03-003 TA-16

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Date: March 7, 2003
Refer to: ER2003-0119

MAR 2003

Mr. John Young, Corrective Action Project Leader
Permits Management Program
NMED – Hazardous Waste Bureau
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Building 1
Santa Fe, NM 87505-6303

SUBJECT: SUBMITTAL OF ADDENDUM TO THE CORRECTIVE MEASURES STUDY (CMS) PLAN FOR POTENTIAL RELEASE SITE (PRS) 16-021(c), REVISION 1

Dear Mr. Young:

Enclosed please find two copies of the CMS Plan for PRS 16-021(c), Revision 1. The initial CMS Plan was submitted to your office September 30, 1998 (EM/ER: 98-392). The Addendum to the CMS Plan, Revision 0 was submitted September 28, 1999 (E/ER: 99-279).

If you have any questions, please contact Don Hickmott at (505) 665-1116 or Lance Woodworth at (505) 665-5820.

Sincerely,

David McInroy, Acting Program Manager
Remediation Program
Los Alamos National Laboratory

Sincerely,

J A Cedillos for

Everett Trollinger, Project Manager
Department of Energy
Los Alamos Site Operations

DM/ET/NR/dv

Enclosure: Addendum to CMS Plan, Rev. 1 (ER2002-0814)

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Addendum to the CMS Plan for PRS 16-021(c), Revision 1

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CONTENTS

1.0 INTRODUCTION **1**

2.0 NEW OR REPLACEMENT SECTIONS **1**

6.1.7 Groundwater Investigations (Deep Perched Zone and Regional Aquifer) 1
6.3.6 Groundwater Investigations (Deep Perched Zone and Regional Aquifer) 2
6.3.6.1 Overview 2
6.3.6.2 Investigation Design 11
6.3.6.3 Sampling Activities 18

3.0 REFERENCES **25**

Appendix H. Geophysics Report

List of Acronyms and Abbreviations

CMS	corrective measures study
CSAMT	controlled-source audio-frequency magnetotelluric
DNT	dinitrotoluene
DQO	data quality objective
ER	environmental restoration (as in ER Project)
HE	high explosives
HMX	1,3,5,7-tetranitro-1,3,5,7-tetrazacyclooctane (cyclotetramethylenetetranitramine)
HPLC	high performance liquid chromatography
HRR	high-resolution resistivity
HSWA	Hazardous and Solid Waste Amendments
ICPES	inductively coupled plasma emission spectroscopy
ICPMS	inductively coupled plasma mass spectroscopy
IM	interim measure
LANL	Los Alamos National Laboratory
MDA	material disposal area
MNA	monitored natural attenuation
NSAMT	natural-source audio-frequency magnetotelluric
PRS	potential release site
RCRA	Resource Conservation and Recovery Act
RDX	1,3,5-trinitro-1,3,5-triazacyclohexane (cyclotrimethylenetrinitramine)
RFI	RCRA facility investigation
RRES-R	Risk Reduction & Environmental Stewardship–Remediation Program
SHB	seismic hazards borehole
TA	technical area
TNT	trinitrotoluene
XRD	X-ray diffraction
XRF	X-ray fluorescence

1.0 INTRODUCTION

This document serves as revision 1 of "Addendum to CMS Plan for Potential Release Site 16-021(c)" (LANL 1999, 64873.3). The insertion instructions and heading numbers apply to the original CMS plan (LANL 1998, 62413.3), and these insertions should replace any insertions from the original addendum. Because the new sections are insertions, acronyms and abbreviations may not be spelled out at first use; however, they are defined in the list that appears after the table of contents.

2.0 NEW OR REPLACEMENT SECTIONS

Insert this new subsection on p. 57, within section 6.1, "Objectives and Scope," just before section 6.2.

6.1.7 Groundwater Investigations (Deep Perched Zone and Regional Aquifer)

The principal goal of this investigation is to determine the extent of contamination in the deep perched zone and regional aquifer that is associated with constituent discharges from TA-16 and, potentially, other nearby sites. Subsidiary goals include (1) determining the rate at which contamination is moving downgradient toward the Pajarito well field or other potential exposure points, and (2) investigating the directions of groundwater flow and the hydrologic gradients within the regional and deep perched saturated zones at TA-16. The results of the investigation will be used to evaluate the effects of regional groundwater contamination on human health or ecological assessment endpoints. The risk assessment for the surface soils, alluvial system, and vadose zone that will be completed under the 260 CMS will be augmented with information about deep groundwaters derived from the investigation outlined in this document. These data will be used to determine the need for, and feasibility of, implementing cleanup remedies within the deep perched and regional groundwater systems contaminated with HE and other constituent discharges from TA-16.

Insert this new section on p. 58, as the final item in the numbered list within section 6.2, "Approach and Implementation."

6. Regional groundwater

   Additional deep boreholes that intersect the regional aquifer will be drilled near TA-16. While the borehole investigations are directly associated with the 260 CMS, the data from those investigations will also be relevant to investigations into other potential HE sources at TA-16 (Fish Ladder Canyon, Martin Spring Canyon, the 90s Line Pond) and at TA-9. The data from these wells will be closely integrated with data from regional wells to be drilled under the "Hydrogeologic Workplan" (LANL 1998, 59599.1). The data from all these wells will be used to

   - determine the presence or absence of contamination and the concentrations of HE and other constituents at locations near regional well R-25;
   - investigate the seasonal variations in contaminant concentrations at these locations;
   - better define the hydrologic gradients, flow directions, and hydrologic properties in both the deep perched and regional saturated zones near TA-16;
   - help determine if multiple plumes exist in the deep perched zone and regional aquifer;

- design a monitoring program for the deep perched zone and regional aquifer; and
- support modeling efforts designed to predict the movement of HE plume(s) at TA-16.

Hydrologic information will be obtained during drilling. Water-level measurements, packer or slug tests, and other hydrologic parameter analyses from the saturated zones will be completed. Core/cuttings will be used to determine lithologies. Where feasible, downhole geophysics will be carried out in each borehole.

Multiple port or single completion wells that comply with the HSWA module of LANL's Hazardous Waste Facility Permit will be installed within these boreholes. Following well development, water from each screened interval will be sampled and submitted for HE, metals, and anion analyses. These analyses will be performed on a quarterly basis until the CMS/CMI for PRS 16-021(c) has been completed. The wells will be instrumented with pressure transducers. Seasonal water-level data will be used to investigate any connectivity among portions of the deep perched and regional saturated zones.

7. Deep perched groundwater studies (FY 03 and FY 04)

   HE contamination is present in the perched zone at R-25. No intermediate-to-deep perched zones, however, were found in the two deep wells drilled to the northeast and southeast of R-25 (CdV-R-15-3 and CdV-R-37-2, respectively), calling into question the extent of the perched zone and associated contamination (Kopp et al. 2002, 73179.9; Hickmott et al. 2002, 73707). During FY 03 and 04, three new intermediate-depth boreholes (700 to 1000 ft deep) will be drilled in an attempt to intersect the deep perched zone seen in regional well R-25. Selection of the well sites will be based on the presence of geophysical anomalies that indicate high conductivity zones. The data from these wells will be used to address the same six issues that were addressed by the deep boreholes, as well as to (1) better constrain the downgradient extent and horizontal continuity of the perched zone, (2) assess the possibility that natural attenuation may be occurring (e.g., by base hydrolysis) in the plume(s), (3) evaluate the utility of geophysical measurements for identifying zones of saturation, (4) assess connectivity with the alluvial system in Cañon de Valle, and (5) determine travel times in the perched zone.

Insert the following sections on p. 81, just before section 6.4, "Data Collection Procedures."

6.3.6 Groundwater Investigations (Deep Perched Zone and Regional Aquifer)

6.3.6.1 Overview

Background and Conceptual Model

HE was detected in regional well R-25 during FY 99 and continues to be detected in ongoing quarterly sampling. R-25 is located approximately 1700 ft east of the 260 outfall [PRS 16-021(c)] (Figure 6.3-8). A major perched saturated zone was present between 747 ft and 1132 ft (Figure 6.3-9), and the regional aquifer extended from 1286 ft to the total depth of the borehole at 1942 ft. Between these two saturated zones is a zone made up of alternating saturated zones and dry rock. The nature and degree of connectivity between these two major zones is unknown. Both major saturated zones appear to contain HE constituents, including RDX, TNT, HMX, and amino-DNTs. RDX is the most abundant constituent; RDX concentrations range from not-detected to above 75 µg/L (Figure 6.3-9). The two highest HE concentrations came from the middle of the perched zone and near the top of the regional aquifer,

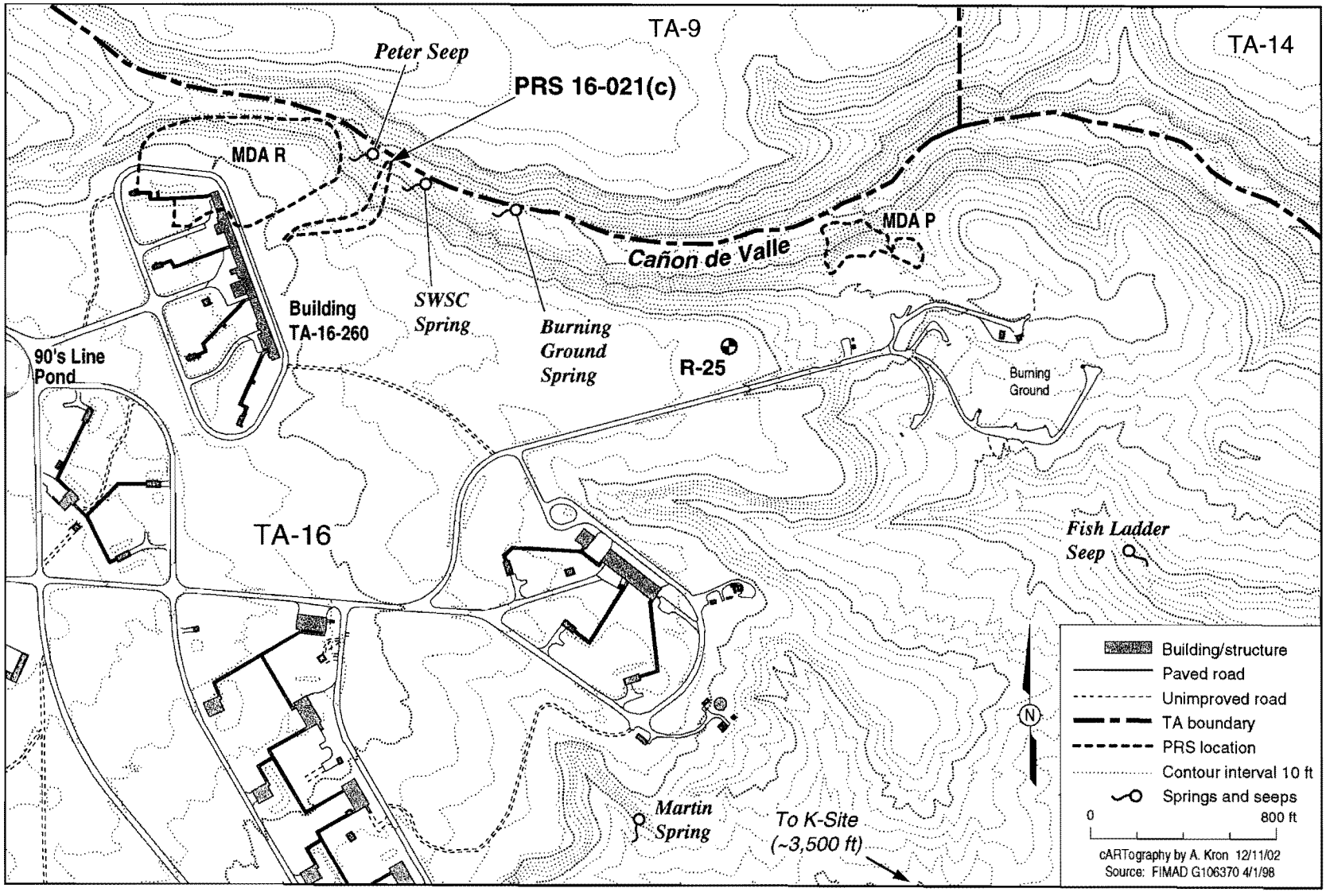

Figure 6.3-8. Location of PRS 16-021(c) and associated physical features

although it is difficult to determine if any leakage has occurred from the upper zone to the lower zone. Following well completion and several rounds of quarterly sampling, it is still unclear if the contamination at the top of the regional aquifer was introduced during drilling. However, quarterly sampling does show that HE concentrations in the regional aquifer have decreased, supporting the idea that HE in the regional aquifer may have been introduced.

As noted in section 2 of this plan, HE contamination of shallow alluvial groundwater in Cañon de Valle and in the TA-16 springs is ubiquitous. RDX and other HE constituents are present in these media at levels greater than those observed in R-25. HE constituents at low levels (< 10 µg/L RDX) have also been observed in springs at TA-9, at TA-18, and in surface and alluvial waters within Pajarito Canyon. It is assumed that liquid discharges at the TA-16 surface constitute the primary historic source of the HE observed at R-25.

Through RFIs, multiple sources of HE contamination have been identified in soils at several technical areas in the western portion of the Laboratory. According to these studies, the largest HE contaminant source term in soils appears to be the 260 outfall (see section 2 of this CMS plan). Other sites with significant (greater than a few hundred µg/g HE in soils) identified HE source terms include the TA-16 Burning Ground and MDA P, MDA R, the TA-11 drop tower (K-Site), the 90s Line Pond (Figure 6.3-8), and the TA-9-48 outfall at TA-9. Although these and other not-yet-identified sources may be contributing HE to deep perched and regional saturated zones, the (former) large contaminant mass at the 260 outfall and its location directly upgradient from regional well R-25 (Figure 6.3-8) suggest that it was the major source of HE in the deep perched and regional saturated zones in the TA-16 region. The majority of contamination in the outfall was removed by an IM performed during FY 00–02 (LANL 2002, 73706). Since 1999, when the initial version of this addendum was issued, no additional sources of HE have been identified through field investigations.

The horizontal hydrologic gradient and flow directions in the regional aquifer are generally eastward from the mountain front of the Jemez Mountains, west of TA-16 (Purtymun 1995, 45344.1) (Figure 6.3-10). The gradient and flow directions in the TA-16 deep perched saturated zone are poorly defined. This zone was found in seismic hazards borehole 3 (SHB-3). Water-level data from this borehole, coupled with that from R-25, suggest that the gradient in the deep perched zone is also from west to east, perhaps with northerly and/or southerly components. Water-level data collected during the drilling of R-25 also suggest a vertical component to hydrologic gradients in the TA-16 area. Downward head gradients appear to exist in both major saturated zones (Stone et al. 1999, 64010.1; Broxton et al. 2002, 72640.1).

The principal recharge zone for the regional aquifer at TA-16 is hypothesized to lie to the west of TA-16, perhaps in association with the Pajarito Fault zone. Multiple recharge sources for the shallow perched zones at TA-16 have been postulated in section 5 of the second 260 outfall RFI report (LANL 1998, 59891.3). These sources included the Cañon de Valle alluvial system and other surface saturated zones (the 90s Line Pond, the steam plant drainage), diffuse surface recharge, recharge from TA-16 outfalls, and fracture-zone recharge. Inasmuch as the shallow saturated zones affect the deep perched zone and the regional aquifer, the deep perched zone and regional aquifer must also have multiple recharge zones. The ultimate surface discharge from the regional aquifer is into the White Rock Canyon springs and the Rio Grande.

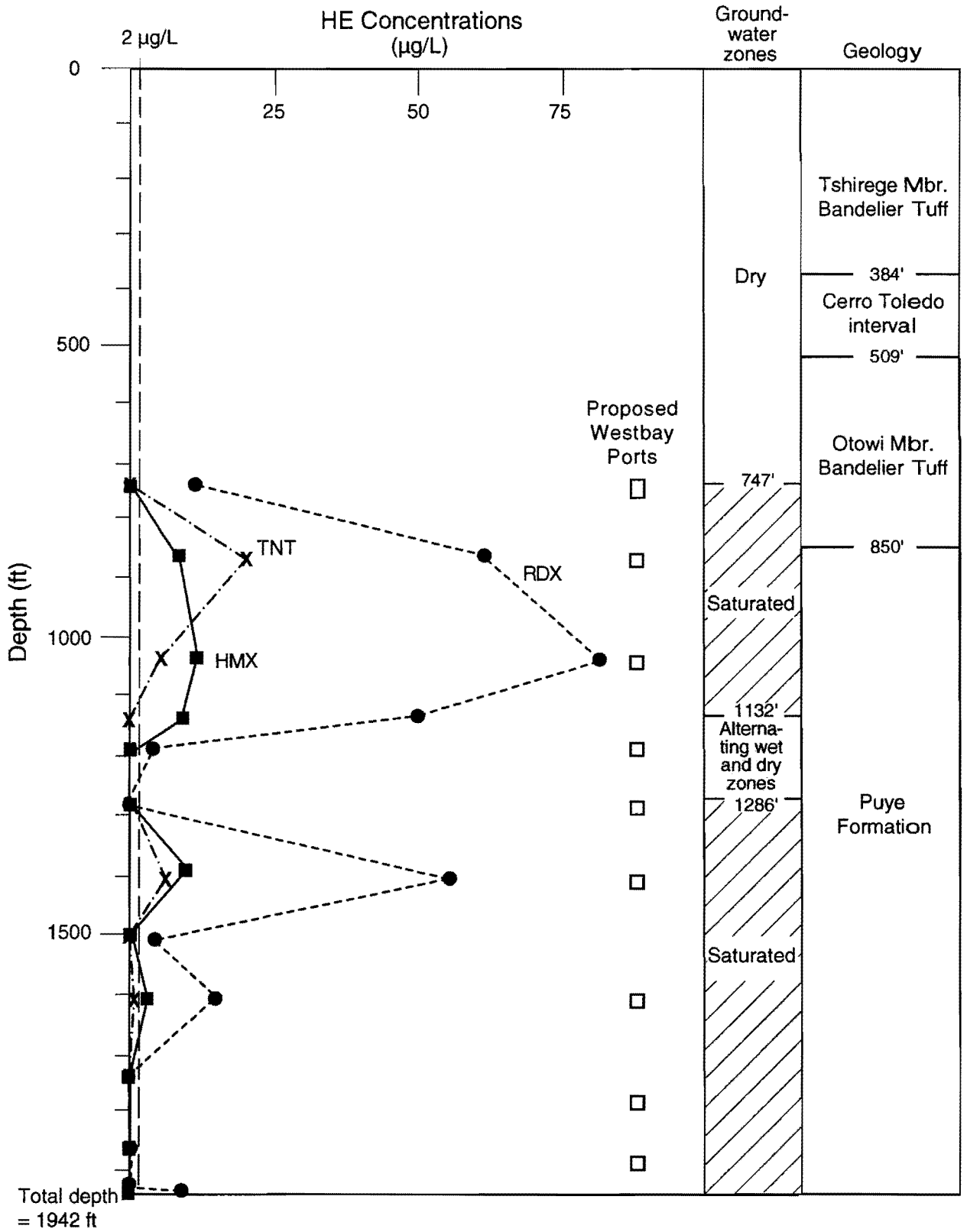

Figure 6.3-9. Distribution of HE compounds detected in deep groundwater at TA-16, borehole R-25

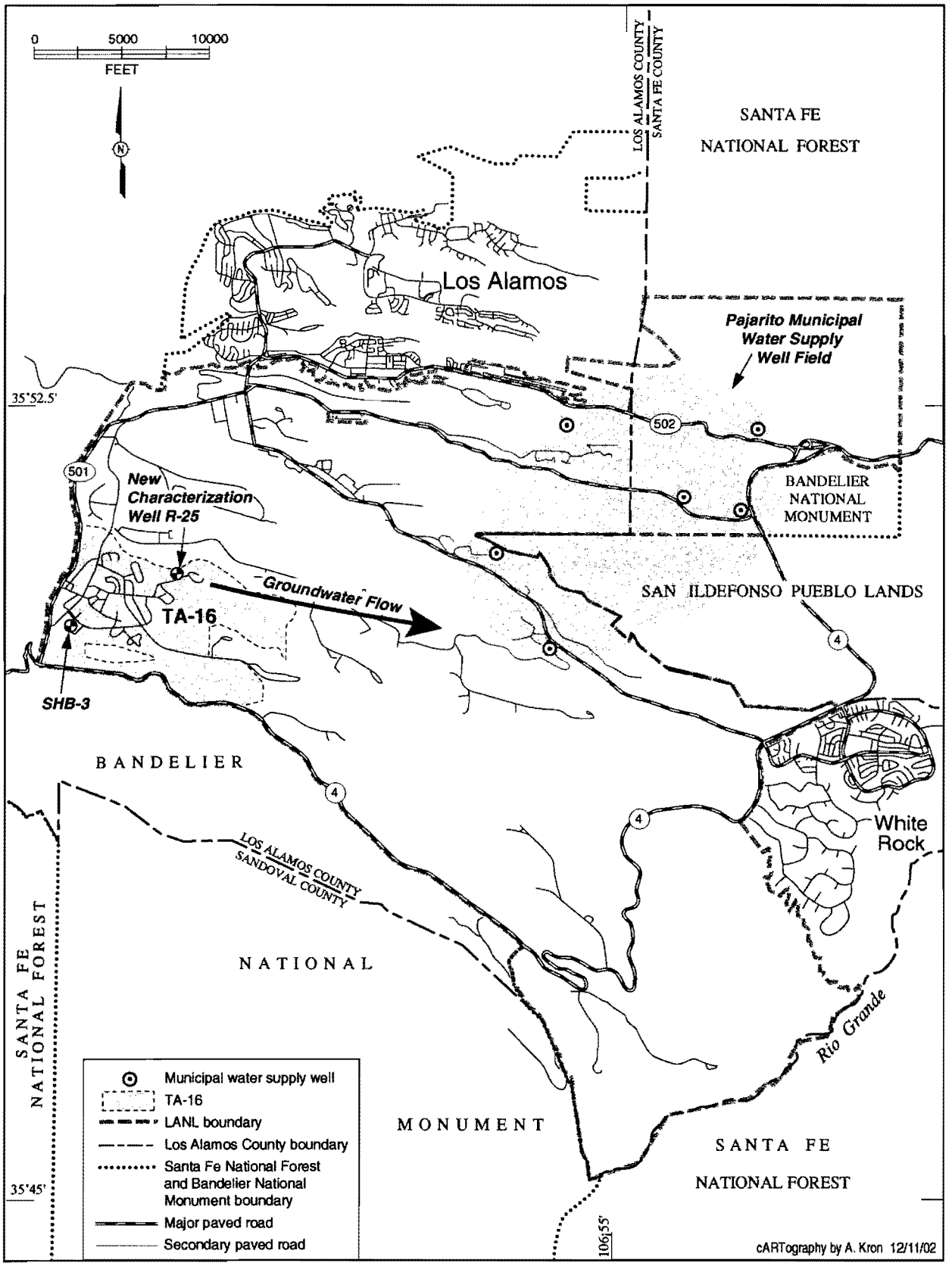

Figure 6.3-10. Location of Pajarito municipal water supply well field relative to TA-16

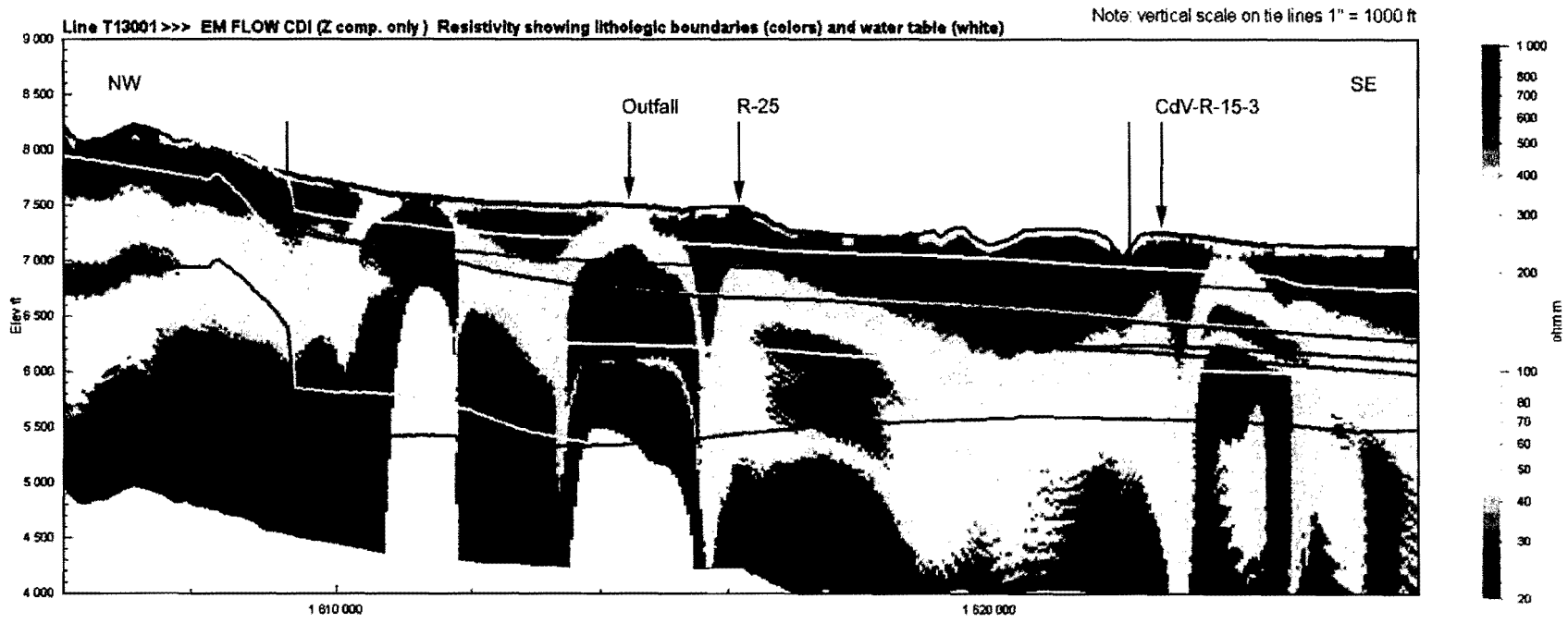

Figure 6.3-11. Northern Fugro line, showing extrapolations from the 260 outfall, R-25, and CdV-R-15-3 to the line
Note: The vertical lines without arrowheads indicate TA-16 boundaries.

FY 03 Refinements to the Conceptual Model

In FY 01, an electromagnetic flyover survey (Fugro) was performed over the Laboratory. This flyover data suggest a more conductive (presumably wetter, perhaps saturated) zone in the western half of TA-16, ending in a steeply dipping zone in the vicinity of R-25 (Figure 6.3-11 and Figure 6.3-12). In these figures, warmer colors such as red indicate more highly conductive regions, suggesting higher moisture content. Wells CdV-R-37-2 and CdV-R-15-3 are located in the less conductive zone further to the east (Figure 6.3-11 and Figure 6.3-12). Note that these wells did not intercept a long-lived perched zone; perched water was seen during drilling, but not subsequent to well installation (Hickmott et al. 2002, 73707; Kopp et al. 2002, 73179.9). A controlled-source audio-frequency magneto-telluric (CSAMT) survey was performed by Zonge Engineering during FY 02. Although the data are still undergoing preliminary analysis, they suggest the presence of discrete heterogeneous sub-vertical conductive layers (presumably wetter, perhaps saturated). Preliminary analysis of the CSAMT data has found the continuous horizontal structures at intermediate depths typical of the perched zone at R-25 to be rare. The perched zone at R-25 has been tentatively linked to a geophysical anomaly in the CSAMT data.

The Fugro data suggest an eastern boundary (or steeply dipping zone) to the perched zone identified at R-25, which is consistent with the lack of a long-lived perched zone at CdV-R-37-2 and CdV-R-15-3. These observations indicate that the conceptual model needs to be refined. The model should include the fact that the perched zone (and any associated contamination) is probably of more limited extent than originally believed and that, where present, may be patchy in nature. The Zonge data support the conceptual model hypothesis that fast vertical pathways may be responsible for recharge to perched zones (where present) and to the regional aquifer, and that subsurface saturated ribbons may be an important hydrologic feature. The lack of contamination in the regional aquifer at wells CdV-R-37-2 and CdV-R-15-3 (Hickmott et al. 2002, 73707; Kopp et al. 2002, 73179.9) also places bounds on the extent of contamination within the framework of the conceptual model.

Problems

The detection of HE in the deep perched and regional saturated zones at TA-16 raises questions concerning potential impacts on receptors. For the purposes of this document, these two major saturated zones will be referred to as separate zones; however, it is not known if they are distinct zones or if both represent parts of the regional aquifer. To assess the risk posed by the site, it will be necessary to determine if there is a realistic exposure pathway—at concentrations above a threshold level of concern (or damage to a natural resource)—from the HE found in the deep groundwater underlying TA-16.

The primary initiative is to define the *boundaries* of any existing plumes rather than, for example, the maximum concentration within a plume (i.e., to determine the highest level of contamination at the present time). There is a key issue with respect to human health risk, and that is whether HE constituents are likely to affect the drinking water wells in the Pajarito well field that lies 7–8 km to the east of R-25 (Figure 6.3-10).

Four classes of data needs are identified. Each type of data bears on problems related to contaminant distribution, fate, and transport. Ultimately, the objective of collecting these data is to accurately predict contaminant concentrations in the deep perched and regional groundwater zones with a high degree of confidence. Such information about contaminant concentrations is needed to determine what type of remedy, if any, will be required for the deep perched and regional saturated zones.

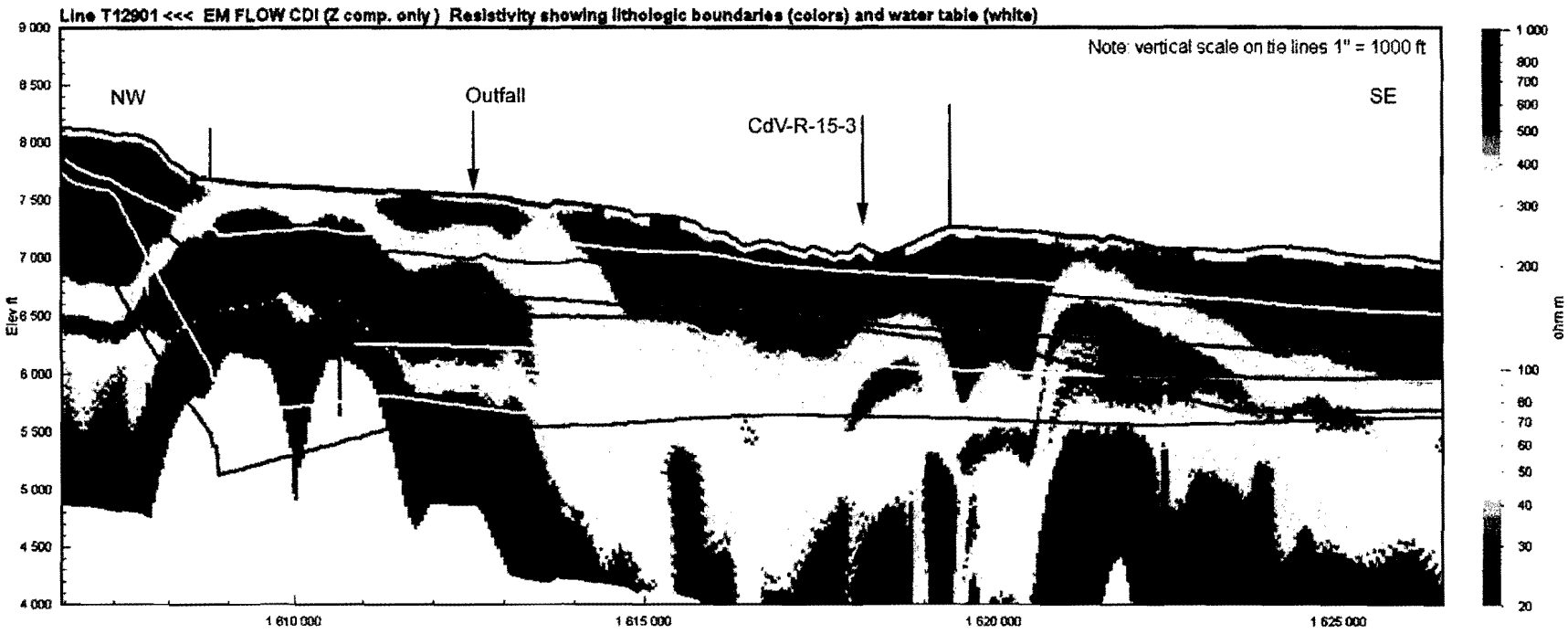

Figure 6.3-12. Southern Fugro line, showing extrapolations from the 260 outfall and CdV-R-37-2 to the line
Note: The vertical lines without arrowheads indicate TA-16 boundaries.

The four classes of data needs are described below (some of the data needs are related to deep wells only; others are relevant to deep and intermediate-depth wells):

1. The concentrations of HE and other anthropogenic constituents need to be determined, at additional locations in the western portion of the Laboratory. The spatial boundaries of—and contaminant distributions within—the HE plume need to be defined for both major saturated zones. Based on the range of flow velocities calculated for the regional aquifer, the putative HE plume could extend as far as 7–8 km to the east of R-25. However, drilling at CdV-R-15-3 and CdV-R-37-2 indicated that the extent of contamination is much smaller than these distances (Hickmott et al. 2002, 73707; Kopp et al. 2002, 73179.9).

   The constituent concentration data from additional deep and intermediate wells are needed to define a monitoring baseline, to define trends in contaminant concentration both laterally and with depth, and to examine other aspects of the temporal and spatial variability of the contaminants in the deep perched and regional saturated zones. All these data will be used as model input and model validation.

   The concentration data will help determine (1) if contaminant concentrations decrease with distance from TA-16, or if there is evidence for a high "pulse" of HE contamination associated with historic HE discharges; (2) if HE-degradation byproducts are present in the deep perched and regional aquifers, and whether information about this can be used to investigate natural attenuation as a corrective action remedy; (3) to what degree the deep perched zone retards or enhances the flow of contaminants to the regional aquifer (applicable for deep wells); (4) how water chemistry provides insight into the geochemical processes occurring in the deep perched and regional aquifers; (5) any required refinements to the conceptual model; and (6) how the mesa-top HE sources and the Cañon de Valle and other alluvial systems may recharge the deeper saturated zones.

2. The hydrologic gradients (both vertical and lateral) need to be determined, for both the regional and the deep perched saturated zones. Such data help define directions of groundwater flow and help optimize placement of monitoring and characterization wells. The data also provide key information for groundwater modeling.

   The gradient data will be used to (1) determine if contaminants enter the system at the top of the deep perched zone and if they are then transported by saturated flow to the bottom of the zone and laterally downgradient; (2) help identify fast pathways within the saturated zones; and (3) determine whether the significant downward vertical gradients identified in R-25 continue to the east or are restricted to the west of the Laboratory near the Pajarito fault zone and the Jemez Mountains front.

3. The horizontal extent and the geometry of the deep perched zone need to be determined. The deep perched zone was present in SHB-3 (1–2 km southwest of R-25) but was not found in the deep test wells that were drilled at TA-49 (4–6 km southeast of R-25) in the late 1950s and early 1960s or in well CdV-R-15-3 or well CdV-R-37-2 (Kopp et al. 2002, 73179.9; Hickmott et al. 2002, 73707).

   Information about the extent and geometry of saturated zones will be used to determine (1) the eastward extent of the deep perched zone, and (2) whether the deep perched zone is a continuous unit that extends for several km from the mountain front eastward or a "tongue" projecting eastward across TA-16. Tongue geometry implies the existence of regions within the deep perched zone with northward and southward hydrologic gradients.

   The extent of the deep perched zone has not been constrained during FY 03. No perched zone was found in CMS well CdV-R-15-3 or well CdV-R-37-2. Geophysical data (Fugro and CSAMT) suggest that the deep perched zone has an eastern boundary and that it may be patchy and discontinuous in

nature, being present as subsurface saturated ribbons or plugs. Intermediate-depth boreholes will help to further constrain the geometry of the deep perched zone.

4. Hydrologic parameters within the vadose zone and the deep perched and regional saturated zones need to be defined to support groundwater modeling. These efforts may provide a better understanding of contaminant transport in the deep perched and regional saturated zones. Such information needs to be gathered from additional points within potential contaminant flow paths downgradient from TA-16.

   Hydrologic parameter data will be used to determine (1) the degree of heterogeneity across hydrologic properties of the Bandelier Tuff and Puye Formation in the western portions of the Laboratory, (2) if lateral variations in lithology are consistent with the current 3-D hydrogeologic model of the Laboratory` and (3) how that model can be refined.

6.3.6.2 Investigation Design

Data from deep wells within, and downgradient from, TA-16 will be used to address questions concerning HE sources, contaminant extent, transport and recharge pathways, contaminant concentration dynamics, and hydrologic gradients. The data will also support efforts to model the deep perched and regional saturated zones. The data will be derived from the regional wells outlined in the "Hydrogeologic Workplan" (LANL 1998, 59599.1) as well as the additional 260 CMS wells described below. Ultimately, the data will support risk assessments that include the deep perched saturated zone and regional aquifers as pathways.

The "Hydrogeologic Workplan" includes plans to drill a series of regional aquifer wells known as *R* wells. Four of these locations are approximately downgradient from TA-16: (1) regional well R-27, planned for Water Canyon near TA-49, approximately 3–4 km southeast of R-25; (2) regional well R-19 (completed), located on a mesa top south of Threemile Canyon, approximately 4–5 km east of R-25; (3) regional well R-18, planned for a location on the rim of Pajarito Canyon, approximately 1–2 km northeast of R-25; and (4) regional well R-30, planned for a location at TA-49, approximately 4–5 km southeast of TA-16 (Figure 6.3-13).

Two regional wells, R-24 and R-26, are also planned for locations west of TA-16. These represent upgradient wells for the purposes of the TA-16 investigations (Figure 6.3-13). All these regional wells will be characterized hydrogeologically. The water and cuttings samples taken from them will be analyzed for a comprehensive suite of constituents, including HE, metals, water quality parameters, and radionuclides. Current planning specifications for these work plan wells can be found in Table 6.3-6. Note that Laboratory-wide background values for groundwater are currently being developed by RRES-R (formerly the ER Project). Both the Laboratory-wide values and the data from the upgradient wells at TA-16 will be used to evaluate, in both the regional and 260 CMS wells, which anthropogenic constituents have been released to groundwater.

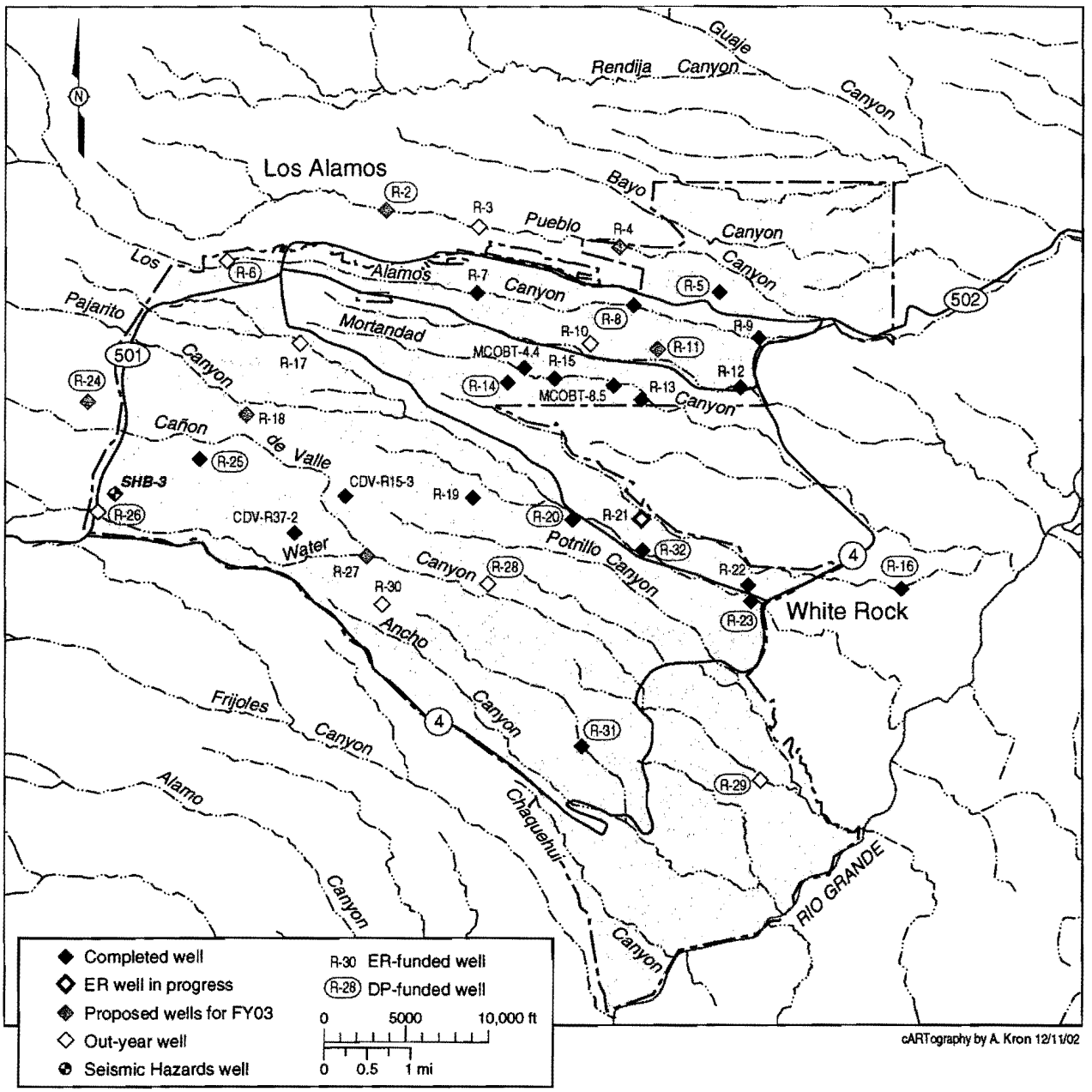

Figure 6.3-13. Proposed wells in the vicinity of TA-16 (*Note:* Locations are approximate and will be finalized following consultations with NMED.)

Table 6.3-6
Planning Specifications for Groundwater Protection Plan Wells That Are Relevant to TA-16 Investigations

Regional Well Designation	Location	Estimated or Actual Depth (ft)	Well Completion Type	Current Estimated Start Date for Drilling
R-27	Water Canyon near TA-49	1840	Multiple	Undetermined
R-19	TA-36	1902.5	Multiple	FY 00—complete
R-18	Rim of Pajarito Canyon	1945	Multiple	FY 03
R-30	TA-49	1580	Single	FY 05
R-24	Mesa north of Cañon de Valle or Water Canyon (on upthrown side of Pajarito Fault)	1476	Multiple	Undetermined
R-26	On downthrown side of Pajarito Fault, across from R-24	1280	Single	FY 03

Note: Specifications are based on the "Hydrogeologic Workplan" (LANL 1998, 59599.1).

The 260 CMS wells, which are described later, will be used to augment the regional wells proposed under the "Hydrogeologic Workplan." The 260 CMS deep drilling program addresses the problem of contamination in the deep perched zone and regional aquifer. To focus on this problem most effectively, this document minimizes, for the time being, consideration of the near-surface source term. This exclusion pertains to not only historic and ongoing surface releases but any contamination currently in the vadose zone; however, data from both the work plan wells and the 260 CMS wells will provide crucial information about recharge sources and transport pathways within the near surface. Although the assessment of sources (especially in the vadose zone) is ultimately crucial to resolving the global problem associated with TA-16 HE discharges, it is not the primary goal of the investigations outlined in this document. The near-surface source term and the vadose zone in the vicinity of Building 260 are currently being addressed by the ongoing CMS process for PRS 16-021(c). Other sources will be investigated by the ongoing RFIs at TA-16 and other TAs in the western half of the Laboratory.

A minimum of two 260 CMS deep wells to the regional aquifer were proposed in the CMS plan addendum of 1999. Two wells were completed in FY 01 and FY 02. One (well CdV-R-15-3) is located to the east of Building 260 and R-25, at TA-15 (Kopp et al. 2002, 73179.9). The other well (well CdV-R-37-2) is located to the southeast of Building 260 and R-25, at TA-37 (Hickmott et al. 2002, 73707) (Figure 6.3-13).

The sites of the initial two wells were chosen by considering the information that could be gathered from the boreholes and the data gaps that could be filled to address the TA-16 groundwater investigation. The data gaps included (1) the nature, extent, and dynamics of HE contamination in the deep perched zone and regional aquifer; (2) the hydrologic gradients in the TA-16 area; (3) the extent and geometry of the deep perched zone; and (4) the hydrologic properties of subsurface geologic units in the deep perched zone and regional aquifer. Equally important siting criteria included the ability of the wells to complement the work plan wells and the following logistical questions:

- Is the location accessible to a large drill rig?
- Does the location fall within the blast radius of an active firing site?
- Does the location lie within the nesting area of a threatened and endangered species?

FY 03 Update to Planned CMS Wells

A minimum of three new intermediate-depth boreholes are proposed. Three locations have been identified that take into account recent controlled-source audio-frequency magnetotelluric (CSAMT) and natural-source audio-frequency magnetotelluric (NSAMT) results. These locations were based on the information that could be gathered from the boreholes and the data gaps that could be filled to address the TA-16 groundwater investigation. The following issues were considered:

1. The extent of HE contamination in the perched zone has not been constrained. Moreover, no perched zone was found in the two deep CMS wells, calling into question the extent of the perched zone and associated contamination. The three proposed intermediate-depth boreholes will be sited to better constrain the downgradient extent of the perched zone and to test for the presence of HE contamination in the perched zone (if present).

2. While defining the extent of the HE plume in the perched zone and in the regional zone, it will be determined if natural attenuation is occurring (e.g., by base hydrolysis) in the plume(s). If HE is detected in new downgradient wells, concentrations will be compared to those found upgradient at R-25, and the presence and concentrations of HE breakdown products will be assessed. These comparisons will be made cautiously in the case of screen 3 from R-25, as data from this screen are subject to problems associated with the screen's construction. The data, along with continued monitoring, will help determine if monitored natural attenuation is a viable option for the deep groundwater at the site. Trends of stable or decreasing HE concentration within the plume, and decreasing concentration over time at any given monitoring location, would support this remediation alternative. The data would also be important for evaluating engineered alternatives for the perched zone and regional aquifer, if active treatment technologies are required.

3. The hydrology of the perched zone needs to be better defined. The static water level in the three proposed boreholes will provide information about potentiometric surfaces when compared with R-25. Modeling the hydrology will be key to addressing this need.

4. The use of surface geophysics for identifying the presence of deep groundwater will be assessed. Geophysical results from an electromagnetic overflight (Fugro) and CSAMT and NSAMT data from Zonge Engineering will be compared to the conceptual model. The results will also be compared to ground-truth data (presence or absence of saturation) from R-25, CdV-R-37-2, CdV-R-15-3, and other boreholes within and surrounding the site. Geophysical anomalies will be compared to surface expressions of water (springs, seeps, canyon surface flows) and to structural anomalies and stratigraphy/degree of welding in Bandelier Tuff to determine the controls on conductivity.

5. If a borehole is placed in Cañon de Valle, the alluvial system would be assessed. High-resolution resistivity (HRR) data from HydroGeophysics, for example, suggest the existence of a losing reach (where water is lost from the surface to subsurface) in Cañon de Valle, west of MDA P, that may be a source of recharge to the perched or regional aquifer. Contaminant levels in the alluvial system and any recharge pathways to deep groundwater would also be assessed. Core would be taken from this well, and anion profiles would be determined. Moisture content measurements from this core would also allow for calibration of HRR and Zonge data. In any such hole, downhole geophysics would be particularly valuable for assessing recharge pathways to deeper groundwater and further constraining the conceptual model.

6. The three proposed intermediate-depth wells will be used to further constrain travel times in the perched zone and regional aquifer using anthropogenic constituents such as HE and tritium.

The three proposed locations are described below and shown in Figure 6.3-14.

1. Cañon de Valle, west of MDA P—This well would be located in the resistivity anomaly (area of low resistivity) noted by HydroGeophysics in the HRR survey (see Appendix H) and in a high-conductivity anomaly in the CSAMT and NSAMT data. This anomaly suggests water is being lost from the canyon alluvial system to the vadose zone and possibly to deeper groundwater.

2. TA-16 mesa top, east of R-25—The Fugro electromagnetic data suggest that the border of the conductive zone is close to the eastern edge of the TA-16 mesa top (Figure 6.3-14). Drilling toward the edge of the mesa would provide a high probability of hitting perched water at a > 700-ft depth, toward the edge of the perched zone (assuming it is continuous downgradient from R-25). Because this location is not in a high-conductivity anomaly in the CSAMT data, it is possible that perched water is not present or is present at significantly greater depth than in R-25.

3. Southeast of R-25, within the more highly conductive zone identified in the Fugro flyover data—This well could be located near P-Site.

Logistical considerations (e.g., moving a large rig into Cañon de Valle) could limit site selection. Sites are located along the geophysical survey lines where the presence of intermediate-depth water is hypothesized based on the CSAMT and NSAMT results.

Data from these intermediate-depth wells will help us to

1. assess the risk to water quality at the Pajarito well field and therefore determine if active treatment of deep groundwater is called for, or if a monitored natural attenuation (MNA) approach will suffice; and

2. decide if more intermediate-depth or deep wells are required (based on the extent of the perched zone and the presence or absence of contamination in the perched zone and/or regional aquifer).

Table 6.3-7 outlines the rationale for drilling the two completed deep wells at their particular locations as well as the rationale for the three new intermediate well locations.

The first well drilled was CdV-R-15-3, the TA-15 well; the second well drilled was CdV-R-37-2, the TA-37 well. Drilling of the first intermediate-depth well will be started during FY 03 (pending availability of funding). The other two wells will be initiated as soon as funding allows, probably during FY 04.

Based on the considerations shown in Table 6.3-7, the first intermediate-depth well to be drilled will be the one in Cañon de Valle. The results from each well will be discussed with NMED personnel in order to reassess the 260 CMS deep groundwater characterization and the ongoing well-installation project. At that time, locations of upcoming wells will be reviewed.

Table 6.3-7
Assessment of Candidates for Well Sites

Location/ Well ID	Pros	Cons
TA-15/ CdV-R-15-3	• Provides insight into TA-18 HE observations • Downgradient from 260, generally upgradient from supply wells • Downgradient from water-losing section of Cañon de Valle • Lies on east-west transect that includes 260, R-25, R-19, and PM-2/PM-4 • Provides insight into geologic "basement structure"	• In concert with R-25 and SHB-3, not optimal for defining principal deep perched zone gradient
TA-37/ CdV-R-37-2	• Easy access • Area not already covered by planned *R* wells • Helps define hydrologic gradient and the plumes' southern boundaries • Provides evaluation of additional sources for contaminants observed in Martin Spring and the Martin hydrohole (2665) • Lies on transect between 260 and R-27 • Provides information about conditions near southern Laboratory boundary	• May not be directly downgradient from 260 in regional aquifer
TA-16/ CdV-16-1(I) (Cañon de Valle)	• Downgradient from 260 and cross-gradient from R-25 • In water-losing section of Cañon de Valle • Could help define the extent of perched zone and associated plumes • Should help evaluate other sources (Burning Ground, MDA P, Cañon de Valle alluvial waters)	• Access for a drill rig may be difficult in Cañon de Valle
TA-16/ CdV-16-2(I) (east of R-25)	• Downgradient from 260 and R-25 • Could help define the extent of perched zone and associated plumes	• Too close to R-25? • Could miss perched zone
TA-16/ CdV-16-3(I) (near P-Site)	• To the southeast of 260, which would help determine southern extent of the deep perched water zone and its hydrologic gradient • Could help define the extent of perched zone and associated plumes	• Could miss perched zone

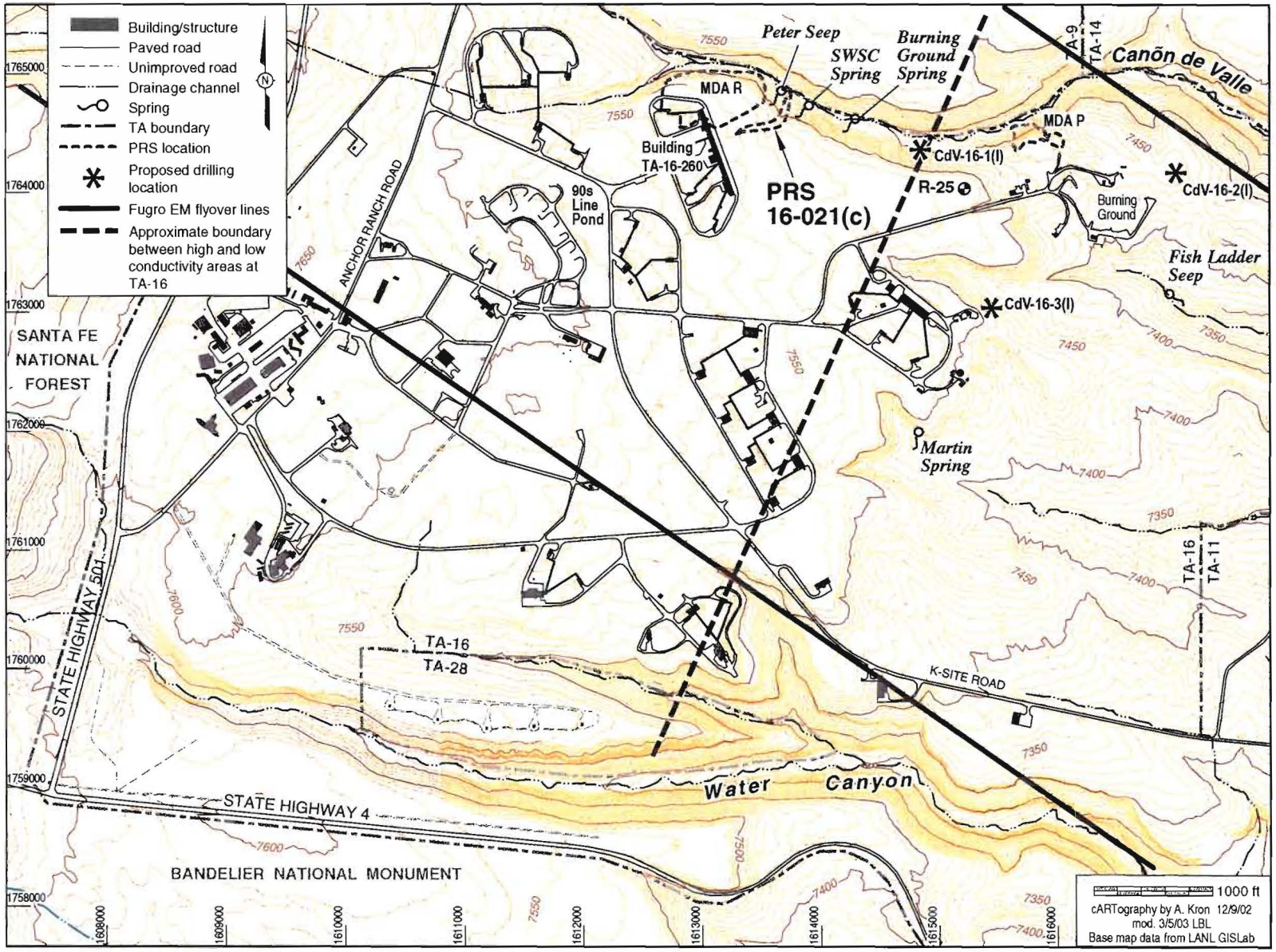

Figure 6.3-14. Proposed drilling locations, showing relation to Fugro lines (heavy solid lines) and approximate boundary between conductive regions to the west and less conductive regions to the east (heavy dashed line) (*Note:* The approximate boundary between conductive regions is drawn as a straight line, but it likely exhibits much greater complexity; the only control points for the boundary position are at the intersections with the Fugro lines. Deep perched water was encountered at R-25, so locally the boundary must extend further east than shown.)

If the data from the deep 260 CMS wells, the intermediate-depth wells, and the "Hydrogeologic Workplan" wells listed above suggest that the HE plumes within the deep perched zone and regional aquifer are not bounded, additional regional or intermediate 260 CMS wells may be drilled. This strategy will be applied, whether the HE in perched and regional groundwater is derived solely from 260 or from multiple sources. The locations of any additional wells will be developed in consultation with NMED personnel as well as members of the public and other stakeholders. Ongoing groundwater modeling efforts will also be used to optimize well location selection.

6.3.6.3 Sampling Activities

The data quality objectives (DQOs) for data collection at these 260 CMS wells are similar, although reduced in scope, to those outlined in the "Hydrogeologic Workplan" (LANL 1998, 59599.1). If relevant changes to the DQOs in the work plan are agreed upon with NMED, similar changes will be implemented for these wells. The data needs are ranked as follows, in descending order of priority:

1. contaminant profiles (for HE, metals, and anions) and water levels;
2. general lithology [from a hydrogeologic perspective, the zone that would be most beneficial to understand would be the layers between the two major saturated zones (deep wells only)]; and
3. various hydrogeologic parameters (e.g., saturated zone thicknesses, saturation levels, head gradients, permeability, and porosity).

One reason for the hydrogeologic parameters receiving the lowest priority is that relevant information from other adjacent wells is available. Another reason is that the primary use for these parameters is as input to models. Due to the heterogeneities of hydrogeologic parameters within lithologies on the Pajarito Plateau, modelers will have to compensate for poorly constrained data through the use of sensitivity analyses.

Borehole Advancement and Well Installation Specifications

The 260 CMS deep wells will be drilled and completed similarly to Type 2 wells, using the terminology of the "Hydrogeologic Workplan" (LANL 1998, 59599.1). The following description of the proposed wells was taken from the work plan, section 4.1.1.2, and modified.

Each of the two wells will be a multiple-completion regional aquifer well. The boreholes for these wells will be drilled to an estimated depth of 1800 ft or at least 200 ft into the regional aquifer. A principal control on the depth of drilling will be whether the HE plume has been bounded in the vertical direction, based on screening results. The number and length of screened intervals will be finalized in the field, in consultation with NMED personnel and based on site-specific findings. Screened zones will be installed in both the deep perched zone (if found) and regional aquifer. The selection of screen size and the selection of filter pack materials will be made following particle-size analysis of geologic cuttings in the zone to be screened.

Applicable borehole advancement/deep well installation specifications are as follows:

- A carbon steel surface casing, approximately 16 in. in diameter, will be set from the land surface to a depth of approximately 10 ft. At locations where alluvium is present, the surface casing will extend approximately 10 ft into the underlying competent layer and will be grouted in place.
- During borehole advancement, the drilling method will employ an outer temporary casing that is advanced to the total depth of the borehole. This is done to maintain borehole integrity, help the

circulation of drilling fluids, and minimize migration of fluids between the deep perched zone and the regional aquifer.

- The well will be constructed of mild carbon steel casing, 5.56-in. in outer diameter, from land surface to the top of the stainless-steel screen. To minimize the potential for corrosion, a transitional coupling will be installed between the two casing types. An annulus ≥ 2 in. will be provided. Approximately 10 ft of blank casing, with an end cap, will be set at the base of the screen. Centralizers will be used at intervals of approximately 100 ft.
- All backfill materials (grout, bentonite, sand) will be tremied/pressure-grouted in place.
- A lockable steel protective cover will be cemented, in place, over the well casing and extending at least 2 ft below ground surface.
- The top of the well will be finished with a concrete pad that measures 4 ft × 4 ft × 4 in. or more.

Figure 6.3-15 shows a general prototype of Type 2 wells. Figure 6.3-16 depicts the multiple-completion configuration.

The new intermediate-depth wells will have a single completion (Fig. 6.3-17) and will be drilled to a depth of approximately 800–1000 ft, or into the top of the deep perched zone, where present. Depth DQOs include drilling through the perched zone until no contamination is found, based on HE screening results, or until dry rock is encountered between the perched zone and the regional aquifer.

Module VIII Requirements

LANL plans to meet the requirements of Module VIII of the Laboratory's Hazardous Waste Facility Permit for these wells/boreholes and, ultimately, to use them for long-term monitoring. Thus, they will fulfill all HSWA module special permit conditions concerning the construction of monitoring wells. The following permit language from the "Hydrogeologic Workplan" is relevant to the typical construction of the wells proposed in this document:

> The monitoring wells installed under this and following sections of this permit shall be constructed using flush-joint, internal upset, threaded (or an equivalent method of joining without rivets, screws and glues) casing manufactured from inert materials. The boreholes for casings and screens shall be a minimum of six (6) inches greater in diameter than the well casing or screen outer diameter. Filter pack and screen slot openings shall be sized based on formation grain size and characteristics. Well screen lengths shall be no more than ten (10) feet in length. The filter pack shall extend no more than two (2) feet above the top of the screen and shall not cross any clay layers which may act as aquitards. If a bentonite seal is used, the bentonite shall be allowed to hydrate a minimum of twelve (12) hours before emplacement of grout. Grout shall be emplaced using a tremie pipe to ensure a consistent seal at depths greater than 5 feet, and grout shall be allowed to set a minimum of twelve hours before initiating development.
>
> Development procedures shall include purging of the well until contaminants introduced during drilling can be assured of being removed. Development shall also include surging with a surge plug, and either

bailing or pumping until the nephelometric turbidity units (N.T.U.) can be consistently measured at five (5) or less, if possible. Well head construction shall include a well pad keyed into the well annulus and a system to secure the well from traffic and unauthorized access. Within thirty (30) days of construction and development of the last well required under this section, the Permittee shall submit to the Administrative Authority a report and map including:

1. Survey of location of each well;
2. Surveyed ground level, top of casing and top of well pad referenced to known elevation datum (NGVD, 1929);
3. Static water level, referenced to mean sea level;
4. Well construction data (including a diagram for each well, detailing total depth, screen placement, gravel pack, annular seal, borehole and casing size [all measured to within 0.1 foot], and well log data; and
5. Well development data.

Any saturated condition encountered will require grouting in a surface casing to prevent any downward migration of surface contamination along the wellbore. Any boring drilled into the main aquifer that encounters perched water shall set conductor pipe to the top of the main aquifer and hydraulically isolate the main aquifer from the deep perched zone. The annular space must be sealed with a bentonite grout or equivalent to prevent shrinkage cracking. (section 4.1.2)

Renewal of Module VIII of the Laboratory's Hazardous Waste Facility Permit is currently being addressed with the NMED. The specifications for the 260 CMS wells as outlined in this document will be modified to reflect any changes in the new Module VIII of the Laboratory's Hazardous Waste Facility Permit that are applicable to regional or monitoring wells.

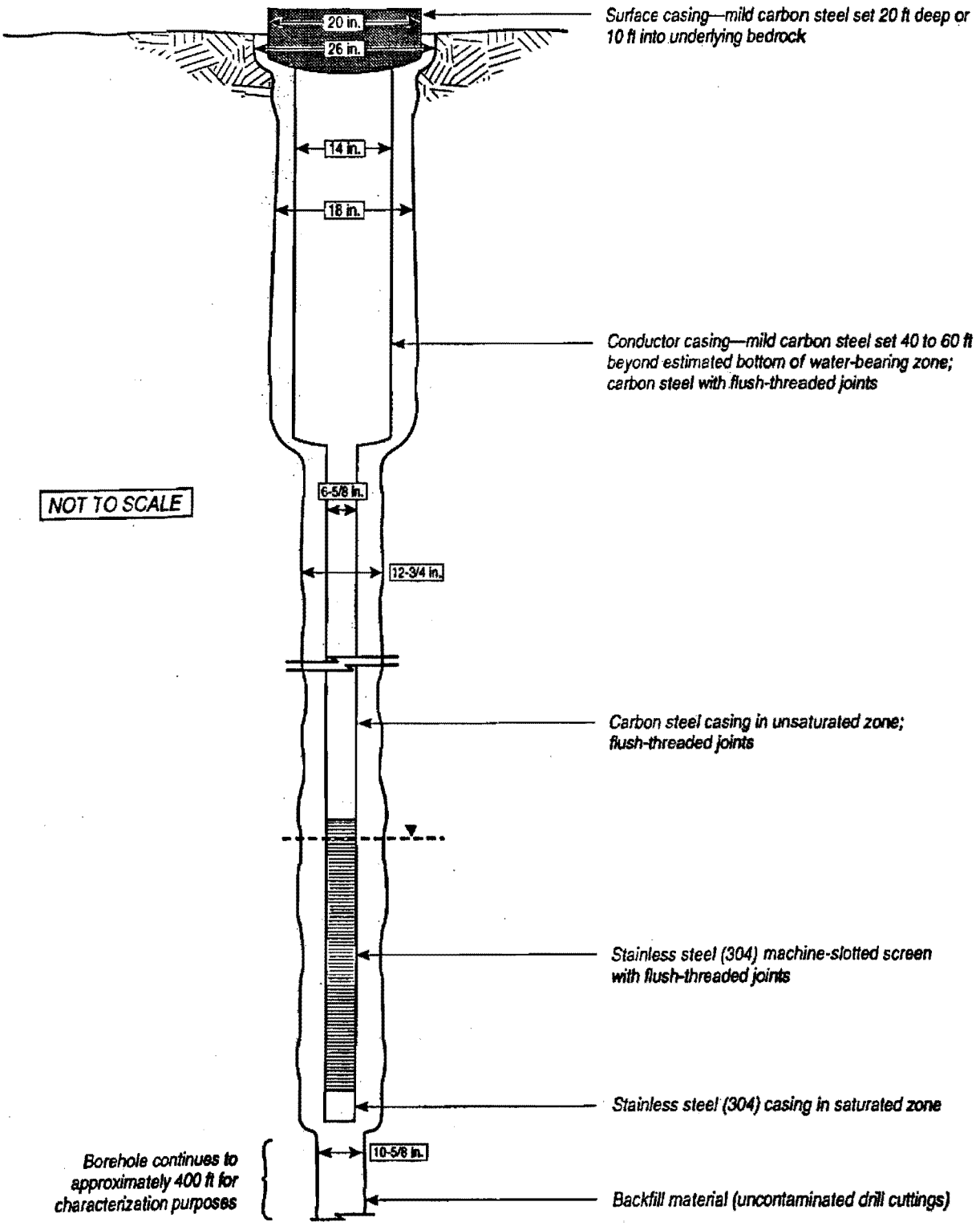

Figure 6.3-15. Schematic of Type 2 and Type 3 (regional) well design; all dimensions are approximate

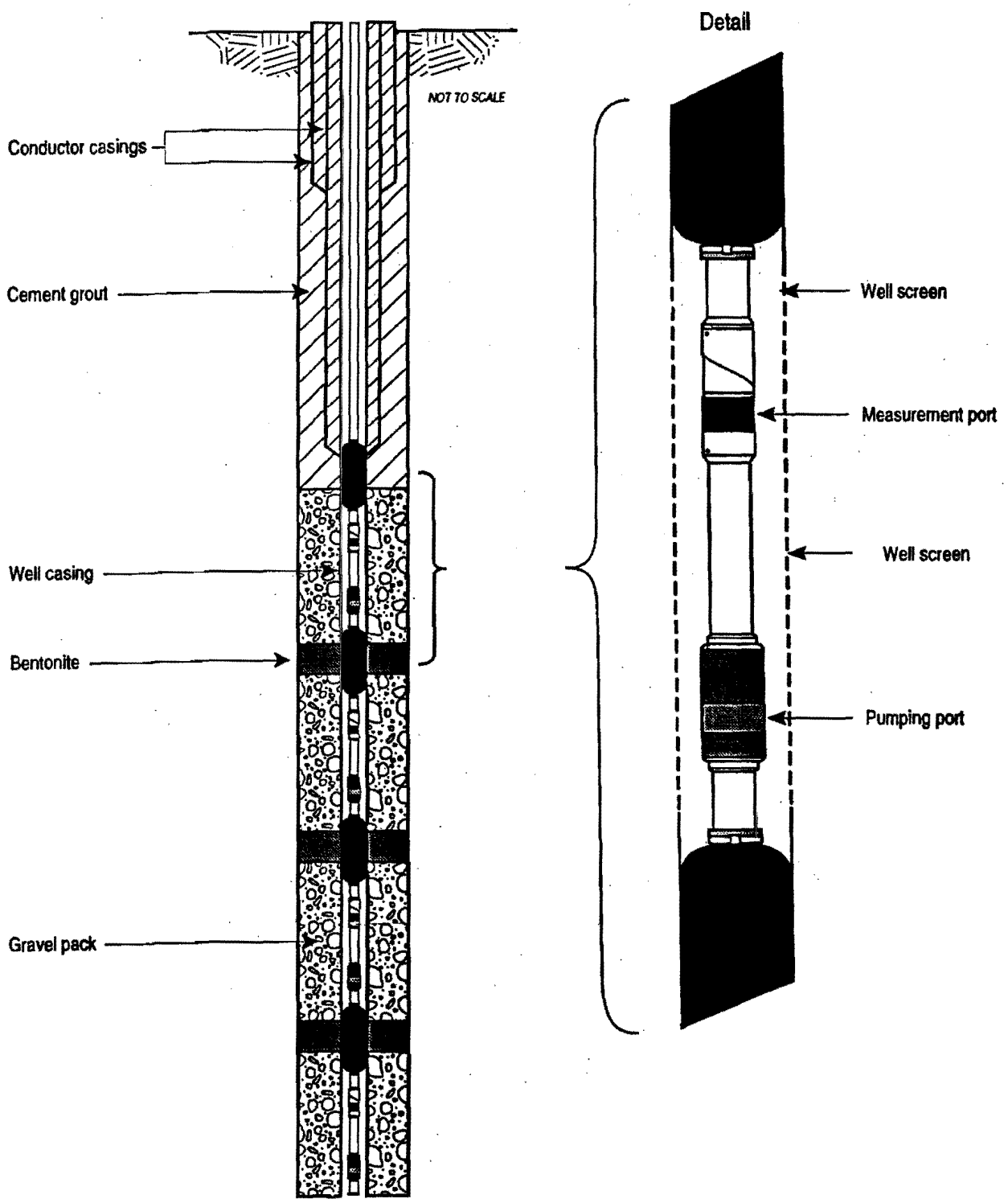

Figure 6.3-16. Westbay-type design for multi-level monitoring

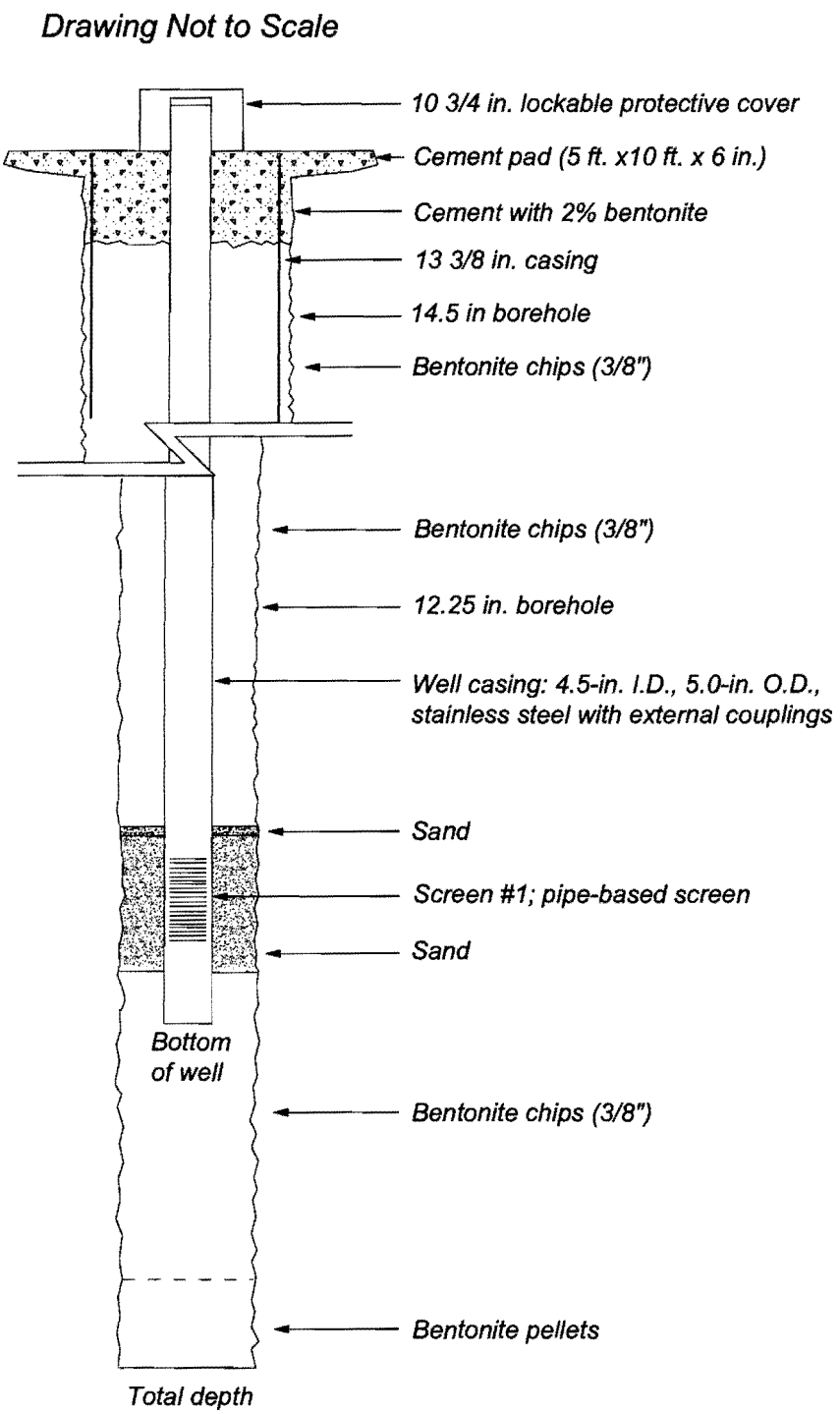

Figure 6.3-17. Schematic single completion well diagram

Borehole and Groundwater Sampling

The well sampling specified for these wells is a subset of what was proposed for the regional wells in the "Hydrogeologic Workplan" (LANL 1998, 59599.1). The key data needs are characterization of contaminant profiles, lithology, and hydrogeologic parameters. These needs will be met through sampling core and/or cuttings as well as groundwater, and through geophysical logging methods.

The following guidelines for sampling, extracted from the "Hydrogeologic Workplan," apply to these 260 CMS wells:

- A comprehensive cased-hole geophysical logging suite will be run through the drill string, immediately prior to the completion of each well.
- Core and cutting samples will be field-screened for HE using the spot test and D TECH immunoassay methods as necessary.
- Packer and slug tests will be completed at key geologic intervals as defined by the technical team hydrologist. These tests may be performed following well completion.
- At least five samples of cuttings or core will be collected from saturated zones for petrographic, X-ray fluorescence (XRF), and X-ray diffraction (XRD) analyses.
- Core sampling for vadose zone anions and stable isotopes ($\delta^{18}O$, δD, and possibly $\delta^{15}N$) will be done. Sampling will be done on a regular interval of 10 or 20 ft for intermediate-depth boreholes.
- Following completion and development of the wells, groundwater samples will be collected on a quarterly basis from each screened interval or Westbay-type port. These samples will be analyzed for the presence of HE, metals, and anions. One quarterly round of samples per year will be analyzed for volatile organic compounds, gross alpha and beta, and a full suite of geochemical parameters as required for geochemical modeling.

Geophysical logging will be conducted on each of the wells. The geophysical logs that will be completed will depend on borehole stability. If open-hole conditions can be maintained, a comprehensive suite of tools will be used. If casing is required, a more limited suite will be deployed.

The geophysical logs may include, but are not limited to, the items on the following list:

- Compensated thermal and epithermal neutron
- Electromagnetic induction
- Array induction
- Elemental capture sonde
- Natural gamma
- Spectral gamma
- Combined magnetic resonance
- Formation microimager
- Triple detector litho-density

- Hostile environment gamma-ray sonde
- Borehole color video (axial and sidescan)
- Accelerator porosity sonde
- General purpose inclinometer
- Pressure temperature sonde
- Full bore spinner

Insert this revised table on p. 84, in section 6.4.4, "Laboratory Analytical Procedures."

Table 6.4-3
Analyte Suites, Methods, and Protocols for Analysis of Soil and Water Samples

Analyte Suite	Analytical Method	Analytical Protocol*
HE	High performance liquid chromatography (HPLC)	SW-846, Method 8330
Metals	Inductively coupled plasma emission spectroscopy (ICPES) or inductively coupled plasma mass spectroscopy (ICPMS)	SW-846, Methods 6010 and 6020
Anions (nitrate, sulfate, perchlorate)	Ion chromatography	EPA Method 300, 310
Fluoride	Ion chromatography	EPA WW 340 series
Chloride	Ion chromatography	EPA WW 325 series
Bromide	Ion chromatography	EPA Method 300, EPA Method 320.1
HCO_3 (bicarbonate)	Titration	SW-846, Method 4500–CO_2
Volatile organic compounds	Gas chromatography mass spectrometry	SW-846, Method 8240
Gross alpha/beta	Gas proportional or liquid scintillation counting	Not available

* Or latest equivalent EPA method.

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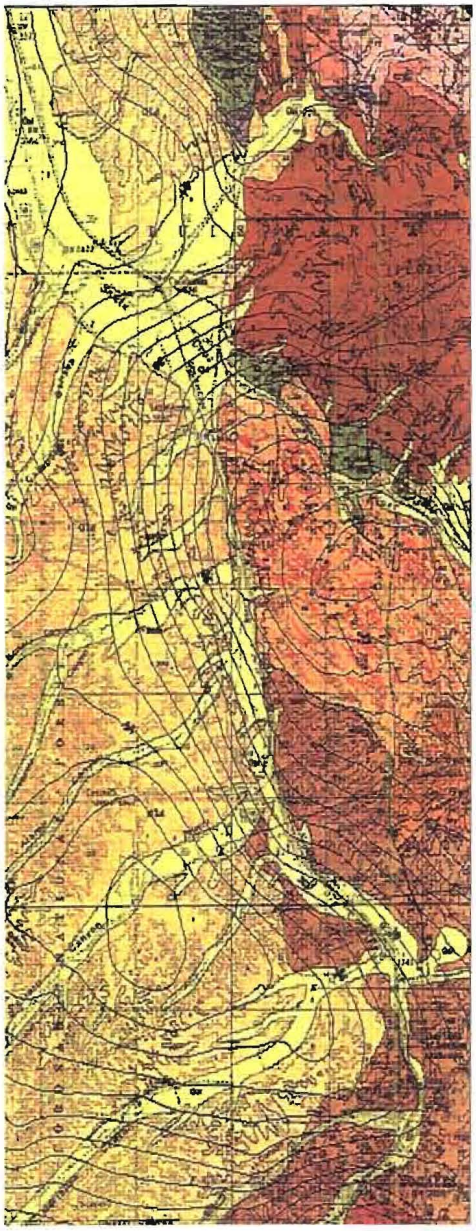
Appendix H

Geophysics Report

hydroGEOPHYSICS, Inc.



REPORT ON GEOPHYSICAL SURVEYIG

AT
CAÑON DE VALLE
TA-16

LOS ALAMOS NATIONAL LABORATORY

Project 2001-048

By:

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For:

IT Corporation

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Mr. Kevin Reid, Hydrogeologist

Geophysical Consulting and Services

1.0 EXECUTIVE SUMMARY

Four lines of High Resolution Resistivity (HRR) and three lines of Refraction Seismic surveying were completed within Cañon de Valle at the Los Alamos National Laboratory (LANL) technical area TA-16. The geophysical surveying was a continuation of the test work performed for IT Corporation and LANL in July of 1999. The 1999 results demonstrated the capability of HRR as a non-intrusive means to detect and characterize subsurface moisture conditions. The 2001 survey was a broader continuation of that effort.

One line of HRR completed in 1999 was repeated in 2001 in order to tie previous geophysical data to recent efforts. Additionally, the repeated line provided a dynamic time-based picture of hydrologic changes over the two-year period. The majority of 2001's HRR surveying (3000 feet) was performed longitudinally along the canyon bottom and, for the most part, parallel to the stream channel. A cross-section profile was acquired near the location of stream profile 16. Refraction seismic data were also acquired at three HRR cross-section profiles in order to support alluvial characterization through the use of a different physical property.

Nearly 19,000 new data points and 4,300 feet of geophysical coverage were acquired during the study. Summary presentations of the processed data are included in this report. As a result of this effort the following observations have been made.

- The most salient feature of the entire survey is an electrically conductive feature dipping downward to the west in the up-gradient direction in the Canyon. This feature appears to start at surface in the area immediately below MDA-P.
- A single significant vertical joint or fracture may have been detected at SP-8.
- Minor joints may have been detected in the HRR data.
- The HRR data suggest that a thin, horizontal welded(?) zone may support much of the surface flow down the canyon.
- The HRR data also suggest the presence of seeps along the south canyon wall.
- Temporal changes in the repeated HRR line suggest short-term effects can be seen in the shallow data near the channel and long-term effects associated with an interpreted seep.
- In general, the Bandelier tuff appears to be an excellent medium for electrical measurements.
- The combination of HRR and refraction seismics was useful, but the seismic data were not as quantitatively useful as at other sites.
- Three-dimensional HRR should be considered for future studies.

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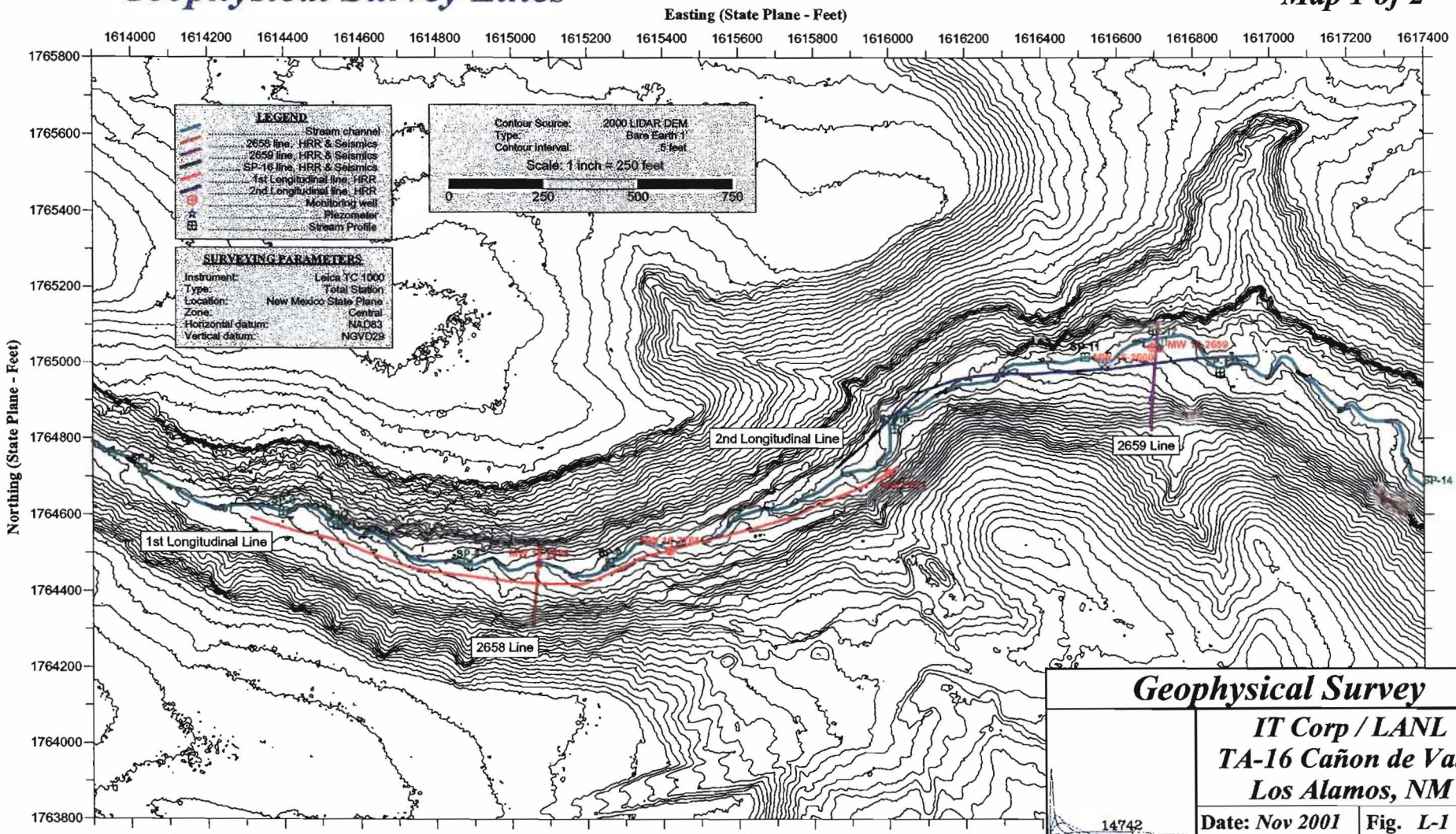
Location Map Of
Geophysical Survey Lines

Map 1 of 2



Geophysical Survey

IT Corp / LANL
TA-16 Cañon de Valle
Los Alamos, NM

14742

Date: Nov 2001 | Fig. L-1

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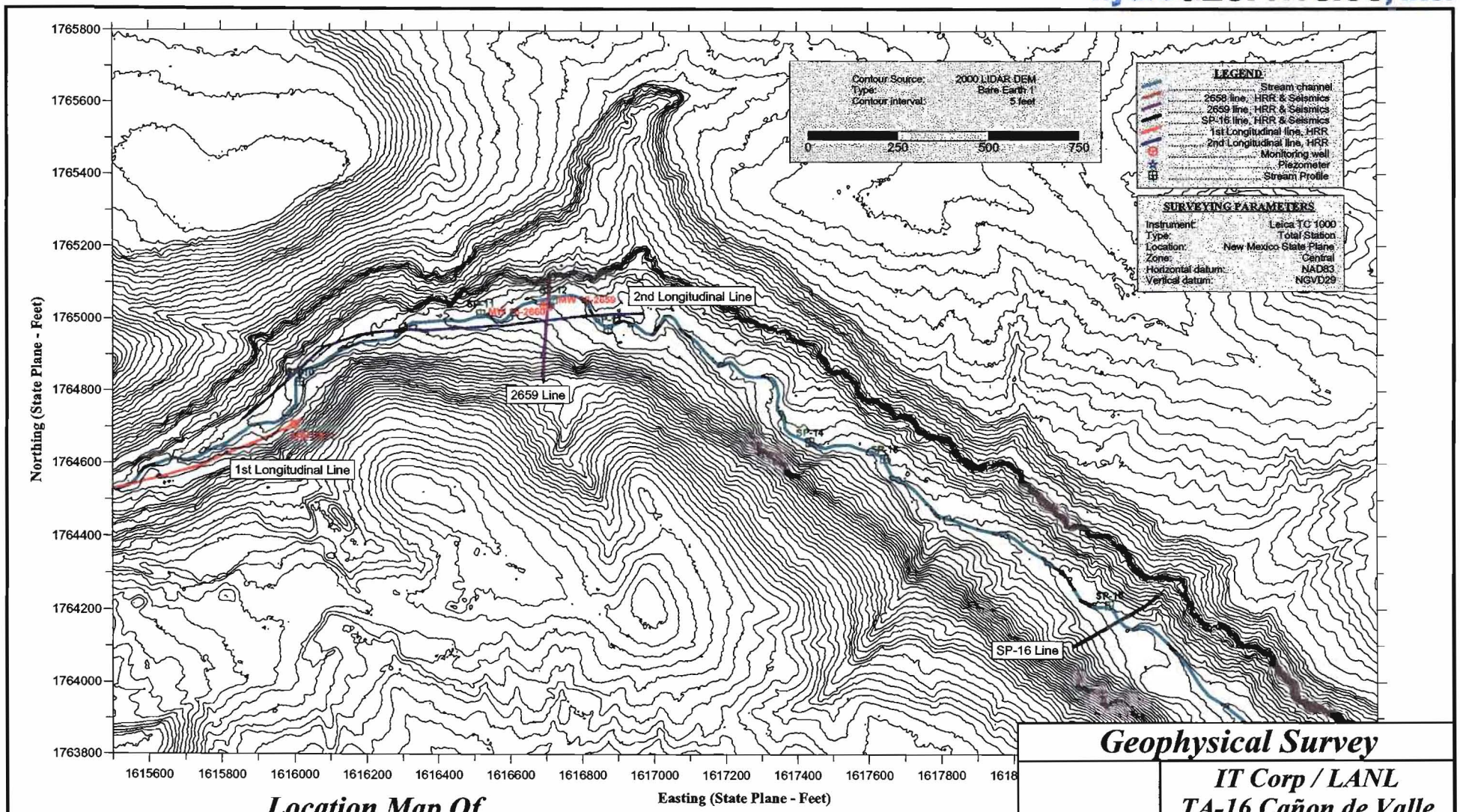

Location Map Of
Geophysical Survey Lines

Map 2 of 2

Geophysical Survey

IT Corp / LANL
TA-16 Cañon de Valle
Los Alamos, NM

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2.0 INTRODUCTION

During the period of September 6th through November 9th 2001, four lines of High Resolution Resistivity (HRR) and three lines of Refraction Seismic surveying were completed within Cañon de Valle at the Los Alamos National Laboratory (LANL) technical area TA-16, New Mexico (herein referred to as the Site). The survey was performed by hydroGEOPHYSICS, Inc. personnel based out of Tucson, Arizona. IT Corporation personnel providing guidance and support were Mr. Peter Gram, Project Manager, and Mr. Kevin Reid, hydrogeologist. Mr Reid was present at all times to oversee and coordinate work performed on Site. Mr. Scott Baldridge and Mr. Don Hickmont were present during all supervisory meetings and represented LANL's and DOE's interests, respectively. hydroGEOPHYSICS personnel who completed the surveys were Mr. James B. Fink, President; Mr. Robert McGill, Project Engineer; Mr. Marc Levitt, Geological Engineer; Mr. Chris Baldyga, Geophysicist; and Mr. Mark Mason, Geological Engineer.

2.1 Objective of Investigation

The geophysical surveys were performed above and below the Material Disposal Area "P" (MDA-P). The objective of the HRR geophysical survey was to define the lateral and vertical extents of saturated alluvium within a portion of Cañon de Valle in Technical Area 16 (TA-16) along the survey lines and within the vicinity of established monitoring wells.

An additional goal was to detect any potential vertical pathways for downward migration of meteoric and ground water within the Bandelier Tuff.

The HRR results were expected to provide cross-sectional areas for subsequent calculations of subsurface flow and additionally characterize both alluvial and bedrock geologic and structural features that may influence hydrologic flow.

The refraction seismic data were expected to support the HRR results by providing a definitive depth-to-bedrock (Bandelier Tuff) profile and additionally identify and, if possible, characterize velocity variations within the Bandelier.

2.2 Site Location

The Site is situated within an incised drainage known as Cañon de Valle, just north of the "Burning Grounds" area of TA-16. A total of five lines were established and subsequently surveyed to provide accurate location and elevation information. The following is a list of established geophysical lines and a description of their corresponding locations.

- **Line 2658** - is located approximately 600 feet west of MDA-P, perpendicular to the axis of the canyon, and crosses the stream channel. The line passes within a foot of monitoring well MW-16-268. HRR and seismics were completed in 2001, and HRR was completed in 1999 (old Line 2). Line 2658 is 200 feet long and is the most upgradient transverse line surveyed.
- **Line 2659** - is located approximately 1000 feet east of MDA-P, perpendicular to the canyon, and crosses the stream channel. The line is centered between monitoring wells MW-16-2659 and MW-16-2660. Seismic data were acquired in 2001, and HRR data were only acquired in 1999 (old Line 1). Line 2659 is 295 feet long.
- **Line SP-16** – is located approximately 2000 feet east of Line 2659, runs perpendicular to the canyon, and crosses the stream channel. The line passes within 10 feet of stream profile location 16 (SP-16). HRR and seismics data were acquired in 2001. Line SP-16 is 300 feet long.
- **1st Longitudinal Line** – begins just west of Burning Ground Spring, is parallel to the long axis of the canyon along the south bank of the stream channel, and ends just east of MDA-P. The line passes through cross sectional Line 2658 at approximately station 750 feet. Only HRR data were acquired in 2001. The 1st Longitudinal Line is 1800 feet long.
- **2nd Longitudinal Line** – begins approximately 75 feet east of the west-end of the 1st Longitudinal Line, but on the north side of the stream channel, and continues down the canyon. The line is parallel to the long axis of the canyon and crosses the stream channel in two locations alternating between the north and south banks. The profile passes through Line 2659 at approximately station 875 feet. Only HRR was completed in 2001. The 2nd Longitudinal Line is 1200 feet long.

2.3 Survey Area & Logistics

From a geophysical standpoint, the Site is fairly accessible but posed a few logistical problems in acquiring data. The most serious problems encountered were from the resistivity data acquisition system and the weather. In order to maximize the resolution of the resistivity survey, we had selected a state-of-the-art, multi-channel, earth-resistivity instrument [Super

Sting R-8] manufactured by Advanced Geosciences, Inc. (AGI). However, transportation over the rough and steep terrain and difficult weather conditions caused frequent problems with various components. To combat these delays we opted to replace the system with a slower, but more resilient and reliable single-channel instrument [AGI Sting R-1], which produced favorable results.

Other logistical problems included difficult travel up and down the steep canyon slopes, and increased security resulting from the laboratory-wide shut-down due to the September 11th tragedy. It should be noted that progress was greatly increased by IT Corporation personnel who sacrificed multiple weekends to provide site access.

A 6-wheeled All Terrain Vehicle (ATV) owned and operated by IT Corporation was used to transport heavy or bulky survey equipment.

All survey profiles were surveyed for horizontal and vertical control using a Leica TC 1000 Total Station provided by IT Corporation. Field measurements were reduced to the New Mexico State Plane coordinate system of 1983 (NAD 83) using the Transverse Mercator Projection for the New Mexico Central Zone. The standard deviation of errors associated with measurements by this instrument are 3 seconds of horizontal and vertical angle measurement and 3 mm ±2ppm distance measurement. All surveying was tied to known control points and an additional network of control points was setup by hydroGEOPHYSICS and IT Corporation personnel.

The HRR survey lines were tied to the established control points, monitoring wells, and any convenient permanent structures. The lines are marked in the field with lath placed at the 100-foot stations and pin-flags at 50-foot stations. All semi-permanent stakes are marked with grid coordinates in standard surveying nomenclature. All stations were initially measured using a fiberglass measuring tape and surveyed with the total-station afterwards.

Figures L-1 and L-2 are the location maps showing HRR and seismic line orientations relative to control points, monitoring wells, and surface topography. The topographic contour map was provided by Mr. Bill Carey of LANL. The contours were provided in DXF format and were created from the 2000 LIDAR 1-minute, bare-earth DEM. These data are described by Carey and Cole (2001), *Description of the CerroGrande Fire Laser-Altimetry (LIDAR) Topography Data Set,* Los Alamos National Laboratory publication LAXXX-MS. The data are in New Mexico State Plane Central US survey feet NAD83 Horizontal datum NGVD29 Vertical datum. All survey measurements are in English units (feet).

3.0 METHODOLOGY

3.1 High Resolution Resistivity

The geophysical resistivity method is based on the capacity of earth materials to conduct an electrical current. The concept behind applying the resistivity method is to detect and map changes or distortions in the imposed electrical field due to inhomogeneities (changes in electrical properties of some sort) occurring in the ground. These changes in the electric field can be measured on the ground surface, in boreholes, or with a combination of the two. Measurements are made with a minimum of four electrodes in contact with the ground. Various electrode arrangements have been used over the decades, most of which involved collinear arrays with names such as Schlumberger, Wenner, dipole-dipole, three-array, pole-pole (also called "normal" in borehole logging), and many more. Each array shows merit in specific environments and all (ideally) produce useful information.

For the HRR surveying, data were acquired using the pole-pole array which uses a four pole system of electrodes with two remote electrodes placed a minimum 2000 feet away from the survey lines, and two roving electrodes along each survey line. The two roving electrodes used a minimum electrode spacing of five feet and a maximum spacing of two hundred feet. Transmitter stations were incremented every five or ten feet depending on data density requirements. The instruments used for the HRR surveying are battery powered with built-in data-logging capabilities. In areas that surveying switched between the two units, a survey overlap was performed to detect, and compensate for, any variations between the two instruments. Hand-transcribed field notes were maintained for in-field data quality control and production purposes.
When using the single channel resistivity instrument (Sting R-1), only one receiving rover electrode could be read per transmission of electrical signal. Eight receiving rover electrodes could be recorded simultaneously using the Super Sting R-8 instrument.

The data were processed with a hydroGEOPHYSICS proprietary software package that incorporates, and compensates for, variation in topography. A rigorous quality control procedure was maintained to identify and either edit or delete questionable data points. Color-contoured cross-sections of the data were made using Golden Software's, Surfer software package (Version 7.0). The results of the survey are included with this report. The figures represent calculated apparent resistivity values plotted relative to surficial topography.

3.2 Refraction Seismics

Seismic refraction surveys model geologic structure based on the behavior of artificial acoustic energy introduced into the earth. This behavior can be traced along individually traveled, refracted ray paths. Refraction seismics can be used to detect interfaces between horizons of increasing acoustic velocity. Essentially, compressive energy is introduced into the earth and the subsequent behavior of the earth is monitored by a series of collinear geophones spaced at regular intervals along the ground surface.

Compressional (P) waves are compressional-dilational events in which the wave front travels in the direction of a propagating wave and is the first form of energy detected by the geophones. The earth-coupled geophones provide time-motion histories (seismic traces) that are recorded by a seismograph. Initial arrivals of the head waves are then selected from each seismic trace and travel times (in milliseconds) are determined. Formation velocities are then estimated from inverting linear sequences of travel times. The velocities at which refracted waves travel is generally a function of gross media densities, which are influenced by joint apertures, micro-fracturing density, and other structural characteristics that can be caused by weathering, including secondary porosity. Among measurable geophysical properties, the range of rock densities is one of the more constant, least variable parameters. However, the specific density of a particular rock type can be extremely variable. Densities may be satisfactorily derived from velocities.

All seismic surveying was completed using a 24-channel Geometrics Stratagem Seismograph and geophones. Geophone interval was 5 feet. Multiple (9-12) shot points were recorded per spread and were acquired using a 12-pound sledge hammer striking a thick steel plate as the energy source. Shot records were viewed and printed after each shot to verify data integrity. The shot record (seismogram) was also saved to diskette and stored for subsequent processing.

Processing

The complexity of the data was such that we used two different processing packages to extract and interpret specific geologic features. The first interpretation package used to produce depth cross-sections is written by Rimrock Geophysics, Inc. and is called Seismic Interpretation Package (SIP ver. 4.1). The SIP package uses a delay-time method to obtain a first-approximation depth model. This model is further refined through a series of ray tracing and model adjustment iterations that seek to minimize the difference between the field data and the corresponding data produced by a two-dimensional cross-sectional model.

The processing steps consist of selecting first arrival times for each shot point, inputting geophone and shot-point geometries, assigning layers to appropriate velocity slopes and inverting data to velocity layers. The process is slowly refined by manual interation through evaluation of the results and repetition of the process until a satisfactory fit to the data is obtained.

The program displays views of both raw and datum-corrected time-distance (T-D) plots, allowing character and quality to be checked. Primary quality criteria are reciprocal times for reverse shots and parallelism between layers of corresponding velocities. Layers were chosen by grouping together matching first-break velocities that displayed as linear trends on the T-D plots.

It is important to note that certain assumptions have to be made to complete most computer model inversions. In many situations, the geologic conditions defy the programmed assumptions and may adversely affect the resulting interpretation. In the case of the SIP package, the following are assumed:

Layers are horizontally continuous from end to end (i.e. no pinch-out).
Layer velocities increase with depth (i.e. no velocity inversion.)
There is no horizontal change in velocities (i.e. lateral isotropy).
There are no sharp vertical offsets between layers.

The second interpretation software package used was written by Optim and is called SeisOpt 2D. This program produced the color-contoured velocity section that is helpful in revealing velocity gradients within host lithologies. SeisOpt is a refraction velocity optimization routine that replaces the traditionally manual iterative inversion process by automatically "tuning" optimized fits between observed and calculated models. Data are processed by importing first-break-picks, defining survey geometry, and establishing a modeling grid onto which the velocity optimization will be fit. The only real supervision is in defining the grid mesh resolution such that it does not over- or under-sample the data. To allow representative comparison between the two packages, we imported the same "first-break-picks" that were used in SIP.

Although the Optim software also has some basic assumptions it does allow lateral velocity variation because it does not predefine specific layers. The software is also better suited for handling sharp vertical offsets between layers, such as faults and fractures. It also provides a useful velocity gradient that is helpful in interpreting the difference between geologic layers.

4.0 RESULTS & INTERPRETATION

3.1 HRR Interpretation

This year's (2001) project was a continuation of work performed in 1999. Results of the new work suggest that certain assumptions and interpretations presented in the previous report are justified, but, some others can be improved. In order to provide a more comprehensive discussion, we have included the 1999 interpretations with updated version based on the 2001 survey results. We have tried to point out both consistencies and differences between the two phases of surveying.

HRR survey results are plotted in color-contoured, geo-electric, cross-sectional format and are combined with corresponding seismic data sections where applicable. The HRR sections represent geometrically-constrained, direct-inversions with no pre-defined model parameters invoked. Section colors represent the inverted apparent resistivity values. Higher values are expressed in warm colors, while lower values are shown in cool colors. As a background comment, *typical* values for undisturbed geologic media (not necessarily encountered during these surveys) range from a few ohm-meters for saturated clays, tens of ohm-meters for saturated silts and sands, a few to several hundreds of ohm-meters for dry alluvium, and hundreds to thousands of ohm-meters for bedrock.

Apparent resistivity values for the entire survey span more than an order of magnitude, from 100 to 1200 ohmmeters. Generally, the higher values represent competent or welded Bandelier with associated, low-moisture content. Although the implication is that low-moisture content represents unsaturated conditions, low bulk porosity may allow saturated conditions with minimal moisture. Electrically, we cannot discriminate between unsaturated conditions in porous media and saturated conditions in low-porosity media. Both situations represent equivalent, low-total-moisture content.

We have previously assumed that the lowest apparent resistivity values represent saturated alluvium. More recent results suggest that increased porosity and-or permeability within the Bandelier will allow a sufficient increase in moisture such that the electrical conductivity is enhanced. Similarly, a fixed level of porosity and permeability will appear more conductive with increased ionic content (increase in total dissolved solids [TDS]). Again, we cannot discriminate between alluvium saturated with low TDS water and porous Bandelier partially saturated with higher TDS water.

Previous discussions with LANL personnel suggested that the HRR lines were located entirely within the Qbt3 unit of the Bandelier. Accordingly, we assumed a monolithologic environment for bedrock and that any variations observed in the HRR data represented either locally derived alluvium or physical property differences within the Bandelier. These differences may have indicated competent Bandelier (Qbt3), chemically weathered Qbt3, and alluvium derived from Qbt3 and younger units.

The addition of refraction seismics and the increased area of surveying now suggest that at least two units of the Bandelier Tuff, Units 3 and t3, may exist within the site. "One problem is that the sub-units of the Bandelier Tuff are highly variable over short distances [and] Unit 3 is variably welded, being most welded near the top" (S. Baldridge, personal communication). The variably welded nature of the tuff units makes geophysical interpretation difficult because of the increased range of physical properties that may exist within each unit due mostly to differences in moisture content. Resistivity and seismics are both sensitive to bulk density changes. An increase in bulk density generally includes a decrease in moisture content which results in an increase in electrical resistivity. Also, an increase in bulk density generally includes an increase in acoustic velocity. These sympathetic changes in geophysical responses makes it difficult to distinguish between changes in character within a single lithology versus a change in lithology. From the physical property standpoint, electrical properties have a much greater range than acoustic properties which suggests that electrical methods should have an edge in intra-lithologic characterization.

HRR survey results appear to define both the lateral and vertical extent of saturated alluvium and increased moisture content in the Bandelier (within the immediate vicinity of the lines). Where alluvium is interpreted to exist, interpreted depths range from 7 to possibly over 30 feet. We suspect that the greater depths are more likely saturated portions of Bandelier with chemically enhanced porosity. Consequently, we can only offer depth limits for alluvium and not specifically a single, well-defined depth at any particular location. Intuitively, significant thicknesses of alluvium do not seem likely. Depth values are derived from geometrically-constrained, resistivity inversion and are referenced to elevations determined by total station surveying to local control previously established by IT Corporation.

Virtually all locations visited within the canyon show an asymmetry in both geology and vegetation. The north side of the canyon is frequently cliff-like and has minimal vegetation. The south side is frequently a slope and is typically well vegetated. The differences in vegetation are likely related to simple north-facing and south-facing exposures. This is mentioned only for the reason that the presence along the south side of the canyon of extensive root systems, mulching due to dead vegetation, and protection from direct solar heating will tend to create a situation which will be favorable for increased moisture

retention. Such differences in moisture may have an influence on the electrical resistivity data that may not be directly related to lithology.

The following paragraphs describe each individual survey line in detail.

Line 2658 (Line 2 of 1999)

Line 2658 is the most upgradient transverse line surveyed. Based on the relationship of known outcrop and high resistivity values, competent bedrock is interpreted to underlie the length of the line. Both ends of the line terminate in the Qbt3 horizon of the Bandelier on opposite sides of the canyon.

From the north, high resistivity values drop off quickly, nearly mimicking the joint-controlled vertical cliff face on the north side of the drainage. Bedrock is partially exposed at the south end of the line and is interpreted to be very shallow from the south end to approximately station 60. The somewhat localized resistivity high between stations 60 and 140 likely represents more competent Bandelier. There is an interesting lack of persistence to depth of the increased resistivities. We suggest this indicates a thin, welded horizon within the Bandelier that has resisted erosion and chemical weathering, and, has low moisture content.

Between stations 160 and 170 there is a conspicuous and very localized resistivity low. We interpret this feature to represent weak seepage. We believe it is present due to the above-mentioned thin welded horizon acting as an aquitard to downward percolating meteoric water.

North of station 60 there is a distinct decrease in shallow apparent resistivities that were originally thought to represent only saturated alluvium. Subsequent investigations have shown such relatively low values to represent both saturated alluvium and saturated, weathered Bandelier.

At the extreme northerly limit of the line occur the lowest apparent resistivities encountered on the line. Because of their proximity to the exposed cliff face we interpret these low resistivities to represent the presence of increased moisture due to fracture saturation. The responses in this area are undoubtedly complicated by the strong two- and three-dimensional influences of the cliff face and associated joints.

The repetition of the old Line 2 and the new Line 2658 are shown on Figure 2658-R-R. As best as possible, the same electrode locations for the previous line were used for the repeat measurements. The sections show essentially the same characteristics with some differences

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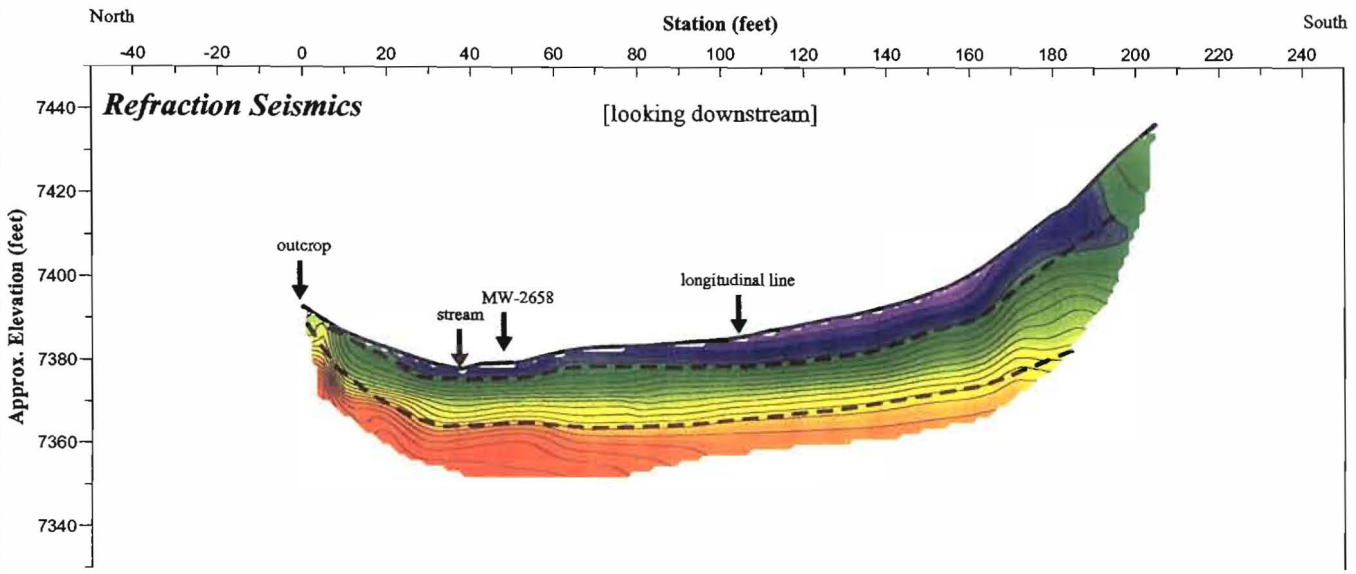
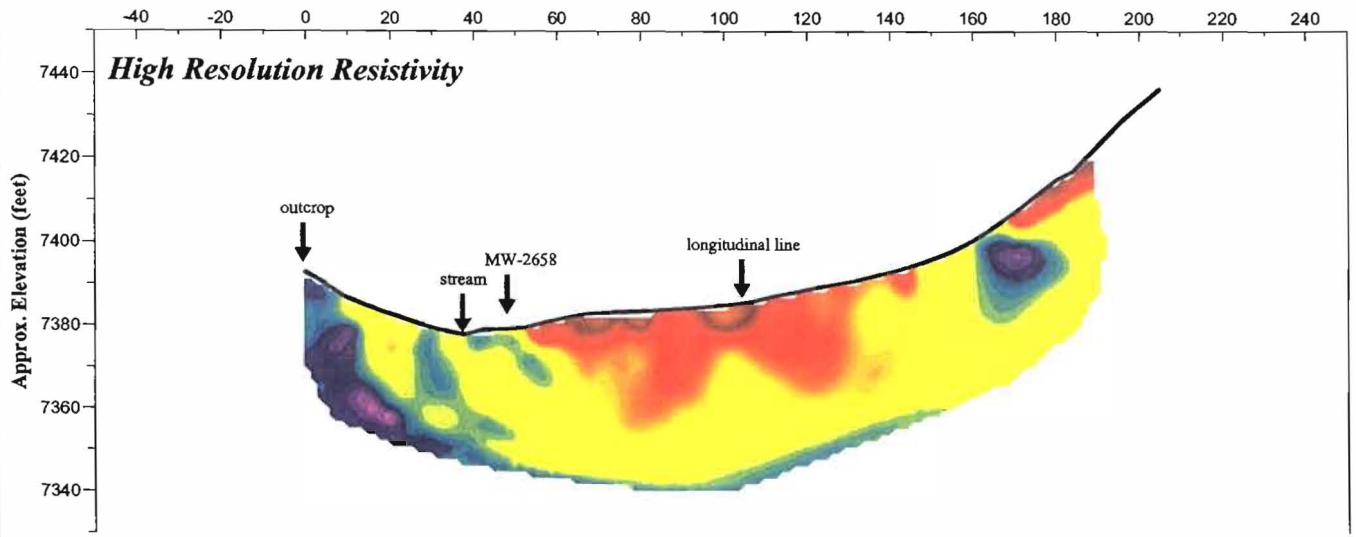
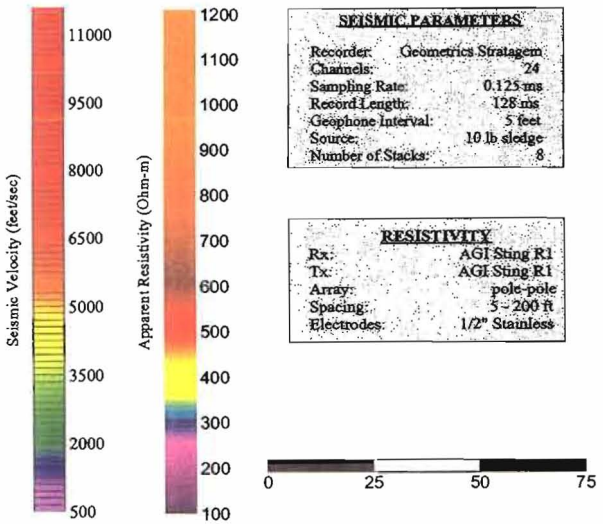
Comparison Sections of High Resolution Resistivity and Seismic Refraction Line 2658







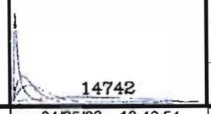
SEISMIC PARAMETERS

Recorder:	Geometrics Stratagem
Channels:	24
Sampling Rate:	0.125 ms
Record Length:	128 ms
Geophone Interval:	5 feet
Source:	10 lb sledge
Number of Stacks:	8

RESISTIVITY

Rx:	AGI Sting R1
Tx:	AGI Sting R1
Array:	pole-pole
Spacing:	5 - 200 ft
Electrodes:	1/2" Stainless

Geophysical Survey



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Date: *Nov 2001* | **Fig.** *2658-R-S*

FILE: 2658-HRR-SEIS. SRF V.7 | 2001-048 | 04/25/02 13:46:54 | 2302 North Forbes Blvd. • Tucson, AZ 85745 • (520) 647-3315

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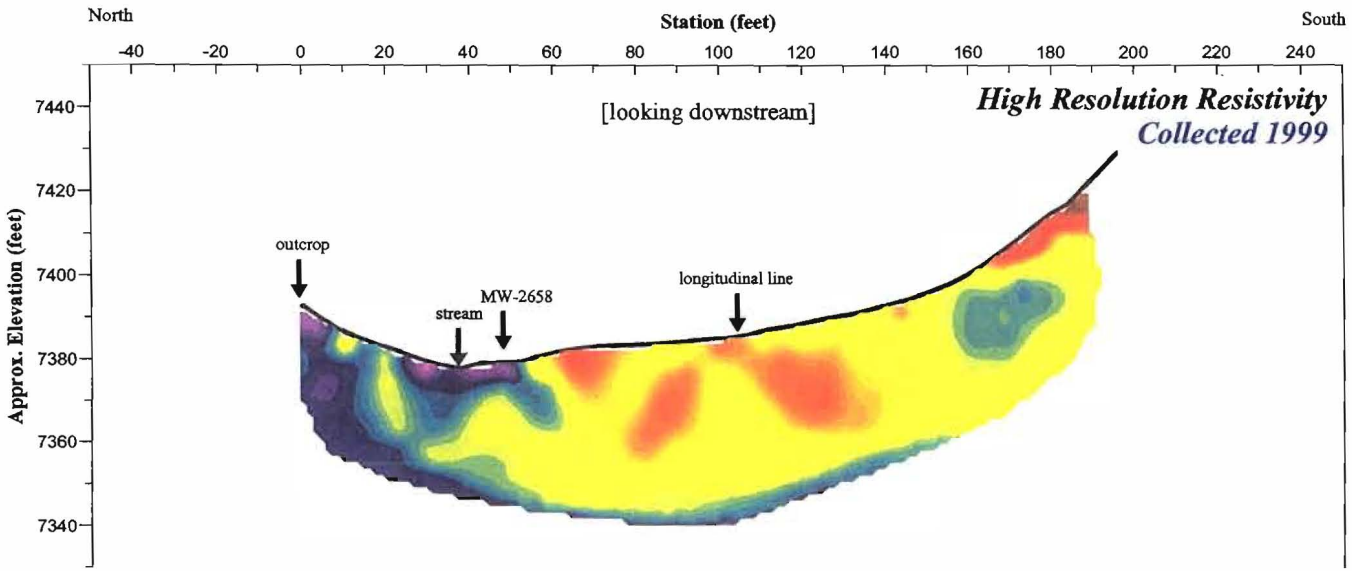
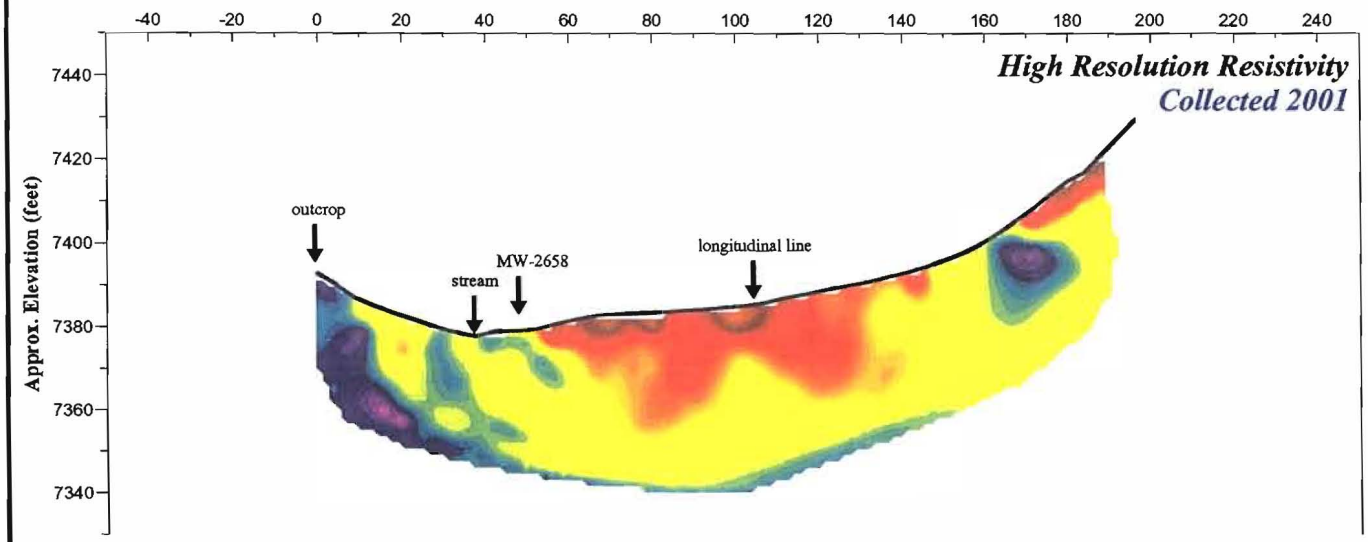
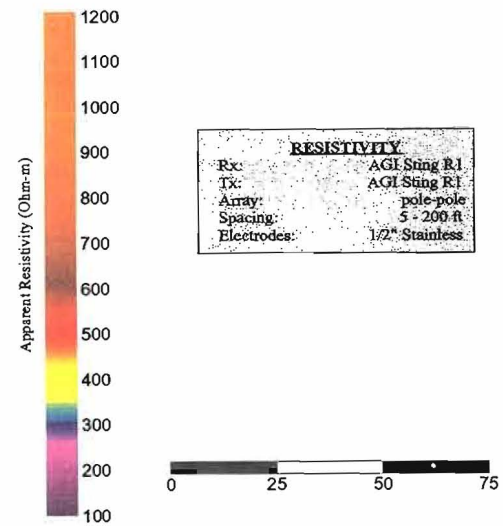
Comparison Sections of High Resolution Resistivity for Years 1999 & 2001 Line 2658







Geophysical Survey

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Los Alamos, NM

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Date: Nov 2001 | Fig. 2658-R-R

FILE: 2658-HRR-HRR. SRF V.7 | 2001-048 | 04/25/02 13:32:31 | 2302 North Forbes Blvd. • Tucson, AZ 85745 • (520) 647-3315

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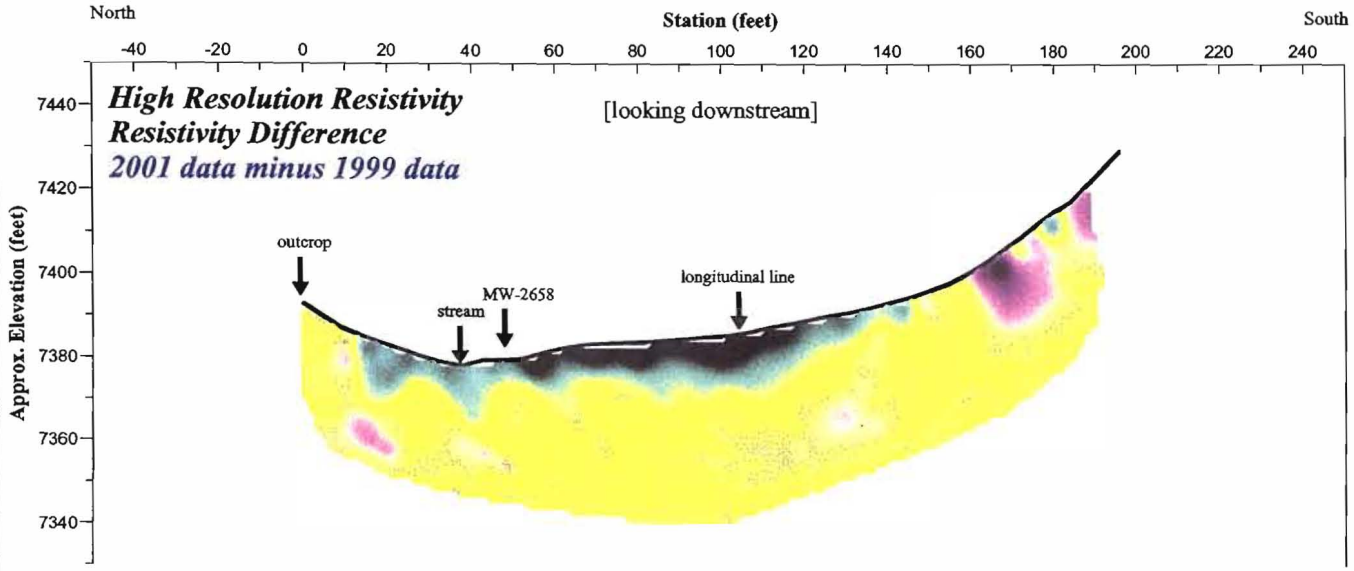
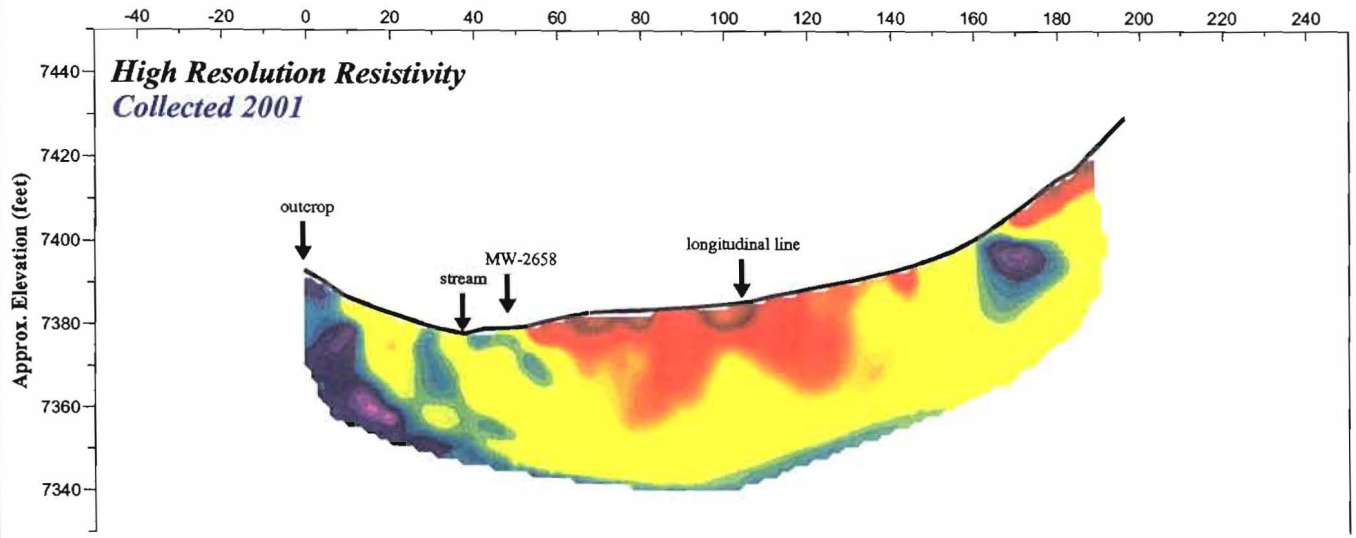
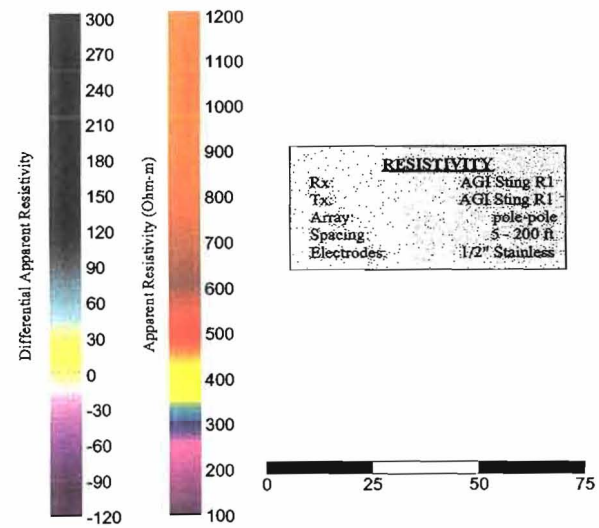
Comparison Sections of High Resolution Resistivity for Years 1999 & 2001 Line 2658







Geophysical Survey

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Los Alamos, NM

Date: *Nov 2001* | **Fig.** *2658-D*

FILE: 2658-HRR-HRR. SRF V.7 | 2001-048 | 04/25/02 13:34:53 | 2302 North Forbes Blvd. • Tucson, AZ 85745 • (520) 647-3315

in values throughout the line. A two-year time difference section is presented in Figure 2658-D. The differences in the repeated data show three areas of interest.

First, the most salient feature is the shallow zone of substantially increased resistivities shown in dark blue. The 2001 resistivities are much higher than those of 1999. Because this is a strictly surficial response, we attribute this change to a lack of precipitation prior to the 2001 measurements and-or the presence of precipitation prior to 1999 measurements.

Secondly, the localized resistivity low at station 170 actually became more conductive in 2001. We attribute this increase in conductivity to an increase in seeped moisture due to time-lagged precipitation. We believe that this change (i.e. an increase in conductivity at a specific location) supports the interpretation of this feature as indicating a seep.

The third difference is a very slight increase in conductivity in the strong low resistivity feature at depth at the north end of the line. As with the above-mentioned seep, we believe that the subtle increase in conductivity in this area also indicates time-lagged precipitation, but with a different transit time compared to the seep. As mentioned, this area is likely structurally controlled and, consequently, will likely have a higher hydraulic conductivity, thereby passing meteoric water more quickly than the porosity-dominated seep.
It is interesting to note that the deep, low resistivities that appear for nearly the entire length of the line show no detectable change in the two-year period. Other changes observed on the repeat section are too subtle to have any significance.

The refraction seismic section shows a three-layer case with velocities increasing with depth. Velocities range from around 300 meters per second (1000 ft/sec) to around 2000 meters per second (6000 ft/sec). The seismic and electrical data show little correlation. The shallow resistive feature has no identifiable signature in the seismic data. Additionally, the localized resistivity features suggestive of increased moisture also have no seismic signature.

The low velocity surface layer tends to thicken to the south with a maximum around station 160 (at the base of the slope). Intuitively, this would appear to be more representative of the anticipated character of the thin veneer of alluvium than the electrical data. ?

The other noteworthy feature of the seismic data is the lateral persistence of the identifiable velocity horizons. No structural offsets or incised erosional features are evident.

Line 2659 (old Line 1)

As was observed on Line 2658 Line, and based on the relationship of known outcrop and high resistivity values, competent bedrock is interpreted to underlie the length of Line 2659. The north end of the line terminates in the Qbt3 horizon of the Bandelier Tuff.

As with Line 2658 there is a relatively high resistivity feature near the center of the line interpreted to represent more competent Bandelier. A noteworthy difference, however, is that Line 2659 shows low resistivity at depth, whereas Line 2658 shows resistivity increasing with depth. Nevertheless, the shallow, higher resistivities are interpreted to represent a welded horizon.

This welded horizon may also be responsible for the localized low resistivity feature occurring at the south end of the line between stations 200 and 220. Again, as with Line 2658, this feature is interpreted to represent a weak seep whose presence is due to the underlying welded horizon.

In the vicinity of the drainage the resistivities are low and likely represent both saturated alluvium and weathered, saturated Bandelier.

The refraction seismic data show a much more interesting character for Line 2659 compared to Line 2658. However, this particular line posed major problems in modeling. We suspect that strong three-dimensional effects influenced the data to such a degree that one-dimensional modeling cannot compensate. Consequently, we discuss the model results here, but we do not have much confidence in the results.

Overall, Line 2659 shows only two velocity layers. The high velocities observed on Line 2658 are, in these model results, missing on Line 2659. One localized area at the south end of Line 2659 shows high velocities, but they are in an area of changing topography and relatively sharp lateral changes in velocity such that they are questionable. Most likely, higher velocities are present in the lithologies of the south cliff (slope) of the canyon, but they are poorly represented in this section.

The south end of the line also shows a much thicker low velocity layer compared to Line 2658. This may be indicated in the resistivity data by the decrease in resistivities already discussed, but again, we are suspicious of the results because of the unusual outcome.

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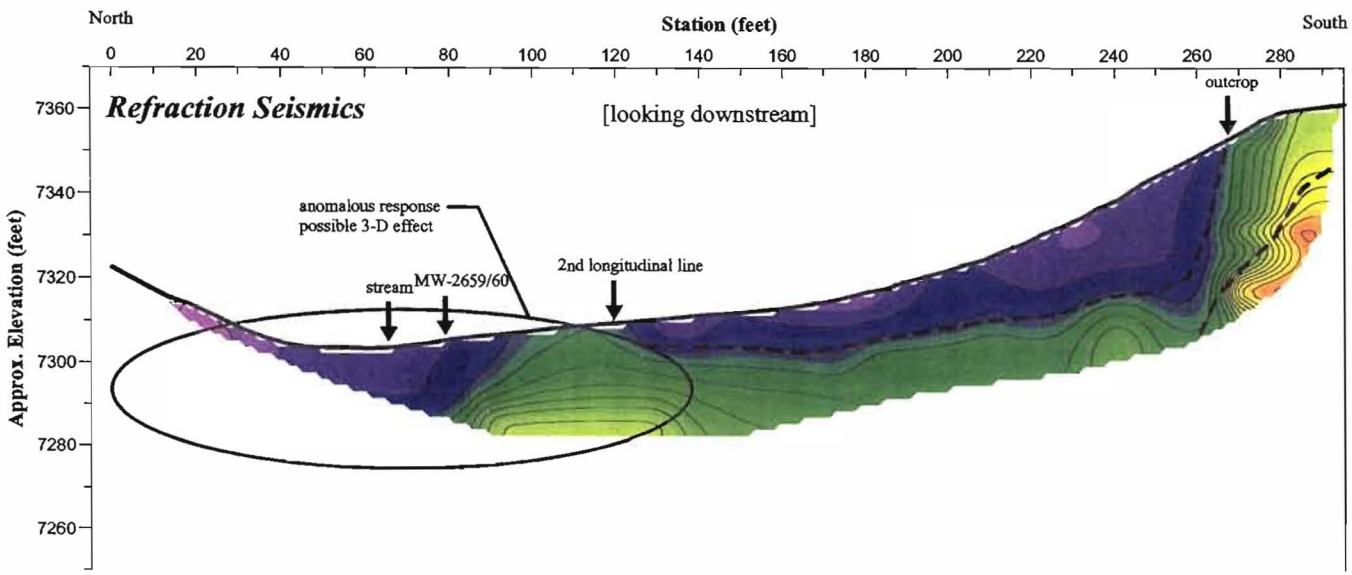
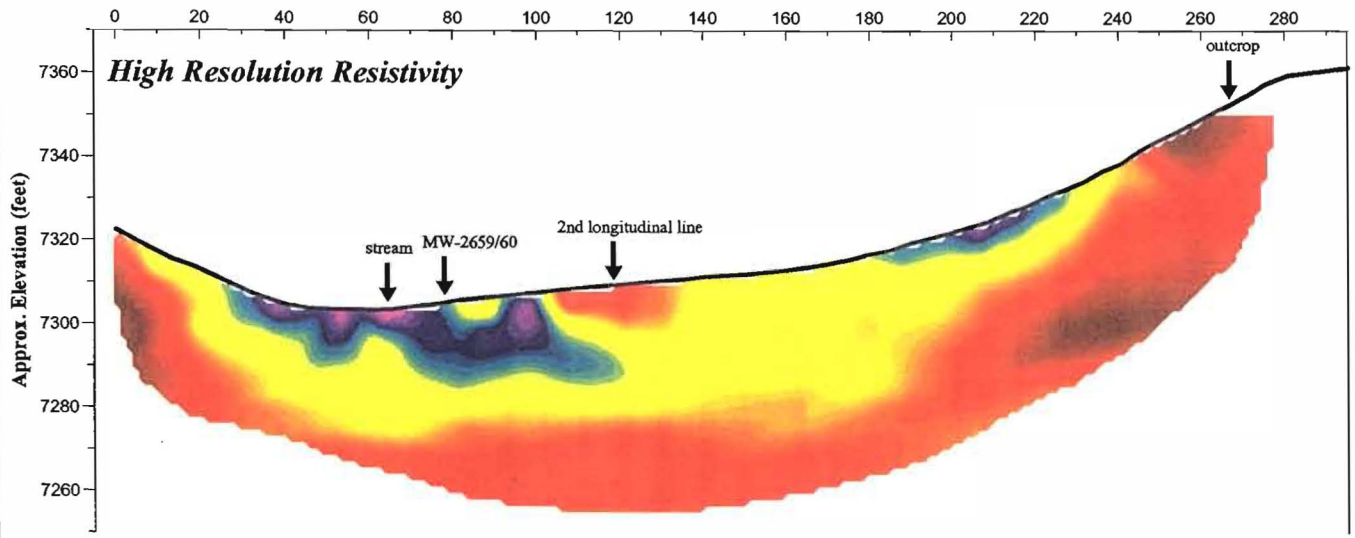
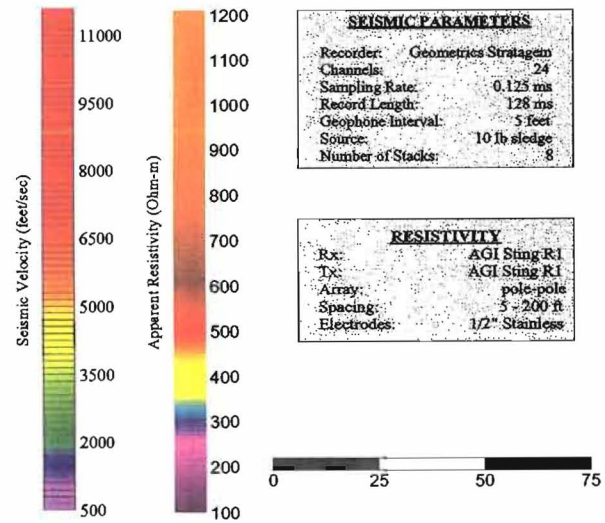
Comparison Sections of High Resolution Resistivity and Seismic Refraction Line 2659







SEISMIC PARAMETERS

Recorder:	Geometrics Stratagem
Channels:	24
Sampling Rate:	0.125 ms
Record Length:	128 ms
Geophone Interval:	5 feet
Source:	10 lb sledge
Number of Stacks:	8

RESISTIVITY

Rx:	AGI Sting R1
Tx:	AGI Sting R1
Array:	pole-pole
Spacing:	5 - 200 ft
Electrodes:	1/2" Stainless

Geophysical Survey

14742

IT Corp / LANL
TA-16 Cañon de Valle
Los Alamos, NM

Date: Nov 2001 | Fig. 2659-R-S

FILE: 2659-HRR-SEIS. SRF V.7 | 2001-048 | 04/25/02 13:49:50 | 2302 North Forbes Blvd. • Tucson, AZ 85745 • (520) 647-3315

Line SP-16

This line is located a considerable distance downstream from the other lines. In a gross sense, it has similar characteristics to those of Lines 2658 and 2659; i.e. a shallow resistive layer, a localized low in the south end, and low resistivities at intermediate depths. The most obvious difference is in the character of those responses.

The surficial high resistivity zone occurs between stations 40 and 180. We interpret this zone to represent a welded unit, although, the surface soil at the time of the survey was extremely dessicated and could be responsible for the resistive appearance. It appears to be very thin and is immediately underlain by a weak low resistivity zone that should represent an increase in moisture. This increase in moisture should also occur within the Bandelier, which outcrops north of station 40, but probably does not represent subsurface flow. There was no surface flow at the time of either survey. Indeed, in the immediate vicinity of the drainage there is only a weakly defined conductive feature compared to the two upstream lines. Because of the presence of outcrop in the extreme northern end of the line electrode emplacement was difficult and actually prevented extension of the line farther to the north.

The localized low resistivity zone to the south is much larger on Line SP-16 than on either of the other two lines. As with the two other lines, we interpret this low to represent seepage along the top of a welded unit within the Bandelier. A stepped character to the north side of the low resistivity zone may indicate faulting. There is even a weaker, but somewhat sympathetic response in the seismic data.

1st Longitudinal Line

The 1st Longitudinal Line extends from the vicinity of Burning Ground Spring to around 100 feet downstream from the east end of the MDA-P site. The 1st Longitudinal Line is presented in Figure Long 1-R and is labeled "Longitudinal Line 1". The line may be separated into two segments based on the general similarity in the character of responses. The upstream portion would consist of the stretch from the beginning of the line to approximately station 850 (about halfway between MW-2658 and SP-9). The downstream portion of the line would consist of the stretch between station 850 and the east end of the MDA-P (around station 1600. With the information presently available we cannot determine if the difference in electrical response between these two stretches is due to primary lithologic differences within the Bandelier or subsequent weathering, erosion, and structural influences.

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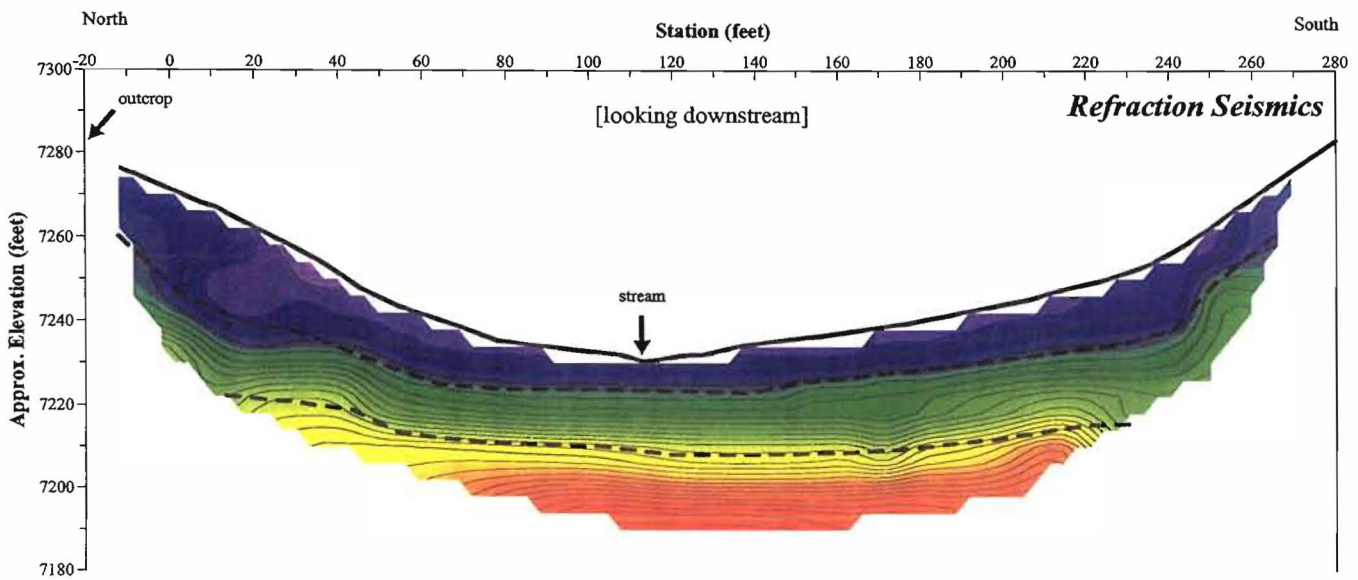
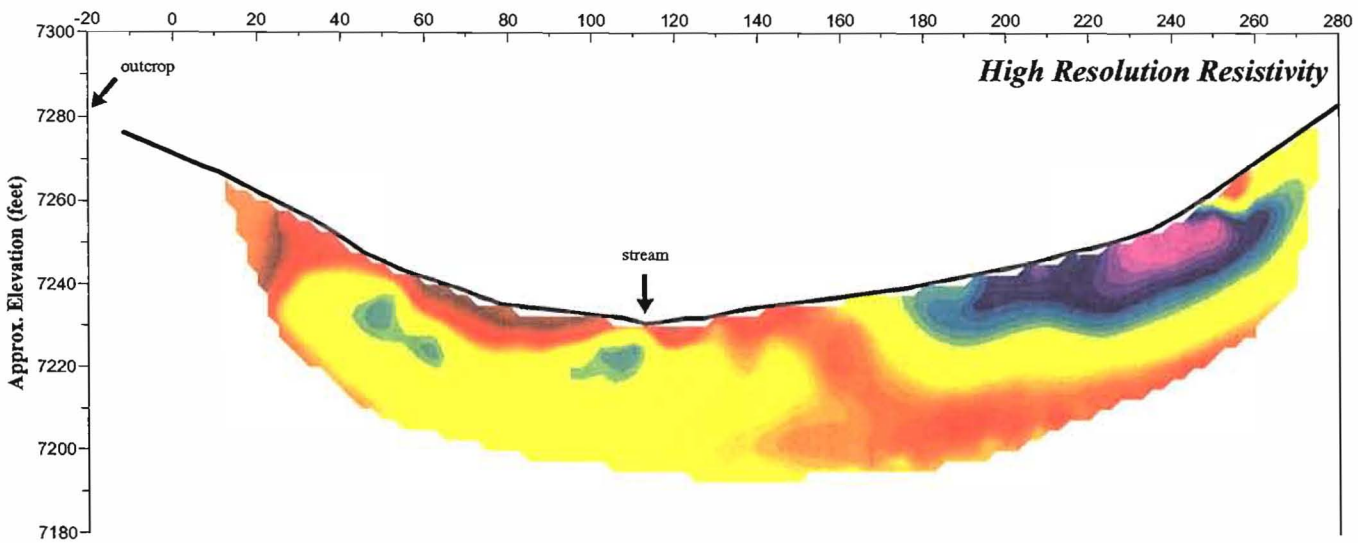
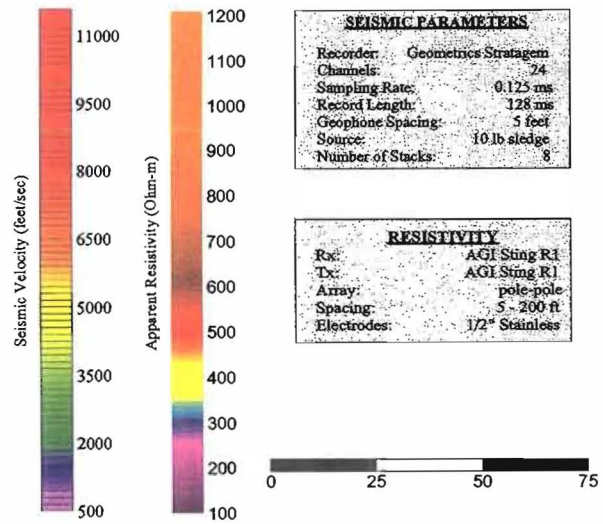
Comparison Sections of High Resolution Resistivity and Seismic Refraction Line SP-16







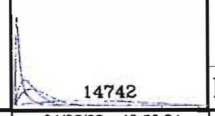
SEISMIC PARAMETERS

Recorder:	Geometrics Stratagem
Channels:	24
Sampling Rate:	0.125 ms
Record Length:	128 ms
Geophone Spacing:	5 feet
Source:	10 lb sledge
Number of Stacks:	8

RESISTIVITY

Rx:	AGI Sting R1
Tx:	AGI Sting R1
Array:	pole-pole
Spacing:	5 - 200 ft
Electrodes:	1/2" Stainless

Geophysical Survey



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Los Alamos, NM

Date: *Nov 2001* | Fig. *SP16-R-S*

FILE: SP-16-HRR-SEIS. SRF V.7 | 2001-048 | 04/25/02 13:50:34

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At any rate, the upstream stretch of the line is characterized by a three-layered earth appearance. The near-surface responses are more resistive and the deepest responses more conductive than the middle layer. We interpret the middle layer, which ranges in apparent resistivity from 350 to 450 ohmmeters, to be representative of the "normal" or "background" Bandelier. Variations against this background are items of interest and comprise this discussion.

The thin, surficial resistive layer apparently consists of a combination of relatively dry alluvium and more competent Bandelier, perhaps due to welding. In either case, this thin zone contains less moisture than the background Bandelier. From one-dimensional modeling, an *average* thickness of this surficial layer is 1.5 meters (about 5 feet) assuming a true layer resistivity of 1000 ohmmeters and a background true resistivity of 400 ohmmeters. An interesting observation in the thin surficial zone is the undulating character of the bottom of the zone. We propose that the shallow est areas (where the yellow peaks occur) may represent jointing within the Bandelier. The implication is that the joints would have a slight increase in moisture content and therefore a slightly lower resistivity. Possibly the indentations indicated in the topography along the south canyon wall may be related. Some trenching along one or two of these might prove interesting. These might also be detectable with a shallow EM system, such as a Geonics EM-38, a Geophex GEM-2, or a Geonics EM-31. In any case, the response would be very weak in an EM system, but, with proper loop geometry these features might be detected and mapped inexpensively. The HRR results offer well-defined locations to be tested.

A very interesting observation is made at Burning Ground Spring. The HRR line crosses the surface flow from the spring and actually has two electrodes placed in the flowing water. The surface flow is indicated by the very-localized, low-resistivity feature immediately beneath the pointer on Figure Long 1-R (located between stations 50 and 100). What is of greater interest is the localized resistivity low located down and to the east of the surface flow. We interpret this feature to possibly represent sub-surface flow, or at least a higher degree of saturation within the background Bandelier as a direct result of the presence of the spring-flow. This is rather conclusive evidence that infiltration into the Bandelier takes place on a localized basis and is, obviously, controlled by the source (as opposed to wide areas of equal saturation as in granular-flow aquifers). This further suggests that these localized zones of increased saturation may be readily mapped geophysically.

Another shallow conductive feature occurs at Stream Profile Number 8 (SP-8). The source of this response is unknown, but it may also be a joint that is saturated and has a larger aperture than the previously proposed joints.

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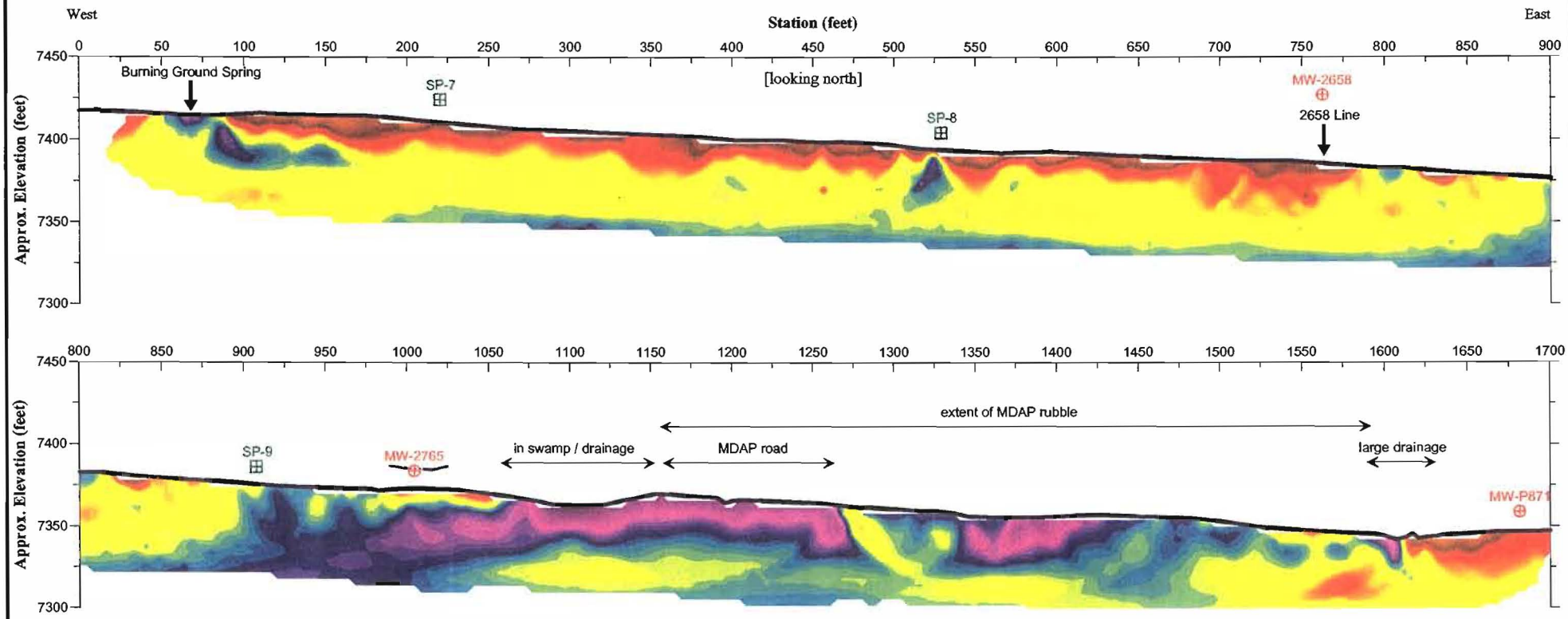
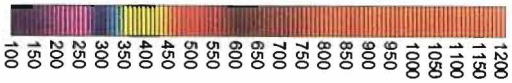
High Resolution Resistivity
1st Longitudinal Line



Apparent Resistivity (Ohm-m)



RESISTIVITY	
Rx:	AGI Sting R1/R8
Tx:	AGI Sting R1/R8
Array:	pole-pole
Spacing:	5 - 400 ft
Electrodes:	1/2" Stainless

0 25 50 75 100 125

Geophysical Survey

14742

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TA-16 Cañon de Valle
Los Alamos, NM

Date: *Nov 2001* **Fig.** *Long1-R*

FILE: 2001-LONGITUDINAL-LINE-BOTH-SPREADS.SRF | 2001-048 | 04/25/02 13:57:27 | 2302 North Forbes Blvd. • Tucson, AZ 85745 • (520) 647-3315

The relatively-conductive deeper data are suggestive of a reasonably uniform increase in moisture content at depth, i.e. approximately 50 feet or greater. This relatively conductive response persists for nearly the entire length of the 1st Longitudinal Line, but it is entirely absent in the 2nd Longitudinal Line.

The most salient feature of the entire HRR survey occurs on the lower stretch of the 1st Longitudinal Line. It is the relatively conductive feature (shown in purple) that has a surface expression in the canyon beneath MDA-P. What is most intriguing is the fact that this conductive response has a very gentle downward dip in the up-gradient direction of the canyon. We interpret this response to represent an area or zone of elevated TDS that is sourced at MDA-P. We see little evidence in the HRR data of increased conductivities down gradient in the canyon from MDA-P.

No transverse HRR line crosses this zone within the stretch where it is evident in the longitudinal line. Consequently, the width of this zone is unknown. However, the fact that it appears to be equally detectable nearly 200 feet up-stream from MDA-P suggests it has substantial width (relative to the HRR survey parameters), perhaps up to fifty feet. We don't believe that it is following a single joint or fracture, although we cannot exclude that possibility.

Certainly, we would like to see at least two transverse HRR lines across this feature. Additionally, it would be interesting to determine if this zone had a EM response with any of the aforementioned EM systems.

2nd Longitudinal Line

The 2nd Longitudinal Line is shown in Figure Long 2-R. It has a more consistent response character for the length of the line compared to the 1st Longitudinal Line. However, the response is so different from the 1st Longitudinal Line that it might as well have been run in a different canyon. It is difficult to believe that these two lines are from the same canyon, let alone that they are contiguous.

The 2nd Longitudinal Line also shows a three-layered earth character, but the resistivity relationships between the layers is different from the 1st Longitudinal Line. In this instance, there is a thin resistive surficial layer that is discontinuous along the line. It overlies a more conductive zone that is also discontinuous along the line. These two discontinuous "layers" overlie a third, resistive layer that is continuous for the length of the line.

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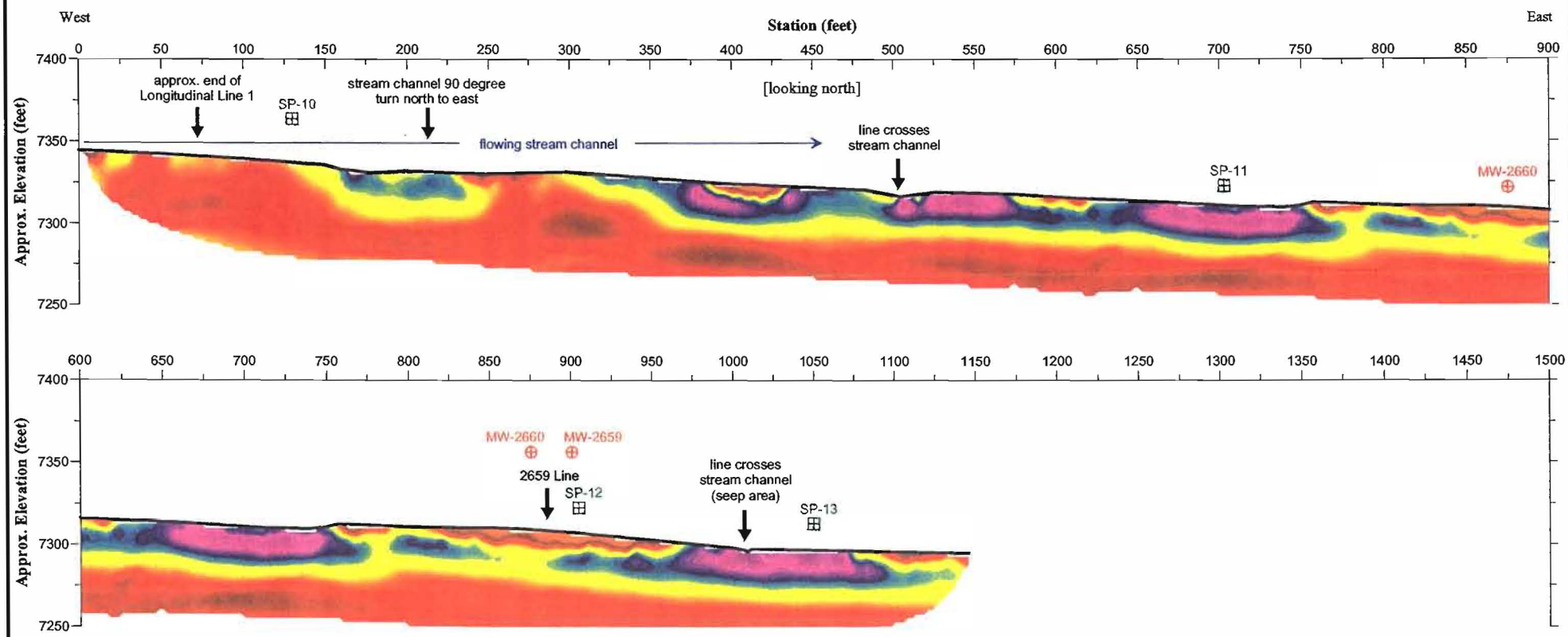
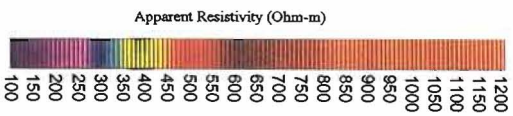
High Resolution Resistivity
2nd Longitudinal Line





RESISTIVITY

Rx:	AGI Sting R1
Tx:	AGI Sting R1
Array:	pole-pole
Spacing:	5 - 400 ft
Electrodes:	1/2" Stainless

0 25 50 75 100 125

Geophysical Survey

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TA-16 Cañon de Valle
Los Alamos, NM

Date: Nov 2001 | **Fig. Long2-R**

FILE: 2001-2ND-LONGITUDINAL.SRF | 2001-048 | 04/25/02 13:59:14 | 2302 North Forbes Blvd. • Tucson, AZ 85745 • (520) 647-3315

At the two locations where the line crosses the drainage channel the resistive surficial "layer" disappears and the "second" relatively conductive second layer appears to be exposed to the surface. This is pretty good evidence that much of the second relatively conductive "layer" is likely caused by lateral infiltration into the near-surface weathered Bandelier and alluvium. Additionally, according to the line location on the plan map (Figure L-1) there is a relatively good relationship between the more conductive zones and proximity to the channel. This type of relationship is not seen on the 1st Longitudinal Line.

This second "layer" or zone of increased moisture content appears to be no greater than fifty feet thick. There is no evidence in the HRR section of any area or zone where the surface flow is accessing deeper horizons with any significant volume, as is evident upstream from MDA-P in the 1st Longitudinal Line. A few transverse HRR lines in the vicinity of the conductive zones might prove interesting in the ability to map the width of the zone of increased moisture (i.e. cross-sectional area).

Line 2659 is a transverse line but it crosses the canyon in a location where the second, relatively conductive layer is only weakly indicated. However, the combination of the two lines tends to confirm that the discontinuous conductive and resistive zones are, indeed, localized and don't necessarily extend for great distances along the canyon axis. This further suggests that multiple lines of HRR in select areas used to delineate more completely these zones may indicate other sources for the moisture besides the main channel.

4.0 SUMMARY

The HRR and refraction seismic surveys were particularly successful. The detection and partial mapping of the conductive zone near MDA-P was a surprise and will, hopefully, help direct future remediation efforts.

The efficacy of the HRR method is very good. Although only single lines were surveyed, the few instances where transverse lines were run showed good correlation and offer the promise of the ability to delineate any shallow, slightly conductive zone desired.

The temporal changes observed in the single line that was repeated from two years ago show large changes that both indicate a decrease in moisture associated with the drainage and an increase in moisture related to a seep. This clearly indicates the potential benefit of a permanent installation.

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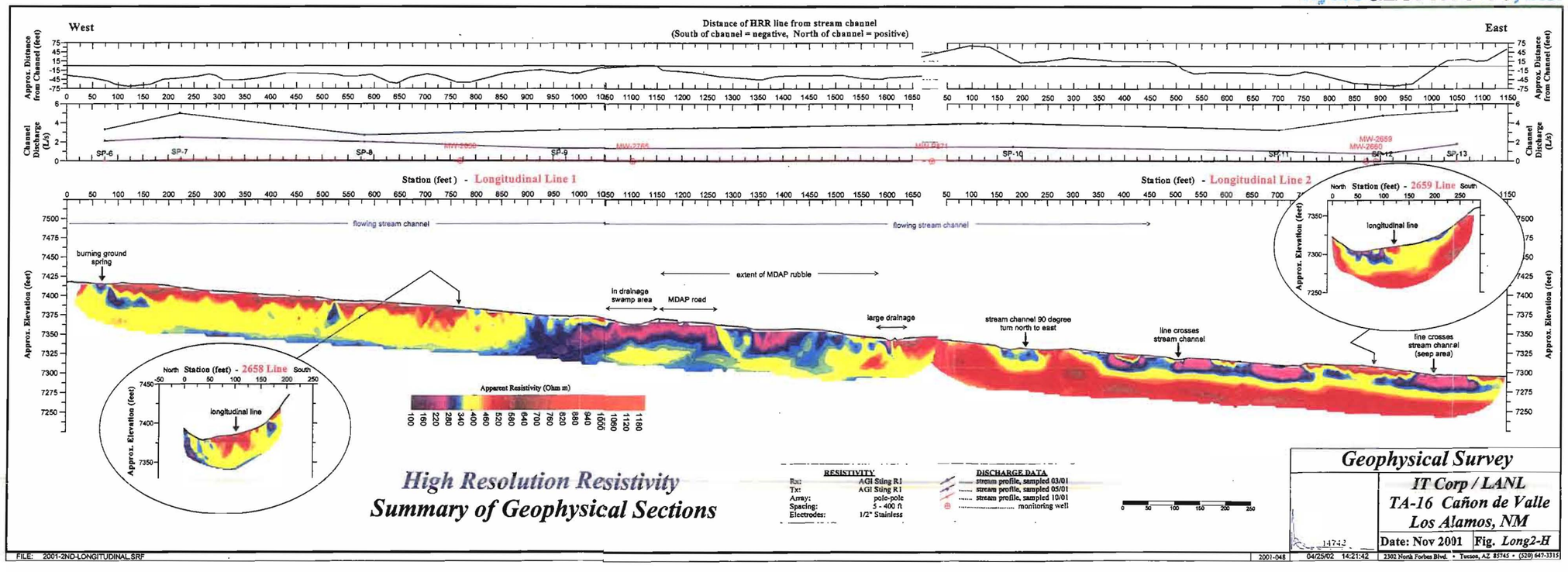


So far, we have identified three unique areas based on their electrical signatures in the HRR data; 1. the upper stretch of the 1st Longitudinal Line, 2. the lower stretch of the 1st Longitudinal Line, and 3. the entire length of the 2nd Longitudinal Line. Although these three stretches of the canyon differ in electrical characteristics, the question of why remains unanswered.

The refraction seismics proved to be a weaker method, in this instance. Generally, refraction data are more accurate and offer higher resolution for the quantitative data produced during modeling. It seems that the thickness of alluvium in the canyon is so small that the refraction method, as it was applied, is of limited use. Additionally, where a suitable thickness of alluvium was encountered the velocity contrast between the alluvium and underlying weathered Bandelier did not produce a well-defined interface in the data.

5.0 RECOMMENDATIONS

We recommend some follow-up augering or trenching along the conductive feature associated with MDA-P. It would be beneficial to confirm, through chemistry, the source of the increased conductivity.

We recommend multiple permanent installations for HRR. Such installations would help resolve and monitor two particular items: 1. temporal changes in the volume of shallow sub-flow at various locations the drainage as demonstrated by the repeat data on Line 2568, and 2. with proper location, temporal changes in flow from critical seeps.

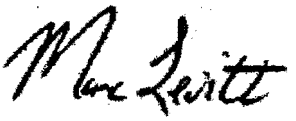
We recommend potential mapping of the known springs to determine both their source and discharge paths.

We recommend some test work be performed using a variety of EM instruments to see if the proposed joints can be detected and mapped. For these instruments to produce the most beneficial results, some careful planning should be done prior to data acquisition. In particular, the grids should be properly tied to the existing HRR stations, and, data density should be maximized (preferably time-based) to best resolve the lateral locations of interesting responses. Survey lines should also be oriented orthogonal to the strike of the features, which, in general, appears to parallel the axis of the canyon. Pre-survey line brushing would more easily allow time-based (higher resolution) surveying.

We also persist in suggesting that more magnetic surveying be done to see if the responses seen in 1999 might lead to more diagnostic features that would help unravel the subtle differences within the Bandelier in Cañon de Valle. Magnetic surveying can done easily and is very affordable for large areas to be covered. The canyon would pose its own problems, but, magnetics might prove useful because of the possible relationship between increased magnetic susceptibility and the more permeable(?) horizon presumably associated with it. Allen Cogbill indicated that he had a Geometrics G-858 cesium-vapor magnetometer available. A second sensor will be required for the magnetometer to operate in gradiometer mode, but may have to be rented separately. A suitable base station should be used if such magnetic surveying is to be done. These data should also be acquired in conjunction with any EM work.

The interpretations presented herein are based on the information presently available and may change substantially with additional information.

Respectfully submitted,



James B. Fink, Ph.D., P.E. (geophysical), R.L.S.
President

Marc T. Levitt
Project Engineer

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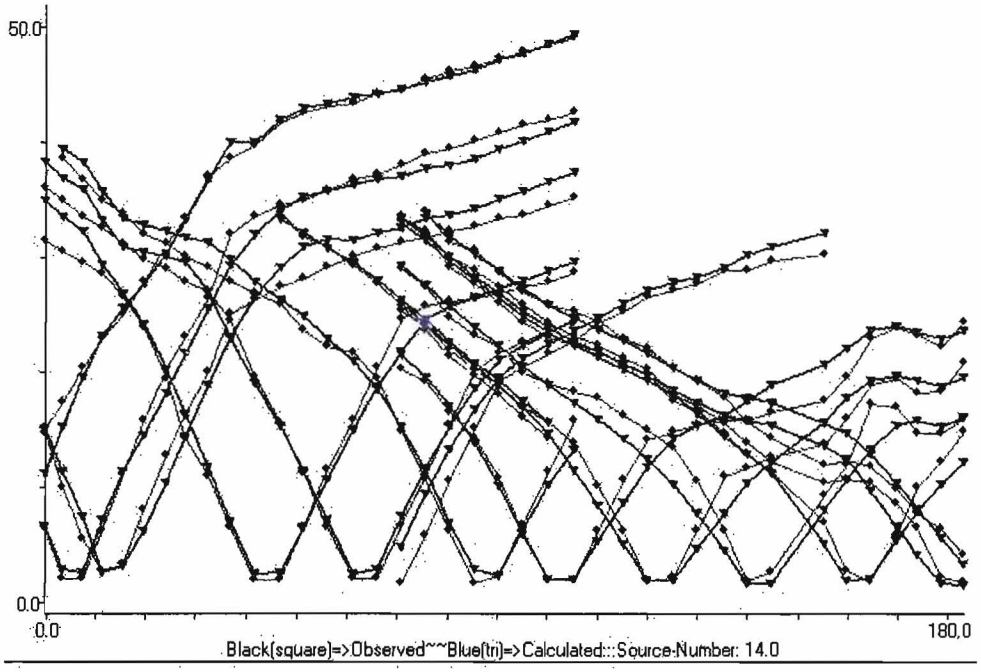
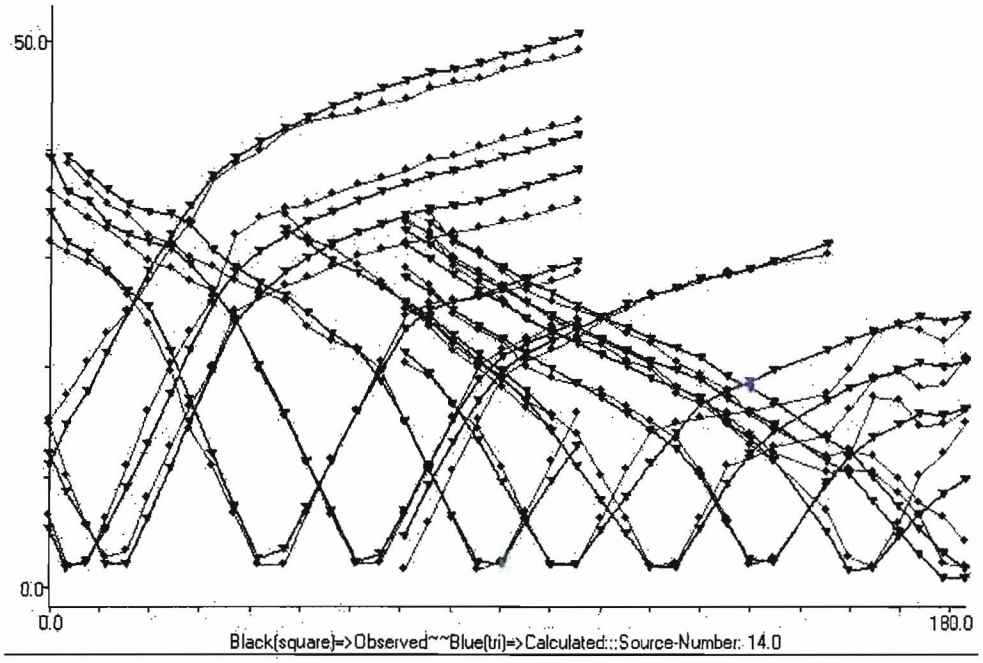
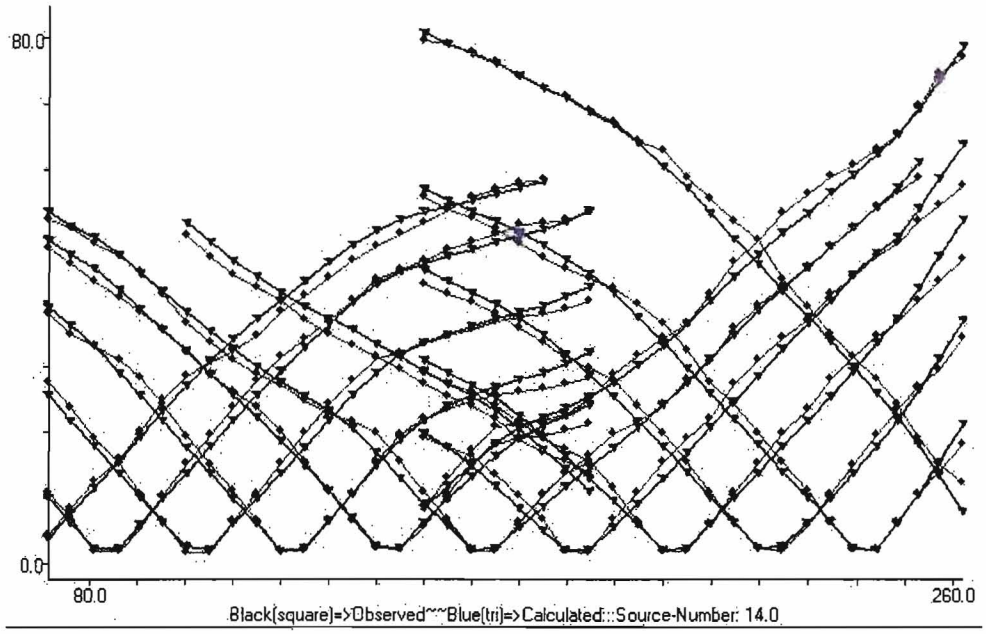
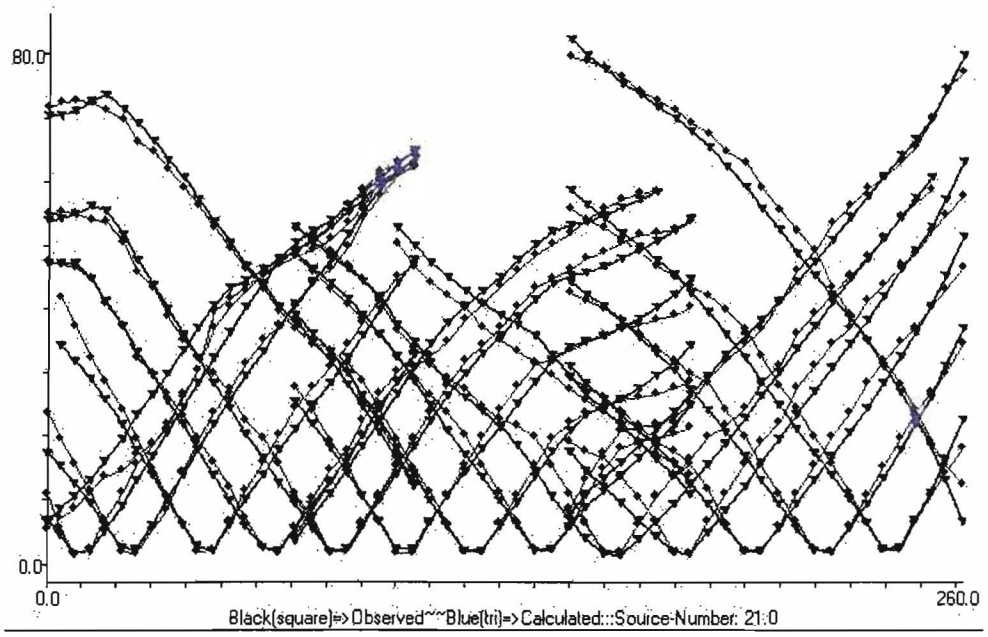


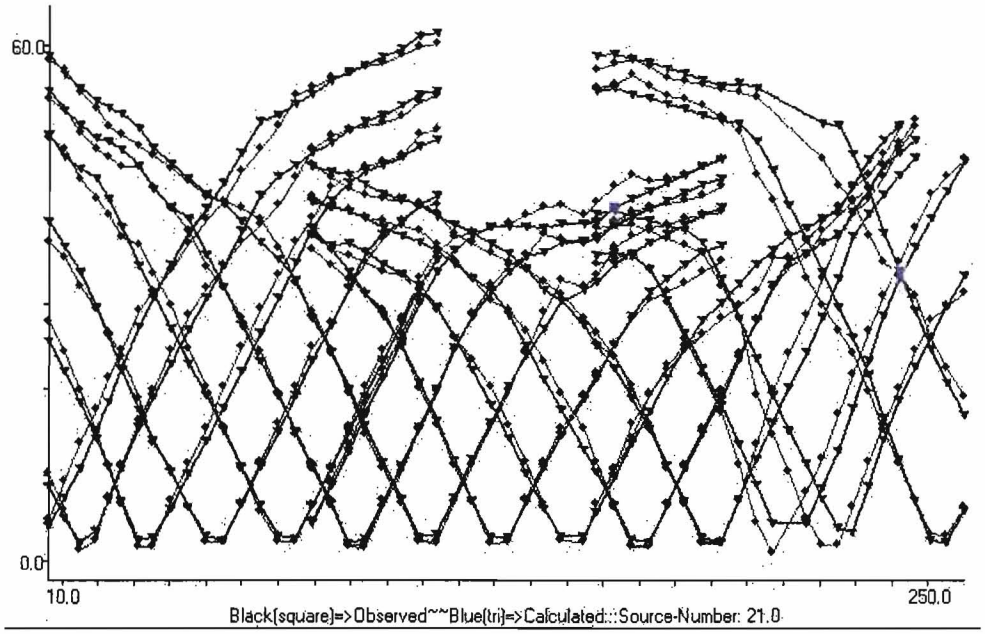


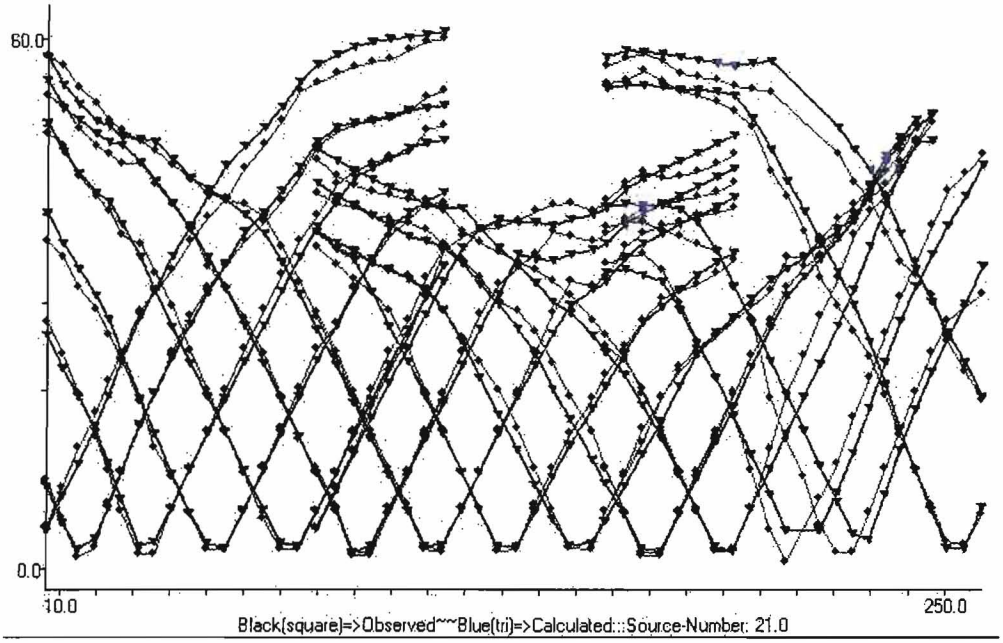
Time Distance Plots for Line 2658
[showing two selected model resolutions]





Time Distance Plots for Line 2659
[showing two selected model resolutions]





Time Distance Plots for Line SP-16
[showing two selected model resolutions]