TR-16

Department of Energy

National Nuclear Security Administration
Los Alamos Site Office
Los Alamos, New Mexico 87544

MAY 11 2004

CERTIFIED MAIL/RETURN RECEIPT

Mr. John Young
NMED-Hazardous Waste Bureau
2905 Rodeo Park Drive East,
Building 1
Santa Fe, NM 87505-6333

Dear Mr. Young:

Subject: Completion Report for Intermediate Well CdV-16-1(i)

Enclosed are two copies of the Completion Report for Intermediate Well CdV-16-1(i), which was completed by the Department of Energy. If you have any questions regarding this matter, please contact Don Hickmott at (505) 667-8753 or Tom Whitacre at (505) 665-5042.

Mat Johansen
Groundwater Program Manager

OPM:5TW-010

Enclosure

cc w/o enclosure:
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TA -16

FINAL
WELL CdV-16-1(i) COMPLETION REPORT
LOS ALAMOS NATIONAL LABORATORY
LOS ALAMOS, NEW MEXICO
PROJECT NO. 37151/9.12

Prepared for:

The United States Department of Energy and the
National Nuclear Security Administration through the
United States Army Corps of Engineers
Sacramento District

Prepared by:

KLEINFELDER
8300 Jefferson NE, Suite B
Albuquerque, New Mexico 87113

May 7, 2004

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LIST OF ACRONYMS AND ABBREVIATIONS

AITH	array induction tool, version H
ASTM	American Society for Testing and Materials
bgs	below ground surface
°C	degrees Celsius
CD	compact disc
CMR™	Combinable Magnetic Resonance
CMS	Corrective Measures Study
CNTG	compensated neutron tool, model G
CQMP	Contractor Quality Management Program
DOE	Department of Energy
DP	Drilling Plan
DTH	down-the-hole
DTW	depth to water
DVD	digital video disc
ECS	Elemental Capture Spectroscopy
EES	Earth and Environmental Sciences
EnviroWorks	EnviroWorks, Inc.
EPA	Environmental Protection Agency
ESA	Engineering Science and Applications
FMI	formation microimager
ft	feet
ft^3	cubic feet
g	grams
g/cc	grams per cubic centimeter
gal	gallon
GEL	General Engineering Laboratories
gpd	gallons per day
gpm	gallons per minute
GPS	global positioning system
HE	high explosives
HSA	hollow-stem auger
IC	ion chromatography
ICPES	inductively coupled (argon) plasma emission spectroscopy
ICPMS	inductively coupled (argon) plasma mass spectrometry
ID	inner diameter
in	inches
IRMS	isotope ratio mass spectrometry
KA	Kleinfelder, Inc.
KBr	potassium bromide
LANL	Los Alamos National Laboratory
LC/MS/MS	liquid chromatrography/mass spectrometry/mass spectrometry
MDL	Method Detection Limit
mil	1/1000th of an inch
NAD	North American Datum
NGS	natural gamma spectroscopy

NGVD	National Geodetic Vertical Datum
NMED	New Mexico Environment Department
NOI	Notice of Intent
NTU	nephelometric turbidity unit
OD	outer diameter
PMP	Project Management Plan
ppk	parts per thousand
ppm	parts per million
PRS	Potential Release Site
psi	pounds per square inch
PVC	polyvinyl chloride
QL	quantitation limit
RL	reporting limit
SSHASP	Site-Specific Health and Safety Plan
TD	total depth
TLD	triple detector lithodensity
TOC	Total Organic Carbon
USACE	United States Army Corps of Engineers
µg/L	micrograms per liter
µS/cm	microsiemens per centimeter
WDC	WDC Exploration & Wells

ABSTRACT

Well CdV-16-1(i) is located in Cañon de Valle, within Technical Area 16 (TA-16) of Los Alamos National Laboratory (the Laboratory, or LANL). This well is being installed by the Department of Energy (DOE) as part of the Addendum to the Corrective Measures Study (CMS) Plan for Potential Release Site (PRS) 16-021(c) Revision 1 (LA-UR-02-7366, 2003). This well will be used to identify potential contamination in aquifers that may be associated with effluents containing high explosives (HE) discharged from TA-16 and possibly other nearby sites.

The data obtained from drilling this well will be used with similar data from other wells in the area to improve the conceptual model for geology, hydrogeology, and hydrochemistry in this area, as well as provide constraints on numerical models that address contaminant migration in the vadose (unsaturated) zone and the regional aquifer.

Phase I of the drilling was conducted from October 6 to October 20, 2003. During this phase a corehole was drilled to collect continuous core for geochemical analysis and contaminant profiling, as well as identification of significant perched water zones. Continuous core was collected from the surface to a depth of 200 feet (ft) below ground surface (bgs). A perched water zone was identified during drilling at 50 ft to 80 ft bgs, and a temporary piezometer was installed to monitor water levels and water quality.

Phase II of the drilling was conducted from October 31 to November 12, 2003. During this phase, the borehole was drilled using air and fluid-assisted air-rotary methods to a total depth of 683 ft bgs. Samples of drill cuttings were collected at regular intervals for stratigraphic, petrographic, and geochemical analysis. The stratigraphy encountered during borehole drilling included, in descending order, alluvium, ash-flow tuffs of the Tshirege Member of the Bandelier Tuff, Cerro Toledo interval, and ash-flow tuffs of the Otowi Member of the Bandelier Tuff. The CdV-16-1(i) well was installed in a perched zone with a screen interval from 624 ft to 634 ft bgs. A groundwater screening sample was collected at a depth of 595 ft to 600 ft bgs during Phase II drilling. An additional groundwater sample was collected from the screen interval after well development. Groundwater samples were submitted to LANL for analysis. Following well development, a constant rate-pumping test was conducted at Well CdV-16-1(i) to determine aquifer properties.

1.0 INTRODUCTION

This completion report summarizes the drilling, well construction, well development, and related activities conducted from September 25, 2003 through spring 2004 for Well CdV-16-1(i). CdV-16-1(i) was drilled and installed for Los Alamos National Laboratory's (LANL) Groundwater Protection Program as part of the Addendum to the Corrective Measures Study (CMS) Plan for Potential Release Site (PRS) 16-021(c) Revision 1 (LA-UR-02-7366, 2003). The CdV-16-1(i) investigation was funded and directed by the Department of Energy (DOE). Kleinfelder, Inc. (KA), under contract to the US Army Corps of Engineers (USACE), was responsible for executing the drilling, installation, testing, and sampling activities with technical assistance from LANL.

The information presented in this report was compiled from field reports and activity summaries generated by KA, LANL, and subcontractor personnel. All original source documents are on file in the KA Albuquerque office. Results of the field activities are discussed briefly and shown in tables and figures contained in this report. Detailed analysis and interpretation of geologic, geochemical, and hydrologic data will be included in separate technical documents prepared by LANL.

CdV-16-1(i) is located in Technical Area (TA-16) in Cañon de Valle, as shown in Figure 1.0-1. This well was installed to identify any contamination in deep perched groundwater that may have been impacted by high explosives (HE) released to the canyon as effluent discharged from TA-16 and possibly other nearby sites.

Data from CdV-16-1(i) will be evaluated in conjunction with data from other area wells to form the technical basis for the design of a groundwater monitoring system, if needed. Water quality, geochemical, hydrologic, and geologic information obtained from CdV-16-1(i) will augment existing knowledge of regional subsurface characteristics and distribution of contaminants downgradient of potential release sites.

2.0 PRELIMINARY ACTIVITIES

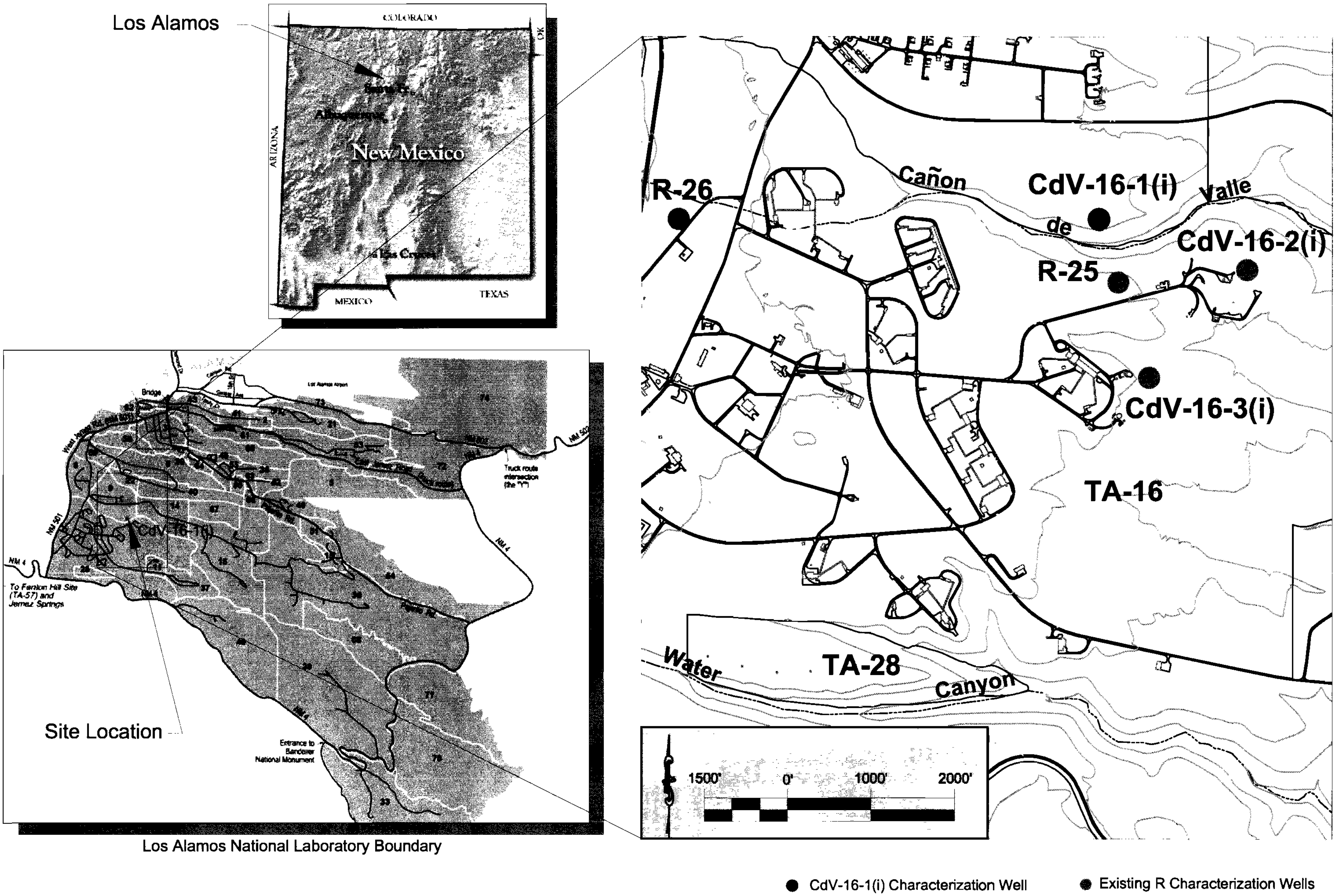
Preliminary activities at CdV-16-1(i) included administrative and site preparation.

2.1 Administrative Preparation

KA received contractual authorization to start administrative preparation tasks in the form of a notice to proceed on July 11, 2003. As part of this preparation, KA developed a Project Management Plan (PMP), a Contractor's Quality Management Program (CQMP), a Security Plan, a Site-Specific Health and Safety Plan (SSHASP) and a Drilling Plan (DP) for the work at CdV-16-1(i). The LANL host facility was Engineering Sciences and Applications (ESA). Necessary permits and access agreements were obtained prior to beginning fieldwork.

2.2 Site Preparation

EnviroWorks, Inc. (EnviroWorks) was subcontracted by KA to conduct site preparation. Activities included site clearing, access road improvement, construction of the drill pad, and construction of a lined borehole-cuttings containment area. Site preparation was begun on September 25, 2003 and completed on October 10, 2003.



Note: CdV-16-1(i) Well Identification Modified from Proposed R Characterization Well Location Map Provided by Los Alamos National Laboratory

KLEINFELDER		SITE LOCATION MAP Well CdV-16-1(i) LANL Well Program Los Alamos National Laboratory Los Alamos, New Mexico	FIGURE 1.0-1
Drawn By: C. Landon	Date: March 2004		
Project No.: 37151	Filename: FIGURE 1.0-1		
Scale: 1" = 2000'	Revision: 0		

Site preparation began with improvements to an existing access road and pad construction. The CdV-16-1(i) drill pad was cleared of vegetation and graded with a front-end loader. A primary layer of base-course gravel was distributed over the drill pad, equipment storage area and on the access road, as necessary. Drill pad construction was completed with an additional graded layer of base-course gravel. To store CdV-16-1(i) drilling fluids and borehole cuttings, a 20 ft wide by 40 ft long by 7 ft deep borehole-cuttings containment area was excavated along the pad boundary. A secondary containment area was constructed with straw bales and lined with 6-mil polyethylene to accommodate a 21,000-gallon (gal) tanker trailer for storing well development water. Safety barriers and signs were installed around the borehole-cuttings containment area and at the site entrance. Office and supply trailers, generators, and safety lighting equipment were moved to the site during subsequent mobilization of drilling equipment.

Sediment from site preparation work was controlled on-site through the use of silt fences and straw bales. In accordance with the 401/404 permit issued for the project, no sediments were added to the nearby stream channel.

Potable water was provided by a canvas fire hose connected to a fire hydrant located adjacent to Building No. 379, approximately 1000 feet to the south of the drill site. A backflow preventer was installed at the hydrant.

3.0 SUMMARY OF DRILLING ACTIVITIES

Drilling activities at the CdV-16-1(i) site were completed in two phases during October through November 2003.

Phase I drilling was performed from October 6 to October 20, 2003. The objectives of Phase I drilling were to collect continuous rock core samples for geologic characterization and determination of moisture, anion, stable isotope, radionuclide, high explosives and tritium distributions in the upper section of the borehole. The core was to be visually examined for geologic properties and to determine geologic contacts. Additionally, groundwater samples were to be collected from significant perched water zones, if encountered. Planned total depth (TD) for core drilling was 200 ft below ground surface (bgs).

Phase II drilling was performed from October 31 to November 6, 2003. The objectives of borehole drilling were to (1) collect cuttings of encountered geologic formations, (2) collect groundwater samples from significant perched water zones, if identified, and from the regional aquifer, (3) provide a borehole for geophysical measurements and (4) install a single-screen monitoring well in the regional aquifer. The planned TD for borehole drilling was 900 ft bgs.

Phase I and II drilling activities were performed generally in one 12-hour shift per day, 7 days per week by the drill crew and two site geologists. DTW measurements were taken at the beginning and end of every shift to check for the presence of water. Drilling equipment was removed from the borehole at the end of each shift to facilitate measurement of possible groundwater.

Figure 3.0-1 summarizes drilling data and graphically depicts groundwater and geologic conditions encountered during drilling at CdV-16-1(i). Table 3.0-1 details the chronology of drilling and other on-site activities at CdV-16-1(i). Sections 3.1 and 3.2 discuss specific corehole and borehole drilling activities, respectively.

Location: Cañon de Valle
North of R-25, TA-16

Description: Brass Marker
Northing: 1764415.2
Easting: 1615078.2
Elevation: 7382.17

Description: Well Casing
Northing: 1764413.0
Easting: 1615079.9
Elevation: 7384.21

Coring:
(0' - 10') Split Spoon
(10' - 200') HQ Coring

Drilling:
(0' - 12') 13-3/8" Air Rotary Casing Hammer
(12' - 683') 12-1/4" Tri-Cone
(12' - 95') Air Rotary
(95' - 683') Fluid assisted Air Rotary

Data Collection:
- Hydrologic Properties: Proposed Constant Rate Discharge Pumping Test: 3/01/04 - 3/05/04
- Cores/Cuttings submitted for geochemical and contaminant characterization: 11
- Ground Water Samples Submitted
  Regional Ground Water -
  Screening Sample: 11/05/03
  Well Sample: 12/16/03
- Geologic Properties
  Cuttings submitted for minerology, petrography, and chemistry: 7

Borehole Logs:
- Lithologic: 0' - 683'
- Video (LANL tool): 0' - 568'
- Schlumberger logs:
  - Compensated Neutron Log: 11/07/03: Open Hole: 50'-680'
  - Triple Litho-Density: 11/07/03: Open Hole: 50'-680'
  - Array Induction Tool: 11/07/03: Open Hole: 50'-674'
  - Elemental Capture Sonde: 11/07/03: Open Hole: 50'-675'
  - Natural GR Spectroscopy: 11/07/03: Open Hole: 50'-674'
  - Combinable Magnetic Resonance: 11/07/03: Open Hole: 50'-662'
  - Fullbore Formation Micro Imager: 11/07/03: Open Hole: 568'-682'

Corehole Logs:
- Lithologic: 0' - 200'

Core Drilling Completed: 10/06/03 - 10/16/03
Rotary Drilling Completed: 11/02/03 - 11/06/03
Contract Geophysics: 11/07/03
Well Installation: 11/09/03 - 11/12/03

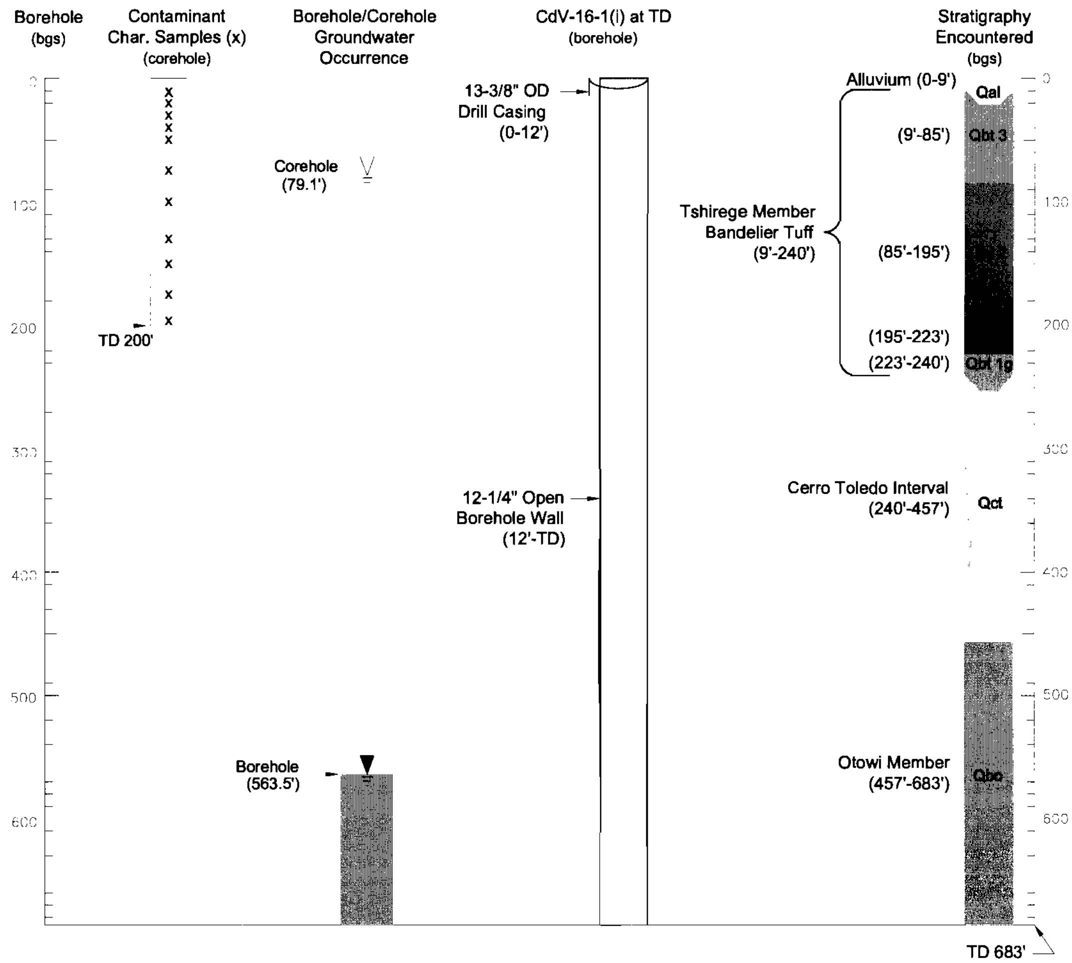
Well Developed: 12/05/03 - 12/17/03
- Casing:
  4.5" I.D. / 5.0" O.D. A304 Stainless Steel casing with external couplings
- Number of Screens:
  One (1) 4.46" ID wire wrapped stainless steel with external couplings.
  Screen: 5.27" OD Rod based 0.020 slot
- Screen Interval:
  Screen: 624' - 634'

Well Development performed by swabbing, bailing, and pumping.
Total Volume Purged: 5468 gallons

Aquifer Testing
Total Volume Pumped: 2,526 gallons

Temporary Corehole Piezometer Completion
- Casing - 2" OD Sched. 40 PVC threaded
- Casing Interval - 0 - 50'
- Number of Screens - One (1) 2" OD Sched. 40 PVC 0.010 slotted
- Screen Interval - 50' - 80'

Geologic contacts for CdV-16-1(i) were determined from core samples, cuttings, borehole video, and geophysical logs.



Legend

Qal = Alluvium
Qbt3 = Tshirege Member of Bandelier Tuff Unit 3
Qbt2 = Tshirege Member of Bandelier Tuff Unit 2
Qbt1v = Tshirege Member of Bandelier Tuff Unit 1v
Qbt1g = Tshirege Member of Bandelier Tuff Unit 1g
Qct = Cerro Toledo Interval
Qbo = Otowi Member

▼ Saturated Water

▽ Perched Water

Notes:
1. Coordinates - NM State Plane Grid Central Zone (North America) Datum - 1983 (NAD83); expressed in feet.
2. Elevations - National Geodetic Vertical Datum (NGVD29); expressed in feet above mean sea level.
3. Surface completion and surveying to be performed February 2004
4. All depths are below ground surface (bgs).
5. Drill casing removed prior to well installation.
6. Permanent corehole piezometer was installed across moisture zone first encountered at 70 ft. bgs.
7. Water level measurement in the piezometer was 79.1 ft. bgs. when sounded on 11-02-03.

KLEINFELDER

Drawn By: C. Landon	Date: March 2004
Project No.: 37151	Filename: Figure 3.0-1
Scale: Not-To-Scale	Revision: 0
Reviewed By: F. Schelby	Approved By: A. Kuhn

Well Summary Data Sheet for Well CdV-16-1(i)
Los Alamos National Laboratory
Los Alamos, New Mexico

FIGURE **3.0-1**

Table 3.0-1 Operations Chronology for Well CdV-16-1(i)

TASK DESCRIPTIONS	DATE						
	Sep-03	Oct-03	Nov-03	Dec-03	Jan-04	Feb-04	Mar-04
SITE PREPARATION ACTIVITIES	9/25-10/10						
CORE HOLE DRILLING AND SAMPLING							
Mobilization		10/6					
Continuous Coring		10/6-10/16					
Piezometer Construction		10/17					
Plug & Abandon Corehole		10/16-10/20					
BOREHOLE DRILLING AND SAMPLING							
Mobilization		10/31-11/2					
Air-Rotary			11/2-11/4				
Fluid Assisted Air-Rotary			11/4-11/6				
Groundwater Screening Sampling			11/5				
BOREHOLE GEOPHYSICS							
Schlumberger Logging			11/7				
LANL Video			11/8				
WELL DESIGN AND CONSTRUCTION			11/9-11/12				
WELL DEVELOPMENT				12/5-12/17			
GROUNDWATER WELL SAMPLING				12/16			
HYDROLOGIC TESTING							3/1-3/5
SITE RESTORATION							Not Completed to Date

NOTES: Site restoration activities will begin after receiving NMED discharge approval.

3.1 Core Drilling Activities

On October 6, 2003, KA mobilized the StrataStar 15 hollow-stem auger (HSA) drill rig and support equipment to the CdV-16-1(i) site. Core drilling was performed with an 8-in. outer diameter (OD) HSA through the alluvium to the top of the Tshirege Member of the Bandelier Tuff. Sample collection was performed with 1.5-ft and 2-ft long split-spoon samplers. KA switched to conventional air-rotary core drilling at 9.8 ft bgs to core through the Tshirege Member. On October 7, 2003 continuous core was collected from 10 ft to 60 ft bgs with a 9-ft by 3-in OD diameter conventional core barrel. At 60 ft bgs, the core barrel and 5 ft of drill rod parted from the drill stem. On October 8, 2003, the drillers were able to thread onto the top of the rod in the corehole and retrieve the core barrel. Approximately 3 gal of potable water were added to the corehole as lubrication to assist in retrieving the core barrel. KA drillers redrilled the corehole with the HSA to 60 ft bgs to provide drill casing to stabilize the corehole sidewalls. Coring using a conventional core barrel advanced from 60 to 65 ft bgs. KA switched to a Geobarrel® sampling system due to poor recovery and continued air-rotary core drilling from 65 to 75 ft bgs. Due to unconsolidated corehole material and lost air circulation, KA drillers then advanced the HSA to 75 ft bgs to mitigate these problems. Air-rotary core drilling continued through the Tshirege Member of the Bandelier Tuff from 75 ft to 92.5 ft bgs. KA switched to conventional core barrel sampling at 92.5 ft bgs to obtain better recovery for the changed lithology. On October 9, 2003, at the beginning of the drill shift, 13.5 hours after coring, an attempt was made to determine if water was present in the corehole; no water was observed. The drillers again advanced the HSA from 75 ft to 95 ft bgs to provide hole stability. Wet cuttings and between 3 and 5 gallons of free water were observed at the ground surface, indicating the presence of perched groundwater. Air-rotary core drilling advanced the corehole to 115 ft bgs. Wet core samples were observed from 110 ft to 115 ft bgs, so drilling was stopped to measure water in the corehole. However, no water was detected in the corehole with the electronic sounder. Air-rotary core drilling continued from 115 ft to 125 ft bgs.

At 125 ft bgs, the conventional core barrel and the lower portion of the HQ drill stem unthreaded downhole. Drillers began overdrilling from 75 ft to 109 ft bgs with the HSA to retrieve the core barrel and HQ drill stem. On October 10, 2003, at the beginning of the shift, depth to water was measured; no water was present. Efforts to retrieve the lost drill pipe and corebarrel continued for the remainder of the shift. On October 13, 2003, the HSA was advanced using approximately 40 gal of potable water to assist drilling. With the HSA at 125 ft bgs, the HQ drill stem and core barrel were retrieved. KA attempted to continue air-rotary core drilling but due to lithologic conditions and auger cuttings at the bottom of the hole, the drillers switched to fluid-assisted air rotary drilling. Drilling fluids consisted of potable water and QUIK-FOAM®. At the end of the shift on October 14, 2003, the drillers had redrilled through the cuttings to 125 ft bgs.

Again, prior to start of drilling on October 15, 2003, DTW was measured; no water was present. Air-rotary core drilling resumed at 125 ft bgs and continued in the Tshirege Member of the Bandelier Tuff to 200 ft bgs. On October 16, 2003, the corehole was terminated at 200 ft bgs as specified in the Addendum to the CMS plan for PRS 16-021(c) Revision 1.

A temporary piezometer was installed in the corehole with a screened interval from 50 to 80 ft bgs to collect water from the perched water zone. Construction details are included in Section 7.3 of this report.

3.2 Borehole Drilling Activities

Phase II drilling was performed by WDC Exploration & Wells (WDC) using a Star 50-CH Failing/Speedstar air/mud rotary drill rig equipped with conventional circulation drilling rods, tricone bits, down-the-hole (DTH) hammer bits, and support equipment. Drilling fluid mixing and circulation equipment for Phase II included a mixing tank and pump assembly, with a generator to power the mixing unit. CdV-16-1(i) was drilled using air-rotary and fluid-assisted air-rotary drilling techniques. Drilling fluids were used as needed to improve borehole stability, minimize fluid loss, and facilitate cuttings removal from the borehole. Drilling fluids consisted of potable water with QUIK-FOAM® (surfactant) and EZ-MUD® (polymer).

On October 31 and November 1, 2003 WDC mobilized the drill rig and equipment to the CdV-16-1(i) site for Phase II borehole drilling. On November 2, 2003 WDC began drilling using a 12u ¼-in. button-tooth tricone bit and air-rotary methods. WDC advanced 13 ⅜-in OD drill casing to refusal at 12 ft bgs. The borehole was drilled to 14.5 ft bgs. Due to casing lengths, the initial 13 ⅜-in OD drill casing was removed and different sized casing joints installed.

On November 3, 2003, drilling resumed to 63 ft bgs. Moist to wet cuttings were observed from 54 ft to 63 ft bgs in the upper Tshirege Member of the Bandelier Tuff. Drilling ceased to allow water to accumulate in the borehole for 35 minutes. Approximately one inch of water, not enough for sample collection, was measured in the borehole. The borehole was subsequently advanced to 95 ft bgs.

On November 4, after 13 hours of no drilling activity, the bottom of the borehole was measured at 89 bgs due to slough in the hole; no water was present. Drilling resumed with fluid-assisted air-rotary drilling methods. Potassium bromide (KBr) was added to the fluids as a tracer to aid in determining the occurrence of groundwater saturation. The borehole advanced out of the Tshirege Member of the Bandelier Tuff and into the volcanic sediments of the Cerro Toledo interval to a depth of 403 ft bgs.

On the morning of November 5, 2003, after 16 hours of inactivity, DTW was measured; no water was present. The borehole was advanced to 643 ft bgs. Field observations including increased water production from the drilling discharge line indicated the possible presence of groundwater at 603 ft bgs. Drilling activities were stopped to allow water to accumulate in the borehole. After approximately 4 hours, DTW was measured at 567 ft bgs.

The water in the borehole was allowed to stabilize for 16 hours and was measured at 564 ft bgs on November 6, 2003. Drilling continued and the borehole advanced to 683 ft bgs. In concurrence with DOE, LANL, and the New Mexico Environment Department (NMED), KA determined that the borehole had penetrated over 100 ft into the groundwater; therefore, drilling was terminated. The borehole was prepared for geophysical logging.

Table 3.2-1 shows the total amount of fluids introduced and recovered from the borehole during drilling, well construction, and well development at CdV-16-1(i).

Table 3.2-1
Introduced and Recovered Fluids

Material	Amount (Gallons)
QUIK-FOAM®	15
EZ-MUD®	15
Potable water for Drilling	3,550
Potable water for Well Construction	2,673
Recovered Fluids[a]	8,976

[a] Recovered fluids represents approximate fluids recovered during drilling and well development.

4.0 SAMPLING AND ANALYSIS OF CORE, CUTTINGS AND GROUNDWATER

During drilling at CdV-16-1(i), soil and groundwater samples were collected according to the Scope of Services. Core and groundwater samples were submitted to LANL for analysis. Core was collected from CdV-16-1(i) and analyzed for geochemical constituents. Cuttings collected from CdV-16-1(i) may be analyzed for mineralogic, petrographic, and geochemical properties by LANL. Groundwater samples were analyzed for organic, inorganic and radiochemical compounds.

4.1 Core and Cuttings Sampling

Eleven samples of core were collected from the vadose (unsaturated) zone during drilling from 11.3 ft bgs to 200 ft bgs. Core samples were collected from the alluvium and Tshirege Member of the Bandelier Tuff at CdV-16-1(i). Approximately 500 to 1000 g of core or cuttings samples were placed in appropriate sample jars in protective plastic bags before they were analyzed by Earth and Environmental Sciences –6 (EES-6), Coastal Science Laboratories, and General Engineering Laboratories (GEL). These samples were analyzed for high explosive compounds, cations, anions, and metals for characterization purposes. The core results will be reported in the investigation report for the Cañon de Valle watershed.

During Phase II drilling, cuttings were collected from the discharge line at 5-ft drilling depth intervals. A portion of the cuttings was sieved (at >#10 and >#35 mesh or >#35 and >#60 for finer grain samples) and placed in chip-tray bins along with an unsieved portion. These chip trays were studied to determine lithologic characteristics and used to prepare the lithologic logs. The remaining cuttings were sealed in Ziploc® bags, labeled, and archived in core boxes. Up to seven samples may be removed by LANL for mineralogic, petrographic, and geochemical analyses. No cuttings samples were submitted for contaminant characterization analysis.

Sample analysis results will be included in a future LANL investigation report for Cañon de Valle.

4.2 Groundwater Sampling

Two groundwater samples were collected from CdV-16-1(i). During Phase II drilling, groundwater was encountered in the borehole at 567 ft bgs. A groundwater-screening sample (Sample ID #GW16-04-52692) was collected from this depth. After completion of well development activities, a groundwater well sample (Sample ID #GW16-04-52693) was collected from the screened interval (624 ft to 634 ft bgs). Samples were submitted to LANL for analysis. Groundwater samples were analyzed for anions, stable isotopes, radionuclides, metals, high explosives, and tritium.

4.3 Geochemistry of Sampled Waters

During drilling operations at borehole CdV-16-1(i), alluvial groundwater was encountered beneath Cañon de Valle. No alluvial groundwater samples were collected because this alluvial aquifer is routinely sampled elsewhere as part of the TA-16 investigations.

An upper perched groundwater zone was encountered at a depth of 79.1 ft bgs at CdV-16-1(i). A groundwater sample was not collected from this depth because of insufficient sample volume.

A lower perched groundwater zone was encountered at a depth of 563 ft bgs. A screening groundwater sample (Sample ID # GW16-04-52692) was collected from this depth on December 12, 2003 and analyzed for HE compounds. The screening groundwater sample collected from the perched zone at CdV-16-1(i) borehole was lifted using a bailer. Concentrations of 1,2-dinitrobenzene, HMX, and RDX were 0.329, 1.01, and 19.0 μg/L, respectively. Analytical results are on file with P. Longmire, LANL.

On December 16, 2003, a groundwater sample (Sample ID # GW16-04-52963) was collected after well development from the lower perched zone, within the Otowi Ash Flows, from 624 to 634 ft bgs. This sample was collected using a submersible pump. The groundwater sample was analyzed for cations, anions, metals, total organic carbon (TOC), stable isotopes, radionuclides, high explosives, and tritium. Analytical results for this groundwater sample are provided in Appendix A.

5.0 BOREHOLE GEOPHYSICS

Using LANL-owned and subcontractor-owned tools, KA and Schlumberger performed borehole geophysics logging operations at CdV-16-1(i).

5.1 Schlumberger Geophysical Logging

Schlumberger personnel conducted geophysical logging in the CdV-16-1(i) borehole on November 7, 2003. The primary purpose of the Schlumberger logging was to characterize the conditions in the hydrogeologic units penetrated by the CdV-16-1(i) borehole, with emphasis on gathering moisture distribution data, identifying water zones, measuring capacity for flow (porosity and moisture), and obtaining lithologic/stratigraphic data. Secondary objectives included evaluating borehole geometry and determining the degree of drilling fluid invasion along the borehole wall.

Schlumberger personnel used a suite of geophysical logging tools in the cased and uncased portions of the borehole; the suite included the following tools:

- Combinable Magnetic Resonance (CMR™) tool measures the nuclear magnetic resonance response of the formation, which is used to evaluate total and effective water-filled porosity of the formation and to estimate pore size distribution and in situ hydraulic conductivity.
- Array Induction Tool, version H (AITH™) measures formation electrical resistivity and borehole fluid resistivity, thus evaluating the drilling fluid invasion into the formation,

the presence of moist zones away from the borehole wall, and the presence of clay-rich zones.

- Triple detector Litho-Density (TLD™) measures formation bulk density related to porosity, photoelectric effect related to lithology, and borehole diameter using a single-arm caliper.
- Natural Gamma Spectroscopy (NGS™) measures spectral and overall natural gamma ray activity, including potassium, thorium, and uranium concentrations, thus evaluating geology and lithology.
- Elemental Capture Spectroscopy (ECS™) measures concentrations of hydrogen, silicon, calcium, sulfur, iron, aluminum, potassium, titanium, chlorinity, and gadolinium to characterize mineralogy, lithology, and water content of the formations.
- Epithermal Compensated Neutron Tool, model G (CNTG™) measures volumetric water content beyond the casing to evaluate formation moisture content and porosity.
- Full-Bore Formation Micro-Imager (FMI™) measures electrical conductivity images of the borehole wall and the borehole diameter with a two-axis caliper to evaluate geologic bedding and fracturing, including strike and dip of these features, fracture apertures, and rock textures.

Additionally, a calibrated natural gamma tool was used to record gross natural gamma-ray activity with each logging method (except the NGS™ run) to correlate depth runs between each of the surveys conducted.

Important results from the processed geophysical logs in CdV-16-1(i) include the following:

1. The well water level was stable throughout the logging acquisition, remaining between 568–569 ft bgs for all four logging runs.

2. The processed logs do not indicate that the bottom of the borehole section that was logged (maximum depth of 666 ft bgs) is fully saturated with water. Both total and moveable water content steadily increase below 520 ft (especially below the standing water level at 569 ft), reaching 35% and 10-15% of total rock volume, respectively, near the bottom. However, the total porosity of the volcanic tuff is very high (45%), and, thus, water saturation never reaches above about 85% (defined as percent of pore space filled with water). As a result of the high total and moveable water content, the log-estimated hydraulic conductivity is as high as two gal/day/ft^2 across this interval.

3. Two very large, near-vertical fractures are clearly delineated from the electrical imaging log at 598 ft and 626 ft. The fractures dip around 85 degrees towards the northeast and northwest. The estimated aperture of these fractures is close to one inch – suggesting they could be significant conduits for flow if they extend much beyond the borehole.

4. The processed logs do not indicate any significant fully water saturated (perched) zones above the standing water level (659 ft). Water content and estimated water saturation generally decreases above this depth up to 305 ft. Above 305 ft water content and saturation is highly variable. The highest total and moveable water content occurs in the zone 258 – 302 ft, ranging 20-40% and 5-20%, respectively.

5. The processed logs indicate that relatively significant amounts of clay are present in the following zones: 42-90 ft, 215-230 ft, and 238-247 ft. In general, the processed logs indicate the presence of minor amounts of clay above 308 ft.
6. Interpreted bed boundaries across the imaged interval 580-690 ft have variable dip azimuths (direction beds are dipping to), the greatest clustering to the northwest and southwest, and dip angles (angle from horizontal) less than 10 degrees.

Table 5.1-1 summarizes geophysical well logging conducted in CdV-16-1(i) by KA/LANL and Schlumberger. Schlumberger's report is presented in Appendix C, along with the geophysical logs, compiled as a montage on the compact disc [CD] on the back cover of this report.

Table 5.1-1
Borehole Logging Surveys Conducted in CdV-16-1(i)

Operator	Date	Method	Cased Footage (ft bgs)	Open-hole Interval (ft bgs)	Remarks
Schlumberger	November 7, 2003	Logging suite[a]	0-12	12-680[b]	Schlumberger borehole logging conducted prior to well construction
KA/LANL	November 8, 2003	Video	0-12	12-568	Open-borehole video to groundwater

[a] Schlumberger suite of borehole logging surveys included triple detector litho-density, array induction tool, epithermal compensated neutron tool, elemental capture spectroscopy, full-bore formation microimager, natural gamma spectroscopy, and combinable magnetic resonance. A calibrated natural gamma tool was also used for correlation between tool runs.
[b] Variable effective depths, see Figure 3.0-1 and Appendix C

5.2 Kleinfelder-Supported Video Logging

On November 8, 2003, video logging was performed in the CdV-16-1(i) borehole using down hole tools provided by LANL. The video logs were used to identify perched water zones and aid in lithologic contact identification. The video log of the open borehole was digitized onto a digital video disc (DVD) and is included as Appendix B.

6.0 LITHOLOGY AND HYDROGEOLOGY

A preliminary assessment of the hydrogeologic features encountered during drilling operations at CdV-16-1(i) is presented below. Included are summary descriptions of geologic units identified during characterization of the core and cuttings samples. LANL EES-6 staff provided preliminary geologic contact zones. Groundwater occurrences are discussed based on drilling evidence, open-hole video logging, geophysical logging, KBr tracer monitoring, and water level measurements.

6.1 Stratigraphy and Lithologic Logging

Rock units and stratigraphic relations are interpreted from the visual examination of CdV-16-1(i) core and cuttings samples and preliminary interpretation of geophysical data. Units are briefly discussed in order of younger to older occurrence. The interpretations presented below are preliminary and may be revised upon future analysis of petrographic, geochemical, mineralogical, and geophysical logging data. A lithologic log containing detailed descriptions of textures and lithologic composition of sample intervals is presented in Appendix D. This log is based on the core samples to 200 ft bgs and the cuttings samples from 200 ft bgs to total depth.

During drilling, winnowing of the fine portion of the rock unit occurs. This can potentially increase the concentration of lithics and crystals in some cuttings samples. The descriptions provided below, and in the lithologic log, are in part derived from observations of the cuttings samples. Therefore, the actual rock unit character may vary from the provided description.

Alluvium, Qal (0 ft to 9 ft bgs)

Core samples showed that unconsolidated alluvium was intersected in CdV-16-1(i) in the interval from ground surface to approximately 9 ft bgs. Samples indicated that this interval is made up of silty sands and gravels composed of tuffaceous and other volcanic detritus. Subangular to subrounded clasts are composed of abundant devitrified, densely welded tuff, dacite and andesite lithics, and quartz and sanidine crystals. These sediments are likely derived from the Bandelier Tuff and the Tschicoma Formation.

Tshirege Member of the Bandelier Tuff, Qbt (9 ft to 240 ft bgs)

Rhyolitic ash flows of the Tshirege Member of the Bandelier Tuff have been divided into four separate cooling units in the general region of the Pajarito Plateau (Broxton and Reneau, 1995). The drilled CdV-16-1(i) section from 9 ft to 240 ft bgs is interpreted to represent Qbt 3, Qb t2, Qbt 1v and Qbt 1g. The tuff section is locally typified by dense welding that is characteristic of ash flows occurring in the western part of the plateau.

Qbt 3 was intersected from 9 ft to 85 ft bgs. Core samples indicated that Qbt 3 is a crystal-rich tuff that is densely to weakly welded. Abundant quartz, sanidine, and mafic phenocrysts typically make up 25 to 35% of the cuttings by volume. The remainder is generally comprised of up to 5% devitrified flattened pumice fragments (up to 4 cm) and less than 5% volcanic xenoliths in a matrix (60 to 70% by volume) of fine-grained ash. The degree of welding varies from densely welded at the top of Qbt 3 to weakly welded toward its base.

Core samples indicated that Qbt 2, occurring in the section from 85 ft to 195 ft bgs, is a crystal-rich tuff that is densely welded. The cuttings consist of 40 to 60% by volume quartz, sanidine, and altered ferromagnesian phenocrysts; up to 10% devitrified, flattened pumice; and up to 10% dark-colored volcanic xenoliths in a matrix (up to 40% by volume) of fine-grained ash.

Qbt 1, the basal cooling unit of the Tshirege Member, is separated into upper devitrified (Qbt 1v) and lower glassy (Qbt 1g) subdivisions (Broxton and Reneau, 1995). CdV-16-1(i) intersected Qbt 1v from 195 ft to 223 ft bgs. The coarse-fraction (i.e., the plus No. 10 sieve-size) of most cuttings samples in this interval is made up of more than 50% welded tuff fragments (locally as much as 90% by volume) and less than 50% dacitic and other intermediate volcanic lithic fragments that represent xenolithic inclusions. Fine-fraction samples (i.e., the plus No. 35 sieve-size) are made up dominantly of quartz and sanidine crystals with subordinate amounts of volcanic lithics.

Qbt 1g occurs in the interval from 223 ft to 240 ft bgs. Cuttings samples from Qbt 1g contain abundant tuff fragments, white vitric pumices, and lithic fragments that indicate a variety of intermediate volcanic lithologies including dacite, rhyolite, and obsidian.

Cerro Toledo Interval, Bandelier Tuff, Qct (240 ft to 457 ft bgs)

Volcaniclastic sedimentary and tephra deposits of the Cerro Toledo interval regionally separate the Tshirege and Otowi Members of the Bandelier Tuff. Preliminary interpretation of geophysical logs suggests that the Cerro Toledo interval occurs in borehole CdV-16-1(i) from 240 ft to 457 ft bgs.

Cuttings from Qct indicate weakly cemented fine-grained deposits of sand with varying amounts of silt and clay and less than 5% gravel-size clasts. Detrital constituents in the coarse fraction of most cuttings samples are generally comprised of more than 50% intermediate to felsic volcanic lithics and less than 50% pumice. Lithic fragments most commonly include aphanitic and porphyritic varieties of dacite, andesite, porphyritic rhyolite, and obsidian. Pumices are generally vitric and pinkish to white in color.

Otowi Member of the Bandelier Tuff, Qbo (457 ft to 683 ft bgs)

Rhyolitic ash-flow tuff representing the Otowi Member of the Bandelier Tuff was intersected in CdV-16-1(i) from 457 ft to the bottom of the borehole at 683 ft bgs. Cuttings showed that the Otowi Member is locally pumiceous, lithic-bearing, and weakly welded to nonwelded. The coarse fraction of most cuttings samples from the Qbo section is made up of varying amounts of vitric pumice fragments (locally as much as 85% by volume) and volcanic lithics that represent xenolithic inclusions. Xenolithic constituents (commonly more than 50% by volume) include aphanitic and porphyritic dacite, andesite, and vitrophyre. Pumice fragments are generally glassy and white or orange-brown in color. Fine-fraction cuttings samples are made up dominantly of quartz and sanidine crystals with subordinate amounts of volcanic lithics and pumice.

6.2 Groundwater Occurrences and Characteristics

The Scope of Services indicated that perched groundwater could occur in the upper 200 ft of the stratigraphic section at CdV-16-1(i). No projected depth or associated hydrogeologic unit was stated in the scope. The anticipated depth to the regional water table was assumed to occur at approximately 1160 ft bgs, based on the nearby well R-25.

A potential zone of perched groundwater was indicated by wet core samples from 50 ft to 75 ft bgs during Phase I drilling. With the corehole advanced to 95 ft bgs, a depth to water (DTW) measurement taken following 12 hours of inactivity indicated no water accumulation. Wet cuttings were nevertheless produced while reaming the borehole back down to 95 ft bgs. A DTW reading was again attempted with the corehole advanced to 115 ft bgs; however, no free water was detected. After drilling to a depth of 125 ft bgs while using a nominal volume of potable water to lubricate the auger string, a sounder reading indicated DTW at 99.8 ft bgs and a 1-liter sample was collected for lab analysis. However, this sample was considered to be drilling fluid and was not analyzed. No additional perched groundwater zones were observed while drilling from 125 ft to 200 ft bgs, the TD of the corehole.

A temporary piezometer was constructed in the corehole to monitor the possible perched groundwater zone in the upper part of the Tshirege Member of the Bandelier Tuff. The screened interval was installed from 50 ft to 80 ft bgs. DTW was measured at 79.1 ft bgs in the completed piezometer on November 2, 2003. On March 24, 2004 DTW was measured to be 79.8 ft bgs.

During Phase II drilling, moist to wet cuttings were observed while drilling from 54 ft to 63 ft bgs in the upper Tshirege Member of the Bandelier Tuff. After 13 hours of no drilling activity, no water was present. Increased water production from the drilling discharge line indicated the possible presence of groundwater at 603 ft bgs. On November 5, 2003, a DTW of 567 ft bgs was measured. DTW was determined to be at 563.5 ft bgs on December 9, 2003 prior to well development.

Results of sampling and analysis for KBr in drilling fluids during Phase II indicated a possible unconfirmed zone of perched groundwater at a depth of 193 ft bgs. No water was observed on the video log at this depth. In addition, there is no indication of significant saturated zones from the geophysical logging. KBr results also indicated an influx of groundwater from the formation at a depth of approximately 563 ft bgs. These KBr results confirmed drilling observations of saturation.

A comparison of the inflow KBr concentration and the KBr concentration in the cuttings is shown in Figure 6.2-1.

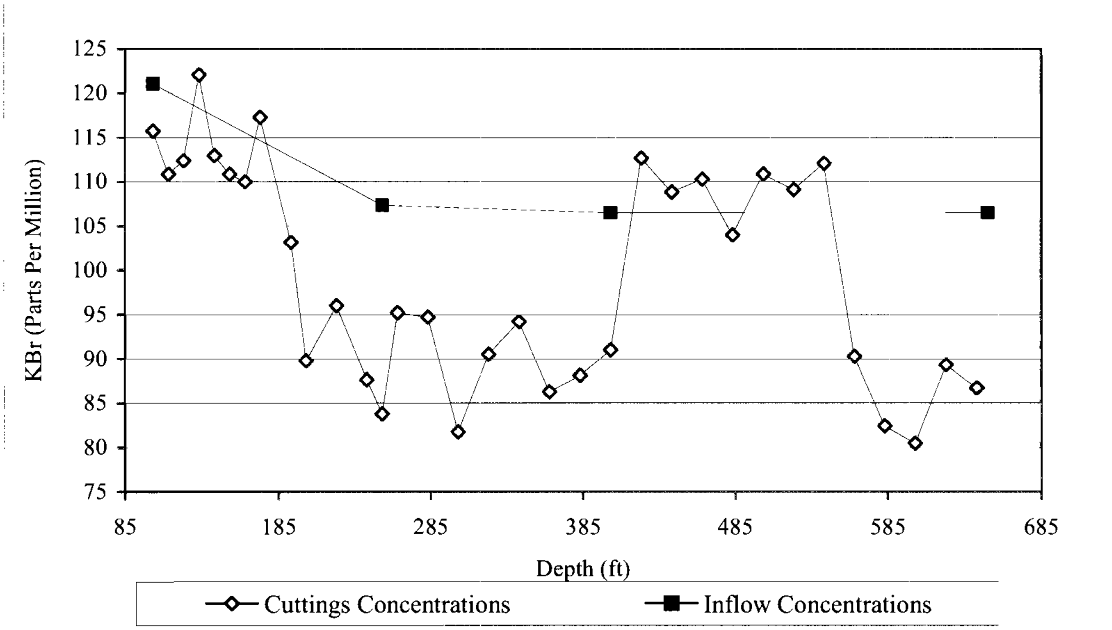


Figure 6.2-1. KBr Concentrations in Borehole at Well CdV-16-1(i)

Detailed results of geophysical logging relating to water occurrence and logs for all Schlumberger surveys are presented in Appendix C. Appendix C is stored on the CD attached to the back cover of this report.

7.0 WELL DESIGN AND CONSTRUCTION

CdV-16-1(i) was installed as a hydrogeologic characterization and groundwater monitoring well. Following approval of the well design by DOE, LANL and NMED, KA received the final construction specifications for CdV-16-1(i) on November 9, 2003. Well installation activities were performed from November 10 to November 12, 2003.

7.1 Well Design

Data from geophysical logs, borehole geologic samples, and field water levels were analyzed to determine the screen placement interval for CdV-16-1(i). Design of Well CdV-16-1(i) was performed in accordance with Section 2.2 of the CQMP prepared by KA for this project. The well was designed with a single screen interval to monitor potential contaminants in the upper part of the groundwater zone in the Otowi Member of the Bandelier Tuff.

7.2 Well Construction

CdV-16-1(i) was constructed of 4.46-in inner-diameter (ID)/5.0-in-OD, type A304 stainless-steel casing fabricated to American Society for Testing and Materials (ASTM) A312 standards. The casing and screens were factory cleaned before shipment and delivery to the site. Additional decontamination of the stainless-steel components was performed on site prior to well construction using a high-pressure steam cleaner and scrub brushes. One 10-ft nominal length of 5-in OD compatible, 0.020-in continuous slot rod-based well screen was used. The screened interval is 624.0 ft to 634.0 ft bgs. Stainless-steel casing was placed below the screen to construct a 23.8 ft sump. Figure 7.2-1 is a schematic as-built diagram of the completed CdV-16-1(i) well.

External couplings, also of type A304 stainless steel fabricated to ASTM A312 standards, were used to connect individual casing and screen joints. Centralizers were installed above and below the well screen. In addition, a centralizer was placed approximately 100 ft above the screen interval. Centralizers for CdV-16-1(i) are located at 535 ft, 627 ft and 634 ft bgs (Figure 7.2-1).

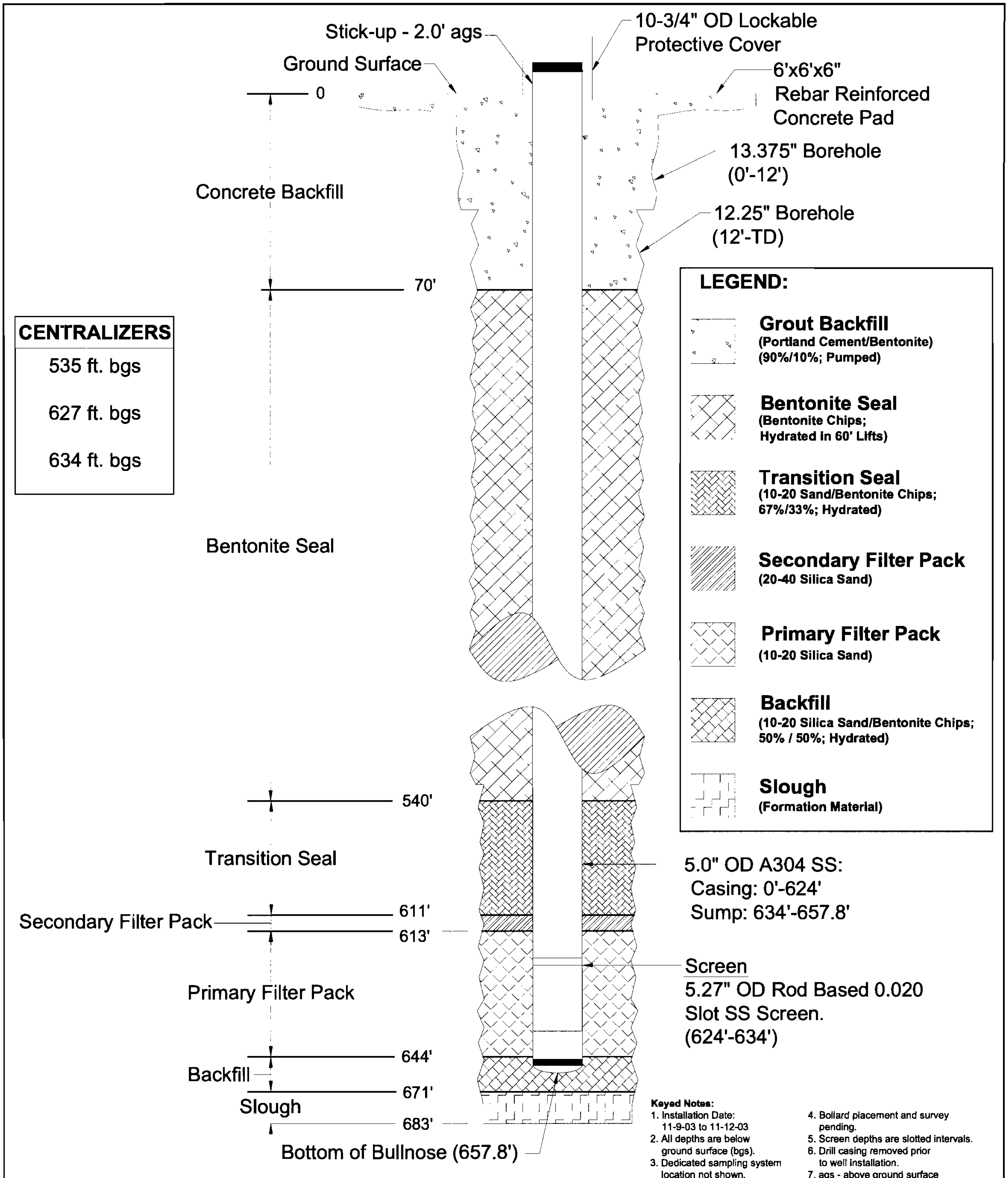
7.2.1 Annular Fill Placement

The well casing and screen were lowered in the hole and the bottom of the sump was set at 657.8 ft bgs. Placement of annular fill consisted of using a 2.5-in OD steel tremie pipe to deliver various materials to specified backfill intervals. Approximately 12 ft of formation material sloughed into the borehole from 683 ft to 671 ft bgs. Annular fill consisting of a 50:50 mixture of 10/20 sand and hydrated bentonite chips was placed above formation material in the annular space between 671 ft and 644 ft bgs. A primary filter pack consisting of 10/20 silica sand was placed across the screen interval from 644 ft to 613 ft bgs. A secondary filter pack consisting of 20/40 silica sand was placed above the primary filter pack from 613 ft to 611 ft bgs. Prior to placement, filter pack materials were generally mixed with potable water to form a slurry. A transition seal, consisting of a 44:56 mixture of 10/20 sand and hydrated bentonite chips, was placed above the secondary filter between 611 ft and 540 ft bgs. The annulus was then filled from 540 ft to 70 ft with a bentonite seal consisting of ⅜-in bentonite chips. The bentonite seal was hydrated in approximately 60 ft lifts. Concrete backfill, consisting of Portland cement with 6% bentonite, was placed from 70 ft bgs to ground surface. The quantities of annular fill materials used in the completion of CdV-16-1(i) are presented in Table 7.2-1.

Table 7.2-1
Annular Fill Materials Used in Well CdV-16-1(i)

Material	Volume[a]	Mix[b]
Backfill: 10/20 sand and bentonite	25.23	50:50
Primary Filter Seal: 10/20 sand	21.0	-
Secondary Filter Seal: 20/40 sand	1.5	-
Transition seal: 10/20 sand and bentonite	45.96	44:56
Bentonite Seal: ⅜-in. Chips	269.24	-
Concrete Backfill (September 10, 2003)	35.61	Portland cement with 6% bentonite
Potable water	357.33	-

[a] Volumes are presented in cubic feet (ft^3).
[b] Mix ratios are computed by volume.



KLEINFELDER

Drawn By: C. Landon	Date: March 2004	**Schematic Diagram of As Built Well CdV-16-1(i)** Los Alamos National Laboratory Los Alamos, New Mexico	FIGURE **7.2-1**
Project No.: 37151	Filename: Figure 7.2.-1		
Scale: Not-To-Scale	Revision: 0		
Reviewed By: F. Schelby	Approved By: M. Everett		

7.3 Piezometer Construction

A temporary piezometer was installed in the open corehole to monitor the potential zone of perched water observed during Phase I drilling. Piezometer construction was performed on October 17, 2003. The temporary piezometer was completed using 2-in OD, Schedule 40 flush-jointed polyvinyl chloride (PVC) casing with 0.010-in slotted screen and was screened across the interval 50 ft to 80 ft bgs. A bentonite seal was placed from 200 ft to 82 ft bgs. A filter pack of 10/20 silica sand was then tremied across the screened interval from 82 ft to 45 ft bgs. A final bentonite seal was placed from 45 ft to ground surface. A total of 25 bags of 10/20 silica sand and 42 bags of bentonite granules were used in backfilling the piezometer annulus. Figure 7.3-1 is a schematic as-built diagram of this temporary piezometer.

8.0 WELL DEVELOPMENT, HYDROLOGIC TESTING AND COMPLETION ACTIVITIES

Well development activities at CdV-16-1(i) were conducted from December 5 to December 17, 2003. Well development procedures included well screen bailing, swabbing, and pumping. A total of 5468 gal of water were removed during well development and testing activities.

Hydrologic testing of CdV-16-1(i), consisting of a constant rate pumping and recovery test, began on March 1, 2004 and was completed on March 5, 2004.

8.1 Well Development

Well development at CdV-16-1(i) was performed in two stages. The initial stage consisted of bailing and swabbing the screened interval and sump to remove bentonite materials, drilling fluids, and formation sands and fines that had been introduced into the well during drilling and installation activities. Bailing activities were conducted by WDC using a 5-gal capacity, 3-in OD by 10-ft long stainless-steel bailer. Bailing activities continued until water clarity improved. Water turbidity was not measured during the bailing and swabbing process. Bailing was followed by swabbing across the screened interval to enhance filter-pack development. A swabbing tool consisting of a 4.25-in OD, 1-in thick rubber disc attached to the drill rod was lowered into the well and drawn repeatedly across the screened interval for approximately one hour.

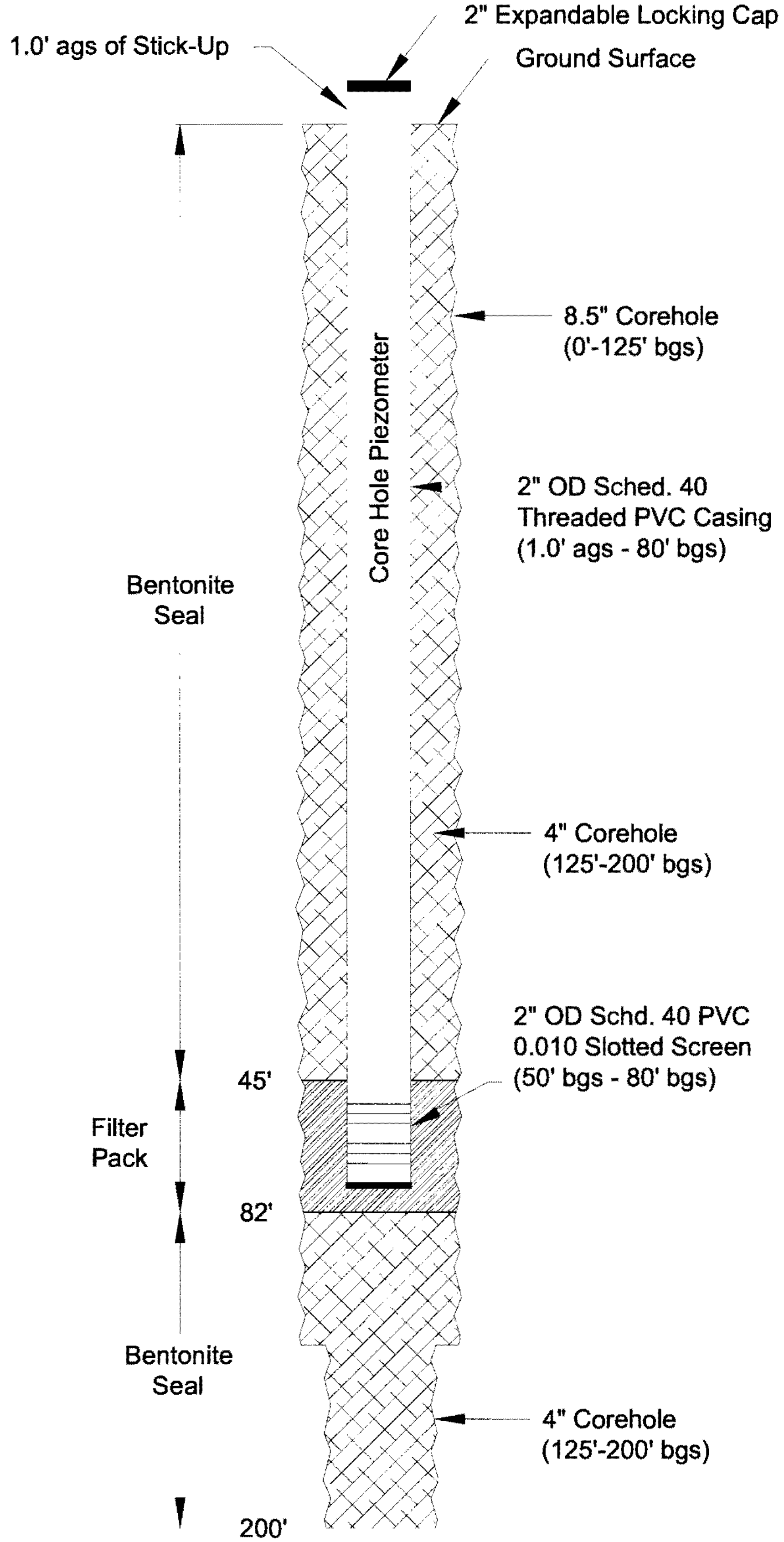
Following swabbing, pump development procedures were applied to the screened interval (624 ft to 634 ft bgs) using a 10 horsepower, 4-in Grundfos submersible pump. The pump intake was lowered to the screened interval and cycled on at a nominal rate of approximately 2.5 gal per minute (gpm). The pump intake was then drawn across the length of the screened interval. While pumping at CdV-16-1(i), water samples were collected for water quality parameter measurements.

Criteria for well development were based on field water-quality parameters (pH, temperature, specific conductance, turbidity and TOC). To monitor progress during each development stage, samples of water were periodically collected and parameter measurements were recorded. The primary objective of well development was to remove suspended sediment from the water until turbidity, measured in nephelometric turbidity units (NTU), was less than 5 NTUs for three consecutive samples. TOC provides a quantitative measurement for evaluating potential residual drilling fluid including EZ-MUD® and QUIK-FOAM®. Similarly, other measured parameters were required to stabilize before terminating development procedures.

Location: Cañon de Valle
(North of R-25) TA-16

Survey Coordinates / Elevations:
- Coordinates: NAD83
- Elevation: NGVD29

Description: Core Hole Piezometer
Northing: 1764400.0
Easting: 1614974.0
Elevation: 7385.58



LEGEND:

Bentonite Seal
(Bentonite Chips, Hydrated)

Filter Pack
(10-20 Silica Sand)

Keyed Notes:

1. Completion Date: 10-17-03
2. All depths are below ground surface (bgs)
3. ags: above ground surface

KLEINFELDER

Drawn By: C. Landon	Date: March 2004
Project No.: 37151	Filename: Figure 7.3-1.dwg
Scale: Not To Scale	Revision: 0
Reviewed By: S. Metzger	Approved By: A. Kuhn

Schematic Diagram of
Temporary Corehole Piezometer
Well CdV-16-1(i)
Los Alamos National Laboratory
Los Alamos, New Mexico

FIGURE
7.3-1

Table 8.1-1 presents the final water quality parameter data values measured during the well development process. Figure 8.1-1 illustrates the effects of pump development on measured field parameters.

Table 8.1-1
Water Removed and Final Water Quality Parameters During CdV-16-1(i) Well Development and Aquifer Testing

Method	Water Removed (gal)	pH	Temperature (°C)	Specific Conductance (μS/cm) [(a)]	Turbidity (NTU)	TOC (ppm)
Bailing/Swabbing Screen	75	NM[(b)]	NM	NM	NM	NM
Pumping Screen	5,393	6.5	13.3	0.1	4.21	1.61
Aquifer Testing	2,526	NM	NM	NM	NM	NM
Total	**7,994**	–	–	–	–	–

[(a)] Specific conductance is reported in microsiemens per centimeter (μS/cm).
[(b)] NM = Not measured.

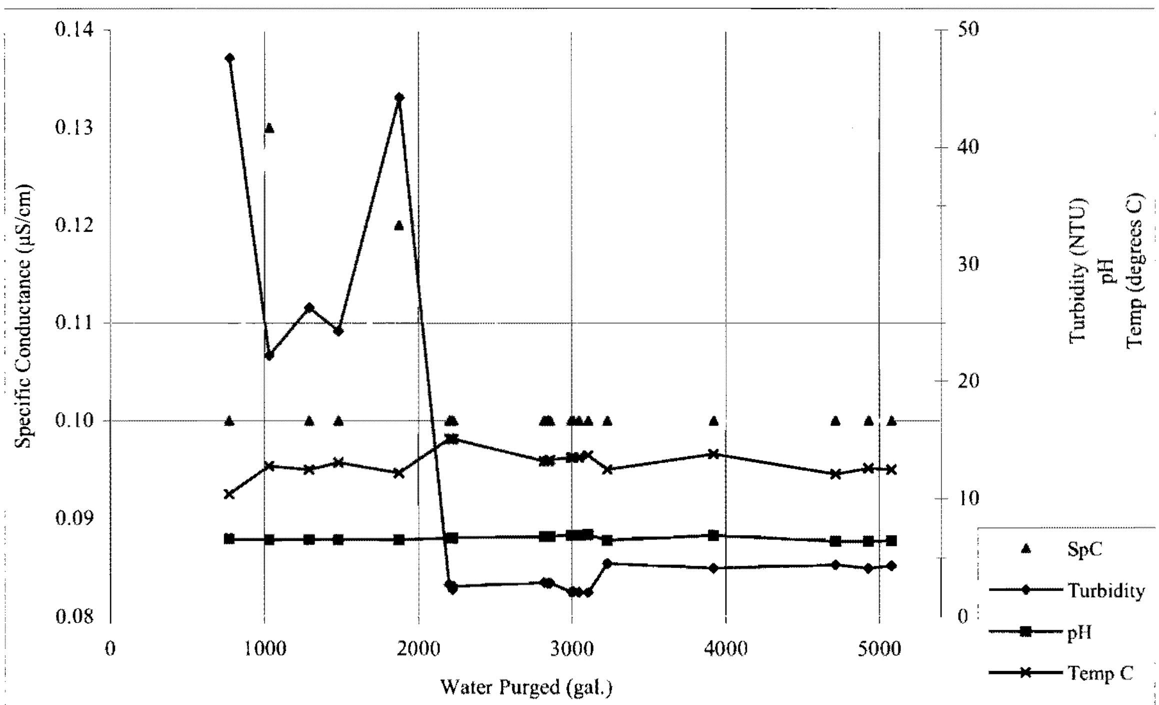


Figure 8.1-1. Effects of Pump Development on Water Quality Parameters at Well CdV-16-1(i)

8.2 Hydrologic Testing

Hydrologic testing at CdV-16-1(i) was performed from March 1, 2004 to March 5, 2004. Testing of CdV-16-1(i) consisted of a few hours of trial pumping, 3 days of background monitoring, 24 hours of constant-rate pumping, and 39 hours of recovery (also providing additional background data). The 24-hour constant-rate pumping test was performed on March 1, 2004, at a rate of 1.6 gpm. The complete report is included in Appendix E. The following information was determined from the pumping, recovery and slug tests conducted in CdV-16-1(i):

1. The barometric efficiency was near 100 percent, based on the observation of no discernable correlation between barometric pressure and the non-vented transducer hydrograph.
2. Implementation of the inflatable packer did not eliminate the effects of casing storage, presumably because of air that was entrained in the casing and filter pack when the pumping water level was drawn into the well screen.
3. The data showed evidence of leaky check valves and coupling joints in the drop pipe string.
4. Slug test methods, which distinctly underestimate the lower-bound *K*, yielded estimates of 0.21 and 0.27 feet per day. Specific capacity test methods, which slightly overestimate the lower-bound *K*, yielded estimates of 0.41 and 0.47 feet per day. Taken together, these results suggest a probable lower-bound hydraulic conductivity in a range of about 0.35 to 0.40 feet per day.
5. Hantush analysis of recovery data yielded *K* value ranges of 0.4 to 0.58 ft per day for the trial pumping and 0.37 to 0.67 ft per day for the long-term test, with more severe anisotropy yielding higher values. The known steep vertical gradients in the vicinity of CdV-16-1(i) imply severe anisotropy. This, in turn, suggests a realistic hydraulic conductivity range of about 0.50 to 0.70 ft per day. This result shows excellent consistency with the identified lower-bound hydraulic conductivity range estimate.

8.3 Dedicated Sampling System Installation

At the time of this report, installation of a dedicated sampling system has not been completed. It is anticipated that a dedicated submersible pump will be installed in Spring 2004.

8.4 Wellhead Completion

The surface completion for CdV-16-1(i) was completed on December 20, 2003 and involved placing a reinforced (2,500 pounds per square inch [psi]) concrete pad, 6-ft wide by 6-ft long by 6-in. thick, around the well casing. A brass survey pin was installed in the northwest corner of the pad. A 10.75-in. steel casing with locking lid protects the well riser. The pad was designed to be slightly elevated, with base course graded up around the pad to allow for drainage.

8.5 Geodetic Survey

The location of Well CdV-16-1(i) was determined by geodetic survey on March 23, 2004, using a Leica TCR303 electronic total station. Lynn Engineering and Surveying, Inc. conducted the survey. The original geodetic survey is on file in the KA Albuquerque office. Coordinates and elevations were obtained from the brass monument at Monitoring Well R-25 using a Static Global Positioning System (GPS).

This survey located the brass cap monument at Well CdV-16-1(i) in the concrete pad, the top of the stainless-steel well casing and the temporary piezometer. Table 8.5-1 summarizes the results of readings conducted for various components of the completed wellhead. The coordinates shown are in New Mexico State Plane Grid Coordinates, Central Zone (North American Datum, 1983 [NAD 83]), expressed in feet. Elevation is expressed in ft amsl relative to the National Geodetic Vertical Datum of 1929 (NGVD 29).

Table 8.5-1
Geodetic Data for Well CdV-16-1(i)

Description	Northing	Easting	Elevation [a]
Brass cap in CdV-16-1(i) pad	1764415.2	1615078.2	7382.17
Top of stainless-steel casing	1764413.0	1615079.9	7384.21
Temporary Piezometer [b]	1764400.0	1614974.0	7385.58

[a] Specific Measured in ft alms relative to the National Geodetic Vertical Datum of 1929.

[b] Top of pvc casing

8.6 Site Restoration

Fluids and cuttings produced during drilling and development were sampled in accordance with the Notice of Intent (NOI) to Discharge, Hydrogeologic Workplan Wells and filed with the NMED. Approval to discharge drilling and development water was received via e-mail from the NMED on March 4, 2004. A copy of the NMED discharge approval and the sample analysis is included in Appendix F. Silt fencing and straw bales have been left in place to minimize possible sediment impacts from future precipitation.

Future site restoration activities will include: (1) removal and land application of water from the borehole-cuttings containment area, (2) removal of the polyethylene liner and borehole cuttings from the borehole-cuttings containment, (3) removing the containment area berms and (4) backfilling and grading the containment area. The cuttings will be thin-spread on-site after NMED approval has been obtained. Site re-seeding will be performed in the Spring of 2004.

9.0 DEVIATIONS FROM THE CdV-16-1(i) SCOPE OF SERVICES

Appendix G compares the actual characterization activities performed at CdV-16-1(i) with the planned activities described in the "Hydrogeologic Workplan" (LANL 1998, 59599) and the Scope of Services. For the most part, drilling, sampling, and well construction at CdV-16-1(i) was performed as specified in the Scope. The main deviations from planned activities are summarized as follows:

- Planned borehole depth – the Scope anticipated that the borehole would be drilled to a TD of 900 ft bgs, approximately 50 ft below the regional water table that was projected to occur at 850 ft bgs. The completed CdV-16-1(i) borehole was drilled to 683 ft bgs TD, 120 ft below the measured depth of groundwater at 563 ft bgs.

- Number of core/cuttings samples – eleven (11) core samples were submitted for contaminant analysis and moisture content. The Scope indicated a total of nine (9) samples would be collected for analysis.

10.0 ACKNOWLEDGEMENTS

D. Schafer of Schafer and Associates contributed the hydrologic testing section of this report.

E. Tow, P. Schuh, and R. Lawrence of Tetra Tech EM, Inc., Albuquerque, NM, contributed to the preparation of this report.

EnviroWorks, Inc provided site preparation and restoration activities.

Lynn Engineering & Surveying, Inc. provided the final geodetic survey of finished well components.

N. Clayton of Schlumberger provided processing and interpretation of borehole geophysical data.

P. Longmire of LANL contributed the geochemistry section of this report.

Tetra Tech EM, Inc. provided support for well site geology, sample collection, and hydrologic testing.

WDC Exploration & Wells provided rotary drilling services.

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Appendix A

Groundwater Analytical Results

GROUNDWATER ANALYTICAL RESULTS

During drilling operations at borehole CdV-16-1(i), alluvial groundwater was encountered beneath Cañon de Valle. No alluvial groundwater samples were collected because this alluvial aquifer is routinely sampled as part of the TA-16 investigations. Perched groundwater was encountered at a depth of 79.1 ft bgs at CdV-16-1(i). A groundwater sample was not collected from this depth because of insufficient sample volume. A lower perched zone was encountered at a depth of 563 ft bgs. A screening groundwater sample (Sample ID # GW16-04-52692) was collected from this depth on December 12, 2003 and analyzed for high explosive (HE) compounds. Concentrations of 1,2-dinitrobenzene, HMX, and RDX were 0.329, 1.01, and 19.0 μg/L, respectively. The screening groundwater sample collected from the lower perched zone at CdV-16-1(i) borehole was lifted using a bailer.

Core samples were collected from the alluvium and Tshirege Member of the Bandelier Tuff at CdV-16-1(i). Eleven samples of core were collected from the vadose (unsaturated) zone during drilling from 5 to 200 ft bgs. Approximately 500 to 1000g of core or cuttings samples were placed in appropriate sample jars in protective plastic bags before being analyzed by EES-6, Coastal Science Laboratories, and General Engineering Laboratories (GEL). These samples were analyzed for high explosive compounds, cations, anions, and metals for characterization purposes. Core results will be in the investigation report for the Cañon de Valle watershed.

Geochemistry of Sampled Waters from Well CdV-16-1(i)

On December 16, 2003, a groundwater sample (Sample ID # GW16-04-52963) was collected after well development from the lower perched zone, within the Otowi Ash Flows, from 624 to 634 ft bgs. This sample was collected using a submersible pump. Analytical results for this groundwater sample are provided in Table A.1-1. Temperature, turbidity, and pH were determined on-site during sampling of the upper saturated zone. Both filtered (metals, trace elements, and major cations and anions) and non-filtered (tritium, TOC, and stable isotopes) samples were collected for chemical analyses. Aliquots of the samples were filtered through a 0.45-μm Gelman filter. Groundwater samples were acidified with analytical-grade HNO3 to a pH of 2.0 or less for metal and major cation analyses at EES-6. Alkalinity was determined at EES-6 using standard titration techniques.

Groundwater samples were analyzed by EES-6 using techniques specified in the U.S. Environmental Protection Agency (EPA) SW-846 manual. Ion chromatography (IC) was the analytical method for bromide, chloride, fluoride, nitrate, nitrite, oxalate, perchlorate, phosphate, and sulfate. The method detection limit (MDL) for perchlorate using IC is 0.002 ppm or mg/L (2 ppb or 2 μg/L). Perchlorate was also analyzed by General Engineering Laboratories (GEL) using the liquid chromatography/mass spectrometry/mass spectrometry (LC/MS/MS) method. This method is more sensitive than the IC method, having an MDL of 0.00005 mg/L (0.050 μg/L) and a reporting limit (RL) or quantitation limit (QL) of 0.0002 mg/L (0.2 μg/L). Inductively coupled (argon) plasma emission spectroscopy (ICPES) was used for calcium, magnesium, potassium, silica, and sodium. Aluminum, antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, nickel, selenium, silver, thallium, vanadium, uranium, and zinc were analyzed by inductively coupled (argon) plasma mass spectrometry (ICPMS). The precision limits (analytical error) for major ions and trace elements were generally less than ±10% using ICPES and ICPMS. High explosive compounds were analyzed by using the LC/MS/MS method.

Concentrations of tritium were determined by electrolytic enrichment and direct counting at the University of Miami. Stable isotopes of oxygen (oxygen-18 and oxygen-16, δ18O) and hydrogen (hydrogen and deuterium, δD) were analyzed by Geochron Laboratories (Cambridge, Massachusetts) using isotope ratio mass spectrometry (IRMS). Stable isotopes of nitrogen (nitrogen-15 and nitrogen-14, δ15N) were analyzed by EES-6 using IRMS. Analytical results for hydrogen and oxygen stable isotopes are pending for CdV-16-1(i).

Table A.1-1
Hydrochemistry of Upper Saturated Zone Groundwater at Well CdV-16-1(i) (filtered samples except as noted)

Depth (ft)	**624-634**
Geologic Unit	**Bandelier Tuff**
Date Sampled	**12/16/03**
Sample ID No.	**GW16-04-52693**
pH	6.45
Temperature (°C)	13.3
Specific Conductance (μS/cm)	Not reported
Turbidity (NTU)	4.21
Alkalinity (ppm $CaCO_3$/L)	54.5
Al (ppm)	1.23
Sb (ppm)	[0.001], U
As (ppm)	0.0009
B (ppm)	0.050
Ba (ppm)	0.024
Be (ppm)	[0.001], U
HCO_3 (ppm)	66.5
Br (ppm)	0.18
Cd (ppm)	[0.001], U
Ca (ppm)	11.0
Cl (ppm)	4.91
ClO_4 (mg/L) (LC/MS/MS)	Results pending
ClO_4 (ppm) (IC)	[0.002], U
Cr (ppm)	0.0018
Co (ppm)	[0.001], U
Cu (ppm)	0.0079
F (ppm)	0.06
Fe (ppm)	0.59
Pb (ppm)	0.0015
Mg (ppm)	4.53
Mn (ppm)	0.034
Hg (ppm)	[0.00005], U

Table A.1-1 (Continued)
Hydrochemistry of Upper Saturated Zone Groundwater at Well CdV-16-1(i) (filtered samples except as noted)

Mo (ppm)	0.0031
Ni (ppm)	0.002
NO_3 (ppm) (as N)	0.65
NO_2 (ppm) (as N)	[0.01], U
C_2O_4 (ppm) (oxalate)	[0.01], U
PO_4 (ppm) (as P)	0.01
K (ppm)	1.72
Se (ppm)	[0.001], U
Ag (ppm)	[0.0002], U
Na (ppm)	13.4
SiO_2 (ppm)	69.8
Sr (ppm)	0.085
SO_4 (ppm)	9.92
Tl (ppm)	[0.001], U
U (ppm)	0.0014
V (ppm)	0.004
Zn (ppm)	0.055
TOC (ppm), non filtered	1.61
RDX (μg/L), non filtered	Results pending
HMX (μg/L), non filtered	Results pending
TDS (ppm) (calculated)	194
$\delta^{15}N$ (‰), non filtered	+5.39 ±1.16
δD (‰), non filtered	Results pending
$\delta^{18}O$ (‰), non filtered	Results pending

Note: U = not detected. Silica concentrations were calculated from measured silicon (ICPES). Bicarbonate concentrations were calculated from measured alkalinity. TOC = total organic carbon. TDS = total dissolved solids ‰ = permil.

Appendix B

Borehole Video
(DVDs included)

Appendix C

Schlumberger Geophysical Report and Montages
(CD included)

TABLE OF CONTENTS

1.0 SUMMARY

This report describes the borehole geophysical logging measurements acquired in characterization well CdV-16-1(i) by Schlumberger, logged in November 2003 prior to well completion. The report (1) summarizes the technology, measurements, and procedures employed, and (2) presents the processed results from these measurements and discusses their interpretation. The logging suite was acquired from 30 ft to 686 ft below ground surface, when the borehole was open below 12 ft, drilled with 12.25 in diameter bit size, and contained 13.375 in outer diameter freestanding steel casing above 12 ft.

The primary purpose of the geophysical logging was to characterize the geologic/hydrogeologic section intersected by the well with emphasis on determining regional aquifer groundwater level, perched groundwater zones, moisture content, capacity for flow, and the stratigraphy/mineralogy of geologic units. A secondary purpose of the geophysical logging was to evaluate the borehole conditions such as borehole diameter versus depth, deviation versus depth, and degree of drilling fluid invasion. These objectives were accomplished by measuring, nearly continuously, along the length of the well: (1) total and effective water-filled porosity and pore size distribution, from which an estimate of effective water hydraulic conductivity is made, (2) bulk density (sensitive to total water- plus air-filled porosity), (3) bulk electrical resistivity at multiple depths of investigation, (4) bulk concentrations of a number of important mineral-forming elements, (5) spectral natural gamma ray, including potassium, thorium, and uranium concentrations, (6) bedding and fracture orientation, fracture aperture, and geologic texture, (7) borehole inclination and azimuth, and (8) borehole diameter.

Preliminary results of these measurements were generated in the logging truck at the time the geophysical services were performed and are documented in field logs provided on-site. However, the measurements presented in the field results are not fully corrected for borehole conditions and are provided as separate, individual logs. The field results were reprocessed by Schlumberger to (1) correct/improve the measurements, as best as possible, for borehole/formation environmental conditions, (2) perform an integrated analysis of the log measurements so that they are all coherent, and (3) combine the logs in a single presentation, enabling integrated interpretation. The reprocessed log results provide better quantitative property estimates that are consistent for all applicable measurements, as well as estimates of properties that otherwise could not be reliably estimated from the single measurements alone (e.g. total porosity inclusive of all water and air present, water saturation, mineralogy).

The geophysical log measurements from Well CdV-16-1(i) provide good quality results that are consistent with each other through most of the borehole. The quality of some measurements was degraded across intervals where the borehole contains large washouts and/or rugose hole. The measurements most affected by the adverse borehole conditions were ones that have a shallow depth of investigation and require close contact to the borehole wall—the bulk density, photoelectric effect, and the porosity measurements. The greatest impact on the log processing was erroneously high estimated porosity in the problem zones. Through the integrated analysis and interpretation of all the logs, the individual shortcomings of the specific measurements are reduced. Thus, the integrated log analysis results (e.g. the optimized water-filled porosity log) are the most robust single representation of the geophysical log results—providing a wealth of valuable high resolution information on the geologic and hydrogeologic environment of the CdV-16-1(i) locale.

Important results from the processed geophysical logs in CdV-16-1(i) include the following:

1. The well water level was stable throughout the logging acquisition, remaining between 568–569 ft below ground surface for all four logging runs.

2. The processed logs do not indicate that the bottom of the borehole section that was logged (maximum depth of 666 ft below ground surface) is fully saturated with water. Both total and moveable water content steadily increase below 520 ft (especially below the standing water level at 569 ft), reaching 35% and 10–15% of total rock volume, respectively, near the bottom. However, the total porosity of the volcanic tuff is very high (45%), and , thus, water saturation never reaches above about 85% (defined as percent of pore space filled with water). As a result of the high total and moveable water content, the log-estimated hydraulic conductivity is as high as two gal/day/ft^2 across this interval.

3. Two very large, near-vertical fractures are clearly delineated from the electrical imaging log at 598 ft and 626 ft. The fractures dip around 85 degrees towards the northeast and northwest. The estimated aperture of these fractures is close to one inch – suggesting they could be significant conduits for flow if they extend much beyond the borehole.

4. The processed logs do not indicate any significant fully water saturated (perched) zones above the standing water level (659 ft). Water content and estimated water saturation generally decreases above this depth up to 305 ft. Above 305 ft water content and saturation is highly variable. The highest total and moveable water content occurs in the zone 258 – 302 ft, ranging 20–40% and 5–20%, respectively.

5. The processed logs indicate that relatively significant amounts of clay are present in the following zones: 42–90 ft, 215–230 ft, and 238–247 ft. In general, the processed logs indicate the presence of minor amounts of clay above 308 ft.

6. Interpreted bed boundaries across the imaged interval 580–690ft have variable dip azimuths (direction beds are dipping to), the greatest clustering to the northwest and southwest, and dip angles (angle from horizontal) less than 10 degrees.

2.0 INTRODUCTION

Geophysical logging services were performed in characterization well CdV-16-1(i) by Schlumberger in November 2003, prior to initial well completion. The purpose of these services was to acquire in situ measurements that help characterize the borehole, near-borehole, and abutting geologic formation environment. The primary objective of the geophysical logging was to provide in situ evaluation of formation properties (hydrogeology and geology) intersected by the well. This information was (and is) used by scientists, engineers, and project managers in the Los Alamos Characterization and Monitoring Well Project to design the well completion, better understand subsurface site conditions, and assist in overall decision-making.

The primary geophysical logging services performed by Schlumberger in well CdV-16-1(i) were the:

- Combinable Magnetic Resonance (CMR*) tool to measure the nuclear magnetic resonance response of the formation, which is used to evaluate total and effective water-filled porosity of the shallow formation and to estimate pore size distribution and in-situ hydraulic conductivity;
- Compensated Neutron Tool (CNT*) to measure volumetric water content of the formation, which is used to evaluate moist/porous zones;
- Triple detector Litho-Density (TLD*) tool to measure formation bulk density and photoelectric factor, which are used to estimate total porosity and lithology;
- Array Induction Tool, (AIT*) to measure formation electrical resistivity at five depths of investigation and borehole fluid resistivity, which is used to evaluate drilling fluid invasion into the formation (an indicator of relative permeability and water saturation), presence of moist zones far from the borehole wall, and presence of clay-rich zones;
- Formation Micro-Imager (FMI*) tool to measure electrical conductivity images of the borehole wall in fluid-filled open hole and borehole diameter with a two-axis caliper – used for evaluating geologic bedding and fracturing, including strike and dip of these features and fracture apertures, and rock texture;
- General Purpose Inclinometry Tool (GPIT*) to measure borehole deviation and azimuth in OH – used to evaluate borehole position versus depth and to orient FMI images;
- Natural Gamma Spectroscopy (NGS) tool to measure gross natural gamma and spectral natural gamma ray activity, including potassium, thorium, and uranium concentrations, which is used to evaluate geology/lithology, particularly the amount of clay and potassium-bearing minerals;
- Elemental Capture Spectroscopy (ECS*) tool to measure elemental weight percent concentrations of a number of elements – used to characterize mineralogy and lithology of the formation

*Mark of Schlumberger

In addition, calibrated gross gamma ray (GR) was recorded with every service except the NGS, for the purpose of depth matching the logging runs to each other. Table 2.1 summarizes the geophysical logging runs performed in CdV-16-1(i).

Table 2.1
Geophysical logging services, their combined tool runs and intervals logged, as performed by Schlumberger in borehole CdV-16-1(i)

Date of Logging	Borehole Status	Run #	Tool 1	Tool 2	Tool 3	Depth Interval (ft)
7-Nov-2003	Open hole below 12 ft. Bit size of 12.25 in. Steel casing above 12 ft. Casing OD of 13.375 in.	1	FMI	GPIT	GR	580–690ft
Same	Same	2	ECS	CMR	GR	55–686 ft
Same	Same		AITH	NGS		30–680 ft
Same	Same	1	TLD	CNT	GR	42–680 ft

A description of these geophysical logging tools can be found on the Schlumberger website (http://www.hub.slb.com/index.cfm?id=id11618).

3.0 METHODOLOGY

This section describes the methods employed by Schlumberger for performed geophysical logging services in Well CdV-16-1(i), including the following stages/tasks:

- Measurement acquisition at the well site
- Quality assessment of logs
- Reprocessing of field data

3.1 Acquisition procedure

Once the well drilling project team notified Schlumberger that CdV-16-1(i) was ready for geophysical well logging, the Schlumberger district in Farmington, NM, mobilized a wireline logging truck, the appropriate wireline logging tools and associated equipment, and crew to the job site. Upon arriving at the LANL site, the crew completed site entry paperwork and received a site-specific safety briefing.

After arriving at the well site, the crew proceeded to rig up the wireline logging system, including:

- Parking and stabilizing the logging truck in a position relative to the borehole that is best for performing the surveys;
- Setting up a lower and an upper sheave wheel (the latter attached to, and hanging above, the borehole from the drilling rig/mast truck);

- Threading the wireline cable through the sheaves; and
- Attaching the appropriate sonde(s) for the first run to the end of the cable.

Next, pre-logging checks and any required calibrations were performed on the logging sondes and the tool string was lowered into the borehole. If any of the tools required active radioactive sources (in this case a neutron and gamma source for the CNT/ECS and TLD, respectively), just prior to lowering the tool string the sources were taken out of their carrying shields and placed in the appropriate tool source-holding locations using special source handling tools. The tool string was lowered to the bottom of the borehole and brought up at the appropriate logging speed as measurements were made. At least two logging runs (one main and one repeat) were made with each tool string.

Upon reaching the surface any radioactive sources were removed from the tools and returned to their appropriate storage shields, thus eliminating any radiation hazards. Any post-logging measurement checks were performed as part of log quality control and assurance. The tool string was cleaned as it was pulled out of the hole, separated and disconnected.

The second tool string was attached to the cable for another logging run, followed by subsequent tool strings and logging runs. After the final logging run was completed the cable and sheave wheels were rigged down.

Before departure, the logging engineer printed field logs for on site distribution and sent the data via satellite to the Schlumberger data archiving center. The Schlumberger data processing center was alerted that the data were ready for post-acquisition processing.

3.2 Log Quality Control and Assessment

Schlumberger has a thorough set of procedures and protocols for ensuring that the geophysical logging measurements are of very high quality. This includes full calibration of tools when they are first built, regular recalibrations and tool measurement/maintenance checks, and real-time monitoring of log quality as measurements are made. Indeed, one of the primary responsibilities of the logging engineer is to ensure, before and during acquisition, that the log measurements meet prescribed quality criteria.

A tool specific base calibration that directly relates the tool response to the physical measurement using the designed measurement principle is performed on all Schlumberger logging tools when first assembled in the engineering production centers. This is accomplished through a combination of computer modeling and controlled measurements in calibration models with known physical parameters.

The base calibration is augmented through regular "master calibrations" for most Schlumberger tools – typically performed every one to six months in local Schlumberger shops (such as Farmington, NM), depending on tool design. Master calibrations consist of controlled measurements using specially designed calibration tanks/jigs and internal calibration devices that are built into the tools. The measurements are used to fine-tune the tool's calibration parameters and to verify that the measurements are valid.

In addition, on every logging job, on-site before and after "calibrations" are executed for most Schlumberger tools directly before/after lowering/removing the tool string from the borehole.

For most tools these represent a measurement verification instead of an actual calibration – used to confirm the validity of the measurements directly before acquisition and to ensure that they have not drifted or been corrupted during the logging job.

All Schlumberger logging measurements have a number of associated depth-dependent quality control (QC) logs and flags to assist with identifying and determining the magnitude of log quality problems. These QC logs are monitored in real-time by the logging engineer during acquisition and are used in the post-acquisition processing of the logs to determine the best processing approach for optimizing the overall validity of the property estimates derived from the logs.

Additional information on specific tool calibration procedures can be found on the Schlumberger web page (http://www.hub.slb.com/index.cfm?id=id11618).

3.3 Processing Procedure

After the geophysical logging job was completed in the field and the data archived, the data were downloaded to the Schlumberger processing center. There the data were processed, in the order below, to (1) correct the measurements for near-wellbore environmental conditions and redo the raw measurement field processing for certain tools using better processing algorithms, (2) depth match the log curves from different logging runs, and (3) model the near-wellbore substrate lithology/mineralogy and pore fluids through integrated log analysis. Separately, the FMI electrical image was processed to produce scaled and normalized high-resolution images that were interpreted to identify geologic features and compute fracture apertures. Afterwards an integrated log montage was built to combine and compile all the processed log results.

Environmental Corrections and Raw Measurement Reprocessing

If required, the field log measurements were processed to correct for conditions in the well, including fluid type (drilling mud or air), presence of steel casing, and (to a much lesser extent) pressure, temperature, and water salinity. Basically these environmental corrections entail subtracting from the measurement response the known influences of the set of prescribed borehole conditions. In CdV-16-1(i) the log measurements requiring these corrections are the CNT porosity, TLD density, and NGS spectral gamma ray logs.

Two CNT neutron porosity measurements are available – one that measures thermal ("slow") neutrons and one that measures epithermal ("fast") neutrons. Measurement of epithermal neutrons is required to make neutron porosity measurements in air-filled hole. In water/mud filled hole both the CNT epithermal and thermal neutron measurements are valid, but the thermal neutron porosity has better statistical precision. Both epithermal and thermal neutron porosity measurements were made in CdV-16-1(i) since the borehole was partly water-filled (below 568 ft) and partly air-filled (above 568 ft). Epithermal neutron porosity was processed at the field site for borehole fluid type (air versus water), and other environmental conditions, and didn't require any further processing. The thermal neutron porosity measurement was reprocessed for borehole conditions, although the results were very similar to the field logs. Thus, for further processing and analysis (e.g. ELAN analysis), the reprocessed thermal neutron porosity log was used, in addition to the field processed epithermal neutron porosity log.

The NGS spectral gamma ray are affected by the material (fluid, air, casing) in the borehole because different types and amounts of these materials have different gamma ray shielding properties; the NGS measures incoming gamma rays emitted by radioactive elements in the formation surrounding the borehole. The processing algorithms try to correct for the damping influence of the borehole material. The NGS logs from CdV-16-1(i) were reprocessed to fully account for the environmental effects of the borehole fluid (drilling mud and air) and hole size.

The measurements cannot be fully corrected for borehole washouts or rugosity, since the specific characteristics of these features (e.g., geometry) are unknown and their effects on the measurements often too significant to account for. Thus, the compromising effects of these conditions on the measurements should be accounted for in the interpretation of the log results.

Depth-Matching

Once the logs were environmentally corrected for the conditions in the borehole and the raw measurement reprocessing was completed, the logs from different tool runs were depth-matched to each other using the AIT-NGS tool run as the base reference. Gamma ray was used as the common correlation log measurement for depth-matching the different runs.

Integrated Log Analysis

An integrated log analysis, using as many of the processed logs as possible, was performed to model the near-wellbore substrate lithology/mineralogy and pore fluids. This analysis was performed using the Elemental Log Analysis (ELAN[*]) program (Mayer and Sibbit, 1980; Quieren et al, 1986) – a petrophysical interpretation program designed for depth-by-depth quantitative formation evaluation from borehole geophysical logs. ELAN estimates the volumetric fractions of user-defined rock matrix and pore constituents at each depth based on the known log measurement responses to each individual constituent by itself[1]. ELAN requires an a priori specification of the volume components present within the formation—fluids, minerals, and rocks. For each component, the relevant response parameters for each measurement are also required. For example, if one assumes that quartz is a volume component within the formation and the bulk density tool is used, then the bulk density parameter for this mineral is well known to be 2.65 g/cc.

The logging tool measurements, volume components, and measurement response parameters used in the ELAN analysis for CdV-16-1(i) are provided in Table 3.1. The final results of the analysis – an optimized mineral-fluid volume model – are shown on the integrated log montage, 3rd track from the right (inclusive of the depth track). To make best use of all the measurement data and to perform the analysis across as much of the well interval as possible (42–666 ft), as many as possible of the processed logs were included in the analysis, with less weighting applied to less robust logs. Not all the tool measurements shown in Table 3.1 are used for the entire interval analyzed, as not all the measurements are available, or of good quality, across certain sections of the borehole. To accommodate fewer tool measurements certain model constituents are removed from the analysis in a few intervals. Most notably, at the top of the log interval

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[1]Mathematically this corresponds to an inverse problem – solving for constituent volume fractions from an (over)determined system of equations relating the measured log results to combinations of the tool measurement response to individual constituents

(above 55 ft) there is no CMR or ECS logs, requiring the removal of capillary bound water from the ELAN model (since CMR is the only tool that measures that property), as well as a number of minerals (since the ECS provides the most information about matrix geochemistry).

The ELAN analysis was performed with as few constraints or prior assumptions as possible. A considerable effort was made to choose a set of minerals or mineral types for the model that is representative of Los Alamos area geology and it's volcanic origins. For the ELAN analysis, the log interval in CdV-16-1(i) was assumed to be entirely within the Bandelier Tuff and a mineral suite considered representative of this volcanic tuff was used (primary "minerals" silica glass, quartz, sanidine, and montmorillinite with accessory minerals augite, calcite, and pyrite). In addition, information from the project geologists about intersected units within the Bandelier Tuff (glassy versus crystalline tuff units) was used to constrain the proportion of quartz versus glass in the ELAN analysis. The results of laboratory analyses of Bandelier Tuff core samples from around the LANL site was used to determine the representative mineral suite and quartz-glass proportions.

No prior assumption is made about water saturation—where the boundary between saturated and unsaturated zones lies (e.g. the depth to the top of the regional aquifer or perched zones). Thus, the presence and amount of air in the pore space is unconstrained. Total porosity and water-filled porosity are also left unconstrained throughout the analysis interval. Thus, interpretations should be made from the ELAN results with the understanding that the mineral-fluid model represents a mathematically optimized solution that is not necessarily a physically accurate representation of the native geologic formation. Within this context, the ELAN model is a robust estimate of the bulk mineral-fluid composition that accounts for the combined response from all the geophysical measurements.

Table 3.1
Tool measurements, volumes, and respective parameters used in the CdV-16-1(i) ELAN analysis .

Volume / **Tool Measurement**	**Air**	**Capillary Bound Water**	**Water**	**Silica Glass**	**Augite**	**Montmorillinite**	**Pyrite**	**Sanidine**	**Calcite**	**Quartz**
Bulk density (g/cc)	–0.16	1.00	1.00	2.33	3.08	2.1	4.99	2.56		2.64
Epithermal neutron porosity (ft^3/ft^3)	0.03	1.00	1.00	0.0	-0.01	0.6	0.17	-0.01	0.0	-0.04
Thermal neutron porosity (ft^3/ft^3)	0.07	1.00	1.00	0.0	0.02	0.65	0.01	-0.01	0.0	-0.07
Volumetric photoelectric effect	0	0	0.40	4.2	23.8	4.4	82.1	7.0	14.1	4.8
Total CMR water-filled porosity (ft^3/ft^3)	0	1.0	1.0	0	0	0.425	0	0	0	0
CMR bound fluid volume (ft^3/ft^3)	0	1.0	0	0	0	0.425	0	0	0	0
Resistivity (ohm-m)	Very high	91	91	Very high	Very high	1.4	Very high	Very high	Very high	Very high
Dry weight silicon (lbf / lbf)	0.0	0.0	0.0	0.47	0.23	0.26	0	0.38	0	0.47
Dry weight calcium (lbf / lbf)	0.0	0.0	0.0	0.0	0.10	0.01	0.0	0.0	0.405	0.0
Dry weight iron (lbf / lbf)	0.0	0.0	0.0	0.0	0.11	0.04	0.47	0.02	0.0	0.0
Dry weight sulfur (lbf / lbf)	0.0	0.0	0.0	0.0	0.0	0.0	0.53	0.0	0.0	0.0
Dry weight aluminum (lbf / lbf)	0.0	0.0	0.0	0.0	0.02	0.11	0.0	0.10	0.0	0.0
Wet weight potassium (lbf / lbf)	0.0	0.0	0.0	0.0	0.003	0.005	0.0	0.102	0.0	0.0
Weight water (lbf / lbf)	0.0	1.0	1.0	0.0	0.0	0.18	0.0	0.0	0.0	0.0

4.0 RESULTS

Preliminary results from the wireline geophysical logging measurements acquired by Schlumberger in CdV-16-1(i) were generated in the logging truck at the time the geophysical services were performed and are documented in field logs provided on-site. However, the measurements presented in the field results are not fully corrected for undesirable (from a measurement standpoint) borehole and geologic conditions and are provided as separate, individual logs. The field log results have been processed (1) to correct/improve the measurements, as best as possible, for borehole/formation environmental conditions and (2) to depth-match the logs from different tool runs in the well. Additional logs were generated from integrated analysis of processed measured logs, providing valuable estimates of key geologic and hydrologic properties.

The processed log results are presented as continuous curves of the processed measurement versus depth and are displayed as (1) one page, compressed summary log displays for selected directly related sets of measurements (see Figures 4.1, 4.2, and 4.3) and (2) an integrated log montage that contains all the key processed log curves, on depth and side by side. The summary log displays address specific characterization needs, such as moisture content, water saturation, and lithologic changes. The purpose of the integrated log montage is to present, side by side, all the most salient reprocessed logs and log-derived models, depth-matched to each other, so that correlations and relationships between the logs can be identified.

Important results from the processed geophysical logs in CdV-16-1(i) are described below.

Well Water Level

The standing water level in CdV-16-1(i) was stable during the November 7, 2003 logging, remaining between 568–569 ft below ground surface for all four logging runs.

Regional Aquifer

The processed geophysical log results suggest that CdV-16-1(i) does not penetrate a fully water-saturated zone at the bottom of the primary log interval (666 ft). While the estimated pore volume water saturation[2] computed from the ELAN integrated log analysis increases below 520 ft, particularly below the well standing water level (569 ft), the maximum water saturation is 80–88% near the bottom of the well. Estimated water saturation computed directly from bulk density and water content – over the likely maximum possible range of grain density for the volcanic tuff (2.25–2.65 g/cc) – also never reaches 100%. The steady increase in water saturation below 520 ft is due to an increase in estimated water-filled porosity, from 20% at 520 ft to about 35% at the bottom of the well, while total porosity[3] remains relatively constant at 40–45%. Moveable water content (effective porosity) increases as well, from approximately 5% of total rock volume at 560 ft to 10–15% at the bottom of the well. These results suggest that the geologic section below the standing well water level (569 ft) contains a significant amount of water and the water is mobile, but the high porosity tuff might not be fully saturated. These

[2] Water saturation is defined in this report as the volumetric fraction of the total pore space occupied by water – the rest being occupied by air.

[3] Water-filled porosity is defined in this report as the fraction of the total rock volume occupied by water. Total porosity is defined as fraction of the total rock volume occupied by water plus air, plus any other fluid or gas (non-solid).

conditions would not preclude water flow from the formation into the well. Water-phase hydraulic conductivity, estimated from the ELAN analysis, varies mostly between about 0.1–2 gal/day/ft^2 across this interval. Also two very large, near-vertical fractures in the tuff are clearly delineated from the FMI image at 598 ft and 626 ft. The estimated aperture of these fractures is close to one inch – suggesting they are significant conduits for flow if they extend much beyond the borehole.

Vadose Zone Perched Water

As noted above, the processed geophysical logs suggest that the Regional Aquifer likely is not penetrated by CdV-16-1(i) and, thus, the entire depth interval corresponds to the vadose zone. Hydrogeologic observations and interpretations from the processed logs are provided below for the logged interval, from bottom to top.

520–666 ft:
As described above, the interval at the bottom of the well has high water-filled porosity and water saturation – generally increasing with depth below 520 ft and peaking at approximately 35–40% and 80–85% of total rock volume, respectively, in the interval 620–660 ft. Moveable water content follows the same trend, peaking at 10–15% of total rock volume across the same interval.

458–520 ft:
In the interval 458–520 ft the ELAN estimated water saturation is relatively constant at 50% of total rock volume. Water-filled and total porosity averages about 24% and 48%, respectively, as estimated from the ELAN analysis. Moveable water content averages a low 2–3% of total rock volume across this interval.

310–458 ft:
The interval 310–458 ft is characterized by a lower water content than the section below , averaging 15%, and a correspondingly lower water saturation ranging mostly 25–35%. Total porosity ranges 37–45%. Moveable water content is slightly higher than below – about 3–4% increasing to 4–5% above 360 ft.

302–310 ft:
The interval 302–310 ft is characterized by a sharp decrease in total porosity to 30% of total rock volume. However, water-filled porosity and moveable water content remain similar to the zone directly below (14% and 4%, respectively).

258–302 ft:
This interval is characterized by very high porosity, that is highly variable (40–60%), and high water-filled porosity and moveable water content, both of which are also highly variable (20–40% and 5–20%, respectively). Water saturation ranges 35–70%.

244–258 ft:
Total and water-filled porosity are significantly lower than above and below – dropping to 22% and 10%, respectively. Moveable water content is also low (about 4%).

208–244 ft:
Total and water-filled porosity are both high, and highly variable, in this interval – generally ranging 40–60% and 25–33%, respectively. There is a thin zone (218–222 ft) with sharply lower

porosity – 25% and 10% total and water-filled porosity, respectively. Porosity jumps up again above this zone, but starts dropping steadily to the top of the interval at 208 ft. Moveable water content is highest from 228–238 ft, reaching 5–12%.

<u>94–208 ft</u>:
Total porosity decreases steadily from 208 ft to 150 ft, dropping to 13%. Water-filled porosity and moveable water content remains between 6–8% and 2–3%, respectively. At 148 ft the porosity sharply increases to then steadily decreases again in the upward direction, dropping to 8% at 102 ft. Similarly, water-filled porosity peaks at 11% then generally decreases upward, dropping to 5% by 102 ft.

<u>42–94 ft</u>:
This interval is characterized by higher total and water-filled porosity than the interval below (28–38% and 10–22%, respectively), but there is a very large borehole washout across the whole interval that could be causing elevated porosity measurements.

Geology

The processed geophysical log results delineate the geologic material and many of the formation contacts intersected by CdV-16-1(i). The generalized geologic stratigraphy observed from the logs – independent of any other information – across the logged interval is as follows (depth below ground surface):

- **<u>42–94 ft</u>: Clay-rich, porous volcanic tuff** – characterized by moderately high total porosity (25–40% of total rock volume), high sanidine and silica glass content, moderate quartz content, and clay content as high as 15% of total volume.
- **<u>94–165 ft</u>: Low porosity volcanic tuff** – characterized by low total porosity (13–25% of total rock volume), high sanidine and silica glass content, moderate quartz content, and minor, but consistent, amounts of clay
- **<u>165–230 ft</u>: Porous volcanic tuff** – characterized by moderately high total porosity (25–40% of total rock volume), high sanidine and silica glass content, moderate quartz content, and minor amounts of clay (especially at bottom of interval)
- **<u>230–244 ft</u>: Very high porosity, heterogeneous volcanic pumice/tuff** – characterized by very high total porosity (47–60% of total rock volume), high sanidine and silica glass content
- **<u>244–258 ft</u>: Clay-rich, lower porosity volcanic tuff** – characterized by relatively low total porosity (20–30% of total rock volume), high sanidine and silica glass content, and clay content as high as 15% of total volume
- **<u>258–302 ft</u>: Very high porosity, heterogeneous volcanic pumice/tuff** – characterized by very high total porosity (40–65% of total rock volume), high sanidine and silica glass content, and minor amounts of clay
- **<u>302–310 ft</u>: Porous volcanic tuff** – characterized by moderately high total porosity (30–35% of total rock volume), high sanidine and silica glass content

- **310–458 ft: High porosity volcanic tuff** – characterized by high total porosity (37–45% of total rock volume), high sanidine and silica glass content, and minor amounts of clay
- **458–520 ft: Very high porosity volcanic pumice/tuff** – characterized by very high total porosity (48% of total rock volume), high sanidine and silica glass content, and very small amounts of clay
- **520–666 ft: High porosity volcanic tuff** – characterized by high total porosity (40–45% of total rock volume), high sanidine and silica glass content, and trace amounts of clay

4.1 Summary Logs

Three summary log displays have been generated for CdV-16-1(i) to highlight the key hydrogeologic and geologic information provided by the processed geophysical log results:

- Porosity summary log showing continuous hydrogeologic property logs, including total and moveable water content and water saturation – to highlight hydrologic information obtained from the integrated log results (Figure 4.1)
- Density and clay content summary showing a continuous logs of formation bulk density and estimated grain density, as well as photoelectric factor (sensitive to mineralogy) and estimated clay volume – to highlight key geologic rock matrix information obtained from the log results (Figure 4.2)
- Spectral natural gamma ray and lithology summary showing a high vertical resolution, continuous volumetric analysis of formation mineral and pore fluid composition (based on an integrated analysis of the logs) and key lithologic/stratigraphic correlation logs from the spectral gamma ray measurement (concentrations of gamma-emitting elements) – to highlight the geologic lithology, stratigraphy and correlation information obtained from the log results (Figure 4.3)

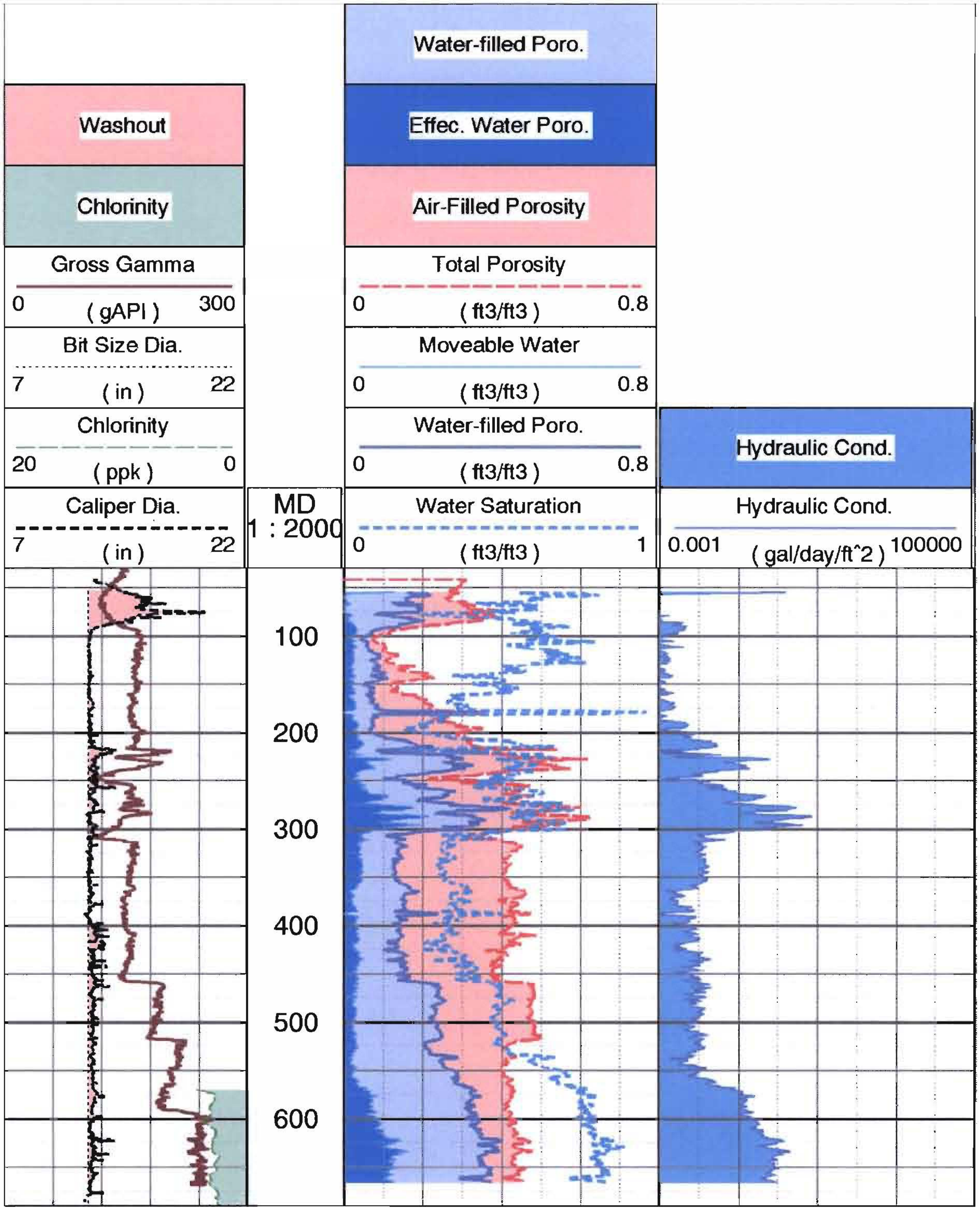

Figure 4.1. Summary porosity logs in CdV-16-1(i) borehole from processed geophysical logs, interval 42–666 ft, with caliper, gross gamma, apparent chlorinity, water saturation, and water hydraulic conductivity logs. Porosity, water saturation, and hydraulic conductivity logs are derived from the ELAN integrated log analysis.

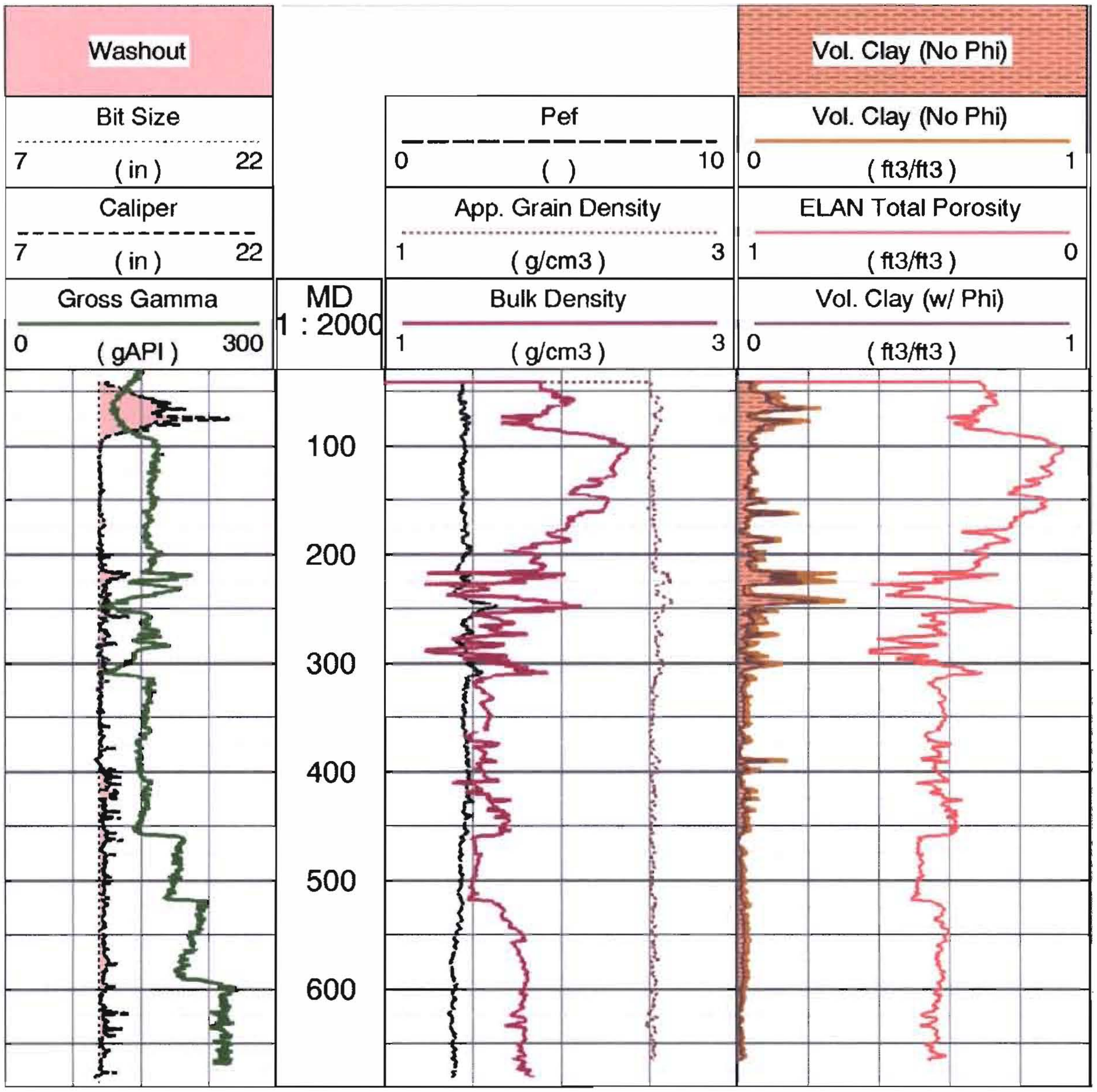

Figure 4.2. Summary bulk density and volume clay logs in CdV-16-1(i) borehole from processed geophysical logs, interval 42–680 ft. Also shown – caliper, gross gamma, apparent grain density, and total porosity logs (the latter two derived from the ELAN analysis).

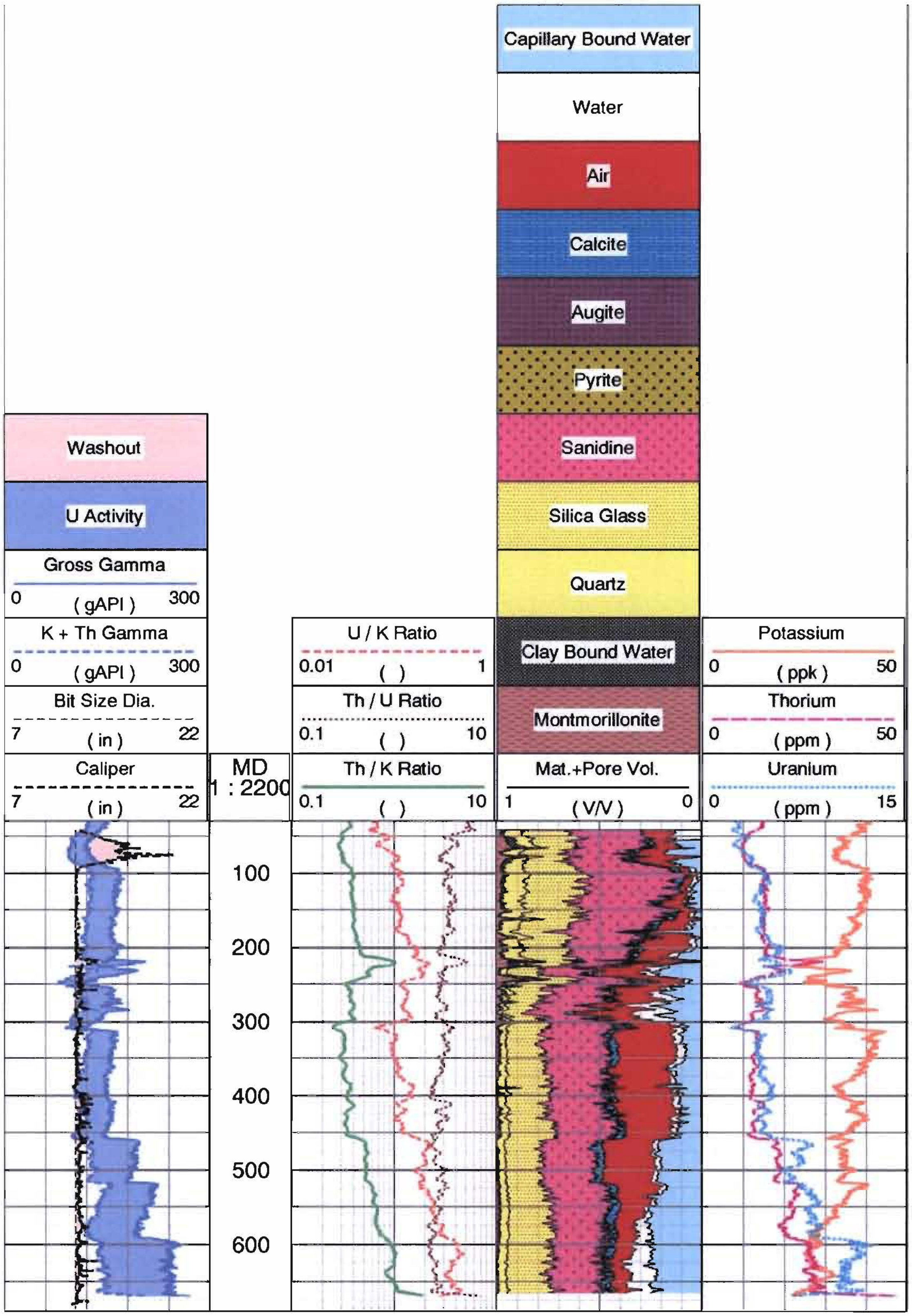

Figure 4.3. Summary spectral natural gamma ray logs and ELAN mineralogy/lithology and pore fluid model from CdV-16-1(i) borehole, interval 42–666 ft. Caliper log is also shown.

4.2 Integrated Log Montage

This section summarizes the integrated geophysical log montage for CdV-16-1(i). A description of each log curve in the montage follows—organized under the heading of each track, starting from track 1 on the left-hand side of the montage. Note that the descriptions in this section focus on what the curves are and how they are displayed; the specific characteristics and interpretations of the CdV-16-1(i) geophysical logs are provided in the previous section.

Track 1–Depth

The first track on the left contains the depth below ground surface in units of feet, as measured by the geophysical logging system during the AIT logging run. All the geophysical logs are depth-matched to the spectral gross gamma measurement run with the AIT.

Track 2–Basic Logs

The second track on the left (inclusive of the depth track) presents basic curves:

- gamma ray (thick black), recorded in API units and displayed on a scale of 0 to 300 API units;
- two calipers from the FMI (thin dotted and dashed pink) and one from the TLD (thin solid pink) with bit size as a reference (dashed-dotted black) to show washout (pink shading), recorded as hole diameter in inches and displayed on a scale of 10 to 20 in.;
- spontaneous potential or SP (dashed red – valid only below the borehole water level), recorded in millivolts and displayed on a relative scale;
- bulk chlorinity (dashed green with green shading), recorded in parts per thousand (ppk) and displayed on a scale of 10 to 0 ppk (left to right);
- borehole deviation displayed as a tadpole every ten feet (light blue dots and connected line segments) – the "head" marks the angular deviation from vertical at that particular depth, on a scale of zero to 5 degrees, and the "tail" shows the azimuth of the deviation, true north represented by the tail facing straight towards the top of the page.

Two gamma ray curves from the NGS are presented:

- total gross gamma (thick solid black curve) and
- gross gamma minus the contribution of uranium (dashed black).

Track 3–Resistivity

The third track displays the resistivity measurements from the AIT, spanning most of the open hole section. All the resistivity logs are recorded in units of ohmmeters and displayed on a logarithmic scale of 2 to 2000 ohm-m.

Six electrical resistivity logs from the AIT are displayed:

- Borehole fluid resistivity (solid orange curve)–only valid in water-filled hole

- Bulk electrical resistivity at five median depths of investigation–10 in. (black solid), 20 in. (long-dashed blue), 30 in. (short-dashed red), 60 in. (dashed-dotted green), and 90 in. (solid purple)–each having a two-foot vertical resolution.

The area between the 10 in. and 90 in. resistivity curves, representing radial variations in bulk resistivity (potentially from invasion of drilling fluids), is shaded:

- blue when the 10 in. resistivity is greater than the 90 in. resistivity (labeled "resistive invasive") and

- yellow when the 90 in. resistivity is greater than the 10 in. resistivity (labeled "conductive invasive").

A high vertical resolution (~8 in.), shallow-reading (~2 in.) micro-resistivity log from the MCFL is also displayed in this track (solid pink curve).

Track 4–Porosity

The fourth track displays the primary porosity log results. All the porosity logs are recorded in units of volumetric fraction and displayed on a linear scale of 0.75 (left side) to negative 0.1 (right side). Specifically, these logs consist of

- CNT water-filled borehole thermal neutron porosity (solid sky blue curve)–thermal neutron porosity valid only in the water-filled borehole;

- CNT epithermal neutron porosity (solid light blue curve)–epithermal neutron porosity processed for both air-filled and water-filled hole;

- CMR total water-filled porosity (solid black);

- CMR effective water-filled porosity (dashed green);

- CMR bound water porosity (light blue area shading)–representing by the area between the CMR total and effective water-filled porosities;

- Total porosity derived from bulk density and ELAN water-filled porosity using 2.65 g/cc (dotted red curve), 2.45 g/cc (long-dashed red curve), and 2.25 g/cc (dashed red curve)–with red shading between the 2.25 and 2.65 g/cc saturation curves to show the range; and

- ELAN water-filled porosity (dashed-dotted cyan)–derived from the ELAN integrated analysis of all log curves to estimate optimized matrix and pore volume constituents.

Track 5–Density

The fifth track displays the:

- bulk density (thick solid maroon curve) on a scale of 1 to 3 grams per cubic centimeter (g/cc);

- Pe (long-dashed black curve) on a scale of 0 to 10 non-dimensional units;

- density correction (dashed orange curve) on a scale of -0.75 to 0.25 g/cc; and

- apparent grain density (dashed-dotted brown curve), derived from the ELAN analysis, on a scale of 2 to 4 g/cc.

Grey area shading is shown where the Pe increases above 3 (indicating the presence of heavy, possibly mafic, minerals) and orange shading is shown where the density correction is greater than the absolute value of 0.25 (indicating the density processing algorithm had to perform a major correction to the bulk density calculation).

Track 6–NGS Spectral Gamma

The sixth track from the left displays the spectral components of the NGS measurement results as wet weight concentrations:

- potassium (solid green curve) in units of parts per thousand (ppk) and on a scale of -50 to 50 ppk;
- thorium (dashed brown) in units of parts per million (ppm) and on a scale of 50 to -50 ppm; and
- uranium (dotted blue) in units of parts per million (ppm) and on a scale of 20 to 0 ppm.

Track 7–CMR Porosity

Track 7 displays various CMR water-filled porosities along with measurement quality flags–valid only in the open hole section. The porosity and measurement quality logs are presented on a scale of 0.5 to zero volume fraction and discrete blocks originating from the left side, respectively. Specifically, the CMR logs shown in this track are:

- Total water-filled porosity (solid black curve)–representing the total water volume fraction measured by the CMR;
- Three millisecond (ms) porosity (short-dashed brown)–representing the water volume fraction corresponding to the portion of the CMR measured T2 distribution that is above 3 ms, a cutoff that is considered to be representative of the break between clay-bound water (less than 3 ms) and all other types of water (greater than 3 ms);
- Effective water-filled, or free fluid, porosity (solid pink)–representing the water volume fraction that is moveable (can flow), based on a 33 ms T2 distribution cutoff that is considered representative of the break between bound water (less than 33 ms) and moveable water (greater than 33 ms) in clastic rocks;
- Clay-bound water (brown area shading between total and 3 ms porosity logs)–representing the water volume fraction that is bound within clays;
- Capillary-bound water (pink area shading between 3 ms and effective porosity logs)–representing the water volume fraction that is bound within matrix pores by capillary forces;
- CMR wait-time flag (red area shading)–activates when there is significant measurement response at late T2 times, corresponding to large amounts of completely free ("bathtub") water and often associated with washouts or very large pores;

- CMR measurement noise flag (yellow and orange area shading)–activates when there is potentially detrimental amounts of measurement noise detected by the tool, at moderate (yellow) and high (orange) levels.

Track 8 –Pore Size Distribution

Track 8 displays the water-filled pore size distribution as determined by the CMR–shown as binned water-filled porosities and valid only in the open hole section. The binned porosity logs are presented on a scale of 0.5 to zero volume fraction with colored area shading corresponding to the different bins:

- Hydroxyl volume (defined by the difference between thermal neutron porosity and the CMR total porosity)–slanted purple hashed shading
- Clay-bound water–brown area shading;
- Micro pore and small pore water (the sum comprising capillary-bound water)–gray and blue area shading, respectively;
- Medium pore, large pore, and late decay (the sum comprising effective water-filled porosity)–yellow, red, and green area shading, respectively.

Track 9–CMR T2 Distribution (Waveforms)

The CMR T2 distribution is displayed in Track 9 as green waveform traces at discrete depths. The horizontal axis, corresponding to relaxation time in milliseconds, is on a logarithmic scale from 0.3 to 3000 ms. Also plotted are the:

- T2 logarithmic mean (solid blue curve) and
- T2 cutoff time used for differentiating between bound and free water (solid red line)–a constant 33 ms in this case.

Track 10–CMR T2 Distribution (Heated Amplitude)

Track 10 displays the T2 distribution in another way–on a heated color scale where progressively "hotter" color (green to yellow to red) corresponds to increasing T2 amplitude. The remaining aspects of the display are the same as in Track 9, except that the T2 logarithmic mean is shown as a solid white curve and the T2 cutoff is not displayed.

Track 11–CMR Hydraulic Conductivity

Track 11 displays several estimates of hydraulic conductivity (*K*) derived from the CMR measurement and the ELAN integrated log analysis (the latter primarily sensitive to the CMR measurement of moveable water), presented on a logarithmic scale of 10^{-4} to 10^{6} gallons per day per feet squared (gal/day/ft^2):

- A *K* versus depth estimate derived from using the SDR permeability equation applied to the processed CMR results, converted to hydraulic conductivity (dashed purple curve);

- A *K* versus depth estimate derived from using the Timur-Coates permeability equation with total and moveable water content derived from the ELAN analysis, converted to hydraulic conductivity (solid blue curve); and
- An intrinsic *K* versus depth estimate (assuming full saturation) using the Timur-Coates permeability equation with total and effective porosity values derived from the ELAN analysis, converted to hydraulic conductivity (dotted cyan).

Track 12– FMI Image (Dynamic Normalization)

Track 12 displays the FMI image, processed with dynamic normalization so that small-scale electrical resistivity features are amplified in the image. (With dynamic normalization the range of electrical resistivity amplitudes – colors in the image – is normalized across a small moving depth window.) The image is fully oriented and corresponds to the inside of the borehole wall unwrapped, such that the left-hand side represents true north, half-way across the image is south, and the right-hand side is north again. The four color tracks in the image correspond to portions of the borehole wall contacted by the four FMI caliper pads; the blank space in between is the portion of the borehole wall not covered by the pads.

Also displayed are the interpreted bed boundaries (thin blue sinusoids) and electrically conductive fractures (red sinusoids).

Track 13– FMI Bedding and Fractures

Track 13 displays the interpreted bed boundaries and fractures picked from the FMI image, shown in two ways:

- Individually as tadpoles at the depths the bedding plane or fracture crosses the midpoint of the borehole – where the "heads" (circles/triangles) represent the dip angle and the "tails" (line segments) represent the true dip azimuth (direction the bed is dipping towards). Bed boundaries are shown as circular headed blue and black tadpoles and electrically conductive fractures are shown as red circular headed and black triangular headed tadpoles.
- Summed as dip azimuth rose histograms (green colored fan plots for bed boundaries) – where the number of bed boundaries having a dip direction within a particular sector are summed, thus highlighting the predominant dip directions.

Track 14– FMI Image (Static Normalization)

Track 14 displays the FMI image again, but in a different way – processed with static normalization to highlight larger scale features and trends. (With static normalization the range of electrical resistivity amplitudes – colors in the image – is normalized across the entire length of the log interval.) A calibrated, very high resolution FMI pad resistivity log overlays the image (thin solid black curve).

Track 15– Fracture Aperture and High Resolution Porosity

Track 15 displays the estimated hydraulic aperture of any interpreted electrically conductive fractures (red circles on logarithmic scale of 0.001 to 10 inch) – computed using an FMI image scaled to the AIT shallow resistivity. Also displayed is the computed fracture porosity (dashed-dotted bold blue curve on linear scale of 0.01 to 0 ft^3/ft^3), fracture density (green solid curve on scale of 0 to 1 per foot), fracture trace length (short-dashed purple curve on scale of 0 to 2 per foot), and cumulate number of fractures (dotted bold black curve on scale of 0 to 8 fractures). In addition a high-resolution thermal neutron porosity log is displayed (solid thin blue).

Tracks 16 to 22 – Geochemical Elemental Measurements

The narrow tracks 16 to 22 present the geochemical measurements iron (Fe) and silicon (Si), sulfur (S) and calcium (Ca), potassium (K) and estimated aluminum (Al), titanium (Ti) and gadolinium (Gd), and hydrogen (H) and bulk chlorinity (Cl) —from left to right respectively, in units of dry matrix weight fraction (except H wet weight fraction, Cl and K in ppk).

Track 23–ELAN Mineralogy Model Results (Dry Weight Fraction)

Track 23 displays the results from the ELAN integrated log analysis (the matrix portion)–presented as dry weight fraction of mineral types chosen in the model:

- Montmorillonite clay (brown/tan)
- Quartz (yellow with small black dots)
- Silica glass (orange)
- Sanidine (violet)
- Augite (maroon)
- Pyrite (cross-hatched red)
- Calcite (cyan).

Track 24–ELAN Mineralogy-Pore Space Model Results (Wet Volume Fraction)

Track 24 displays the results from the ELAN integrated log analysis–presented as wet mineral and pore fluid volume fractions:

- Montmorillonite clay (brown/tan)
- Clay-bound water (checkered gray-black)
- Quartz (yellow with small black dots)
- Silica glass (yellow with large black dots)
- Sanidine (violet)
- Pyrite (tan with large black squares)
- Augite (maroon)
- Calcite (cyan)
- Air (red)

- Moveable water (white)
- Capillary-bound water (light blue).

Track 25–Summary Logs

Track 25, the second track from the right, displays several summary logs that describe the fluid and air-filled volume measured by the geophysical tools, including water saturation:

- Optimized estimate of total volume fraction water from the ELAN analysis (solid dark blue curve and area shading);
- Optimized estimate of moveable volume fraction water (effective porosity in fully saturated conditions) from the ELAN analysis (dashed cyan curve and green area shading);
- Optimized estimate of total volume fraction of air-filled porosity from the ELAN analysis (solid red curve and dotted red area shading);
- Optimized estimate of water saturation (percentage of pore space filled with water) from the ELAN analysis (dashed-dotted purple curve);
- Water saturation as calculated directly from the bulk density and geochemical estimated porosity using a grain density of 2.65 g/cc (dotted light blue curve), 2.45 g/cc (long-dashed light blue curve), and 2.25 g/cc (dashed light blue curve)–with light blue shading between the 2.25 and 2.65 g/cc saturation curves to show the range;
- Integrated estimated relative water flow from the CMR log that mimics a flow meter (spinner) acquired under flowing conditions (solid green line coming from left-hand side at bottom of logged interval);
- Potential for water flow indicator from the CMR log (block cyan coming from the right-hand side of the track).

The porosity curves scale from 0 to 1 total volume fraction, left to right; the water saturation scales from 0 to 1 volume fraction of pore space, from left to right. The relative water flow is on a scale of 0 to 1 relative volumetric flow rate from left to right. The flow indicator is a binary-valued flag that rises to halfway through the first division from the right on the x-axis when the CMR measurement indicates a potential for flow.

Track 26–Depth

The final track on the right, same as the first track on the left, displays the depth below ground surface in units of feet, as measured by the geophysical logging system during the AIT-NGT logging run.

5.0 REFERENCES

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Appendix D

Lithology Log

Lithologic Descriptions of Core and Drill Cuttings at Borehole CdV-16-1(i)

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Qal, alluvium	No core attempted.	0.0-2.5	7382.17-7379.67
	Unconsolidated sediments, silty sand (SM), dark brown (7.5YR 3/2), 10% silt, 80% fine to medium sand, 10% organic matter (roots, etc.), soft; dry.	2.5-2.9	7379.67-7379.27
	No core recovery.	2.9-5.0	7379.27-7377.17
	Same material as that in interval 2.5-2.9 ft bgs.	5.0-5.4	7377.17-7376.77
	Unconsolidated sediments, silty gravel (GM), light brown (7.5YR 5/3), 10% silt, 40% fine to medium sand, 50% gravel; gravel (up to 5 cm) composed of subangular to subrounded clasts of densely welded tuff and dacite; local hematite alteration.	5.4-5.9	7376.77-7376.27
	No core recovery.	5.9-7.5	7376.27-7374.67
	Unconsolidated sediments, silty sand (SM) with gravel, light brown (7.5YR 5/3), 15% silt, 65% fine to medium sand, 20% gravel; similar to interval 5.4-5.9 ft bgs.	7.5-8.5	7374.67-7373.67
	No core recovery. Note: base of alluvium and contact with underlying Unit 3 of the Tshirege Member of the Bandelier Tuff is interpreted to be at 9 ft bgs.	8.5-10.0	7373.67-7372.17
Qbt 3, Tshirege Member of the Bandelier Tuff	Volcanic tuff, dark reddish gray (10YR 4/1) to pale red (10R 4/2), densely welded, crystal-rich. Composed of 2-3% gray devitrified pumice, flattened; 25% quartz, sanidine, and Ferromagnesium phenocrysts (up to 2 mm), 10% black to dark brown lithics, and 50-60% fine-grained ash matrix; core dry.	10.0-20.0	7372.17-7362.17
	Volcanic tuff, dark reddish gray (10YR 4/1) to pale red (10R 4/2), densely welded, crystal-rich. Composition similar to interval 10.0-20.0 ft bgs.	20.0-30.0	7362.17-7352.17
	Volcanic tuff, dark reddish gray (10YR 4/1), densely welded, crystal-rich. Composed of 4-5% gray devitrified pumice, flattened (up to 3 cm); 25-30% quartz, sanidine, and altered mafic phenocrysts (up to 2 mm), 8-10% dark brown, aphanitic volcanic lithics, and 50-60% fine-grained ash matrix; core dry.	30.0-38.0	7352.17-7344.17
	Volcanic tuff, dark reddish gray (10YR 4/1), densely welded, crystal-rich. Composed of 4% gray devitrified pumice with salt-and-pepper coloration, flattened (up to 4 cm); 25-30% quartz, sanidine, and altered mafic phenocrysts (up to 2 mm), 2% dark brown, aphanitic volcanic lithics (up to 3 cm), and 60-70% fine-grained ash matrix; core dry.	38.0-45.0	7344.17-7337.17
	Volcanic tuff, dark reddish gray (10YR 4/1), moderately welded, crystal-rich. Composed of 4% gray devitrified pumice with salt-and-pepper coloration, flattened (up to 4 cm); 25-30% quartz, sanidine, and altered mafic phenocrysts (up to 2 mm), 2% dark brown, aphanitic volcanic lithics (up to 3 cm), and 60-70% fine-grained ash matrix; core dry.	45.0-50.0	7337.17-7332.17
	Volcanic tuff, dark reddish gray (10YR 4/1), moderately welded, crystal-rich. Composed of 10% devitrified pumice with salt-and-pepper coloration, flattened (up to 1 cm); 25% quartz, sanidine, and altered mafic phenocrysts (up to 2.5 mm), 5-10% dark brown, subangular volcanic xenoliths (up to 2 cm), and 50% fine-grained ash matrix; core slightly moist.	50.0-60.0	7332.17-7322.17
	No core recovery	60.0-65.0	7322.17-7317.17

Lithologic Descriptions of Core and Drill Cuttings at Borehole CdV-16-1(i)

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Qbt 3, Tshirege Member of the Bandelier Tuff	Volcanic tuff, pale red (2.5YR 4/3), moderately to poorly welded, crystal-rich. Composed of 5-10% light gray devitrified pumice; 30-40% quartz, sanidine, and altered mafic phenocrysts (up to 1.5 mm), 5-10% volcanic xenoliths (up to 3 cm) that are strongly argillized, and 60% fine-grained ash matrix; core slightly to very moist.	65.0-75.0	7317.17-7307.17
	Volcanic tuff, dark reddish gray (2.5YR 4/1), poorly welded, crystal-rich. Composed of 15% devitrified pumices (up to 1 cm) that are strongly altered and decomposed; 25% quartz, sanidine, and altered mafic phenocrysts (up to 3 mm); trace strongly altered volcanic xenoliths, and 50% fine-grained ash matrix; core slightly moist.	75.0 -85.0	7307.17-7297.17
Qbt 2, Tshirege Member of the Bandelier Tuff	Volcanic tuff, dark reddish gray (2.5YR 4/1), poorly welded to nonwelded, crystal-rich. Composed of 10% devitrified pumices (up to 1 cm) that are strongly altered and decomposed; 35% quartz, sanidine, and mafic phenocrysts (up to 3 mm); up to 5% strongly altered volcanic xenoliths, and 50% fine-grained ash matrix; core slightly moist. Note: core indicates decrease in degree of welding at the base of Unit 3; contact with underlying Qbt 2 of the Tshirege Member placed at 85 ft bgs.	85.0-90.5	7297.17-7291.67
	Volcanic tuff, reddish brown (2.5YR 4/3), moderate to densely welded, crystal-rich, friable. Composed of 5-10% devitrified pumices (up to 1 cm) that are strongly altered and decomposed; 30-40% quartz, sanidine, and mafic phenocrysts (up to 2 mm); trace volcanic xenoliths, and 50% fine-grained ash matrix; core slightly to moderately moist. Note: high-angle clay-filled joint/fracture, 2 cm wide, intersects core from 95.9 to 103.5 ft bgs; clay is light to dark brown, highly plastic.	90.5-100.0	7291.67-7282.17
	Volcanic tuff, dark reddish gray (2.5YR 3/1), very densely welded, crystal-rich, friable. Composed of 50-60% quartz, sanidine, and Fe-oxide altered mafic phenocrysts (up to 2 mm); 1-3% volcanic xenoliths, almost no identifiable pumice, and 60% fine-grained ash matrix; core is wet. Note: high-angle clay-filled joint/fracture, 3 cm wide, continues to 104.8 ft bgs; 1-mm-wide, clay-filled horizontal joint at 111.2 ft bgs.	100.0-117.0	7282.17-7265.17
	Volcanic tuff, dark reddish gray (2.5YR 3/1), very densely welded, crystal-rich. Composition similar to interval 100.0-117 ft bgs. This interval contains an anomalous component (up to 20% by volume) of lithic inclusions comprised of subanglar crystal rich-tuff (up to 5 cm) and dark gray porphyritic dacite, clasts (up to 4.5 cm). Clay-filled joints/fractures also characterize this interval. Joint at 60 degrees to core axis (c.a.), 2-3 mm wide, occurs at 120.4 to 120.7 ft bgs; sub-horizontal fracture (88 degrees core axis), 1.5 cm wide, intersects at 120.6 ft bgs and has black Mn-oxide selvage.	117.0-126.0	7265.17-7256.17
	Volcanic tuff, dark reddish brown (2.5YR 3/1), densely welded, crystal-rich. Composed of 2% devitrifed, deformed pumices that are often in contact with other volcanic lithics; 25-30% quartz, sanidine, and altered mafic phenocrysts (up to 4 mm); 10-15% subangular to rounded volcanic xenoliths of dark gray dacite; and 60% fine-grained ash matrix. Subvertical clay-filled fracture, 2-3 mm wide, intersects core surface at 129.5 ft bgs; clay-filled fracture at 60 degrees to the core axis (1 mm wide) occurs from 132.5 to 134.8 ft bgs.	126.0-135.0	7256.17-7247.17

Lithologic Descriptions of Core and Drill Cuttings at Borehole CdV-16-1(i)

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Qbt 2, Tshirege Member of the Bandelier Tuff	Volcanic tuff, dark reddish brown (2.5YR 3/1), densely welded, crystal-rich, coarse lithic inclusions. Composition similar to interval 126.0-135.0. Clay-filled fracture at 25 degrees from the core axis occurs from 137.9 to 139.9 ft bgs.	135.0-140.0	7247.17-7242.17
	Volcanic tuff, reddish brown (5YR 5/2), very densely welded, crystal-rich. Composition similar to interval 126.0-135.0 ft bgs. Trace pumices, subrounded, devitrified; xenoliths angular to subangular (up to 1.3 cm); core slightly moist.	140.0-150.0	7242.17-7232.17
	Volcanic tuff, reddish brown (5YR 5/2), very densely welded, crystal-rich. Composition similar to interval 126.0-135.0 ft bgs; lithology continues to be of uniform texture and composition.	150.0-155.0	7232.17-7227.17
	Volcanic tuff, dark reddish gray (2.5YR 4/1) to weak red (2.5YR 4/2), densely welded, crystal-rich. Composed of 2% devitrifed, deformed pumices (aspect ratio 1:5) that are subangular to subrounded; 25-30% quartz, sanidine, and mafic phenocrysts (up to 2.5 mm); 5-10% volcanic xenoliths of variable size and composition, dominantly dacitic; and 60% fine-grained ash matrix; core is moist to slightly moist. Note: lithics commonly form thin, sub-horizontal lenses/layers that are locally bounded by pumices fragments, yielding a weakly bedded structure.	155.0-175.0	7227.17-7207.17
	Volcanic tuff, reddish brown (2.5YR 5/2), densely welded, crystal-rich. Composed of 3-5% white to light gray devitrifed pumices (up to 2 cm) that are subangular to subrounded; 15-20% quartz, sanidine, and mafic phenocrysts (up to 1.5 mm); 5-10% dark-colored volcanic xenoliths (up to 1.5 cm); and 65% fine-grained ash matrix; core is dry to slightly moist. Note: decreasing crystal content, increased percentage of lithics, and diminishing degree of welding with depth in this interval; tuff is weakly welded to nonwelded at 187.3 to 188.0 ft bgs.	175.0-190.0	7207.17-7192.17
	Volcanic tuff, reddish brown (2.5YR 5/2), moderately welded, crystal-rich, lithic-rich. Composed of 3% white to light gray devitrifed pumices (up to 2 cm); 10-15% quartz, sanidine, and mafic phenocrysts (up to 1.5 mm); 15-20% subangular to subrounded, dark-colored volcanic xenoliths (up to 5 cm); and 70% fine-grained ash matrix; core is slightly moist. Note: tuff is weakly welded in the interval 194.2-194.4 ft bgs.	190.0-195.0	7192.17-7187.17
Qbt 1v, Tshirege Member of the Bandelier Tuff	Volcanic tuff, pale red (2.5YR 5/2), moderately welded, lithic-rich. Composed of 3-5% white to pinkish white devitrifed pumices (up to 5 cm); 10-15% quartz, sanidine, and mafic phenocrysts (up to 1 mm); 15-20% angular to subangular, dark-colored volcanic xenoliths (up to 2 cm); and 75% fine-grained ash matrix; core is slightly moist. Note: core and cuttings indicate base of Unit 2 and contact with underlying Unit 1v of the Tshirege Member placed at 195 ft bgs	195.0-200.0	7187.17-7182.17
	Volcanic tuff, grayish orange pink (5YR 7/2), weakly to moderately welded. +10F (i.e. sample fraction retained by the No. 10 sieve): composed of 80-90% tuff fragments, 5-10% quartz and sanidine crystals, 5-10% broken and subrounded lithic fragments with oxidized surfaces composed of dacite and other intermediate volcanics, trace pumice fragments. +35F (i.e., sample fraction retained by the No. 35 sieve): 70-75% free quartz and sanidine crystals; 20-25% welded tuff fragments and lithics. Note: samples of drill cuttings were examined for lithologic description in the interval from 200 to 683 ft bgs.	200-203	7182.17-7179.17

Lithologic Descriptions of Core and Drill Cuttings at Borehole CdV-16-1(i)

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Qbt 1v, Tshirege Member of the Bandelier Tuff	Volcanic tuff, grayish orange pink (5YR 7/2), weakly to moderately welded. +10F: composed of 50% welded tuff fragments, 50% angular to subangular volcanic lithic fragments, including gray vitrophyre. +35F: 60-70% free quartz and sanidine crystals; 30-40% welded tuff fragments.	203-213	7179.17-7169.17
	Volcanic tuff, grayish orange pink (5YR 7/2), weakly to moderately welded. +10F: composed of 50% welded tuff fragments, 50% angular to subangular volcanic lithic fragments, including dacite and gray vitrophyre. +35F: 60-70% free quartz and sanidine crystals; 30-40% welded tuff fragments. Note: cuttings indicate base of Qbt 1v and contact with underlying Qbt 1g of the Tshirege Member placed at 223 ft bgs.	213-223	7169.17-7159.17
Qbt 1g, Tshirege Member of the Bandelier Tuff	Volcanic tuff, grayish orange pink (5YR 7/2), poorly welded. +10F: composed of angular to subangular chips that include tuff fragments, a variety of intermediate volcanics, white vitric pumice, porphyritic rhyolite, and obsidian. +35F: 90-95% tuff fragments, 5-10% lithic fragments.	223-233	7159.17-7149.17
	Volcanic tuff, grayish orange pink (5YR 7/2), poorly welded. +10F: composed of 50-75% white vitric pumices, 25-50% variety of intermediate volcanics similar to interval 223-233 ft bgs. Note: cuttings indicate base of Qbt 1v and contact with underlying Cerro Toledo interval placed at 240 ft bgs.	233-243	7149.17-7139.17
Qct, Cerro Toledo Interval	Volcaniclastic sediments, light brown (5YR 5/6), sand with silt (SP) and clay, poorly graded gravel, fine to coarse sand. +10F: detrital constituents (up to 1 cm, angular to subrounded) composed of intermediate volcanics including aphanitic and hornblende-bearing dacite and rhyolite, vitrophyre and fibrous white vitric pumice. +35F: grains made up of (in order of decreasing relative abundance) quartz and sanidine crystals, pinkish pumice fragments, tuff, and volcanic lithics.	243-248	7139.17-7134.17
	Volcaniclastic sediments, light brown (5YR 5/6), sand with clay, poorly graded (SP-SC), fine to coarse sand, angular to subrounded. +10F: detrital constituents (up to 2 cm) composed of 55-65% intermediate volcanics including aphanitic and hornblende-bearing dacite and rhyolite, porphyritic rhyolite, and obsidian; 35-45% fibrous white pumice. +35F: grains made up of 50% quartz and sanidine crystals, 15-20% pumice fragments, 30-40% volcanic lithics.	248-253	7134.17-7129.17
	Volcaniclastic sediments, moderate orange pink (5YR 8/4), sand with clay and gravel (2-5% of volume), well graded graded (SW-SC), fine to coarse sand, angular to subrounded. +10F/35F: composition similar to that of interval 248-253 ft bgs.	253-268	7129.17-7114.17
	Volcaniclastic sediments, light brown (5YR 5/6), sand with clay and gravel (2-5% of volume), well graded graded (SW-SC), fine to coarse sand, angular to subrounded. +10F/35F: composition similar to that of interval 248-253 ft bgs.	268-278	7114.17-7104.17
	Volcaniclastic sediments, moderate orange pink (5YR 8/4), sand with clay, well graded (SW-SC), fine to very coarse sand, angular to subrounded. +10F: detrital clasts composed of 75-80% pumice and poorly welded tuff fragments, 20-25% hornblende-dacite and aphanitic intermediate and felsic volcanic lithics. +35F: grains made up of 40% pumice, 20% quartz and sanidine crystals, 20% volcanic lithics.	278-298	7104.17-7084.17

Lithologic Descriptions of Core and Drill Cuttings at Borehole CdV-16-1(i)

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Qct, Cerro Toledo Interval	Volcaniclastic sediments, moderate orange pink (5YR 8/4), sand with clay, well graded (SW-SC), fine to coarse sand, angular to subrounded. +10F: detrital clasts (up to 1.5 cm) composed of 50% white vitric, fibrous pumice; 50% other constituents including poorly welded tuff fragments, various intermediate and felsic volcanic lithics (flow-banded, aphanitic, porphyritic, aphyric noted), and hornblende-dacite. +35F: grains made up of 50-55% pumice, 25-30% quartz and sanidine crystals, 20-25% volcanic lithics.	298-308	7084.17-7074.17
	Volcaniclastic sediments, grayish orange pink (5YR 7/2), sand with silt, well graded (SW-SM), fine to coarse sand, angular to subrounded. +10F: detrital clasts composed of 20-30% pumice fragments; 70-80% intermediate volcanic lithics including hornblende-dacite, aphanitic and aphyric varieties of rhyolite, and andesite. +35F: grains made up of 20-25% pumice, 40-50% quartz and sanidine crystals, 30-40% volcanic lithics.	308-323	7074.17-7059.17
	Volcaniclastic sediments, moderate orange pink (5YR 8/4), silty sand (SM), fine to coarse sand, angular to subrounded. +10F: detrital clasts composed of 50% vitric pumice and partly welded tuff fragments; 50% volcanic lithics (up to 5 mm) including dacite, aphanitic and aphyric varieties of intermediate and felsic volcanics, and porphyritic rhyolite. +35F: grains made up of 20-25% pumice, 30-35% quartz and sanidine crystals, 30-35% volcanic lithics.	323-333	7059.17-7049.17
	Volcaniclastic sediments, moderate orange pink (5YR 8/4), silty sand (SM), fine to coarse sand, angular to subrounded. +10F: detrital clasts composed of 25-30% pumice fragments; 70-75% angular to subrounded volcanic lithics including hornblende-dacite, aphanitic and aphyric varieties of intermediate and felsic volcanics, and vitrophyre. +35F: grains made up of 50-60% white and light brown pumice, 20-25% quartz and sanidine crystals, 20-30% volcanic lithics.	333-338	7049.17-7044.17
	Volcaniclastic sediments, moderate orange pink (5YR 8/4), silty sand (SM), fine to coarse sand, angular to subrounded. +10F: Composition similar to that of interval 333-338 ft bgs; pumices display Mn-oxide spots. +35F: grains made up of 25% pumice, 50% quartz and sanidine crystals, 25% volcanic lithics.	338-353	7044.17-7029.17
	Volcaniclastic sediments, light brown (5YR 6/4) to moderate orange pink (5YR 8/4), sandy silt (ML), fine to coarse sand, grains angular to subangular. +10F: detrital clasts composed of 30-35% vitric pumice fragments with Mn-oxide spots; 65-70% volcanic lithics including hornblende-dacite, various intermediate volcanics, vitrophyre, and porphyritic rhyolite. +35F: grains made up of 30-40% pumice, 20-25% quartz and sanidine crystals, 30-45% volcanic lithics.	353-373	7029.17-7009.17
	Volcaniclastic sediments, moderate orange pink (5YR 8/4) to light brown (5YR 6/4), sandy silt (ML), fine to medium sand, grains angular. +10F: detrital clasts composed of 20-25% pinkish vitric pumice fragments with Mn-oxide spots; 75-80% lithics including dacite and other aphanitic, aphyric and porphyritic intermediate and felsic volcanics. +35F: grains made up of 20-25% pumice, 70-75% quartz and sanidine crystals, 5-10% volcanic lithics.	373-393	7009.17-6989.17

Lithologic Descriptions of Core and Drill Cuttings at Borehole CdV-16-1(i)

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Qct, Cerro Toledo Interval	Volcaniclastic sediments, moderate orange pink (5YR 8/4) to moderate brown (5YR 8/4), sandy silty clay (ML-CL), fine to very coarse sand, grains angular to subangular. +10F: detrital clasts (up to 6 mm) composed of 30-35% pinkish vitric pumice fragments with Mn-oxide spots; 40-45% lithics including hornblende-dacite and other intermediate volcanics; 20-25% clay clots. +35F: grains made up of 40-45% pumice, 40-45% quartz and sanidine crystals, 15-20% volcanic lithics.	393-403	6989.17-6979.17
	Volcaniclastic sediments, moderate orange pink (5YR 8/4) to light brown (5YR 6/4), sandy silt (ML), fine to medium sand, grains angular to subangular. +10F: detrital clasts composed of 93-95% varied volcanic lithics including aphyric intermediate and felsic volcanics, dacite, and andesite; rounded to angular pumice fragments (up to 8 mm). +35F: grains made up of 5-10% pumice, 85-90% quartz and sanidine crystals, 5-10% volcanic lithics.	403-423	6979.17-6959.17
	Volcaniclastic sediments, moderate orange pink (5YR 8/4) to light brown (5YR 6/4), sandy silt (ML), fine to very coarse sand, grains angular to subrounded, trace gravel (up to 8 mm). +10F: detrital clasts composed of (in order of decreasing relative abundance) aphanitic, aphyric intermediate and felsic volcanics, other porphyritic volcanics, and pumice fragments. +35F: grains made up of 5-10% pumice, 75-80% quartz and sanidine crystals, 10-15% volcanic lithics.	423-433	6959.17-6949.17
	Volcaniclastic sediments, moderate orange pink (5YR 8/4) to light brown (5YR 6/4), sandy silt (ML), fine to very coarse sand, grains angular to subrounded, trace gravel (up to 8 mm). +10F: detrital clasts composed of 85-90% aphanitic, aphyric intermediate and felsic volcanics, other porphyritic volcanics, and 10-15% pumice fragments. +35F: grains made up of 5-10% pumice, 75-80% quartz and sanidine crystals, 10-15% volcanic lithics.	433-443	6949.17-6939.17
	Volcaniclastic sediments, very pale orange (10YR 8/2) to moderate orange pink (5YR 8/4), sand with silt, well graded (SW-ML), very fine to very coarse sand, grains angular to subrounded, gravel clasts (up to 1 cm). +10F: detrital clasts composed of white, vitric pumice and tuff fragments with Mn-oxide staining/spots; lesser amounts of aphanitic aphyric intermediate and felsic volcanics and hornblende-dacite; local clay clots. +35F: grains made up of 15-20% pumice, 55-60% quartz and sanidine crystals, 20-25% volcanic lithics. Note: cuttings and geophysical logs indicate base of the Cerro Toledo Interval and contact with underlying Otowi Member of the Bandelier Tuff to be at 457 ft bgs	443-458	6939.17-6924.17
Qbo, Otowi Member of the Bandelier Tuff	Volcanic tuff, grayish orange pink (5YR 7/2), weakly welded, lithic rich. WR (i.e., unsieved whole rock sample): has silty texture with medium to coarse sand-size lithics and crystals. +10F: composed mostly of lithic fragments including andesite, dacite, varieties of aphyric, aphanitic intermediate volcanics, and black vitrophyre; some white vitric pumice and tuff fragments with Mn-oxide spots. +35F:5-10% pumice, 45-50% quartz and sanidine crystals; and 45-50% lithics.	458-473	6924.17-6909.17

Lithologic Descriptions of Core and Drill Cuttings at Borehole CdV-16-1(i)

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Qbo Otowi Member of the Bandelier Tuff	Volcanic tuff, very pale orange (10YR 8/2) to pale yellowish brown (10YR 6/2), weakly welded, lithic rich. WR: has silty texture with 20-30% lithics (up to 3 mm) and crystals. +10F: poor sample returns; composed mostly of lithic fragments including dacite and aphyric, aphanitic intermediate volcanics, 20-30% brown pumice. +35F: 5-10% pumice, 30-40% quartz and sanidine crystals, and 50-60% lithics.	473-483	6909.17-6899.17
	Volcanic tuff, very pale orange (10YR 8/2) to pale yellowish brown (10YR 6/2), weakly welded. WR: has silty texture. +10F: composed of 60-70% white vitric and locally dark-colored pumices (up to 4 mm) with frequent Mn-oxide spots; 30-40% lithic fragments (up to 4 mm) including vitrophyre and aphanitic volcanic rocks. +35F: 15-20% pumice, 50-60% quartz and sanidine crystals, and 25-30% lithics.	483-518	6899.17-6864.17
	Volcanic tuff, very pale orange (10YR 8/2) to pale yellowish brown (10YR 6/2), weakly welded. WR: has silty texture. +10F: composed of 40-50% white vitric and orange-colored pumices (up to 4 mm) with local Mn-oxide spots; 50-60% varied lithic fragments (up to 4 mm) including aphanitic intermediate volcanics and vitrophyre. +35F: 30-35% pumice, 30-35% quartz and sanidine crystals, and 30-35% lithics.	518-538	6864.17-6844.17
	Volcanic tuff, pale orange (10YR 6/2), weakly welded. WR: has abundant (20-30% by volume) clay. +10F: varieties of lithics (up to 5 mm) composed of (in order of decreasing relative abundance) brown to gray aphyric, aphantic volcanics, white vitric pumices with Mn-oxide spots, and obsidian. +35F: 5-10% pumice, 70-75% quartz and sanidine crystals, and 15-20% lithics. Note: interval 543-548 ft bgs changes coloration to grayish orange (10YR 7/4) and contains no clay.	538-553	6844.17-6829.17
	Volcanic tuff, pale orange (10YR 6/2), weakly welded, minor clay noted in WR. +10F: composition generally similar to that of 538-553 ft bgs. +35F: 5-10% pumice, 70-75% quartz and sanidine crystals, and 15-20% lithics.	553-563	6829.17-6819.17
	Volcanic tuff, very pale orange (10YR 8/2) to moderate orange pink (5YR 8/4), weakly to moderately welded. WR: has silty texture made up of milled ash. +10F: composed of 90% lithics (up to 4 mm), dominantly dark-colored aphyric, aphanitic varieties of intermediate volcanics; and 10% white pumices. +35F: 5-10% pumice, 85-90% quartz and sanidine crystals, and 1-5% lithics.	563-568	6819.17-6814.17
	No cuttings returned; no sample available for examination.	568-583	6814.17-6799.17
	Volcanic tuff, very pale orange (10YR 8/2) to moderate orange pink (5YR 8/4), weakly welded. WR: has silty texture made up of milled ash. +10F: composed of 93-95% varied lithics including dark-colored, flow-banded, aphyric, aphanitic volcanics; minor hornblende-dacite; and trace sandstone(?) fragments. +35F: 5-10% pumice, 70-75% quartz and sanidine crystals, and 15-20% lithics.	583-603	6799.17-6779.17
	Volcanic tuff, very pale orange (10YR 8/2), weakly welded. WR: has silty texture. +10F: composed of 85- 90% varied lithics including porphyritic and aphyric rhyolite, aphanitic intermediate volcanics, and minor dacite; 10-15% white vitric pumices. +35F: 30-35% pumice, 30-35% quartz and sanidine crystals, and 30-35% lithics.	603-623	6779.17-6759.17

Lithologic Descriptions of Core and Drill Cuttings at Borehole CdV-16-1(i)

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Qbo, Otowi Member of the Bandelier Tuff	Volcanic tuff, very pale orange (10YR 8/2), weakly welded. WR: has silty texture. +10F: varied angular to subrounded fragments comprised of 55-60% varied lithics including aphyric, aphanitic intermediate volcanics; porphyritic dacite and andesite, porphyritic rhyolite, trace obsidian; 40-50% white vitric pumice; and 1-3% quartz and sanidine crystals. +35F: 2-5% pumice, 90-95% quartz and sanidine crystals, and 2-5% lithics.	623-638	6759.17-6744.17
	Volcanic tuff, very pale orange (10YR 8/2), weakly welded. WR: has silty texture. +10F/+35F composition generally similar to that of interval 623-638 ft bgs; increase in pumice abundance in +10F to 50-60%.	638-663	6744.17-6719.17
	Volcanic tuff, very pale orange (10YR 8/2), weakly welded. WR: has silty texture. +10F: composed of 85-90% white vitric pumices; 10-15% lithic fragments (up to 5 mm) including varied aphyric and porphyritic intermediate volcanics, dacite, porphyritic rhyolite, and vitrophyre; and 1-2% quartz and sanidine crystals. +35F: 40-45% pumice, 40-45% quartz and sanidine crystals, and 10-20% lithics.	663-683	6719.17-6699.17
	BOREHOLE TOTAL DEPTH IS 683 FT BGS.		

Note: Core samples were collected and described in the CdV-16-1(i) interval from 0 to 200 ft bgs. Samples of drill cuttings were collected in the interval from 0 to 683 ft bgs. Descriptions presented in this lithlog are based on those made during visual examination of core from 0 to 200 ft bgs and from drill cuttings from 200 to 683 ft bgs.

Note: ASTM standards were used in describing the texture of drill chip samples for sedimentary rocks such as alluvium and the Puye Fanglomerate. ASTM method D 2488-90 incorporates the Unified Soil Classification System (USCS) as a standard for field examination and description of soils. The following is a glossary of standard USCS symbols used in the CdV-16-1(i) lithlog.

SP	Poorly graded gravel
SM	Silty Sand
SP-SC	Poorly graded sand with clay to clayey sand (gradational)
ML	Silt
ML-CL	Sandy silt to sandy clay (gradational)
SW-ML	Well-graded sand with silt to silt (gradational)
SW-SC	Well-graded sand with clay to sand clay (gradational)
SW-SM	Well-graded sand with silt to silty sand (gradational)

Note: Cuttings were collected at nominal 5-ft intervals and divided into three sample splits: (1) unsieved, or whole rock (WR), sample; (2) +10F sieved fraction (No. 10 sieve equivalent to 2.0 mm); and (3) +35F sieved fraction (No. 35 sieve equivalent to 0.50 mm).

Note: The term "per cent" (%), as used in the above descriptions, refers to relative abundance by volume for a given sample component.

Note: Contact locations are based on cuttings retrieval. There is general agreement between this borehole log and the geophysics report.

REFERENCE:

ASTM D2488-90. Standard Practice and Identification of Soils (Visual-Manual Procedure)

Geologic Society of America, 1995, Rock-color chart with genuine Munsell color chips, 8th printing.

Appendix E

Hydrologic Testing Report and Test Data
(CD included)

CDV-16-1(i)HYDROLOGIC TESTING REPORT AND TEST DATA

INTRODUCTION

This section describes the analysis of constant-rate pumping and recovery tests conducted on Well CdV-16-1(i). The primary objective of the analysis was to determine the hydraulic properties of the sediments screened in CdV-16-1(i).

CdV-16-1(i) is completed in a high porosity interval of the Otowi Member of the Bandelier Tuff with a 10-foot-long well screen installed from 624 to 634 feet below land surface. The static water level is approximately 568 to 569 feet below land surface, placing the top of the well screen 54 feet below the water table.

Testing of CdV-16-1(i) consisted of a few hours of trial pumping, 3 days of background monitoring, 24 hours of constant-rate pumping, and 39 hours of recovery (also providing additional background data).

Trial pumping occurred on February 27, 2004. It consisted of 151 minutes of pumping at highly variable rates, eventually stabilized at 1.6 gpm, from 12:04 pm to 2:35 pm; 13 minutes of recovery from 2:35 pm to 2:48 pm; and 24 minutes of pumping at 1.4 gpm from 2:48 pm to 3:12 pm. Then the well was shut down and recovery/background data were recorded for more than 3 days, from 3:12 pm on February 27 until 4:55 pm on March 1.

The constant-rate pumping test was started at 4:55 pm on March 1 and continued for 24 hours until 4:55 pm on March 2. Following shutdown, recovery data were recorded for more than 39 hours, from 4:55 pm on March 2 to 8:16 am on March 4. The latter portion of the recovery data served as supplementary background data.

CdV-16-1(i) was very low yielding, producing a sustained pumping rate of less than 2 gpm. The pump used for the test was rated at about 20 gpm and, thus, had to be valved back to near shut-in conditions to control the discharge to a rate that could be sustained by the well. This extreme operating condition made it difficult to control the pumping rate accurately. In particular, the data showed that when the pump was first started, the initial rate was excessive, drawing the pumping water level into the well screen. This allowed air to enter the well, likely filling the space between the inflatable packer and the top of the well screen, as well as a portion of the filter pack. The presence of the air space beneath the packer negated the attempt to eliminate casing storage effects and, thus, the test data were affected by draining and refilling of the casing and filter pack.

BACKGROUND DATA

The background water level data collected in conjunction with running the pumping test allow the analyst to see what water level fluctuations occur naturally in the aquifer and help distinguish between water level changes caused by conducting the pumping test and changes associated with other causes.

Background water level fluctuations have several causes, among them barometric pressure changes, operation of other wells in the aquifer, earth tides and long-term trends related to weather patterns. The background data hydrographs from the CdV-16-1(i) tests were compared to barometric pressure data from the area to determine if a correlation existed.

Previous pumping tests have demonstrated a barometric efficiency for most wells of between 90 and 100 percent. Barometric efficiency is defined as the ratio of water level change to barometric pressure change, expressed as a percentage. In the early pumping tests conducted as part of this project, down hole pressure was monitored using a *vented* transducer. This equipment measures the *difference* between the total absolute pressure applied to the transducer and the barometric pressure, this difference being the true height of water above the transducer.

Later pumping tests in the project, including the CdV-16-1(i) pumping test, utilized a *non-vented* transducer for the background monitoring. This device simply records the total absolute pressure on the transducer, that is, the sum of the water height plus the barometric pressure. This results in an attenuated "apparent" hydrograph in a barometrically efficient well. Take as an example a 90 percent barometrically efficient well. When monitored using a vented transducer, an *increase* in barometric pressure of 1 unit causes a *decrease* in recorded down-hole pressure of 0.9 units, because the water level is forced downward 0.9 units by the barometric pressure change. However, using a non-vented transducer, the total measured pressure *increases* by 0.1 units (the combination of the barometric pressure increase and the water level decrease). Thus, the resulting apparent hydrograph changes by a factor of 100 minus the barometric efficiency, and in the same direction as the barometric pressure change, rather than in the opposite direction.

When the non-vented transducer is used in combination with an inflatable packer, the output is the same as what would be measured without the packer. Because the packer isolates the water in the well from atmospheric pressure, the changing barometric pressure has no direct effect on the water level. The only effect is the indirect effect on the aquifer as a whole. Using the example of a 90 percent barometrically efficient well, an increase in barometric pressure of 1 unit would cause a general aquifer pressure increase of 0.1 units (100 percent minus the barometric efficiency). Thus, the barometric effect is muted and, again, the "apparent" water level hydrograph recorded by the non-vented transducer in conjunction with an inflatable packer is indistinguishable from that recorded by a non-vented transducer without an inflatable packer.

Barometric pressure data were obtained from the Los Alamos National Laboratory TA-54 tower site from RRES-Meteorology and Air Quality. The TA-54 measurement location is at an elevation of 6548 feet above mean sea level (amsl), whereas the wellhead elevation is 6881 feet amsl. Furthermore, the static water level in CdV-16-1(i) was about 570 feet below land surface, making the water table elevation 6311 feet amsl. Therefore, the measured barometric pressure data from TA-54 had to be adjusted to reflect the pressure at the elevation of the water table within CdV-16-1(i).

The following formula was used to adjust the measured barometric pressure data:

$$P_{WT} = P_{TA54} \exp\left[-\frac{g}{3.281R}\left(\frac{E_{CDV} - E_{TA54}}{T_{TA54}} + \frac{E_{WT} - E_{CDV}}{T_{WELL}} \right) \right]$$

where,

P_{WT} = barometric pressure at the water table inside CdV-16-1(i)
P_{TA54} = barometric pressure measured at TA-54
g = acceleration of gravity, in m/sec^2 (9.80665 m/sec^2)

R = gas constant, in J/Kg/degree Kelvin (287.04 J/Kg/degree Kelvin)
E_{CDV} = land surface elevation at CdV-16-1(i), in feet (6881 feet)
E_{TA54} = elevation of barometric pressure measuring point at TA-54, in feet (6548 feet)
E_{WT} = elevation of the water level in CdV-16-1(i), in feet (6311 feet)
T_{TA54} = air temperature near TA-54, in degrees Kelvin (assigned a value of 28 degrees Fahrenheit, or 270.9 degrees Kelvin)
T_{WELL} = air temperature inside CdV-16-1(i), in degrees Kelvin (assigned a value of 52 degrees Fahrenheit, or 284.3 degrees Kelvin)

This formula is an adaptation of an equation provided by RRES-Meteorology and Air Quality. It can be derived from the ideal gas law and standard physics principles. An inherent assumption in the derivation of the equation is that the air temperature between TA-54 and the well is temporally and spatially constant, and that the temperature of the air column in the well is similarly constant.

The corrected barometric pressure data reflecting pressure conditions at the water table were compared to the apparent water level hydrograph to discern the correlation between the two.

THICK AQUIFER RESPONSE

A complicating aspect of the R-well pumping tests is that the wells are severely partially penetrating. The typical well design incorporates a relatively short well screen (a few feet to tens of feet in length) installed within a massively thick aquifer (many hundreds of feet or more).

As a result, during pumping, the cone of depression expands not only horizontally, but also vertically, throughout the test. As the cone intercepts a greater and greater aquifer thickness, the data plot reflects a steadily flattening slope, corresponding to the continuously increasing vertical height of the zone of investigation. As a result, later data tend to produce a greater calculated transmissivity than do early data. This complicates the analysis because, for any given slope (or transmissivity value), it is not possible to know what the corresponding aquifer thickness is (vertical extent of the cone of depression).

If an aquitard is encountered at depth, limiting the vertical growth of the cone of depression, the data curve may reach a steady slope, reflecting the transmissivity of the sediments above the aquitard. In that case, a definitive transmissivity can be determined and the hydraulic conductivity can be calculated by dividing the transmissivity by the saturated thickness above the aquitard (if that dimension is known). If no aquitard is encountered, the drawdown curve gets steadily flatter, reflecting a continuum of transmissivities corresponding to the effective depth of the cone of depression at any given time.

IMPORTANCE OF EARLY DATA

When pumping or recovery first begins, the vertical extent of the cone of depression is limited to approximately the well screen length. For most R-well pumping tests, these first few moments of pumping are the only time that the effective height of the cone of depression is known with certainty. Thus, the early data potentially offer the best opportunity to obtain hydraulic conductivity information, because conductivity would equal the earliest-time transmissivity divided by the well screen length.

Unfortunately, in the R-wells, casing storage effects dominate the early-time data, hindering the effort to determine the transmissivity of the screened interval. The duration of casing storage effects can be estimated using the following equation (Schafer, 1978).

$$t_c = \frac{0.6\left(D^2 - d^2\right)}{\frac{Q}{s}}$$

where,

t_c = duration of casing storage effect, in minutes
D = inside diameter of well casing, in inches
d = outside diameter of column pipe, in inches
Q = discharge rate, in gpm
s = drawdown observed in pumped well at time t_c, in feet

In some wells, a secondary casing storage effect can be caused by drainage of the filter packed annulus outside the well casing. When this occurs, the duration of casing storage is even greater and can be approximated as follows:

$$t_c = \frac{0.6\left[\left(D^2 - d^2\right) + S_y\left(4r_w^2 - D_O^2\right)\right]}{\frac{Q}{s}}$$

In this equation, r_w is the borehole radius, in inches; D_O is the outside diameter of the well casing, in inches; and S_y is the short-term drainable porosity of the filter pack (analogous to short-term specific yield). The value of S_y can be expected to range between about 10 and 20 percent in most cases.

In some instances, it may be possible to eliminate casing storage effects by setting an inflatable packer above the tested screen interval prior to conducting the test. Therefore, this option was implemented for the CdV-16-1(i) pumping test. However, as described later, using the packer did not eliminate casing storage effects during the test, because of excessive drawdown allowing air entry into the well screen.

TIME-DRAWDOWN METHODS

Time-drawdown data (as well as some time-recovery data) can be analyzed using a variety of methods. Among them is the Theis method. The Theis equation describes drawdown around a well as follows:

$$s = \frac{114.6Q}{T} W(u)$$

where,

$$W(u)=\int_u^\infty \frac{e^{-x}}{x}dx$$

and

$$u=\frac{1.87r^2S}{Tt}$$

and where,

s	= drawdown, in feet
Q	= discharge rate, in gpm
T	= transmissivity, in gpd/ft
S	= storage coefficient (dimensionless)
t	= pumping time, in days
r	= distance from center of pumpage, in feet

To use the Theis method of analysis, the time-drawdown data are plotted on log-log graph paper. Then, Theis curve matching is performed using the Theis type curve – a plot of the Theis well function $W(u)$ versus $1/u$. Curve matching is accomplished by overlaying the type curve on the data plot and, while keeping the coordinate axes of the two plots parallel, shifting the data plot to align with the type curve, effecting a match position. An arbitrary point, referred to as the match point, is selected from the overlapping parts of the plots. Match point coordinates are recorded from the two graphs, yielding four values – $W(u)$, $1/u$, s and t. Using these match point values, standard formulas are used to compute the aquifer parameters.

An alternative solution method applicable to time-drawdown data is the Cooper-Jacob method (1946), a simplification of the Theis equation (1935) that is mathematically equivalent to the Theis equation for most pumped well data. The Cooper-Jacob equation describes drawdown around a pumping well as follows:

$$s=\frac{264Q}{T}\log\frac{0.3Tt}{r^2S}$$

where,

s	= drawdown, in feet
Q	= discharge rate, in gpm
T	= transmissivity, in gpd/ft
t	= pumping time, in days
r	= distance from center of pumpage, in feet
S	= storage coefficient (dimensionless)

The Cooper-Jacob equation is a simplified approximation of the Theis equation and is valid whenever the u value is less than about 0.05.

For small radius values (e.g., corresponding to borehole radii), u is less than 0.05 at very early pumping times and, therefore, is less than 0.05 for nearly all measured drawdown values. Thus, for pumped wells, the Cooper-Jacob equation usually can be considered a valid approximation of the Theis equation.

According to the Cooper-Jacob method, the time-drawdown data are plotted on a semilog graph, with time plotted on the logarithmic scale. Then a straight line of best fit is constructed through the data points and transmissivity is calculated using:

$$T = \frac{264Q}{\Delta s}$$

where,

T	= transmissivity, in gpd/ft
Q	= discharge rate, in gpm
Δs	= change in head over one log cycle of the graph, in feet

Because the R-wells are severely partially penetrating, another solution considered for determining aquifer parameters is the Hantush equation for partially penetrating wells (1961a, b). The Hantush equation is as follows:

$$s = \frac{Q}{4\pi T}\left(W(u) + \frac{2b^2}{\pi^2 (l-d)(l'-d')} \sum_{n=1}^{\infty} \frac{1}{n^2} \left[\sin\frac{n\pi l}{b} - \sin\frac{n\pi d}{b} \right] \left[\sin\frac{n\pi l'}{b} - \sin\frac{n\pi d'}{b} \right] W\left(u, \sqrt{\frac{K_z}{K_r}}\frac{n\pi r}{b} \right) \right)$$

where, in consistent units, s, Q, T, t, r, S, and u are as previously defined and

b	= aquifer thickness
d	= distance from top of aquifer to top of well screen in pumped well
l	= distance from top of aquifer to bottom of well screen in pumped well
d'	= distance from top of aquifer to top of well screen in observation well
l'	= distance from top of aquifer to bottom of well screen in observation well
K_z	= vertical hydraulic conductivity
K_r	= horizontal hydraulic conductivity

In this equation, $W(u)$ is the Theis well function and $W(u,\beta)$ is the Hantush well function for leaky aquifers. For single-well tests, $d = d'$ and $l = l'$. Aquifer parameters are solved using curve matching similar to the Theis procedure.

RECOVERY METHODS

Recovery data were analyzed by the two methods. One of the methods used was the Theis Recovery Method. This is a semi-log analysis method analogous to the Cooper-Jacob procedure.

In this method, residual drawdown is plotted on a semi-log graph versus the ratio t/t', where t is the time since pumping began and t' is the time since pumping stopped. A straight line of best fit is constructed through the data points and T is calculated from the slope of the line as follows:

$$T = \frac{264Q}{\Delta s}$$

The recovery data are particularly useful compared to time-drawdown data. Because the pump is not running, spurious data responses associated with dynamic discharge rate fluctuations are eliminated. The result is that the data set is generally "smoother" and easier to analyze.

Recovery data also were analyzed using the Hantush method described above. In applying this procedure, simple recovery (difference between residual drawdown and maximum drawdown observed at the end of the pumping period) was plotted versus recovery time (t'). Such a plot can be considered analogous to a time-drawdown plot and is accurate for early and middle data. For late data, however, this approach can sometimes lose accuracy. The reason for possible loss of accuracy is explained as follows.

Theoretically, recovery time must be plotted against *calculated recovery*, which is defined as the difference between the observed residual drawdown and the drawdown that would have occurred had pumping continued (also called extrapolated drawdown):

$$s_c = s_e - s_r$$

where,

s_c = calculated recovery
s_e = extrapolated drawdown
s_r = observed residual drawdown

Substituting simple recovery for calculated recovery is done by substituting the drawdown observed at the end of the pumping period for s_e in the above equation. At early-to-middle recovery times, this substitution introduces little error; but at late times, the discrepancy could become substantial if the extrapolated drawdown deviates significantly from the drawdown observed at the end of the pumping period. Note that in wells where the pumping water level stabilizes during the test, the extrapolated drawdown and the drawdown observed at the end of the pumping test are identical, and no error is introduced by substituting simple recovery for calculated recovery.

Although plotting calculated recovery is theoretically correct, determining the values of extrapolated drawdown to use in computing calculated recovery is problematic. Often, the time-drawdown data are erratic, or biased by changing well efficiency, and can't be extrapolated readily. Even when the time-drawdown data are not erratic, extrapolating the drawdown trend presupposes that future drawdown changes will be similar to those observed during the pumping period. Alternatively, extrapolated drawdown can be determined by mathematical formula, but this approach presupposes particular aquifer coefficients and conceptual model of the well/aquifer system. Thus, regardless of the method used to extrapolate drawdown beyond the pumping period, the validity of the extrapolated values is in doubt. Furthermore, when calculated recovery is used in the graphical procedure, the resulting analysis does not provide independent information on aquifer parameters, but simply reflects the mathematical content of the extrapolation process.

To summarize, either simple recovery or calculated recovery may be plotted against recovery time and analyzed using time-drawdown methods. However, for late times both methods can produce errors. At late time, simple recovery may provide a poor approximation of the calculated recovery. Similarly, obtaining calculated recovery, by extrapolating the time-drawdown trend beyond the pumping period, can introduce a mathematical bias in the data.

SLUG TEST METHODS

For certain data sets, slug test methods may be applied to calculate hydraulic conductivity. Slug tests methods are applied to data describing water level rise or decay following instantaneous removal or injection, respectively, of a finite volume of water.

Hydraulic conductivity values determined from slug tests are generally considered lower-bound estimates of *K*, because they are based on the assumption of 100 percent well efficiency. If the tested well is inefficient (permeability reduction due to formation damage in the vicinity of the borehole face), the casing refill rate following water withdrawal, or the water level decay rate following injection, will be slowed by the lower permeability materials, compared to the rates that would have been observed with no formation damage. The lower refill or decay rate will produce a calculated *K* value less than what would have been computed for an efficient well. [Note: Slug test methods that purport to account for well efficiency are, in practice, unable to identify well inefficiency effects or distinguish them from other data responses.]

Common methods used to analyze slug test data are the Hvorslev method and the Bouwer and Rice method. In each method, the water level response data are plotted on a semilog graph with displacement on the logarithmic scale and time on the linear scale. A straight line of best fit is constructed through the data curve, and the coordinates of any two points on the straight line are used to compute *K*.

Using the Hvorslev method, modified to account for the presence of a drop pipe in the well casing, hydraulic conductivity is calculated as follows:

$$K = \frac{\left(r_c^2 - \frac{d^2}{4}\right)\ln\frac{h_1}{h_2}\ln\left(\frac{L}{2r_w} + \sqrt{1 + \frac{L^2}{4r_w^2}}\right)}{2L(t_2 - t_1)}$$

where, in consistent units,

K = hydraulic conductivity
r_c = inside radius of well casing
d = outside diameter of drop pipe
h_1, h_2 = displacement at times t_1 and t_2
L = well screen length
r_w = borehole radius
t_1, t_2 = time at which displacements h_1 and h_2 are measured

Using the Bouwer and Rice method, modified to account for the presence of a drop pipe in the well casing, hydraulic conductivity is calculated as follows:

$$K = \frac{\left(r_c^2 - \frac{d^2}{4}\right)\ln\frac{h_1}{h_2}\ln\left(\frac{R}{r_w}\right)}{2L(t_2 - t_1)}$$

In this formula, all terms are as defined above, except that *R* is an empirical parameter representing a time-averaged effective radius of influence of the well.

SPECIFIC CAPACITY METHOD

The specific capacity of the pumped well can be used to obtain a lower-bound estimate of hydraulic conductivity. The hydraulic conductivity is computed using formulas that are based on the assumption that the pumped well is 100 percent efficient. The resulting hydraulic conductivity is the value required to sustain the observed specific capacity. If the actual well is less than 100 percent efficient, it follows that the actual hydraulic conductivity would have to be greater than calculated to compensate for well inefficiency. Thus, because the efficiency is unknown, the computed hydraulic conductivity value represents a lower bound. The actual conductivity is known to be greater than or equal to the computed value.

For fully penetrating wells, the Cooper-Jacob equation can be iterated to solve for the lower-bound hydraulic conductivity. However, the Cooper-Jacob equation (assuming full penetration) ignores the contribution to well yield from permeable sediments above and below the screened interval. To account for this contribution, it is necessary to use a computation algorithm that includes the effects of partial penetration. One such approach was introduced by Brons & Marting (1961) and augmented by Bradbury & Rothschild (1985).

Brons and Marting introduced a dimensionless drawdown correction factor, sP, approximated by Bradbury and Rothschild as follows:

$$s_P = \frac{1-\frac{L}{b}}{\frac{L}{b}}\left[\ln\frac{b}{r_w} - 2.948 + 7.363\frac{L}{b} - 11.447\left(\frac{L}{b}\right)^2 + 4.675\left(\frac{L}{b}\right)^3\right]$$

In this equation, L is the well screen length, in feet. Incorporating the dimensionless drawdown parameter, the conductivity is obtained by iterating the following formula:

$$K = \frac{264Q}{sb}\left(\log\frac{0.3Tt}{r_w^2 S} + \frac{2s_P}{\ln 10}\right)$$

To apply this formula, a storage coefficient value must be assigned, although storage coefficient values for the pumice-rich intervals of the Otowi Member of the Bandelier Tuff have not been well documented. In most unconfined settings, the storage coefficient typically ranges from a few percent to 20 percent or more, with the majority of the values falling between approximately 5 and 15 percent. Thus, in the absence of site-specific storage coefficient data for the pumice-rich intervals of the Otowi Member of the Bandelier Tuff, a value of 0.1 may be deemed reasonable. It can be argued that pumice has a somewhat greater porosity than typical sand and gravel materials, thereby increasing the storage coefficient. However, some of the pore space may not be well connected to the bulk porosity and could contain water not easily drained. Based on limited available information, the nominal estimated value of 0.10 was used in the calculations. Fortunately, the calculation result is not particularly sensitive to the choice of storage coefficient value, so a rough estimate of the storage coefficient is adequate to support the calculations.

The analysis also requires assigning a value for the saturated aquifer thickness, *b*, which is generally not known. Fortunately, the calculated value of hydraulic conductivity is usually insensitive to the selected aquifer thickness value, as long as the aquifer thickness is significantly greater than the screen length. This is because saturated aquifer materials far above or below the screened interval contribute little to the yield of the well. Thus, it was expected that an approximate aquifer thickness estimate would suffice for the calculations.

An alternative specific capacity method for partially penetrating screens is a formula presented by Hvorslev (1951) that can be derived directly from Darcy's Law:

$$K = \frac{229}{L}\frac{Q}{s}\ln\left(\frac{L}{2r_w} + \sqrt{1 + \frac{L^2}{4r_w^2}}\right)$$

where,

K = hydraulic conductivity, in gpd/ft^2
Q = discharge rate, in gpm
L = well screen length, in feet
s = drawdown, in feet
r_w = borehole radius, in feet

This formula is derived based on the assumption of infinite aquifer thickness, above and below the well screen, and infinite pumping time. As such, it works reasonably well for short well screens completed in thick aquifers and very long pumping times. As with other specific capacity methods, the resulting *K* value may be considered a lower-bound estimate of the screened zone hydraulic conductivity.

Computing the lower-bound estimate of hydraulic conductivity can provide a useful frame of reference for evaluating the other pumping test calculations.

PUMPING TEST RESULTS

This section describes the detailed data analyses applied to information recorded during the CdV-16-1(i) pumping test.

Background Observations

Figure 1 shows the "apparent" water level hydrograph and the barometric pressure data recorded from February 28 through March 1. These data were recorded well after the brief trail pumping events. Figure 2 shows similar data for March 3 and 4, starting about a day after termination of the 24-hour constant-rate pumping test.

Because the data were recorded using a non-vented pressure transducer, any barometric pressure correlation would be indicated by the apparent hydrograph mimicking the barometric signal, but with a significantly attenuated amplitude (assuming high barometric efficiency, consistent with all other observed R-well responses).

There was no such discernable correlation between aquifer pressures and barometric pressure, suggesting that the CdV-16-1(i) is nearly 100 percent barometrically efficient. Recall that the observed lack of aquifer pressure response to changes in barometric pressure implies that, had no packer been installed, the actual water levels in the well would have responded nearly equally and opposite to changes in barometric pressure, such that the combined pressure (water head plus atmospheric pressure) would have shown negligible change. The observed barometric pressure and aquifer pressure response indicated that barometric corrections to the pumping test data were not necessary, because barometric pressure changes had no discernable effect on the measured pressures in the well.

Trial Pumping and Recovery

Trial testing was performed to verify equipment operation and determine a sustainable pumping rate for the constant-rate test. Trial testing was performed on February 27 and consisted of a) 151 minutes of pumping at a highly variable rate (eventually stabilized at 1.6 gpm) from 12:04 pm to 2:35 pm; b) 13 minutes of recovery from 2:35 pm to 2:48 pm; c) 24 minutes of pumping at 1.4 gpm from 2:48 pm to 3:12 pm; and d) extended recovery/background data collection, following pump shutoff, from 3:12 pm on February 27 to 4:55 pm on March 1.

Figure 3 shows time-drawdown data for the first trial test. Note that the drawdown exceeded 30 feet during the first seconds of pumping, consistent with effective deployment of the inflatable packer in the casing string. However, there was immediate recovery during the first 20 seconds of pumping, suggesting a decline in discharge rate. This is likely explained by leaky check valves allowing the pump to start against less than full head. The result was an initially greater discharge rate, which quickly dropped once the pump operated against full head conditions.

Because the pump was operated at close to shut-in conditions (nearly closed valve on the discharge line), tiny changes in the valve setting caused large changes in pumping rate, as can be seen in the chaotic data fluctuations. Unfortunately, after about six minutes of pumping, the water level was pulled far down into the well screen. This occurrence probably allowed air into the screen and filter pack, permitting drainage of the water between the inflatable packer and the top of the screen, as well as water stored in the filter pack above the screen. This, in turn, caused casing storage effects during subsequent testing, because the trapped air could expand and contract in response to drawdown (pressure) changes.

Calculating the duration of casing storage effects was not possible without knowing how much trapped air there was in the filter pack. The standard casing storage calculation, assuming no packer present, yielded a predicted casing storage duration of several hours, based on casing only, i.e., no filter pack storage. The casing contribution was known to be far less than it would have been without a packer, because the packer was set at about 618 feet and, thus, still effectively isolated the water in the casing above that point. It was not known, however, what the filter pack storage contribution was. Nevertheless, it is likely that the casing storage effect was some tens of minutes.

Toward the end of the pumping period, the discharge rate was adjusted to approximately 1.6 gpm. Figure 4 shows the subsequent recovery curve. The data show classic casing storage response of flat-steep-flat slopes. In fact, most of the data show only the flat-steep portion of the response, suggesting that casing storage was far from over at the end of the 13-minute recovery episode. Because the recovery data were dominated by casing storage effects, aquifer parameters could not be calculated.

Figure 5 shows the subsequent 24-minute 1.4 gpm trial pumping event, with *incremental* drawdown plotted on the *y*-axis. Note that 6 feet of incremental drawdown was observed after mere seconds of pumping. This suggests antecedent drainage of a portion of the drop pipe due to leaky check valves, and the resulting effect of the pump starting against reduced head. Again, most of the drawdown data show the classic flat-steep-flat response, consistent with casing and filter pack storage. It is not known whether casing and filter pack storage effects had been completed, but it appears likely that all of the data were affected. Thus, no aquifer coefficients were computed.

Figure 6 shows recovery from the second trial pumping event, extending for an observation period of three days. Because the previous recovery period sandwiched between the two pumping trials was very brief, the recovery data on Figure 6 were computed as though pumping had been continuous since the onset of the first trial at 12:04 pm, i.e., 188 minutes of pumping. The graph shows the classic casing storage response of a flat-steep-flat data pattern. [Note that time is increasing to the left on the graph, as *t/t'* gets smaller.]

Based on very rough estimates, not included here, combined casing and filter pack storage effects could have persisted for a few tens of minutes. A casing storage duration of 30 minutes, for example, would correspond to a *t/t'* value of 7.3 on the recovery graph. Moving from right to left on the recovery graph, as the curve transitioned from "steep" back to "flat", the concave downward shape persisted throughout the entire recovery period, even though casing storage effects would have become negligible late in recovery. This concave downward shape was attributable to partial penetration effects in which the recovery curve gets steadily flatter as the recovery "cone of impression" expands vertically through greater and greater aquifer thickness. Thus, the dilemma encountered was that partial penetration effects and late casing storage effects appeared identical and indistinguishable (concave downward, gradually flattening). This made it difficult to see where casing storage effects ended and "analyzable" data began.

Partial penetration effects were analyzed using the Hantush method to quantify formation properties. Figures 7, 8 and 9 show curve matching results for assumed anisotropy ratios of 1, 0.1 and 0.01, respectively. Curve matching was performed in such a way as to exclude measurements earlier than about 30 minutes to try to eliminate presumed casing storage effects from the analysis. The hydraulic conductivities obtained from the analysis ranged from 0.40 to 0.58 feet per day, with more severe anisotropy yielding greater hydraulic conductivity. Well CdV-16-1(i) is in a location of known steep downward vertical gradients, suggesting severe vertical anisotropy. Thus, a hydraulic conductivity value at the upper end of the calculated range is probable.

24-Hour Constant-Rate Pumping Test

Figure 10 shows time-drawdown data from the constant-rate pumping test begun at 4:55 pm on March 1 at a rate of 1.6 gpm. The early data show substantial drawdown (about 16 feet) after just seconds of pumping. Normally, casing storage effects cause the initial water level displacement to be very small, consistent with what was seen on the recovery graphs. The rapid drawdown during pumping is a strong indication that antecedent drainage of the drop pipe, through leaky check valves or coupling joints, had occurred, allowing the pump to start up against relatively low head and, thus, over-pump initially.

After several minutes, the effects of minor discharge line valve adjustments can be seen. Because of the near shut-in conditions, small valve adjustments caused large flow rate changes and drawdown fluctuations. However, after several hours, the pumping rate was stabilized and maintained nearly constant for the remainder of the test. Nevertheless, the overall effect of the varying pumping rate, followed by near water level stabilization, precluded using the data to calculate aquifer parameters.

Once the valve setting and pumping rate were stabilized, the drawdown data displayed a highly unique sinusoidal response, as shown on Figures 11 and 12. Figure 11 shows a portion of the data recorded soon after rate stabilization, while Figure 12 shows data toward the end of the test. These data were not relevant to supporting determination of aquifer parameters, but were so unusual and remarkable as to demand archiving and reporting.

Figure 11 shows a water level amplitude of about 0.3 feet with a cycle period of 9.8 minutes, while Figure 12 shows a smaller amplitude and a period of 6.6 minutes. The explanation for this response is not known with certainty, but it may be related to a thermally-induced feedback loop involving either the pump, or the generator, or both.

For example, if the pumping rate increased slightly, the pump might gradually heat up thereby reducing the pump efficiency and, consequently, reducing the discharge rate. This rate reduction could then allow the pump to cool and pump more efficiently, thereby increasing the pumping rate. Thermal responses such as this could have caused the observed oscillatory behavior. Or, a similar phenomenon could have occurred with respect to the generator heating and cooling during the test. Also, it is possible that the two pieces of equipment working in tandem contributed to the observed response via oscillatory heating/cooling and output characteristics.

39-Hour Recovery

Following the completion of the 24-hour pumping test, recovery was measured for 2361 minutes, from 4:55 pm on March 2 to 8:16 am on March 4. Figure 13 shows the resulting recovery graph. The graph shows the classic casing storage response of a flat-steep-flat data pattern.

Similar to the recovery following trial testing, the transition from presumed casing storage to partial penetration effects is not discernable. On Figure 13, an elapsed recovery time of 30 minutes (*very* rough estimate of possible casing storage duration) corresponds to a t/t' ratio of 49.

Figure 14 shows an expanded scale view of the middle to late portion of the recovery curve. The transition from combined partial penetration and presumed casing storage response to only partial penetration response appears seamless, with no indication of where casing storage effects end. Note the minor "blip" starting at a t/t' value of about 52. The cause of this anomaly is not known, but could be related to a sudden, brief check valve malfunction allowing a small volume of water to leak out of the drop pipe.

Partial penetration effects were analyzed using the Hantush method to quantify formation properties. Figures 15, 16 and 17 show curve matching results for assumed anisotropy ratios of 1, 0.1 and 0.01, respectively. Curve matching was performed in such a way as to exclude measurements earlier than about 30 minutes to try to eliminate presumed casing storage effects from the analysis. The hydraulic conductivities obtained from the analysis ranged from 0.37 to 0.67 feet per day, with more severe anisotropy yielding greater hydraulic conductivity. Again, the known steep downward vertical gradients in the area suggested severe vertical anisotropy and, therefore, a hydraulic conductivity value at the upper end of the calculated range, or possibly beyond, depending on actual anisotropy.

Specific Capacity Analysis

Specific capacity data from the 24-hour pumping test were used to compute a lower-bound estimate of hydraulic conductivity using the Brons and Marting method, as well as the Hvorslev formula. After 24 hours of pumping at 1.6 gpm, the observed drawdown was 35.6 feet. For the Brons and Marting procedure, other input parameter values used in the calculation included a borehole radius of 0.51 feet, a well screen length of 10 feet, an estimated storage coefficient of 0.10, and an estimated (arbitrary) aquifer thickness of 200 feet. Based on these inputs, the lower-bound estimate of hydraulic conductivity was calculated to be 0.47 feet per day.

Application of the Hvorslev formula produced a lower-bound hydraulic conductivity estimate of 0.41 feet per day.

Slug Test Analysis

Following the recovery monitoring period, the inflatable packer was deflated in preparation for pulling the pumping string. When this was done, the water level rose 15 feet suddenly, apparently because of the release of water suspended above the packer in the annulus between the drop pipe and the well casing. This implied that coupling joints in the drop pipe had leaked slowly during well testing, allowing a modest volume of water (about 9 or 10 gallons) to flow into the annular space above the packer.

Figure 18 shows the hydrograph corresponding to the release of the water above the packer and the gradual decay in water levels as the released water moved into the aquifer. The hydraulic response created by the sudden release of the suspended water was the equivalent of a slug test in which either water of a solid slug is suddenly added to the well. The resulting water level decay data were analyzed using slug test methods to obtain additional lower-bound estimates of hydraulic conductivity.

Bouwer and Rice Method

Figure 19 shows a semilog Bouwer and Rice plot of the water level data along with a line of best fit. Applying the Bouwer and Rice equation produced a lower-bound hydraulic conductivity estimate of 0.21 feet per day.

Hvorslev Method

Figure 20 shows an additional semi-log plot of the slug test response that was analyzed using the Hvorslev method. Applying the Hvorslev formula to the line of best fit yielded a lower-bound estimate for the hydraulic conductivity of 0.27 feet per day, similar to that obtained using the Bouwer and Rice method.

Note that the slug test hydraulic conductivity values were much lower than the values obtained from the specific capacity methods. It is likely that the specific capacity methods overestimated the lower-bound K values, while the slug test methods underestimated them. There are several reasons for this.

1. The Brons and Marting method can overestimate the lower-bound *K* value somewhat for unconfined conditions. This method is best suited for confined conditions, in which the specific storage (ratio of storage coefficient to aquifer thickness) is a constant. For confined aquifers the specific storage is constant, but for unconfined aquifers, it decreases with increased aquifer thickness. This distinction results in a small overestimate of conductivity using the Brons and Marting calculation.

2. The Hvorslev formula that uses specific capacity data is based on infinite pumping time. This assumption also causes a slight overestimate of the lower-bound *K* value.

3. The slug tests, on the other hand, underestimate the lower-bound *K* value. This is because their derivations are based on the assumption of a fixed radius of influence around the well, whereas the actual radius of influence increases with increased equilibration time. This discrepancy results in a systematic underestimation of the lower-bound *K* value.

SUMMARY

The following information was determined from the pumping, recovery, and slug tests conducted in CdV-16-1(i).

1. The barometric efficiency was near 100 percent, based on the observation of no discernable correlation between barometric pressure and the non-vented transducer hydrograph.

2. Implementation of the inflatable packer did not eliminate the effects of casing storage, presumably because of air that was entrained in the casing and filter pack when the pumping water level was drawn into the well screen.

3. The data showed evidence of leaky check valves and coupling joints in the drop pipe string.

4. Slug test methods, which distinctly underestimate the lower-bound *K*, yielded estimates of 0.21 and 0.27 feet per day. Specific capacity test methods, which slightly overestimate the lower-bound *K*, yielded estimates of 0.41 and 0.47 feet per day. Taken together, these results suggest a probable lower-bound hydraulic conductivity in a range of about 0.35 to 0.40 feet per day.

5. Hantush analysis of recovery data yielded *K* value ranges of 0.4 to 0.58 feet per day for the trial pumping and 0.37 to 0.67 feet per day for the long-term test, with more severe anisotropy yielding higher values. The known steep vertical gradients in the vicinity of CdV-16-1(i) imply severe anisotropy. This, in turn, suggests a realistic hydraulic conductivity range of about 0.50 to 0.70 feet per day. This result shows excellent consistency with the identified lower-bound hydraulic conductivity range estimate.

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Appendix F

NMED Discharge Approval and Discharge Media Analytical Results

------- Forwarded message follows -------
From: "Enz, Robert D." <renz@doeal.gov>
To: "'bbockisch@ nderson er.com'"
<bbockisch@kleinfelder.com>
Date sent: Thu, 4 Mar 2004 07:43:59 -0700
Subject: FW: Land Application of Drilling and Development Water From
CdV-1 6-1(i)

-----Original Message-----
From: Curt Frischkorn [mailto:curt_frischkorn@nmenv.state.nm.us]
Sent: Wednesday, March 03, 2004 4:07 PM
To: john_young@nmenv.state.nm.us; Enz, Robert D.
Cc: karma nderson; Karen McCormack; Whitacre, Thomas; bbeers@lanl.gov
Subject: RE: Land Application of Drilling and Development Water
>From CdV-16-1(i)

Bob:
This email confirms NMEDapproval for the discharge of drilling and development water from Hydrogeologic Workplan well CdV-16-1(i) (described below). The drilling and development water must be discharged as described in the Hydrogeologic Workplan NOI dated July 16, 2002.

Curt Frischkorn
NMED Ground Water Quality Bureau
(505) 827-0078

-----Original Message-----
From: Enz, Robert D. [mailto:renz@doeal.gov]
Sent: Monday, March 01, 2004 11:36 AM
To: 'curt_frischkorn@nmenv.state.nm.us'; 'john_young@nmenv.state.nm.us'
Cc: 'bbeers@lanl.gov'; Whitacre, Thomas
Subject: Land Application of Drilling and Development Water From CdV-16-1(i)

Dear Curt and John,

I am transmitting the analytical screening data from the sampling of Workplan Well CdV-16-1(i) drilling and development water. Workplan Well CdV-16-1(i) is located in Canon de Valle. Approximately 20,000 gallons of drilling and development water was recently produced during the construction of CdV-16-1(i). The details are as follows.

CdV-16-1(i) Drilling and Development Water
Approximately 20,000 gallons of drilling and development water are being stored in a lined pit at the CdV-16-1(i) drill site. Screening analysis of the pit water produced the following results:

CDV No PCBs were detected at concentrations greater than Method Detection Limits (MDLs).
2) No VOAs or SVOAs were detected with the exception of the following:
CDVI acetone at 290 ppb, and
* toluene at 37 ppb (NM WQCC gw std=750 ppb, SDWA MCL=1000 ppb)
It is believed that the acetone detected in the pit water is an artifact of the drilling additive, Quickfoam, that contains isopropyl alcohol. The source of the toluene is unknown.
3) Gross alpha activity is 4.06 pCi/L (+/-1.32 pCi/L), less than the SDWA MCL of 15 pCi/L.
4) Tritium results were nondetect (MDL=430 pCi/L).
3) No perchlorate was detected in the sample at concentrations greater than 0.989 ppb.
4) Analysis of a filtered screening sample showed that no contaminants exceeded NM WQCC Regulation 3103 ground water standards with the exception of the following:
* Fe=2.2 ppm (NM WQCC ground water std=1.0 ppm)
DOE proposes to land apply the pit water to the mesa top land adjacent to the drill site. The application will be conducted in accordance with the terms and conditions of the Hydrogeologic Workplan NOI. Copies of the analytical reports are attached.

Please contact Bob Beers at 667-7969 (office) or 699-2342 (cell) should you have any questions regarding this notification. This notification will be formally transmitted to you via a letter signed by Mat Johansen, DOE Ground Water Compliance Manager.

Bob Enz
------- End of forwarded message -------
KLEINFELDER
EXPECT MORE

Appendix G

Activities Planned for Well CdV-16-1(i)
Compared with Work Performed

Activity	Addendum to CMS Plan for PRS 16-021(c)	Scope of Services for CdV-16-1(i) GSA Task Order 9T3N163PG	CdV-16-1(i) Actual Work
Planned Depth	100 to 500 ft into the regional aquifer	Planned TD of 900 ft bgs, approximately 50 ft below the anticipated zone of substantial saturation, assumed to be at 850 ft bgs.	CdV-16-1(i) drilled to 683 ft bgs TD, approximately 120 feet into the saturated zone. The static water level in this zone was measured at 563 ft bgs.
Drilling Method	Methods may include, but are not limited to HSA, air-rotary/Odex/Stratex, air-rotary/Barber rig, and mud-rotary drilling	Not specified in the Scope of Services.	CdV-16-1(i) drilled using fluid-assisted, open-hole, air- rotary.
Amount of Core	10% of the borehole	Planned Phase I drilling depth, with continuous core sampling, was 200 ft bgs.	Actual CdV-16-1(i) core-sampling depth was 200 ft bgs. Spot coring conducted from 0 ft to 10 ft bgs; continuous coring conducted from 10 ft to 200 ft bgs.
Lithologic Log	Log to be prepared from core, cuttings and drilling performance	Log to be prepared from data provided by core, cuttings, geophysical logs, and drilling performance.	The CdV-16-1(i) lithlog was prepared from core samples in the interval 0-200 ft bgs and from cuttings samples in the interval 0-683 ft. Interpretation of geophysical logs and determination of unit contacts was provided by LANL EES-6.
Number of Water Samples Collected for Contaminant Analysis	A water sample may be collected from each saturated zone, five zones assumed. The number of sampling events after well completion is not specified.	If perched water is encountered in the unsaturated zone, ground water samples to be collected from each perched zones for screening analysis.	No water samples were obtained from the vadose zone because sufficient quantities of water were not present in the perched zones that were encountered. One (1) screening sample collected at 595 ft bgs within the saturated zone during Phase II drilling. One (1) groundwater sample collected from the screen interval (624 ft to 634 ft bgs) of the completed well.
Water Sample Analysis	Initial sampling: radiochemistry I, II, and III, ^{3}H, general inorganics, stable isotopes, VOCs, and metals. Saturated zones: radionuclides (tritium, strontium-90, cesium-137, americium-241, plutonium isotopes, uranium isotopes, gamma spectrometry, and gross alpha, gross beta, and gross gamma), stable isotopes (hydrogen, oxygen, and in special cases nitrogen), major ions (cations and anions), trace metals, and trace elements.	Analytes not specified in the Scope of Services.	Analytes included the following: $^{2}H/^{1}H$, $^{18}O/^{16}O$, Nitrogen isotopes, Americium-241, Gamma spectroscopy, ISOPU, ISOU, Strontium-90, Tritium, Technetium-99, Perchlorate.
Water Sample Field Measurements	Alkalinity, pH, specific conductance, temperature, turbidity	Carbonate alkalinity, pH, specific conductance, temperature, turbidity	No parameters collected for groundwater samples.
Number of Core/Cuttings Samples Collected for Contaminant Analysis	Twenty samples of core or cuttings to be analyzed for potential contaminant identification in each borehole.	Nine (9) core samples to be collected at depths of 10, 20, 30, 40, 50, 75, 100, 150, and 200 ft bgs.	Eleven (11) core samples were collected at depths of 10, 20, 30, 40, 50, 75, 100, 125, 150, 175, and 200 ft bgs and submitted for geochemical and contaminant

Activity	Addendum to CMS Plan for PRS 16-021(c)	Scope of Services for CdV-16-1(i) GSA Task Order 9T3N163PG	CdV-16-1(i) Actual Work
			analysis.
Core/Cuttings Sample Analytes	Uppermost sample to be analyzed for a full range of compounds: deeper samples will be analyzed for the presence of radiochemistry I, II, and III analytes, tritium (low and high detection levels), and metals. Four samples to be analyzed for VOCs.	Determine contaminant distribution, moisture, and anion/^{3}H/isotope profiles in the vadose zone.	Analytes included the following: RADVAN Alpha, Beta, and Gamma, $^{2}H/^{1}H$, $^{18}O/^{16}O$, Nitrogen isotopes, Americium-241, Gamma spectroscopy, ISOPU, ISOU, Strontium-90, Tritium, Technetium-99, anions, and moisture content.
Laboratory Hydraulic-Property Tests	Physical properties analyses will be conducted on 5 core samples and will typically include: moisture content, porosity, particle density, bulk density, saturated hydraulic conductivity, and water retention characteristics.	Up to nine (9) samples to be selected for determination of moisture content profile in the vadose zone at depths from 10 to 200 ft bgs.	Eleven (11) core samples were collected from the vadose zone at depths from 10 to 200 ft bgs and submitted for moisture content analysis.
Geology	Ten samples of core or cuttings will be collected for petrographic, X-ray fluorescence (XRF) and X-ray diffraction (XRD) analyses	The geology task leader to determine the number of samples for characterization of mineralogy, petrography, and geochemistry based on geologic and hydrologic conditions encountered during drilling.	Seven (7) samples of core/cuttings were collected and submitted for analysis for mineralogy, petrography, and geochemistry.
Geophysics	In general, open-hole geophysics includes caliper, electromagnetic induction, natural gamma, magnetic susceptibility, borehole color videotape (axial and sidescan), fluid temperature (saturated), single-point resistivity (saturated), and spontaneous potential (saturated). In general, cased-hole geophysics includes: gamma-gamma density, natural gamma, and thermal neutron.	Typical wireline logging service as planned: open-hole geophysics includes array induction imager, triple lithodensity, combinable magnetic resonance tool, natural gamma, natural gamma ray spectrometry, epithermal compensated neutron log, caliper, full-bore formation micro-imager, elemental capture spectrometer and borehole video. In general, cased-hole geophysics includes triple lithodensity, natural gamma, natural gamma spectrometry, epithermal compensated neutron log, elemental capture spectrometer.	Schlumberger geophysical logging surveys conducted at CdV-16-1(i) included: Compensated Neutron Tool: Cased: none Open Hole: 50 – 680 ft bgs Triple Litho-Density: Cased: none Open Hole: 50 – 680 ft bgs Array Induction Tool: Cased: none Open Hole: 50 –674 ft bgs Elemental Capture Spectroscopy: Cased: none Open Hole: 50 – 675 ft bgs Natural Gamma Spectroscopy: Cased: none Open hole: 50 – 674 ft bgs Combinable Magnetic Resonance: Cased: none Open Hole: 50 – 662 ft bgs Full-bore Fm Micro-imager: Cased: none Open Hole: 568 – 682 ft bgs
Water-Level Measurements	Procedures and methods not specified in "Hydrogeologic Workplan".	Water levels will be determined for each saturated zone by water-level meter or by pressure transducer.	Electric water level meter (sounder) used to measure zones of perched saturation (i.e., attempted measurements) and the regional water table.
Field Hydraulic-Property Tests	Not specified in hydrogeologic work plan	Slug or pumping tests may be conducted in saturated intervals once the well is completed.	Hydraulic pumping tests at CdV-16-1(i) conducted in January 2004.

Activity	Addendum to CMS Plan for PRS 16-021(c)	Scope of Services for CdV-16-1(i) GSA Task Order 9T3N163PG	CdV-16-1(i) Actual Work
Shallow Piezometers	Not specified in hydrogeologic work plan	Not specified in Scope of Services.	A shallow piezometer was installed in the corehole. Casing constructed of 2-in OD schedule 40 PVC. The screened interval was from 50 ft to 80 ft bgs, constructed of 2-in schedule 40 PVC, 0.010 slot well screen. Annular fill consisted of 10/20 silica sand across the screened interval (45-80 ft bgs) and bentonite above and below the filter pack, at 0-45 ft bgs and 80-200 ft bgs, respectively.
Surface Casing	Approximately 20-in. outer diameter (OD) extends from land surface to 10-ft depth in underlying competent layer and grouted in place.	Not specified.	13 ⅜-in. OD steel casing was installed to 12 ft bgs and subsequently removed during CdV-16-1(i) well construction.
Minimum Well Casing Size	6.625-in. OD	4-in. diameter, 304 grade stainless steel casing.	5-in. OD (4.46-in ID) stainless steel casing with external couplings
Well Screen	Machine-slotted (0.01-in.) stainless-steel screens with flush-jointed threads; number and length of screens to be determined on a site-specific basis and proposed to NMED	4-in. diameter, 304 grade stainless steel well screen, estimated to be 10 ft long.	A single screen at CdV-16-1(i) constructed of 5.27-in. OD, wire-wrapped, rod-based stainless-steel, 0.020-in. slot size, with external couplings. The screened interval is from 624 ft to 634 ft bgs.
Sump	Stainless-steel casing with an end cap	Not specified.	Sump constructed of 5-in. OD stainless-steel casing, 13.7 ft long, with end cap.
Backfill	Uncontaminated drill cuttings below sump and bentonite above sump	Not specified.	Slough in the borehole occurs from 683 ft to 671 ft bgs, 14 ft below the bottom of the sump. A 53/47 mix of 10-20 silica sand and bentonite chips was placed from 671 ft to 644 ft bgs, 10 ft below the bottom of the screened interval.
Filter Material	>90% silica sand, properly sized for the 0.010-in. slot size of the well screen; extends 2 ft above and below the well screen	Not specified.	Primary filter pack constructed of 10/20 silica sand placed in the interval from 613 to 644 ft bgs, 10 ft below and 11 ft above the screen. Secondary filter pack constructed of 20/40 silica sand placed above primary filter pack in the interval 611-613 ft bgs.
Transition Seal	N/A*	Not specified.	The transition seal above the secondary filter material composed of a 67:33 mix of 10/20 sand and bentonite chips in the interval 540-611 ft bgs.
Bentonite Seal	N/A	Not specified.	Bentonite chips placed in the annular interval 70-540 ft bgs; All bentonite intervals hydrated with municipal water after emplacement in 50-ft lifts.
Concrete Backfill	N/A	Not specified.	Portland cement with 6% bentonite poured in the interval 0-70 ft bgs.

* N/A – Not specified in the two referenced documents.