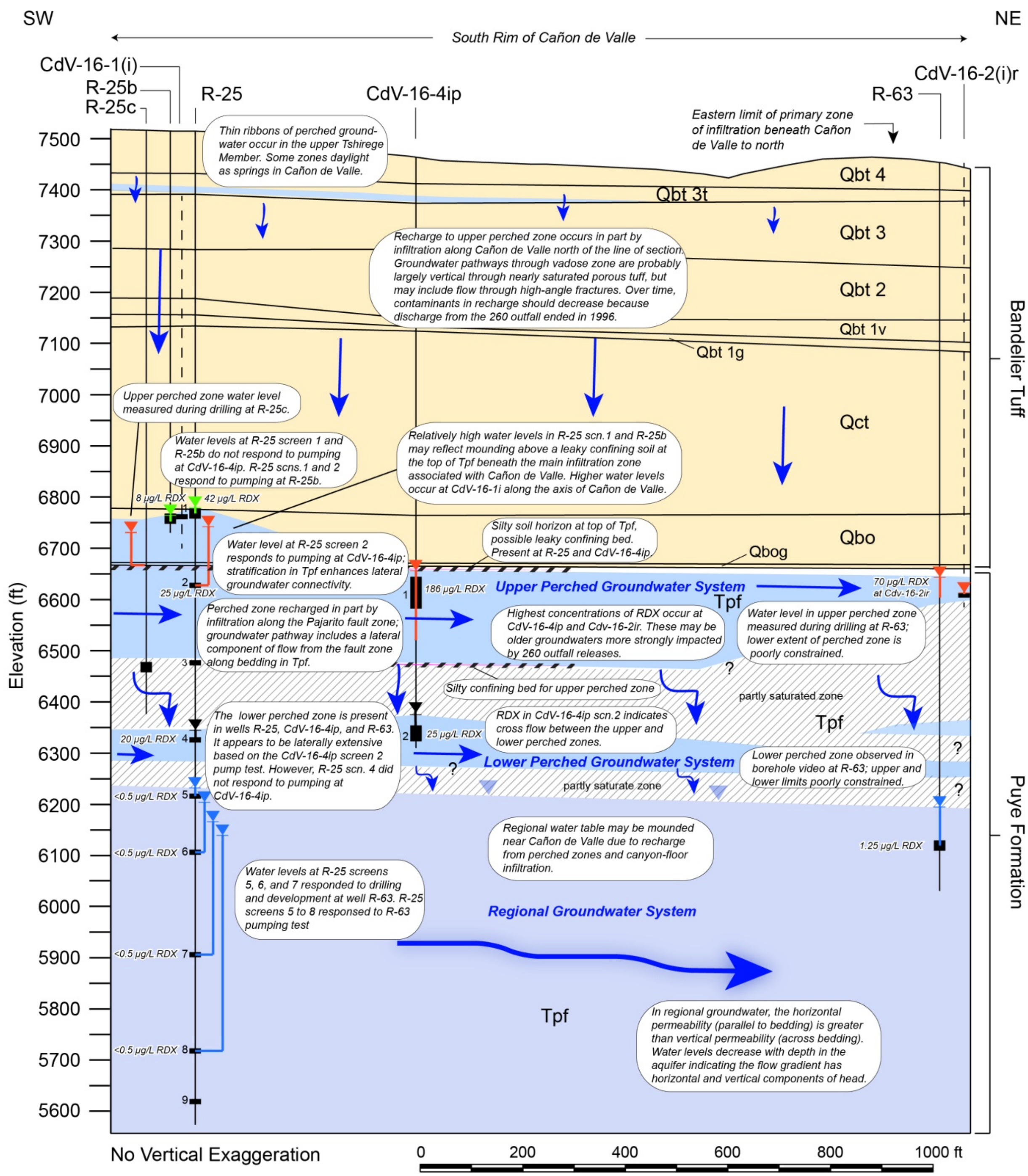

Figure 2 Hydrogeologic cross-section depicting conceptual model for contaminant flow and transport in the north-central portion of TA-16

Table 1
Proposed DC Resistivity Line Lengths and Rationale

Profile Number	Line Length (ft)	Rationale
1	2450	Cross-canyon profile in vicinity of 260 Outfall pond. Potential zone of significant mesa-top infiltration, particularly where pond infiltration is enhanced by proximity to Cañon de Valle. Provides information about (1) western extent of perched groundwater, (2) a potential groundwater mound beneath Cañon de Valle, and (3) the distribution of deep-perched groundwater north and south of Cañon de Valle.
2	3500	Cross-canyon profile west and north of wells R-25 and CdV-16-1(i). Helps constrain western extent of deep-perched groundwater in an area with no well data. Also provides information about a potential groundwater mound beneath Cañon de Valle and the distribution of deep-perched groundwater north and south of Cañon de Valle. Crosses Cañon de Valle in an area where HE-contaminated deep-perched groundwater is known to occur. Key line for siting intermediate deep-perched well(s).
3	3560	Cross-canyon profile near wells R-63 and CdV-16-2(i)r where subsurface data provide ground control for the profiles. Provides information about (1) eastern extent of perched groundwater, (2) a potential groundwater mound beneath Cañon de Valle, and (3) the distribution of deep-perched groundwater north and south of Cañon de Valle. The profile also crosses the eastern end of a potential infiltration zone for HE-contaminated surface water in Fishladder Canyon.
4	5165	Profile on north rim of Cañon de Valle. Provides information about the east-west extent and continuity of deep-perched groundwater on the north side of Cañon de Valle. Also provides information for comparison with profiles 5 and 6 to evaluate a potential groundwater mound beneath Cañon de Valle. Key line for siting intermediate deep-perched well.
5	4770	Canyon-floor profile in Cañon de Valle. Provides information about (1) infiltration pathways beneath the canyon floor, (2) a potential groundwater mound beneath Cañon de Valle, and (3) downcanyon changes in the electrical structure of vadose zone bedrock units that may be related to spatially variable infiltration. Comparison with shallow geophysical profiles collected in 1999 and 2001 will allow evaluation of temporal trends in resistivity in shallow subsurface. Profile traverses an area where HE-contaminated deep-perched groundwater is known to occur. Well data will be used to calibrate the geophysical observations.
6	4820	Profile on south rim of Cañon de Valle. Provides information about the east-west extent and continuity of deep-perched groundwater south of Cañon de Valle. Also provides information for comparison with profiles 4 and 5 to evaluate a potential groundwater mound beneath Cañon de Valle. Profile traverses an area where HE-contaminated deep-perched groundwater is known to occur and where well control for the occurrence of deep-perched groundwater is good. Well data will be used to calibrate the geophysical observations.
Total Length	24,265	