TA-16

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

NOV 28 2005

Mr. James P. Bearzi, Chief
NMED-Hazardous Waste Bureau
2905 Rodeo Park Drive East,
Building 1
Santa Fe, NM 87505-6303

RECEIVED
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NMED Hazardous Waste Bureau

Dear Mr. Bearzi:

Subject: Completion Report for Characterization Well CdV-16-2(i)r

Enclosed are two copies of the Final Completion Report for Characterization Well CdV-16-2(i)r. This submittal fulfills the first well completion report requirement for Fiscal Year 2006 subject to the Consent Order. If you have any questions regarding this report, please contact me at (505)606-0397, or Tom Whitacre at (505)665-5042.

Sincerely,

John C. Ordaz, P.E.
Assistant Manager
Office of Environmental Stewardship

ES: 2TW-015

Enclosures

cc w/o enclosures:
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FINAL
COMPLETION REPORT
CHARACTERIZATION WELL CdV-16-2(i)r
LOS ALAMOS NATIONAL LABORATORY
LOS ALAMOS, NEW MEXICO
PROJECT NO. 49436

Prepared for:

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

Prepared by:

KLEINFELDER

8300 Jefferson NE, Suite B
Albuquerque, New Mexico 87113

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LIST OF ACRONYMS AND ABBREVIATIONS

ASTM	American Society for Testing and Materials
bgs	below ground surface
DOE	US Department of Energy
DTW	depth to water
EES	Environmental and Earth Sciences group
ELAN	elemental analysis
ft	foot/feet
gal.	gallon
gpd	gallons per day
GPS	Global Positioning System
in.	inch
Kleinfelder	Kleinfelder, Inc.
LANL	Los Alamos National Laboratory
NM	not measured
NMED	New Mexico Environment Department
NTU	nephelometric turbidity unit
OD	outer diameter
ppm	parts per million
PRS	potential release site
psi	pounds per square inch
Qbo	Otowi Member of the Bandelier Tuff
Qbog	Guaje Pumice Bed of Otowi Member
Qbt1g	Unit 1g, Tshirege Member of the Bandelier Tuff
Qbt1v	Unit 1v, Tshirege Member of the Bandelier Tuff
Qbt2	Unit 2, Tshirege Member of the Bandelier Tuff
Qbt3	Lower Unit 3, Tshirege Member of the Bandelier Tuff
Qbt3t	Upper Unit 3, Tshirege Member of the Bandelier Tuff
Qbt4	Unit 4, Tshirege Member of the Bandelier Tuff
Qct	Cerro Toledo interval of the Bandelier Tuff
RCT	radiation control technician
TA	Technical Area
TD	total depth
TOC	total organic carbon
Tpf	Puye Formation
µS/cm	microSiemens per centimeter
WDC	WDC Exploration & Wells

ABSTRACT

Characterization Well CdV-16-2(i)r was installed as part of the Groundwater Protection Program in accordance with the "Addendum to the Corrective Measures Study Plan for PRS 16-021(c), Revision 1" (LANL 2003) and the "Drilling Work Plan for Characterization Well CdV-16-2(i)r" (Kleinfelder 2005a). The US Department of Energy contracted and directed the installation of CdV-16-2(i)r with technical assistance from Los Alamos National Laboratory.

CdV-16-2(i)r is located on the mesa top in Technical Area 16. It replaces well CdV-16-2(i), which was drilled and installed in December 2003 but did not sustain water in the well. CdV-16-2(i)r was drilled in an attempt to complete a monitoring well at the same location to evaluate water quality in the deep intermediate perched zone. It was drilled approximately 50 feet northwest of the original well. The primary contaminants of potential concern in the area are high explosives that have been discharged from TA-16 and possibly from other nearby sites. Other potential contaminants being investigated are metals, nitrate, perchlorate, chloride, sulfate, and fluoride.

CdV-16-2(i)r was drilled to 874.4 feet using air-rotary and fluid-assisted air-rotary drilling methods. The stratigraphy encountered during borehole drilling included, in descending order, Tshirege Member of the Bandelier Tuff, Cerro Toledo interval, Otowi Member of the Bandelier Tuff, the Guaje Pumice Bed of the Otowi Member, and the Puye Formation. The well was installed within the upper portion of the Puye Formation with a screened interval from 850 to 859.7 feet below ground surface. The depth to water remained steady after total depth was reached and ranged between approximately 836 and 840 feet below ground surface.

One screening groundwater sample was collected near the end of drilling, one was collected after the well was installed and developed, and a final sample was collected after aquifer testing. A constant-rate aquifer test was conducted to determine the aquifer properties of the deep-perched intermediate zone. The aquifer test demonstrated an average hydraulic conductivity of 3.0 feet/day, assuming a 22-foot saturated thickness, with a strong likelihood of zones of both greater and lesser conductivity. Boundary effects indicate the zone is severely limited in areal extent.

1.0 INTRODUCTION

This completion report summarizes the site preparation, drilling, well construction, well development, aquifer testing, and related activities for Characterization Well CdV-16-2(i)r, drilled in July 2005, at Los Alamos National Laboratory (LANL) for the Groundwater Protection Program. CdV-16-2(i)r replaces well CdV-16-2(i), which was drilled and installed in December 2003 but did not sustain water in the well. CdV-16-2(i)r was drilled in an attempt to complete a monitoring well at the same location to monitor water quality in the deep perched intermediate zone. It was drilled approximately 50 feet (ft) northwest of the original well.

CdV-16-2(i)r is located on the mesa top in Technical Area 16 (TA-16), as shown in Figure 1.0-1. The "Addendum to the Corrective Measures Study Plan for Potential Release Site (PRS) 16-021(c), Revision 1" (LANL 2003) called for this well to monitor water quality in the deep intermediate perched groundwater beneath TA-16. The primary contaminants of potential concern in the area are high explosives that have been discharged from TA-16 and possibly from other nearby sites. Other potential contaminants being investigated are metals, nitrate, perchlorate, chloride, sulfate, and fluoride.

The work was funded and directed by the US Department of Energy (DOE). Kleinfelder, Inc. (Kleinfelder), under contract to the US Army Corps of Engineers, was responsible for executing the drilling, installation, testing, and sampling activities with technical assistance from LANL. Activities were conducted according to the "Drilling Work Plan for Characterization Well CdV-16-2(i)r" (Kleinfelder 2005a).

The objectives at CdV-16-2(i)r were to drill and install a replacement deep intermediate perched zone monitoring well to a maximum total depth of 900 ft below ground surface (bgs). The well was successfully drilled and installed with a screened interval between 850 and 859.7 ft bgs across a productive water-bearing zone. Cuttings were collected at 10-ft intervals from ground surface to 800 ft and at 5-ft intervals from 800 ft bgs to the total depth of 874.4 ft. Because a complete Schlumberger logging suite was obtained from the original well, only natural gamma and conductivity logs were run at CdV-16-2(i)r. Post-installation activities included well development, aquifer testing, groundwater sampling, permanent pump installation and wellhead surveying.

The information presented in this report was compiled from field reports and activity summaries generated by Kleinfelder, LANL, and subcontractor personnel. Original records, including field reports, field logs, and survey records, are on file in Kleinfelder's Albuquerque office and the LANL Records Processing Facility. This report contains brief descriptions of all activities associated with CdV-16-2(i)r, as well as supporting figures, tables and appendices. Detailed analysis and interpretation of geologic, geochemical, and aquifer data will be included in separate technical documents to be prepared by LANL.

2.0 PRELIMINARY ACTIVITIES

Preliminary activities included preparing administrative planning documents and constructing the drill site.

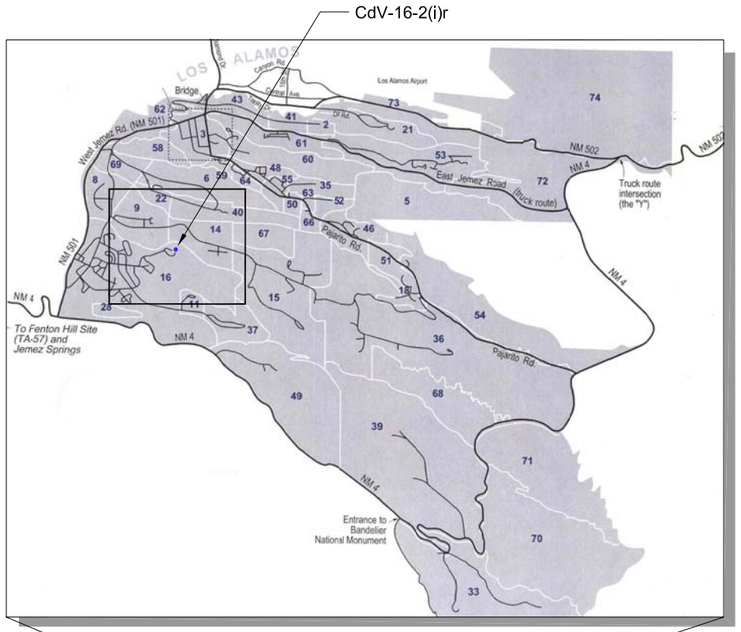
Legend

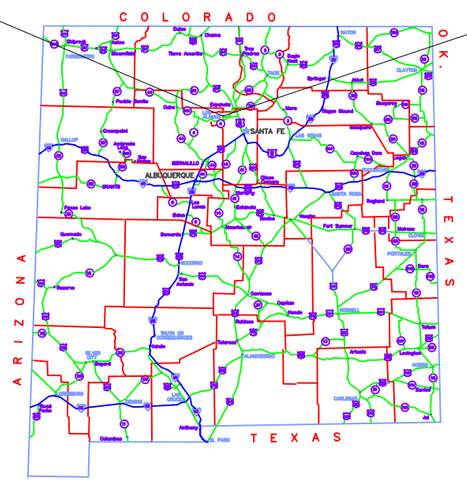
= Intermediate Perched Zone Wells

= Regional aquifer wells

58 = Technical area identification

= 100-ft contours





VICINITY MAP

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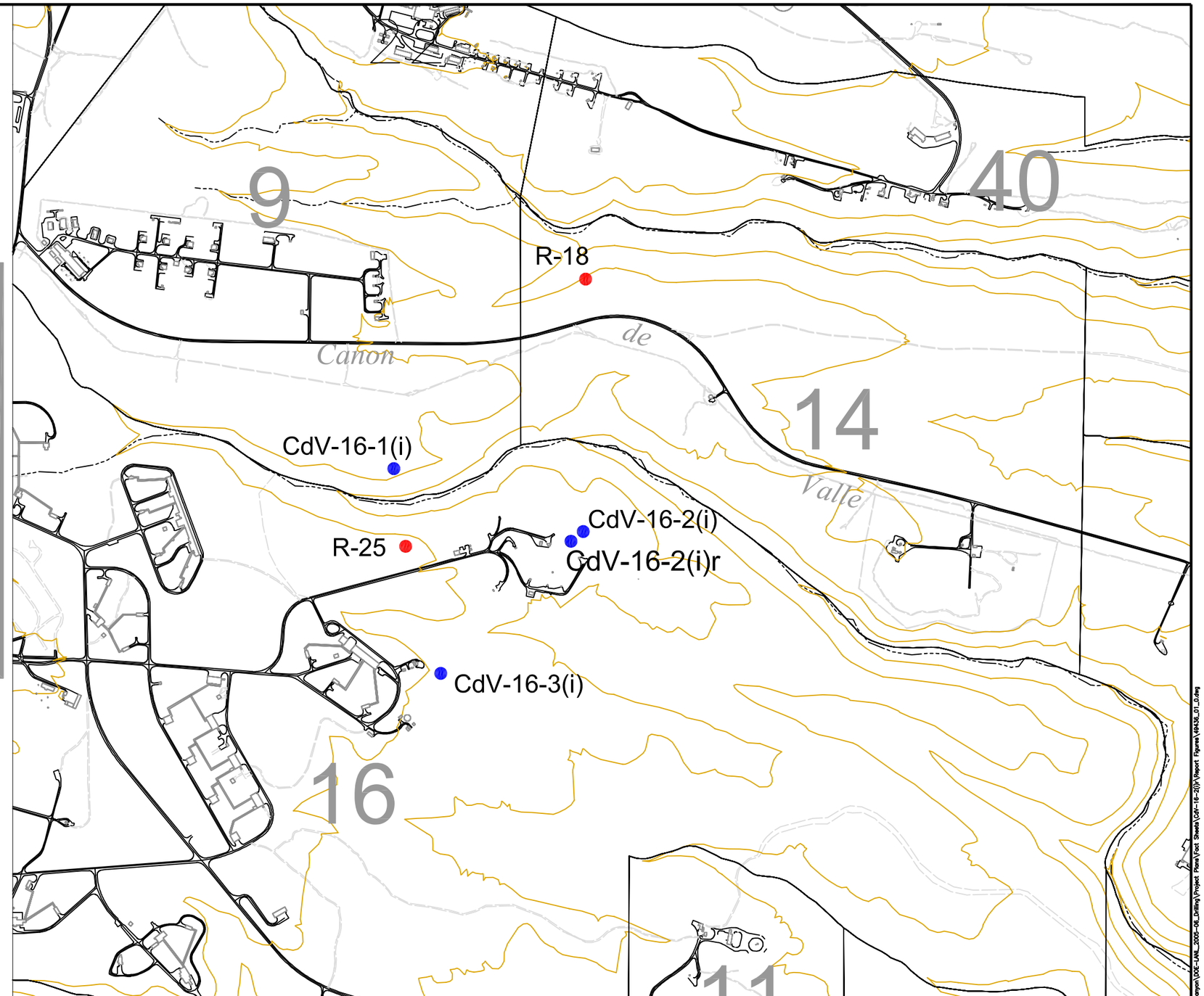

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Project No.: 49436	Filename: 49436_01_0.dwg
Scale: 1" = 1000'	Revision: Rev 0

SITE LOCATION MAP
Characterization Well CdV-16-2(i)r
Cañon de Valle
Los Alamos National Laboratory
Los Alamos, New Mexico

FIGURE
1.0-1

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2.1 Administrative Preparation

Kleinfelder received contractual authorization as a notice to proceed on May 27, 2005. The following documents were prepared to guide the implementation of the scope of work for this well: Drilling Work Plan (Kleinfelder 2005a), Contractor's Quality Management Plan (Kleinfelder 2005b), Site-Specific Health and Safety Plan (Kleinfelder 2005c), and Storm Water Pollution Prevention Plan (Kleinfelder 2005d).

2.2 Site Preparation

The original drill pad for CdV-16-2(i) was used for CdV-16-2(i)r. Site preparation consisted of reapplying gravel to the access road and drill pad, reconstructing and lining the cuttings pit, and installing silt fencing and hay bales to prevent storm water runoff. EnviroWorks, Inc. completed these tasks between July 1 and 6, 2005. The cuttings pit measured approximately 30 ft by 58 ft by 7 ft average depth. Radiation control technicians (RCTs) from LANL's Health, Safety, and Radiation Protection Group-1 were present to screen the site and equipment as necessary.

Office and supply trailers, generators, and safety lighting equipment were moved to the site during the subsequent mobilization of drilling equipment. Potable water was trucked to the site from a hydrant. Safety barriers and signs were installed around the borehole-cuttings containment area and at the pad entrance.

3.0 DRILLING ACTIVITIES

CdV-16-2(i)r was drilled to a total depth of 874.4 ft bgs between July 12 and 24, 2005. The well was completed with one screened interval within the deep perched intermediate zone from 850 to 859.7 ft bgs. Drilling activities were performed generally in one 12-hour shift per day, 7 days per week, by the drill crew and two site geologists. Depth-to-water (DTW) measurements were taken at the beginning and end of most shifts to check for the presence of groundwater. A chronology of drilling and associated activities for CdV-16-2(i)r is presented in Table 3.0-1.

WDC Exploration & Wells (WDC) drilled CdV-16-2(i)r using a Speedstar 50K drill rig. The rig was equipped with conventional drilling rods, tri-cone bits, down-the-hole hammer bits, air compressors, and support equipment. CdV-16-2(i)r was drilled using air-rotary and fluid-assisted air-rotary drilling techniques. Drilling fluids were used, as needed, to improve borehole stability, to minimize fluid loss, and to facilitate cuttings removal from the borehole. Drilling fluids consisted of a mixture of municipal water with QUIK-FOAM®/VersaFoam surfactant and EZ-MUD® polymer. An approximate tally of the total drilling fluids introduced into the borehole, as well as the total drilling fluids recovered, is presented in Table 3.0-2.

On July 11, 2005, WDC began mobilizing drilling equipment and supplies to the site. On July 12, WDC completed setting up and drilled to 10 ft bgs using a 12¼-inch (in.) tricone bit. The temporary 13⅜-in. outer diameter (OD) surface casing was driven to 8.5 ft bgs.

On July 13, 13⅜-in. OD surface casing was set to 9.6 ft bgs, and the borehole was advanced to 260 ft bgs.

On July 14, WDC advanced the 12¼-in.-diameter tri-cone bit from 260 to 562 ft bgs. On July 15, the borehole was advanced to the total depth (TD) of 852 ft bgs. Circulation was lost intermittently between 622 and 662 ft bgs.

Table 3.0-1
Chronology of Activities at CdV-16-2(i)r

TASK	DATES																							
	Jul-05				Aug-05				Sep-05				Oct-05				Nov-05				Dec-05			
SITE PREPARATION ACTIVITIES	7/1 - 6																							
BOREHOLE DRILLING/SAMPLING																								
Mobilization		7/11-12																						
Air-Rotary Drilling		7/12 - 7/24																						
Groundwater Screening Sampling			7/18																					
BOREHOLE LOGGING																								
Geophysical Logging			7/18																					
Video Logging			7/16&18																					
WELL CONSTRUCTION				7/25-30																				
WELL DEVELOPMENT					8/2 - 8/22																			
GROUNDWATER WELL SAMPLING							8/22			9/10														
AQUIFER TESTING										9/9-10														
PUMP INSTALLATION																10/28								
SITE RESTORATION																					Planned to start			

Table 3.0-2
Introduced and Recovered Fluids

Material		Amount (gallons)
Introduced	QUIK-FOAM®/VersaFoam	105
	Defoaming agent	10
	Potable water (air rotary drilling)	12,215
	EZ-MUD®	10
	Total introduced fluids[a]	12,340
Recovered	Total recovered fluids[b]	22,280

[a]Fluid volume introduced during drilling
[b]Estimated fluid volume recovered during drilling, well development, and hydrologic testing

On July 16, water was measured in the borehole at 836.55 ft bgs prior to video logging. During video logging, the DTW was observed at 836.58 ft bgs, but no water-producing zones were noted in the borehole. The bottom of the borehole was 846.5 ft bgs, indicating approximately 5.5 ft of slough had accumulated since the previous day. DOE and LANL project personnel decided to drill to 872 ft bgs and defer further video logging, geophysical logging, and groundwater sampling until the following Monday, July 18. The borehole was advanced to 872 ft bgs.

On July 17, DTW was measured at 837.30 ft bgs and bottom was tagged at 872.9 ft bgs, indicating possible blowout, or deepening of the borehole, below the bit at TD. The drill crew mobilized for well construction.

On July 18, DTW was measured at 837.30 ft bgs. LANL personnel ran a video log as well as natural gamma and induction array logs. After approximately 80 gallons (gal.) of water were bailed from the borehole, a groundwater sample (ID EU0507162IR01) was collected. DTW was 838.08 ft bgs after the sample was collected.

On July 19 and 20, an additional 320 gal. of water were bailed from the borehole. On the afternoon of July 20, when the last 85 gal. had been removed, water level measurements were taken every 10 minutes for 1 hour. The water level in the borehole recovered from 838.22 to 837.70 ft bgs over the 1-hour interval.

On July 22, DTW was measured at 837.30 ft bgs with no borehole activity since July 20. No other work was carried out.

On July 24, DTW was 836.90 ft bgs with no borehole activity since July 20. The bottom of the borehole was tagged at 861.9 ft bgs, approximately 2 ft below the planned screened interval for the well. The drillers tripped the drill string back in the borehole and drilled to the final borehole TD of 874.4 ft bgs. The DTW was measured at 839.83 ft bgs. WDC prepared to set the well and began to lower the tremie pipe into the borehole.

4.0 SAMPLING ACTIVITIES

This section describes the cuttings and groundwater sampling activities at CdV-16-2(i)r.

4.1 Cuttings Sampling

In December 2003, drill cuttings were sampled at 5-ft intervals in CdV-16-2(i) and logged as specified in the Addendum to the Corrective Measures Study Plan for PRS 16-021(c) (LANL 2003). Therefore, in CdV-16-2(i)r, cuttings sample collection was reduced to 10-ft intervals to 800 ft. From 800 ft bgs to the TD of the borehole, samples were collected at 5-ft intervals. No cuttings samples were submitted for laboratory analysis.

To a depth of 800 ft bgs, approximately 500 to 700 milliliters of bulk cuttings were collected from the discharge hose, sealed in Ziploc® bags, labeled, and transferred to the LANL Geology Group task leader. Between 800 ft bgs and TD, cuttings were collected at 5-ft intervals, sieved (using >#10 and >#35 mesh), and placed in chip trays along with unsieved cuttings. The sieved fractions were placed in labeled plastic bags and submitted to LANL. The remaining cuttings were sealed in Ziploc® bags, labeled, and archived in core boxes. LANL RCTs screened all cuttings before they were removed from the site.

4.2 Water Sampling

One screening water sample (ID EU0507162IR01) was collected from the open borehole with a 4-ft bailer on July 18, 2005, after geophysical logging. DTW at that time was 838.08 ft bgs and the sample was collected with a bailer. A second groundwater sample (ID EU0507162IR02) was collected after well development from a depth of 859.6 ft bgs on August 22, 2005. A third sample (ID EU0509162iR01) was collected after aquifer testing on September 10, 2005 from a depth of 856.67 ft bgs. These samples were submitted to EES for analysis of anions, metals and perchlorate per LANL-provided paperwork and containers.

5.0 HYDROGEOLOGY

A brief description of the hydrogeologic features encountered at CdV-16-2(i)r is presented below. The stratigraphy section identifies geologic units encountered in the original boring, CdV-16-2(i), from geologic cuttings and Schlumberger geophysical logs run in that borehole. LANL's EES-6 Group staff provided CdV-16-2(i) geologic contacts. Groundwater occurrence is based upon drilling observations, open-hole video logging, and water-level measurements obtained from CdV-16-2(i)r.

5.1 Stratigraphy

Borehole stratigraphy for well CdV-16-2(i) was presented in the March 2004 Completion Report (Kleinfelder 2004). Because replacement well CdV-16-2(i)r was drilled approximately 50 ft from the previous location, site stratigraphy from the original borehole location is presented in this report. Figure 5.1-1 shows the stratigraphy encountered at CdV-16-2(i) and CdV-16-2(i)r. A detailed lithologic log of CdV-16-2(i) from the March 2004 report is presented in Appendix A.

Tshirege Member of the Bandelier Tuff, Qbt (0 to 395 ft bgs)

Four subunits of the Tshirege Member of the Bandelier Tuff – Qbt1, Qbt2, Qbt3 and Qbt4 – were encountered at CdV-16-2(i) from 0 to 395 ft bgs. Qbt1 and Qbt3 have been further subdivided, as indicated below.

Qbt 4 was present from 0 to 56 ft bgs; it consisted of a poorly welded crystal-rich tuff. Cuttings from this interval typically contained less than 50% welded tuff fragments, up to 45% quartz and sanidine crystals, and up to 30% intermediate composition volcanic lithics including dacite, rhyodacite, and vitrophyre.

The interval from 56 ft to 195 ft is subdivided into upper Qbt 3t, with chemical properties that are transitional between lower Qbt 3 and Qbt 4. Qbt 3t and Qbt 3 were present in the CdV-16-2(i) borehole from 56 to 77 ft bgs and from 77 to 195 ft bgs, respectively. Both units are composed of moderately to poorly welded crystal-rich tuff and are mineralogically and texturally similar. Cuttings samples contained abundant welded, crystal-rich tuff with greater than 50% quartz and sanidine phenocrysts and generally minor quantities of intermediate composition volcanic lithics.

Qbt 2, from 195 to 305 ft bgs, is a moderately welded, crystal-rich tuff. Samples are generally made up of greater than 50% by volume crystal-rich tuff fragments, up to 50% quartz and sanidine crystals, and less than 5% intermediate composition volcanic lithics.

The basal cooling unit of the Tshirege Member is divided into an upper devitrified (Qbt 1v) and lower glassy (Qbt 1g) subunit (Broxton and Reneau 1995). Qbt 1v was present from 305 to 348 ft bgs as tuff fragments, quartz and sanidine crystals, intermediate composition volcanic lithic fragments, and minor devitrified pumice that occur in widely varying amounts. Qbt 1g was present from 348 to 395 ft bgs and contained tuff fragments, fibrous vitric pumices, quartz and sanidine crystals, and lithic fragments of intermediate composition volcanics.

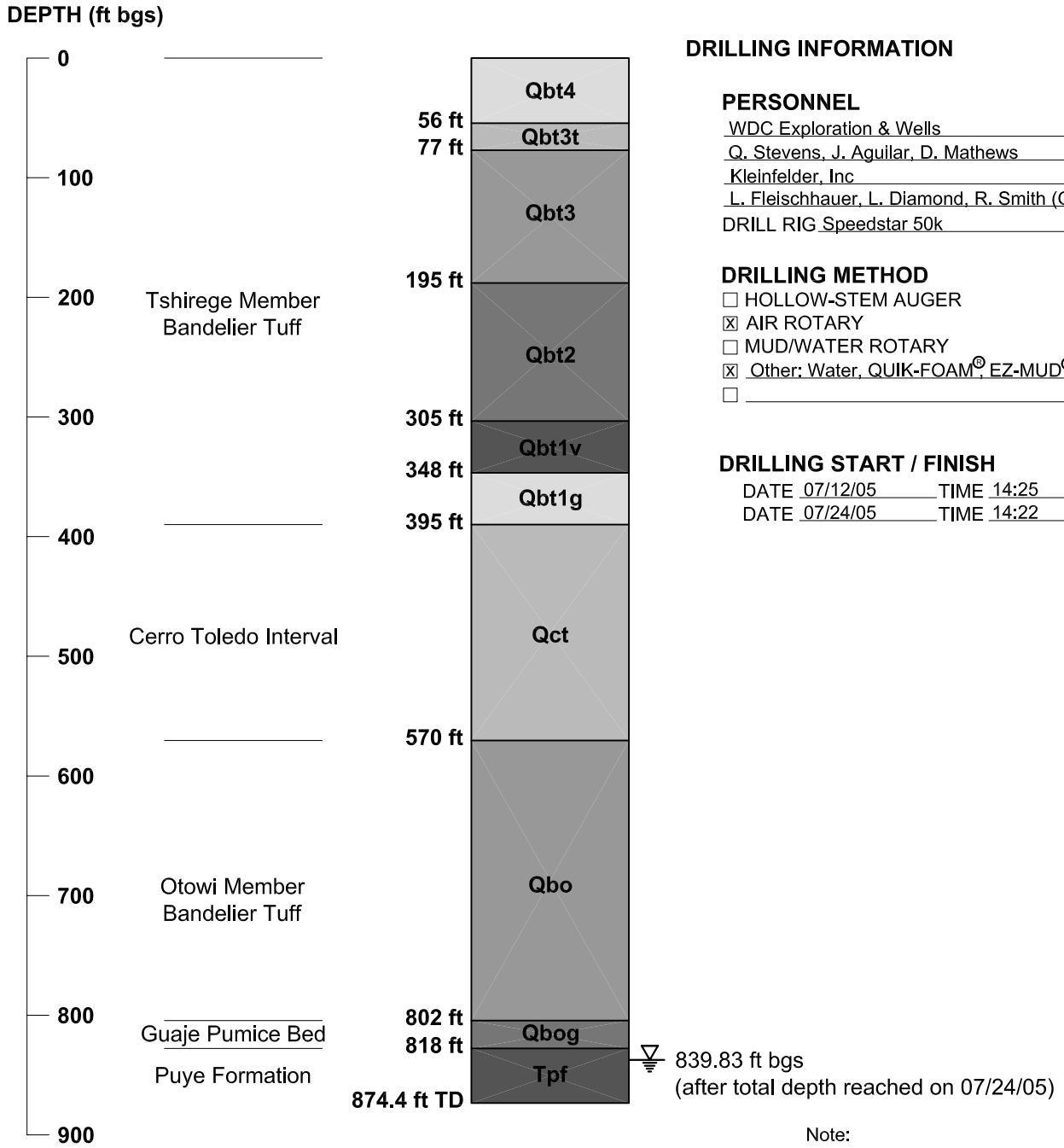
Cerro Toledo Interval, Bandelier Tuff, Qct (395 to 570 ft bgs)

Volcaniclastic sedimentary and tephra deposits of the Cerro Toledo interval separate the Tshirege and Otowi Members of the Bandelier Tuff. The Cerro Toledo interval occurred in borehole CdV-16-2(i) from 395 ft to 570 ft bgs.

This interval contained poorly cemented fine-grained deposits of silt, silty sand, and local silty gravel. Detrital constituents in the coarse-fraction (e.g., >#10 sieve size) generally contained up to 50% intermediate to felsic composition volcanic lithic fragments and up to 50% pumice. Lithic fragments commonly included dacite, andesite, porphyritic rhyolite, and vitrophyre. Pumices were generally fibrous, vitric, and pinkish to white in color. The presence of quartz and sanidine crystals indicates that the Cerro Toledo interval includes a component of reworked Otowi Member tuff.

Otowi Member of the Bandelier Tuff, Qbo (570 to 802 ft bgs)

Rhyolitic ash-flow tuff of the Otowi Member of the Bandelier Tuff was present in CdV-16-2(i) from 570 to 802 ft bgs. The Otowi Member was lithic-bearing, pumiceous, and nonwelded to poorly welded. In general, Qbo was vitric, lithic-rich in the upper 75 ft of the section and strongly pumiceous in the lower 157 ft. The coarse fraction of most cuttings samples contained



DRILLING INFORMATION

PERSONNEL

WDC Exploration & Wells
Q. Stevens, J. Aguilar, D. Mathews
Kleinfelder, Inc
L. Fleischhauer, L. Diamond, R. Smith (Geologists)
DRILL RIG Speedstar 50k

DRILLING METHOD

- ☐ HOLLOW-STEM AUGER
- ☒ AIR ROTARY
- ☐ MUD/WATER ROTARY
- ☒ Other: Water, QUIK-FOAM®, EZ-MUD®, Defoamer
- ☐ _____

DRILLING START / FINISH

DATE 07/12/05 TIME 14:25
DATE 07/24/05 TIME 14:22

Note:
Geologic contacts are preliminary and subject to change.

KLEINFELDER		BOREHOLE SUMMARY DATA SHEET **Characterization Well CdV-16-2(i)r** Cañon de Valle Los Alamos National Laboratory Los Alamos, New Mexico	FIGURE **5.1-1**
Drawn By: C. Bhongir	Date: November 2005		
Project No.: 49436	Filename: 49436_02_0.dwg		
Scale: not-to-scale	Revision: Rev 0		

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varying amounts of pumice fragments (locally as much as 95% by volume) and volcanic lithics that represent xenolithic inclusions. Volcanic constituents (which are locally concentrated to more than 90% by volume in cuttings returns) included aphanitic and porphyritic dacite, andesite, and vitrophyre. Pumice fragments were generally glassy, fibrous, and white or pink in color. Fine fraction (e.g., >#35 sieve size) cuttings samples contained predominantly quartz and sanidine crystals with subordinate amounts of volcanic lithics and pumice.

Guaje Pumice Bed of the Otowi Member of the Bandelier Tuff, Qbog (802 to 818 ft bgs)

The Guaje Pumice Bed is made up of air-fall tephra that regionally form a thin stratigraphic interval at the base of the Bandelier Tuff. No cuttings were recovered for this interval. The upper and lower Qbog contacts were determined by interpretation of geophysical logs.

Puye Formation, Tpf [818 to 1063 ft bgs – CdV-16-2(i)]

The Puye Formation in CdV-16-2(i) contained volcaniclastic sand and gravel deposits from 818 ft bgs to the bottom of the borehole at 1,063 ft bgs, which covers the interval to the TD of 874.4 ft bgs in CdV-16-2(i)r. This sedimentary section was comprised of poorly cemented, fine to coarse detritus representing a range of aphyric and porphyritic volcanic lithologies. Volcanic constituents included hornblende-biotite dacite, rhyodacite, andesite, vitrophyre, and minor local pumice. Sample chips were commonly subrounded and/or broken, indicating an abundance of coarse gravel-size clasts throughout the section.

5.2 Groundwater

Deep intermediate perched zone groundwater occurs in CdV-16-2(i)r within the Puye Formation sand and gravel deposits between approximately 852 and 872 ft bgs. Video logs were run in the open borehole to look for evidence of perched groundwater entering the borehole. The first video log was run on July 16, 2005. With a borehole total depth of 846 ft bgs (slough from 852 ft bgs TD from previous day), standing water was observed in the borehole at 836.85 ft bgs; however, no water-producing zones were observed during video logging.

The second video log was run on July 18, 2005, with a borehole total depth of 872 ft bgs. The geologist's logbook notes that standing water was observed on the video run at 837 ft bgs, but no water-producing zones were recorded above that depth. After the boring was advanced to 872 ft bgs, DTW in the open borehole ranged between 835.89 and 840.08 ft bgs over a 7-day period prior to well construction.

Schlumberger analyses of geophysical logs run in CdV-16-2(i) identified highly variable water content and water saturation in the Puye Formation from 818 to 859 ft. The analysis also noted that saturated zones less than 18 in. thick that are surrounded by unsaturated material are not detectable by geophysical logs. The conductivity log run in CdV-16-2(i)r on July 18, 2005 showed an increase in conductivity at 850 ft bgs.

5.3 Preliminary Groundwater Analytical Results

The analytical data for the three groundwater samples collected from CdV-16-2(i)r, along with a brief summary, are presented in Appendix B. Perchlorate was not detected in the three samples.

6.0 BOREHOLE LOGGING

The following sections discuss the two video logs and natural gamma and array induction geophysical logs run at CdV-16-2(i)r; see Table 6.0-1 for a summary of information.

Table 6.0-1
Borehole Logging

Operator	Date	Tools	Cased Footage (ft bgs)	Open-hole Interval (ft bgs)	Remarks
LANL Greg Helland	7/16/2005	Video Camera	0 - 9.6	9.6 - 846.5	Standing water at 836.58 ft bgs
LANL Mark Everett	7/18/2005	Video Camera	0 - 9.6	9.6 - 872.0	815-837 ratty hole. Standing water at 837 ft bgs
LANL Mark Everett	7/18/2005	Gamma	0 - 9.6	9.6 - 872.0	None
LANL Mark Everett	7/18/2005	Induction	0 - 9.6	9.6 - 872.0	Conductivity increased at 850 ft bgs.

6.1 Video Logging

LANL personnel ran borehole video logs on July 16 and 18, 2005, to look for evidence of water entering the borehole. The video log from July 18 is presented as a DVD in Appendix C.

6.2 Geophysical Logging

Because a full suite of Schlumberger geophysical logs was run at CdV-16-2(i), only natural gamma and array induction logging were specified in the Drilling Work Plan for CdV-16-2(i)r (Kleinfelder 2005a). The logs were run without problem on July 18, 2005. Figure 6.2-1 shows the natural gamma and conductivity logs plotted together along with the local stratigraphy at CdV-16-2(i)r.

7.0 WELL INSTALLATION

Kleinfelder received the final construction specifications from DOE and LANL on July 19, 2005. The well was installed between July 25 and 30, 2005.

7.1 Well Design

Data from geophysical logs, borehole cuttings, field water-level measurements, and field observations were evaluated to determine the placement of the screened interval for the well. The well was designed in accordance with LANL Standard Operating Procedure for Well Construction, Revision 3 (LANL 2001), and DOE and LANL provided an approved well design to Kleinfelder. The well was designed with a single screened interval to monitor groundwater quality in the deep intermediate perched zone within the upper portion of the Puye Formation. The well design was reviewed by the New Mexico Environment Department (NMED) prior to well installation.

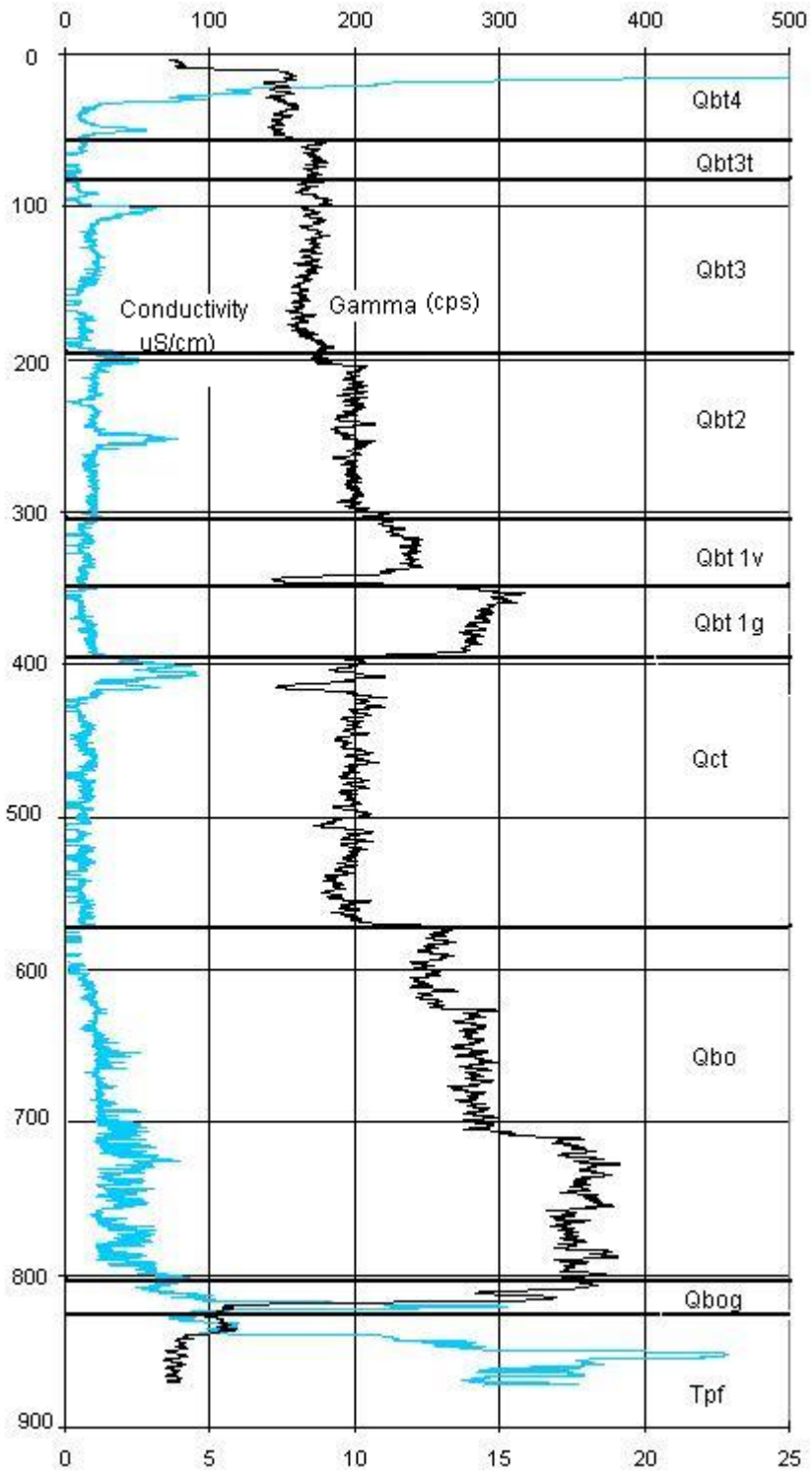


Figure 6.2-1. Natural Gamma and Conductivity Logs for CdV-16-2(i)r.

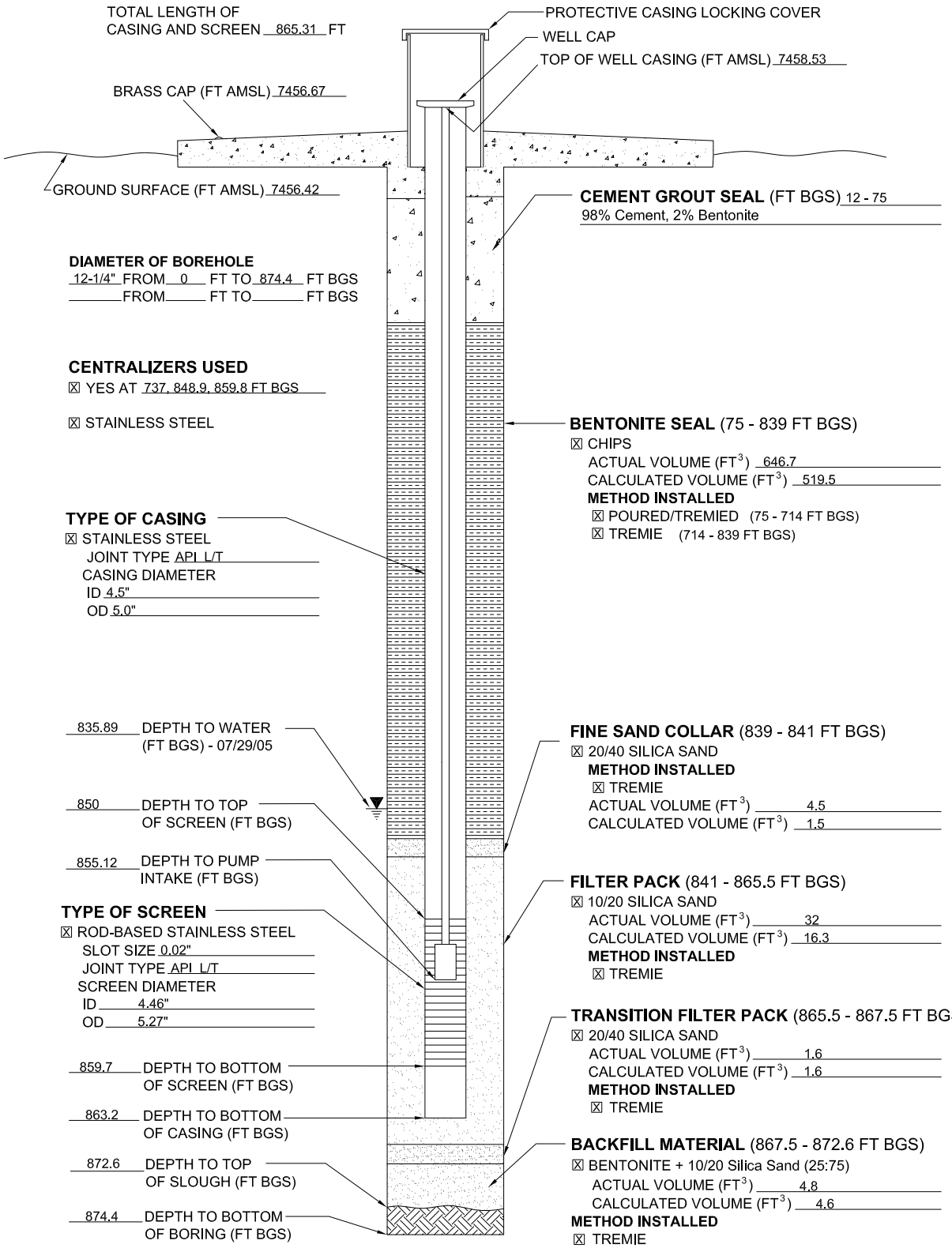
7.2 Well Construction

CdV-16-2(i)r was constructed of 4.5-in. inner diameter/5.0-in. OD, type A304 stainless steel casing fabricated to American Society for Testing and Materials (ASTM) A312 standards. External couplings, also of type A304 stainless steel fabricated to ASTM A312 standards, were used to connect individual casing and screen joints. One nominal 10-ft length of 5.27-in. OD, rod-based, 0.020-in., wire-wrapped well screen was used. The casing and screen were factory-cleaned before shipment and delivery to the site and also decontaminated onsite.

The screened interval chosen for the well was 850 to 859.7 ft bgs. A 3.5-ft deep sump of stainless steel casing was placed below the well screen. Figure 7.2-1 is an as-built schematic showing construction details for the completed well.

Prior to running the well casing into the hole, the bottom of the borehole was tagged at 874.4 ft bgs. A 2.5-in. OD steel tremie pipe was used to deliver annular fill materials during well completion. After the well casing and screen were set in the borehole, the bottom of the borehole was tagged at 872.6 ft bgs, indicating 1.8 ft of slough had accumulated. A mixture of 25% bentonite and 75% 10/20 sand was emplaced from the bottom of the borehole to 867.5 ft bgs. A transition filter pack of 20/40 silica sand was placed above that to 865.5 ft bgs. The primary filter pack of 10/20 silica sand was placed across the screened interval from 865.5 to 841 ft bgs.

After placing the primary filter pack, the WDC development rig was used to swab the screened interval to promote settling and compaction of the filter pack. A fine-sand collar of 20/40 silica sand was then placed above the primary filter pack from 841 to 839 ft bgs. Following placement of the fine sand collar, a bentonite seal composed of bentonite chips was installed to 75 ft bgs. A bridge developed at approximately 500 ft bgs and was discovered on the next pour of chips. WDC advanced a tremie pipe pressurized with water and collapsed the bridge; the top of the bentonite was then tagged at 478 ft bgs. The following day another bridge developed at approximately 185 ft bgs; the tremie pipe was suspended at approximately 175 ft bgs and water was added in an attempt to wash through the bridge. As water was added, the tremie could be advanced further. Eventually, bentonite was tagged at 433 ft bgs in the annulus. From 433 to 163 ft bgs, bentonite was pumped into the annulus with water. From 163 to 75 ft bgs, bentonite chips were poured, and water was added with the tremie. The temporary surface casing was then removed. The cement grout surface seal consisted of 2,500 pounds per square inch (psi) cement with 2% bentonite. Table 7.2-1 summarizes the volumes of annular fill materials used to complete CdV-16-2(i)r. Note that with the primary filter pack and the bentonite seal, the actual volumes of backfill materials exceeded the calculated volumes because of borehole washouts across those intervals.



WELL DEVELOPMENT INFORMATION

WELL COMPLETION BEGAN	WELL DEVELOPMENT BEGAN	DEVELOPMENT METHOD	PARAMETER MEASUREMENTS
DATE 7/25/05 TIME 11:42	DATE 08/02/05 TIME 11:42	☒ SWABBING ☒ BAILING	pH 7.40
WELL COMPLETION FINISHED	**WELL DEVELOPMENT FINISHED**	☒ PUMPING	TEMPERATURE 19.15 °C
DATE 7/30/05 TIME 18:00	DATE 08/22/05 TIME 07:25	TOTAL PURGE VOLUME 11,320 GALLONS	SPECIFIC CONDUCTANCE 132.2 µS
			TURBIDITY 10.5 NTU

KLEINFELDER

Drawn By: C. Bhongir	Date: November 2005
Project No.: 49436	Filename: 49436_03_0.dwg
Scale: not-to-scale	Revision: Rev 0

WELL SCHEMATIC
Characterization Well CdV-16-2(i)r
Cañon de Valle
Los Alamos National Laboratory
Los Alamos, New Mexico

FIGURE
7.2-1

G:\Environ\49436 - DOE Mortandad Canyon\DOE-LANL_2005-06_Drilling\Project Plans\Fact Sheets\CdV-16-2(i)r\Report Figures\49436_03_0.dwg

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Table 7.2-1
Annular Fill Materials Used in Well Construction

Material	Volume
Surface seal: cement slurry	59 ft^3
Bentonite seal: bentonite chips	646.7 ft^3
Fine sand collar: 20/40 silica sand	4.5 ft^3
Primary filter: 10/20 silica sand	32 ft^3
Transition filter pack: 20/40 silica sand	1.6 ft^3
Backfill material: bentonite and 10/20 silica sand (25:75)	4.8 ft^3
Potable water	36,247 gallons

8.0 POST-INSTALLATION ACTIVITIES

Following well installation, the well was developed, an aquifer pump test was conducted, a dedicated pump was installed, and the wellhead was completed and surveyed. Site restoration activities will commence once NMED permission to discharge fluids has been received.

8.1 Well Development

Well development was conducted between August 2 and 22, 2005. The primary objective of well development is to remove suspended sediment from the water until turbidity is less than 5 nephelometric turbidity units (NTUs) for three consecutive samples. Although multiple, consecutive turbidity readings below 5 NTUs were recorded on the afternoon of August 17, 2005, those levels were not sustained in the well. The turbidity reading at the end of development on August 22 was 10.5 NTUs; at the beginning of the aquifer test on September 10, the turbidity level had rebounded to 22.2 NTUs. The level dropped to 12.4 NTUs at the end of the 5-hour pump test on September 10.

Additional water quality parameters measured during development included pH, temperature, specific conductance, and total organic carbon (TOC); parameters were required to stabilize before terminating development procedures. The goal for TOC levels was <2.0 parts-per-million (ppm), indicating that all drill foam residues had been removed from the well. The TOC reading at the end of aquifer testing on September 10, 2005, was 0.60 ppm. Table 8.1-1 shows the volume of water removed during well development and aquifer testing and the resultant water quality parameters and TOC levels. Figure 8.1-1 shows the water quality parameter measurements obtained during development.

CdV-16-2(i)r was initially developed by bailing and swabbing the screened interval to help remove bentonite, drilling fluids, and formation fines introduced during drilling and installation. The swabbing tool was a 4.25-in. OD, 1-in. thick rubber disc attached to the drill rod; it was lowered into the well and drawn repeatedly across the screened interval for approximately 1 hour. A 10-gal. capacity steel bailer was used to bail the well. Approximately 500 gal. of water were removed during swabbing and bailing.

A 7.5-horsepower, 4-in. Grundfos submersible pump was used for the final stage of well development. The pump intake was set within the screened interval, and 10,820 gal. of water were removed by pumping over the course of development.

Table 8.1-1
Final Water Quality Parameters

Method	Water Removed (gal.)	pH	Temperature (°Celsius)	Specific Conductance (µS/cm)	Turbidity (NTUs)	Total Organic Carbon (ppm)
Bailing/Swabbing	500	6.56	17.0	426	>1,000	NM
Pumping	10,820	7.40	19.5	132	10.5	1.77
Aquifer testing	304	7.37	15.2	114	12.4	0.60

µS/cm = microSiemens per centimeter
NM = not measured

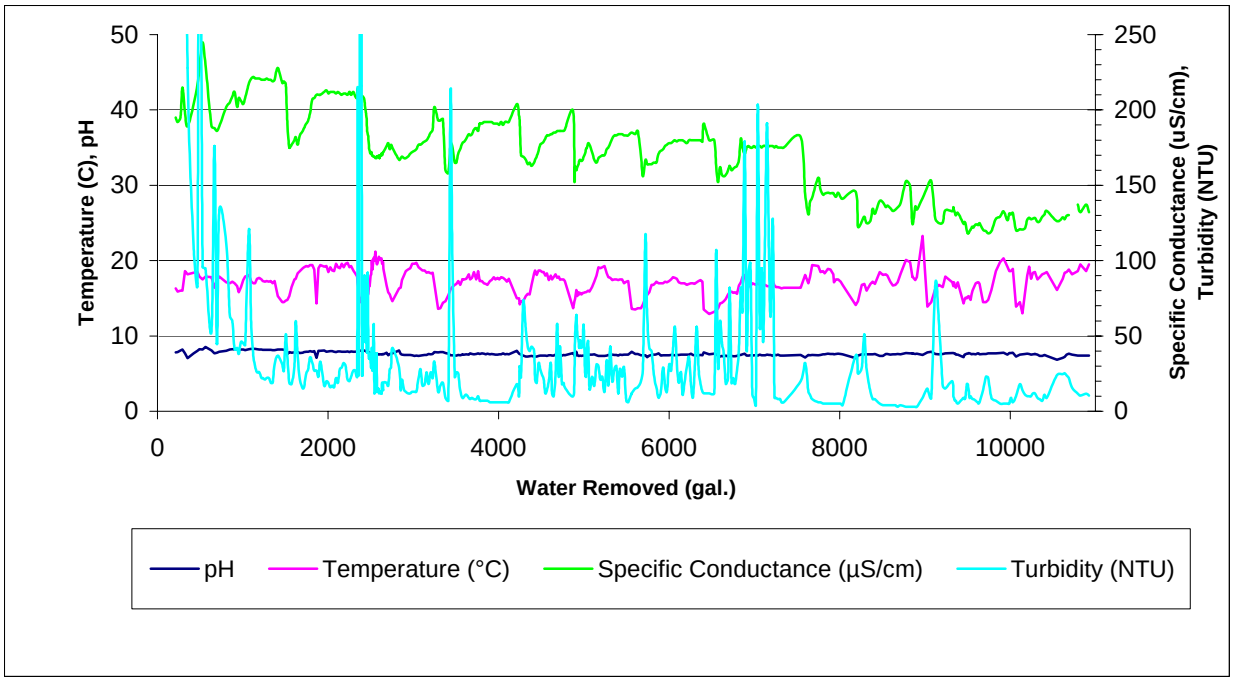

Figure 8.1-1. Water Quality Parameters During Development

8.2 Aquifer Testing

Pump tests were conducted at CdV-16-2(i)r on September 9 and 10, 2005. Water-level recovery data were collected for an additional 3 days after the pump was turned off. The results of the pump test are presented in detail in Appendix D, and the key points are summarized below:

- The CdV-16-2(i)r pumping tests investigated the hydraulic properties of a perched saturated zone near the top of the Puye Formation.
- Water-level changes in CdV-16-2(i)r were nearly identical to barometric pressure changes, implying essentially a 100% barometrically efficient saturated perched zone.

- Use of the inflatable packer successfully eliminated casing storage effects, but could not prevent filter pack draining and refilling (storage effects) from invalidating the early pumping and recovery data.
- The combination of pump capacity and valve size made it impossible to control the discharge rate during the tests, placing a greater reliance on recovery data for determining formation parameter values.
- Testing showed transmissivities ranging from 230 to 570 gallons per day (gpd)/ft. The most reliable values were 410 gpd/ft and 570 gpd/ft, producing an average estimate of 490 gpd/ft, or 66 ft^2/day. Based on an assumed saturated thickness of 22 ft, the average hydraulic conductivity was 3.0 ft/day, although probable heterogeneous conditions imply likely zones of both greater and lesser conductivity.
- The specific capacity data from CdV-16-2(i)r implied a lower bound transmissivity value of around 200 gpd/ft, not in conflict with the pumping tests estimates.
- All of the observed data showed strong boundary effects, suggesting that the pumped zone was severely limited in areal extent rather than laterally extensive.

8.3 Dedicated Sampling System Installation

A dedicated 4.5-in. Grundfos submersible pump was installed on October 28, 2005. The pump intake was set at 855.12 ft bgs, approximately 5 ft below the top of the screened interval.

8.4 Wellhead Completion

A reinforced (2,500 psi) concrete pad, 5 ft by 5 ft by 6 in. thick, was installed around the well casing to provide long-term structural integrity for the well and to prevent surface water from flowing down the outside of the casing. A brass survey pin was embedded in the northwest corner of the pad. A 10.75-in.-diameter steel casing with locking lid was installed to protect the well riser. The concrete pad was slightly elevated above the ground surface, with base-course gravel graded up around the edges.

8.5 Geodetic Survey

Table 8.5-1 presents the geodetic survey data for CdV-16-2(i)r.

Table 8.5-1
Geodetic Data

Description	Northing [a]	Easting	Elevation [b]
Brass cap in CdV-16-2(i)r pad	1764219.40	1616673.24	7456.67
Top of stainless-steel casing	1764217.40	1616674.10	7458.53

[a] Coordinates are New Mexico State Plane Grid, Central Zone, NAD83.
[b] Measured in feet above mean sea level relative to the National Geodetic Vertical Datum of 1929.

8.6 Site Restoration

Fluids and cuttings produced during drilling and development were sampled in accordance with the "Notice of Intent to Discharge, Hydrogeologic Workplan Wells" and filed with the NMED. The analytical results for all of the fluid samples have not been received to date. If the results are below the State of New Mexico Water Quality Control Commission Regulation 3103 groundwater standards, they will be discharged to the ground in accordance with the July 16, 2002, Notice of Intent. A memorandum will be issued when analytical results are received.

Site restoration activities will commence after receiving the analytical data from waste characterization sampling. Site restoration activities will include removing water from the borehole-cuttings containment area and applying it back to the land, removing the polyethylene liner and borehole cuttings from the containment area, and backfilling and grading the containment area. Cuttings will be thinly spread over the site and the site will be reseeded.

9.0 DEVIATIONS FROM PLANNED ACTIVITIES

Appendix E compares the actual drilling and well construction activities performed at CdV-16-2(i)r with the planned activities described in the Drilling Work Plan for CdV-16-2(i)r (Kleinfelder 2005a). In general, drilling, sampling, and well construction at CdV-16-2(i)r were performed as specified in the Drilling Work Plan. The main deviations from planned activities are as follows:

- Planned Borehole Depth – The Drilling Work Plan called for the borehole to be drilled to a target TD of 900 ft bgs; it was drilled to a TD of 874.4 ft bgs.
- Screened Interval – The screened interval called for in the Drilling Work Plan was 20 ft; however, DOE and LANL project personnel chose a screened interval of 10 ft.
- Groundwater Analyses – The Drilling Work Plan identified the analytes for the groundwater analyses to be radionuclides, explosives, metals, and anions. However, the sample paperwork and containers provided by LANL RRES-WQH specified EES anions, metals, and perchlorate.

10.0 ACKNOWLEDGMENTS

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

EnviroWorks, Inc., provided site preparation activities.

P. Longmire of Los Alamos National Laboratory contributed the geochemistry section of this report.

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

WDC Exploration & Wells provided rotary drilling services.

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Appendix A

Lithologic Log

Geologic Unit	Lithologic Description NOTE: THIS INFORMATION WAS OBTAINED FROM CdV-16-2(i), DRILLED IN DECEMBER 2003, APPROXIMATELY 50 FEET FROM CdV-16-2(i)r.	Sample Interval (ft)	Elevation Range (ft above msl)
Qbt 4, Tshirege Member of the Bandelier Tuff	Unconsolidated tuff/volcanic tuff, grayish orange (10YR 7/4), weakly welded or weathered, angular chips. **+10F** (i.e., sample fraction retained by the No. 10 sieve): composed of 95-98% varied intermediate volcanic lithics, 3-5% welded tuff fragments. **+35F** (i.e., sample fraction retained by the No. 35 sieve): 95-98% volcanic lithics, 2-3% quartz and sanidine crystals, 1-2% welded tuff fragments.	0-15	7457.11-7442.11
	Volcanic tuff, grayish orange-pink (5YR 7/2) to very pale orange (5YR 7/2), weakly welded. **WR** (i.e., unsieved whole-rock sample): silty texture. **+10F**: composed of 35-40% welded tuff fragments, 35-40% volcanic lithic fragments including porphyritic dacite and rhyodacite, and vitrophyre. **+35F**: 20-30% quartz and sanidine crystals, 30-40% volcanic lithics, and 20-30% welded tuff fragments.	15-30	7442.11-7427.11
	Volcanic tuff, grayish orange-pink (5YR 7/2), weakly welded. **WR**: silty texture. **+10F**: composed of 93-95% welded tuff fragments, 2-3% intermediate volcanic lithic fragments, 1-2% quartz and sanidine crystals. **+35F**: 25-30% quartz and sanidine crystals, 20-30% volcanic lithics, and 40-50% welded tuff fragments.	30-40	7427.11-7417.11
	Volcanic tuff, grayish orange (10YR 7/4), weakly welded. **WR**: silty texture. **+10F**: no sample returns of this size fraction. **+35F**: 40-45% quartz and sanidine crystals, 10-20% volcanic lithics, and 40-45% welded tuff fragments.	40-50	7417.11-7407.11
Qbt 3t, Tshirege Member of the Bandelier Tuff	Volcanic tuff, grayish orange (10YR 7/4), weakly welded. **WR**: clayey texture. **+10F**: no sample returns of this size fraction. **+35F**: 35-40% quartz and sanidine crystals, 20-30% volcanic lithics, 35-40% welded tuff fragments. **+60F** (i.e., sample fraction retained by the No. 60 sieve): 10-20% volcanic lithics, 60-65% quartz, and sanidine crystals, 20-25% welded tuff fragments. **Note: Top of Qbt 3t is 56 ft bgs based on geophysical logging data.**	50-60	7407.11-7397.11
	Volcanic tuff, grayish orange (10YR 7/4), weakly welded. **WR**: silty texture. **+10F**: no sample returns of this size fraction. **+35F**: 50-55% quartz and sanidine crystals, 20-30% volcanic lithics, and 10-15% welded tuff fragments. **+60F**: 30-40% volcanic lithics, 45-50% quartz and sanidine crystals, 30-40% welded tuff fragments.	60-65	7397.11-7392.11
Qbt 3, Tshirege Member of the Bandelier Tuff	Volcanic tuff, pale yellowish brown (10YR 6/2), weakly welded. **+10F**: no sample returns of this size fraction. **+35F**: 90-95% quartz and sanidine crystals, 5-8% volcanic lithics, and 1-2% welded tuff fragments. **+60F**: 94% volcanic lithics, 5% quartz and sanidine crystals, 1% welded tuff fragments. **Note: Top of Qbt 3 is 77 ft bgs based on geophysical logging data**.	65-85	7392.11-7372.11

Geologic Unit	Lithologic Description NOTE: THIS INFORMATION WAS OBTAINED FROM CdV-16-2(i), DRILLED IN DECEMBER 2003, APPROXIMATELY 50 FEET FROM CdV-16-2(i)r.	Sample Interval (ft)	Elevation Range (ft above msl)
	Volcanic tuff, light brownish gray (5YR 6/1), weakly welded. **WR**: fine-grained sandy texture. **+10F**: no sample returns of this size fraction. **+35F**: 95-98% quartz and sanidine crystals and 2-5% welded tuff fragments. **+60F**: composition similar to that of the +35 sieve fraction.	85-100	7372.11-7357.11
	Volcanic tuff, pale yellowish brown (10YR 6/2) to light brownish gray (5YR 6/1), weakly welded. **WR**: silty sandy texture. **+10F**: no sample returns of this size fraction. **+35F**: 85-95% quartz and sanidine crystals and 10-15% volcanic lithic and welded tuff fragments. **+60F**: composition similar to that of the +35 sieve fraction.	100-105	7357.11-7352.11
	Volcanic tuff, pale yellowish brown (10YR 6/2) to light brownish gray (5YR 6/1), weakly to moderately welded. **WR**: fine to coarse sandy texture. **+10F**: 50% quartz and sanidine crystals and 50% Fe-oxide stained, crystal- and lithic-rich welded tuff fragments. **+35F**: 95-98% quartz and sanidine crystals and 2-5% volcanic lithic fragments.	105-120	7352.11-7337.11
	Volcanic tuff, grayish orange (5YR 7/2), moderately welded. **WR**: silty sandy texture. **+10F**: 25-30% Fe-oxide stained intermediate volcanic lithics (up to 5 mm) and 70-75% crystal-rich welded tuff fragments. **+35F**: 95-98% quartz and sanidine crystals and 2-5% volcanic lithic fragments.	120-130	7337.11-7327.11
	Volcanic tuff, grayish orange (5YR 7/2), moderately welded. **WR**: silty sandy texture. **+10F**: composition similar to that of interval 120-130 ft bgs; 25-30% Fe-oxide stained intermediate volcanic lithics (up to 5 mm) and 70-75% crystal-rich welded tuff fragments. **+35F**: 95-98% quartz and sanidine crystals and 2-5% volcanic lithic fragments.	130-135	7327.11-7322.11
	No sample collected in this interval.	135-140	7322.11-7317.11
	Volcanic tuff, light brownish gray (5YR 6/1), moderately welded. **WR**: silty texture. **+10F**: composed of quartz and sanidine crystals, welded tuff fragments, and abundant fine ash. **+35F**: 60-65% quartz and sanidine crystals and 35-40% tuff fragments.	140-145	7317.11-7312.11
	Volcanic tuff, light brownish gray (5YR 6/1), moderately welded. **WR**: silty sandy texture. **+10F**: no sample returns of this size fraction. **+35F**: composition similar to that of interval 140-145 ft bgs.	145-155	7312.11-7302.11
	Volcanic tuff, grayish orange-pink (10YR 7/2), weakly to moderately welded. **WR**: silty texture. **+10F**: composed of crystal-rich tuff fragments, quartz and sanidine crystals, and volcanic lithic fragments. **+35F**: 95-98% quartz and sanidine crystals and 2-5% tuff and lithic fragments.	155-160	7302.11-7297.11
	Volcanic tuff, grayish orange-pink (10YR 7/2), weakly to moderately welded. **WR**: silty texture. **+10F**: no sample returns of this size fraction. **+35F**: similar composition to that of the 155-160 ft bgs interval.	160-165	7297.11-7292.11

Geologic Unit	Lithologic Description NOTE: THIS INFORMATION WAS OBTAINED FROM CdV-16-2(i), DRILLED IN DECEMBER 2003, APPROXIMATELY 50 FEET FROM CdV-16-2(i)r.	Sample Interval (ft)	Elevation Range (ft above msl)
	No cuttings returns; no sample available for examination in this interval.	165-170	7292.11-7287.11
	Volcanic tuff, pale yellowish brown (10YR 6/2), weakly welded. **WR**: silty sandy texture. **+10F**: poor sample returns of this size fraction; composed of 95-98% quartz and sanidine crystals and 2-5% welded tuff fragments. **+35F**: 98-99% quartz and sanidine crystals and 1-2% tuff fragments.	170-180	7287.11-7277.11
	No cuttings returns; no sample available for examination in this interval.	180-185	7277.11-7272.11
Qbt 2, Tshirege Member of the Bandelier Tuff	Volcanic tuff, pale yellowish brown (10YR 6/2) to light brownish gray (5YR 6/1), weakly welded. **WR**: silty sandy texture. **+10F**: composed of 50% quartz and sanidine crystals and 50% intermediate volcanic (mostly dacite), lithic fragments (subangular to subrounded, up to 2.5 cm). **+35F**: 95-98% quartz and sanidine crystals and 2-5% lithic fragments. **Note: Top of Qbt 2 is 195 ft bgs based on geophysical logging data.**	185-205	7272.11-7252.11
	Volcanic tuff, light brownish gray (5YR 6/1), moderately welded, crystal-rich. **WR**: silty texture. **+10F**: composed predominantly of welded tuff fragments with 5% quartz and sanidine crystals and 1-2% volcanic lithic fragments. **+35F**: 70-75% quartz and sanidine crystals and 20-25% tuff fragments.	205-220	7252.11-7237.11
	Volcanic tuff, light brownish gray (5YR 6/1) to light gray (N7), weakly welded, crystal-rich. **WR**: silty sandy texture. **+10F**: no sample returns of this size fraction. **+35F**: 95-98% quartz and sanidine crystals and 2-5% tuff and volcanic lithic fragments. **+60F**: similar composition to that of the +35F sample.	220-230	7237.11-7227.11
	Volcanic tuff, light brownish gray (5YR 6/1), moderately welded, crystal-rich. **WR**: sandy texture. **+10F**: composed predominantly of welded tuff fragments with 2-5% quartz and sanidine crystals, and 2-3% Fe-oxide-stained volcanic lithic fragments. **+35F**: 50% quartz and sanidine crystals and 50% tuff fragments.	230-245	7227.11-7212.11
	Volcanic tuff, light brownish gray (5YR 6/1), moderately welded, crystal-rich. **WR**: sandy texture. **+10F**: no sample returns of this size fraction. **+35F**: 50% quartz and sanidine crystals and 50% tuff fragments. **+60F**: similar composition to that of the +35F sample.	245-250	7212.11-7207.11
	Volcanic tuff, light brownish gray (5YR 6/1) to brownish gray (5YR 4/1), moderately to weakly welded, crystal-rich. **WR**: sandy texture. **+10F**: composed dominantly of tuff fragments with 3-5% quartz and sanidine crystals and 2-3% Fe-oxide-stained volcanic lithic fragments. **+35F**: 70-75% quartz and sanidine crystals and 30-35% tuff fragments.	250-265	7207.11-7192.11

Geologic Unit	Lithologic Description NOTE: THIS INFORMATION WAS OBTAINED FROM CdV-16-2(i), DRILLED IN DECEMBER 2003, APPROXIMATELY 50 FEET FROM CdV-16-2(i)r.	Sample Interval (ft)	Elevation Range (ft above msl)
	Volcanic tuff, light brownish gray (5YR 6/1) to brownish gray (5YR 4/1), moderately to weakly welded, crystal-rich. **WR**: sandy texture. **+10F**: no sample returns of this size fraction. **+35F**: composition similar to that of the interval 250-265 ft bgs.	265-275	7192.11-7182.11
	Volcanic tuff, light brownish gray (5YR 6/1) to brownish gray (5YR 4/1), moderately welded. **WR**: sandy texture. **+10F**: composed predominantly of tuff fragments with 3-5% quartz and sanidine crystals and 5-7% Fe-oxide-stained volcanic lithic fragments. **+35F**: 50% quartz and sanidine crystals and 50% tuff fragments.	275-290	7182.11-7167.11
	Volcanic tuff, light brownish gray (5YR 6/1), weakly to moderately welded, crystal-rich. **WR**: silty texture. **+10F**: no sample returns of this size fraction. **+35F**: 30-40% quartz and sanidine crystals and 60-70% tuff fragments. **+60F**: similar composition to that of the +35F sample.	290-300	7167.11-7157.11
	Volcanic tuff, light brownish gray (5YR 6/1), weakly to moderately welded, crystal-rich. **WR**: silty sandy texture. **+10F**: composed predominantly of tuff fragments with 2-5% quartz and sanidine crystals and 10-20% volcanic lithic fragments (mostly dacite). **+35F**: 30-40% quartz and sanidine crystals, and 60-70% tuff fragments.	300-305	7157.11-7152.11
Qbt 1v, Tshirege Member of the Bandelier Tuff	Volcanic tuff, light brownish gray (5YR 6/1), weakly to moderately welded, crystal-rich. **WR**: silty texture. **+10F**: composed of 60-70% tuff fragments with 5-7% quartz and sanidine crystals and 10-20% intermediate volcanic lithic fragments (mostly dacite, up to 4 mm). **+35F**: 90-95% quartz and sanidine crystals and 5-10% tuff and volcanic lithic fragments. **Note: Top of Qbt 1v is 305 ft bgs based on geophysical logging data.**	305-315	7152.11-7142.11
	Volcanic tuff, light brownish gray (5YR 6/1), weakly to moderately welded, crystal rich. **WR**: silty texture. **+10F**: composed of 60-70% tuff fragments with 30-35% quartz and sanidine crystals and 5-7% intermediate volcanic lithic fragments (mostly dacite). **+35F**: 90-95% quartz and sanidine crystals and 5-10% tuff and volcanic lithics.	315-325	7142.11-7132.11
	Volcanic tuff, light brownish gray (5YR 6/1), weakly to moderately welded, crystal rich. **WR**: silty sandy texture. **+10F**: poor sample returns; composed of 2-3% tuff fragments, 70-80% quartz and sanidine crystals, and 5-10% intermediate volcanic lithic fragments (mostly dacite, up to 5 mm), trace pumice. **+35F**: 95-98% quartz and sanidine crystals and 3-4% tuff and volcanic lithic fragments, up to 1% pumice.	325-335	7132.11-7122.11

Geologic Unit	Lithologic Description NOTE: THIS INFORMATION WAS OBTAINED FROM CdV-16-2(i), DRILLED IN DECEMBER 2003, APPROXIMATELY 50 FEET FROM CdV-16-2(i)r.	Sample Interval (ft)	Elevation Range (ft above msl)
Qbt 1g, Tshirege Member of the Bandelier Tuff	Volcanic tuff, grayish orange-pink (5YR 7/2), weakly welded, crystal rich. **+10F**: composed of 30-40% tuff fragments with 50% quartz and sanidine crystals and 20-30% intermediate volcanic lithic fragments (up to 4 mm), trace pumice. **+35F**: 95-98% quartz and sanidine crystals, and 2-5% tuff and volcanic lithic fragments. **Note: Top of Qbt 1g is 348 ft bgs based on geophysical logging data.**	335-350	7122.11-7107.11
	Volcanic tuff, grayish orange-pink (5YR 7/2), weakly welded, crystal-rich. **WR**: silty texture. **+10F**: composed of 70-75% quartz and sanidine crystals, 20-25% intermediate volcanic lithic fragments (up to 5 mm), and 2-3% pumice and tuff fragments. **+35F**: 95-98% quartz and sanidine crystals and 2-5% tuff fragments.	350-365	7107.11-7092.11
	Volcanic tuff, grayish orange-pink (5YR 7/2) to moderate orange-pink (5YR 8/4), weakly welded. **+10F**: composed of 50-70% intermediate volcanic lithic fragments (up to 1 cm), 10-15% quartz and sanidine crystals, 10-15% tuff fragments, and 5-7% fibrous, vitric pumice fragments (up to 4 mm). **+35F**: 85-95% quartz and sanidine crystals, 5-7% volcanic lithic fragments, and 1% pumice.	365-380	7092.11-7077.11
Qct, Cerro Toledo interval	No cuttings returns; no sample available for examination in this interval. **Note: Top of Qct is 395 ft bgs based on geophysical logging data.**	380-400	7077.11-7057.11
	Volcaniclastic sediments, very pale orange (10YR 8/2), sandy silt (ML), fine to coarse sand, grains angular to subrounded. **+10F**: detrital constituents (up to 5 mm) composed of 95-98% varied intermediate volcanic lithics and 2-3% white vitric pumice. **+35F**: grains made up of 90-95% quartz and sanidine crystals, 2-5% pumice, and 2-5% volcanic lithics.	400-405	7057.11-7052.11
	Volcaniclastic sediments, very pale orange (10YR 8/2), silty sand (SM). **+10F**: detrital constituents (up to 3 mm) composed of 30-40% varied intermediate volcanic lithics, 50-60% white to pinkish orange, fibrous vitric pumice, and 20-25% quartz and sanidine crystals. **+35F**: grains made up of 30-40% quartz and sanidine crystals, 30-40% pumice, and 30-40% volcanic lithics.	405-420	7052.11-7037.11
	Volcaniclastic sediments, grayish orange-pink (5YR 7/2), sandy silt (ML), very fine to medium sand. **+10F**: no sample returns of this size fraction. **+35F**: grains made up of 40-50% quartz and sanidine crystals, 40-50% pumice, and 10-20% volcanic lithics.	420-425	7037.11-7032.11
	No cuttings returns; no sample available for examination in this interval.	425-435	7032.11-7022.11
	Volcaniclastic sediments, grayish orange-pink (5YR 7/2), silty gravel (GM), gravel clasts subangular to subrounded, up to 1 cm. **+10F**: composed of 100% volcanic lithic clasts including dacite and vitrophyre (obsidian). **+35F**: grains made up of 50-60% quartz and sanidine crystals, 20-25% pumice, and 20-25% volcanic lithics.	435-445	7022.11-7012.11

Geologic Unit	Lithologic Description NOTE: THIS INFORMATION WAS OBTAINED FROM CdV-16-2(i), DRILLED IN DECEMBER 2003, APPROXIMATELY 50 FEET FROM CdV-16-2(i)r.	Sample Interval (ft)	Elevation Range (ft above msl)
	No cuttings returns; no sample available for examination in this interval.	445-450	7012.11-7007.11
	Volcaniclastic sediments, grayish orange (10YR 7/4), silt (ML) with sand, very fine to fine sand. **+10F**: composed of 90-95% varied volcanic lithic clasts including dacite, andesite, porphyritic rhyolite, and vitrophyre; 5-10% pinkish orange, fibrous vitric pumice with Mn-oxide staining. **+35F**: grains made up of 90-95% quartz and sanidine crystals, 3-5% pumice, and 3-5% volcanic lithics.	450-460	7007.11-6997.11
	Volcaniclastic sediments, grayish orange (10YR 7/4), silt (ML) with sand, very fine to fine sand. **+10F**: composed of 50% varied volcanic lithic clasts including dacite, andesite, porphyritic rhyolite, and vitrophyre; 50% pinkish orange, fibrous vitric pumice with Mn-oxide staining. **+35F**: grains made up of 90-95% quartz and sanidine crystals, 3-5% pumice, and 3-5% volcanic lithics.	460-470	6997.11-6987.11
	Volcaniclastic sediments, grayish orange-pink (5YR 8/4), silt (ML) with sand, very fine to fine sand. **+10F**: no sample returns of this size fraction. **+35F**: grains made up of 40-45% quartz and sanidine crystals, 45-50% pumice, and 5-10% volcanic lithics. **+60F**: similar composition to that of the +35F sample.	470-485	6987.11-6972.11
	Volcaniclastic sediments, grayish orange (10YR 7/4), silty sand (SM), very fine to medium sand. **+10F**: composed of 50% fibrous vitric pumice with Mn-oxide spots (up to 3 mm), and 50% intermediate volcanic lithics (up to 3 mm). **+35F**: grains made up of 50-60% quartz and sanidine crystals, 20-30% pumice, and 20-30% volcanic lithics.	485-500	6972.11-6957.11
	Volcaniclastic sediments, very pale orange (10YR 8/2), silty sand (SM), very fine to coarse sand. **+10F**: composed of 50% fibrous vitric pumice with Mn-oxide spots (up to 6 mm), and 50% varied intermediate (including dacite and andesite) volcanic lithics (up to 4 mm). **+35F**: grains made up of 80-90% quartz and sanidine crystals, 5-10% pumice, and 5-10% volcanic lithics.	500-505	6957.11-6952.11
	Volcaniclastic sediments, very pale orange (5YR 8/4), sandy silt (ML), very fine to fine sand. **+10F**: poor sample returns; 100% varieties of porphyritic and aphyric intermediate volcanic lithics. **+35F**: grains made up of 90-95% quartz and sanidine crystals, 2-5% volcanic lithics, and trace pumice.	505-520	6952.11-6937.11
	Volcaniclastic sediments, grayish orange-pink (10YR 8/4) to moderate orange (5YR 8/4), silty sand to sandy silt (SM-ML), very fine to medium sand. **+10F**: composed of 95% varieties of porphyritic and aphyric intermediate volcanic lithics (up to 1 cm) and 5% fibrous pinkish to brown vitric pumice with Mn-oxide spots (up to 3 mm). **+35F**: grains made up of 45% quartz and sanidine crystals, 10% pumice, and 45% volcanic lithics.	520-545	6937.11-6912.11
	No cuttings returns; no sample available for examination in this interval.	545-550	6912.11-6907.11

Geologic Unit	Lithologic Description NOTE: THIS INFORMATION WAS OBTAINED FROM CdV-16-2(i), DRILLED IN DECEMBER 2003, APPROXIMATELY 50 FEET FROM CdV-16-2(i)r.	Sample Interval (ft)	Elevation Range (ft above msl)
Qbo, Otowi Member of the Bandelier Tuff	Volcaniclastic sediments, moderate orange-pink (5YR 8/4) to grayish orange-pink (5YR 7/2), silty sand to sandy silt (SM-ML), and very fine to coarse sand. **+10F**: composed of 75-80% varieties of aphanitic intermediate volcanic lithics (dacite, andesite) and 20-25% pinkish, fibrous vitric pumice. **+35F**: grains made up of 30-35% quartz and sanidine crystals, 30-35% volcanic lithics, and 30-35% pumice. **Note: Top of Qbo is 570 ft bgs based on geophysical logging data.**	550-570	6907.11-6887.11
	Volcanic tuff, grayish orange-pink (5YR 7/2), weakly welded. **WR**: sandy silt texture with very fine to coarse sand-size lithics and crystals. **+10F**: composed of 85-95% varieties of aphanitic and porphyritic intermediate volcanic lithics (up to 1 cm) including andesite and dacite, 10-15% pinkish and white, fibrous vitric pumices. **+35F**: 20-25% pumice, 60% quartz and sanidine crystals, and 20-25% volcanic lithics.	570-585	6887.11-6872.11
	Volcanic tuff, pale yellowish brown (10YR 6/2), weakly welded. **WR**: silt with gravel texture, 15% fine ash. **+10F**: composed of 99% varied aphyric and porphyritic intermediate volcanic lithics including hornblende-dacite and obsidian, 1% pinkish and white, fibrous vitric pumices. **+35F**: 10-15% pumice, 60-70% quartz and sanidine crystals, and 20-25% volcanic lithics.	585-600	6872.11-6857.11
	Volcanic tuff, pale yellowish brown (10YR 6/2), weakly welded. **WR**: silt with gravel particle sizes. **+10F**: composed of 95-98% varied aphyric and porphyritic intermediate volcanic (dacite) lithics (up to 1.5 cm), 2-5% varicolored, fibrous vitric pumices. **+35F**: 5-10% pumice, 45-50% quartz, and sanidine crystals and 45-50% volcanic lithics.	600-625	6857.11-6835.11
	No cuttings returns; no sample available for examination in this interval.	625-645	6832.11-6812.11
	Volcanic tuff, grayish orange (10YR 7/4) to light brown (5YR 6/4), weakly welded. **+10F**: composed of 40-50% varied aphyric and porphyritic intermediate volcanic (some dacite) lithics (up to 5 mm), 50-60% vitric pumices with Mn-oxide staining. **+35F**: 30-40% pumice, 30-35% quartz and sanidine crystals, and 30-35% volcanic lithics.	645-660	6812.11-6797.11
	No cuttings returns; no sample available for examination in this interval.	660-670	6797.11-6787.11
	Volcanic tuff, moderate orange-pink (5YR 8/4), weakly welded. **+10F**: poor sample returns of this size fraction; composed of 50% varied aphyric and porphyritic intermediate volcanic lithics (including dacite), 50% fibrous vitric pumice. **+35F**: 10% pumice, 80% quartz and sanidine crystals, and 10% volcanic lithics.	670-675	6787.11-6782.11
	No cuttings returns; no sample available for examination in this interval.	675-680	6782.11-6777.11

Geologic Unit	Lithologic Description NOTE: THIS INFORMATION WAS OBTAINED FROM CdV-16-2(i), DRILLED IN DECEMBER 2003, APPROXIMATELY 50 FEET FROM CdV-16-2(i)r.	Sample Interval (ft)	Elevation Range (ft above msl)
	Volcanic tuff, moderate orange-pink (5YR 8/4), weakly welded. **+10F**: composed of 50% varied aphyric and porphyritic intermediate volcanic (including dacite) lithics (up to 6 mm); 50% white to pinkish orange, fibrous vitric pumice with Mn-oxide spots. **+35F**: 10-15% pumice, 75-80% quartz and sanidine crystals, and 10-15% volcanic lithics.	680-705	6777.11-6752.11
	Volcanic tuff, moderate orange-pink(5YR 8/4), weakly welded. **+10F**: no sample returns of this size fraction. **+35F**: 90-95% pumice, 2-3% quartz and sanidine crystals and 2-3% volcanic lithics. **+60F**: similar composition to that of the +35F sample.	705-720	6752.11-6737.11
	Volcanic tuff, very pale orange (10YR 8/2), weakly welded. **+10F**: composed of 20-30% varied intermediate volcanic lithics (up to 4 mm), 70-75% white, fibrous vitric pumice with local Mn-oxide spots. **+35F**: 40-50% pumice, 40-50% quartz and sanidine crystals, and 10-15% volcanic lithics. Note: poor sample returns of the **+10F** size fraction in the interval 735-745 ft bgs.	720-750	6737.11-6707.11
	Volcanic tuff, yellowish gray (5Y 8/1), weakly welded. **WR**: silty texture. **+10F**: composed of 85-95% white to light gray, vitric pumice (up to 1 cm), 5-7% volcanic lithics (up to 5 mm) of varied intermediate composition, 1-2% quartz and sanidine crystals. **+35F**: 30-35% pumice, 50-55% quartz and sanidine crystals, and 15-20% volcanic lithics.	750-770	6707.11-6687.11
	Volcanic tuff, yellowish gray (5Y 8/1), weakly welded. **WR**: silty texture. **+10F**: composed of 95-98% white to light gray, vitric pumice (up to 5 mm), 2-5% volcanic lithics of intermediate composition. **+35F**: 45-50% pumice, 50-55% quartz and sanidine crystals, and 2-5% volcanic lithics.	770-785	6687.11-6672.11
	No cuttings returns; no sample available for examination in this interval.	785-790	6672.11-6667.11
Qbog, Guaje Pumice Bed of the Otowi Member	Volcanic tuff, very pale orange (10YR 8/2) to white (N9), weakly welded. **WR**: silty texture. **+10F**: composed of 98-99% white to very light gray, vitric pumice (up to 8 mm), 1-2% volcanic lithics (fragments up to 3 mm) of intermediate composition, and trace quartz and sanidine crystals. **+35F**: 49-50% pumice, 49-50% quartz and sanidine crystals and 1-2% volcanic lithics. **Note: Top of Qbog is 802 ft bgs based on geophysical data.**	790-805	6667.11-6652.11
Tpf, Puye Formation	No cuttings returns; no sample available for examination in this interval. **Note: Top of Tpf is 818 ft bgs based on geophysical logging data.**	805-825	6652.11-6632.11

Geologic Unit	Lithologic Description NOTE: THIS INFORMATION WAS OBTAINED FROM CdV-16-2(i), DRILLED IN DECEMBER 2003, APPROXIMATELY 50 FEET FROM CdV-16-2(i)r.	Sample Interval (ft)	Elevation Range (ft above msl)
	Volcaniclastic sediments, silt (ML) with fine sand, very pale orange (10YR 8/2). **+10F**: poor sample returns of this size fraction; angular to subangular clasts (up to 5 mm) composed of 100% porphyritic and aphyric intermediate volcanics (including hornblende-dacite). **+35F**: 30-35% pumice, 30-35% quartz and sanidine crystals, and 30-35% volcanic lithics. Note: Pumice observed from here to 845 ft bgs is likely from overlying Bandelier Tuff.	825-830	6632.11-6627.11
	Volcaniclastic sediments, poorly graded gravel (GW-GM) with silt, very pale orange (10YR 8/2), gravel clasts angular to subangular, up to 2.5 cm. **+10F**: composed of 100% intermediate volcanics (dominantly andesite and dacite). **+35F**: 20-25% pumice, 20-25% quartz and sanidine crystals, and 50-60% volcanic lithics.	830-835	6627.11-6622.11
	Volcaniclastic sediments, well-graded sand (SW) with gravel, grayish orange-pink (5YR 7/2). **+10F**: composed of 100% varied porphyritic and aphanitic intermediate volcanics (dominantly dacite and andesite). **+35F**: 5-10% pumice, 5-10% quartz and sanidine crystals, and 85-90% volcanic lithics.	835-845	6622.11-6612.11
	No cuttings returns; no sample available for examination in this interval.	845-850	6612.11-6607.11
	Volcaniclastic sediments, well-graded gravel (GW) with silt and sand, medium gray (N5) to very pale orange (10YR 8/2), gravel clasts subrounded (up to 2 cm). **+10F**: composed of 100% porphyritic and aphanitic varieties of intermediate volcanics (dominantly dacite and andesite, trace vitrophyre). **+35F**: 1-2% pumice, 1-2% quartz and sanidine crystals, and 98-99% volcanic lithics.	850-860	6607.11-6597.11
	Volcaniclastic sediments, well-graded gravel (GW) with silt and sand, medium gray (N5) to very pale orange (10YR 8/2), gravel clasts subrounded (up to 1 cm). **+10F**/**+35F**: composition similar to that in the interval 850-860 ft bgs.	860-865	6597.11-6592.11
	Volcaniclastic sediments, silty sand (SM) with gravel, very pale orange (10YR 8/2), gravel clasts angular to subrounded (up to 1 cm). **+10F**: composed of 99% varieties of intermediate volcanics including dacite, rhyodacite, and andesite; trace rose-colored quartz crystal. **+35F**: 1-2% pumice, 1-2% quartz and sanidine crystals, and 96-98% volcanic lithics.	865-870	6592.11-6587.11
	Volcaniclastic sediments, well-graded gravel (GW) with silt and sand, very pale orange (10YR 8/2), gravel clasts angular to subrounded (up to 1 cm). **+10F**/**+35F**: composition similar to that of the interval 865-870 ft bgs.	870-885	6587.11-6572.11
	Volcaniclastic sediments, poorly graded gravel (GP) with silt and sand, very pale orange (10YR 8/2), gravel clasts up to 1 cm. **+10F**: composed of varieties of volcanic lithics including hornblende-dacite, biotite-dacite, rhyodacite, and other intermediate compositions. **+35F**: 1-2% quartz and sanidine crystals and 98-99% volcanic lithics.	885-905	6572.11-6552.11

Geologic Unit	Lithologic Description NOTE: THIS INFORMATION WAS OBTAINED FROM CdV-16-2(i), DRILLED IN DECEMBER 2003, APPROXIMATELY 50 FEET FROM CdV-16-2(i)r.	Sample Interval (ft)	Elevation Range (ft above msl)
	No cuttings returns; no sample available for examination in this interval.	905-910	6552.11-6547.11
	Volcaniclastic sediments, silty sand (SM), light brown (5YR 6/4), medium to coarse sand. **+10F**: poor sample returns of this size fraction; composed of varieties of intermediate volcanics. **+35F**: 2-5% quartz and sanidine crystals and 95-98% volcanic lithics.	910-915	6547.11-6542.11
	Volcaniclastic sediments, silty gravel (GM) with sand, grayish orange-pink (5YR 7/2), gravel clasts up to 1 cm. **+10F**: poor sample returns of this size fraction, composed of varieties of intermediate volcanics including hornblende-dacite. **+35F**: 1% quartz and sanidine crystals and 99% volcanic lithics.	915-925	6542.11-6532.11
	Volcaniclastic sediments, well-graded sand (SW) with silt, very pale orange (10YR 8/2). **+10F**: composed of varieties of intermediate volcanics including dacite and trace abundances of black vitrophyre. **+35F**: 2-3% quartz and sanidine crystals, 97-99% volcanic lithics, and trace pumice.	925-935	6532.11-6522.11
	Volcaniclastic sediments, well-graded sand (SW) with silt and gravel, very pale orange (10YR 8/2). **+10F**: composed of varied clasts (up to 7 mm) of intermediate volcanics including hornblende-dacite. **+35F**: composition similar to that of the +10F sample.	935-945	6522.11-6512.11
	Volcaniclastic sediments, well-graded sand (SW) with silt and gravel, very pale orange (10YR 8/2), gravel clasts up to 2 cm. **+10F**/**+35F**: composition similar to that of interval 935-945 ft bgs.	945-955	6512.11-6502.11
	No cuttings returns; no sample available for examination in this interval.	955-985	6502.11-6472.11
	Volcaniclastic sediments, silty sand (SM) with gravel, very pale orange (10YR 8/2). **+10F**: clasts composed of varied intermediate volcanics, including hornblende-dacite, andesite, trace porphyritic rhyodacite. **+35F**: 1% quartz and sanidine crystals, 98-99% volcanic lithics, and trace pumice.	985-990	6472.11-6467.11
	Volcaniclastic sediments, well-graded gravel (GW) with silt and sand, very pale orange (10YR 8/2). **+10F**/**+35F**: composition similar to that of interval 985-990 ft bgs.	990-1000	6467.11-6457.11
	Volcaniclastic sediments, well-graded sand (SW) with silt and gravel, grayish orange-pink (5YR 7/2). **+10F**: clasts (up to 1.5 cm) composed of varied aphanitic and porphyritic intermediate volcanics, including dacite. **+35F**: 1% quartz and sanidine crystals, 99% volcanic lithics.	1000-1020	6457.11-6437.11
	Volcaniclastic sediments, well-graded sand (SW) with gravel, light gray (N7) to medium gray (N5). **+10F**: clasts (up to 1.5 cm) composed of varied aphanitic and porphyritic intermediate volcanics (mostly dacite and andesite). **+35F**: 1% quartz and sanidine crystals and 99% volcanic lithics.	1020-1035	6437.11-6422.11

Geologic Unit	Lithologic Description NOTE: THIS INFORMATION WAS OBTAINED FROM CdV-16-2(i), DRILLED IN DECEMBER 2003, APPROXIMATELY 50 FEET FROM CdV-16-2(i)r.	Sample Interval (ft)	Elevation Range (ft above msl)
	Volcaniclastic sediments, silty sand (SM), very fine to medium sand, pale yellowish brown (10YR 6/2). **+10F**: clasts (up to 1 cm) composed of varied intermediate volcanics, including dacite, andesite, porphyritic rhyolite, and vitrophyre. **+35F**: 100% volcanic lithics.	1035-1045	6422.11-6412.11
	Volcaniclastic sediments, poorly graded gravel (GP), light gray (N7) to medium gray (N5), clasts up to 1 cm. **+10F**: clasts composed of varied porphyritic intermediate volcanics, including dacite, andesite, and vitrophyre. **+35F**: composition similar to that of the +10F sample.	1045-1055	6412.11-6402.11
	Volcaniclastic sediments, silty sand to sandy silt (SM-ML), light gray (N7) to medium gray (N5). **+10F**: (clasts up to 5 mm) composed of varied intermediate volcanics. **+35F**: composition similar to that of the +10F sample.	1055-1063	6402.11-6394.11
TOTAL DEPTH IS 1063 FT BGS.			

NOTES: American Society for Testing Materials (ASTM) standards were used in describing the texture of drill chip samples for sedimentary rocks such as the Cerro Toledo and the Puye Fanglomerate. ASTM method D 2488-90 (Standard Practice and Identification of Soils [Visual-Manual Procedure]) 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 R-18 lithologic log.

SW Well-graded sand
SP Poorly graded sand
SM Silty fine sand
ML Silt
GP Poorly-graded gravel
GW Well-graded gravel with sand
GM Silty gravel

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 0.5 mm).

The term “percent” (%), as used in the above descriptions, refers to relative abundance by volume for a given sample component.

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

msl = mean seal level

NOTE : THIS INFORMATION WAS OBTAINED FROM CdV-16-2(i), DRILLED IN DECEMBER 2003, APPROXIMATELY 50 FEET FROM CdV-16-2(i)r.

Appendix B

Groundwater Analytical Results

1.0 SAMPLING AND ANALYSIS OF GROUNDWATER AT CdV-16-2(i)r

The depth to water in the perched intermediate zone is approximately 838 ft bgs within the Puye Formation in CdV-16-2(i)r. A screening groundwater sample (EU0507162(i)r01) was collected from the borehole on July 18, 2005 near the end of drilling. The depth to water at the time was 838.08 ft bgs and the sample was collected with a 4-foot long bailer. Another groundwater sample (EU0507162(i)r02) was collected following well development from approximately 859.6 ft bgs on August 22, 2005. A final groundwater sample (EU0509162(i)r01) was collected from approximately 856.7 ft bgs on September 10, 2005 after an aquifer performance test was conducted.

1.1 Analytical Techniques

The borehole and perched groundwater samples were analyzed for total organic carbon (TOC), major ions, perchlorate, and trace elements. High explosive compounds and associated degradation chemicals were not analyzed as part of the screening samples. Both filtered (metals, trace elements, and major cations and anions) and non filtered TOC) samples were collected for chemical analyses. Aliquots of the samples were filtered through a 0.45-µm Gelman filter. Samples were acidified with analytical-grade nitric acid (HNO_3) to a pH of 2.0 or less for metal and major cation analyses. Alkalinity was determined at EES-6 using standard titration techniques.

Groundwater samples were analyzed by EES-6 using techniques specified in the US Environmental Protection Agency SW-846 manual. Ion chromatography (IC) was the analytical method for bromide, chloride, fluoride, nitrate, nitrite, oxalate, perchlorate, phosphate, and sulfate. The instrument detection limits for perchlorate by IC were 0.005 and 0.0005 parts per million (ppm); no matrix interference was observed from other inorganic and organic anions. Inductively coupled (argon) plasma optical emission spectroscopy (ICPOES) 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 ICPOES and ICPMS.

1.2 Analytical Results

Analytical results for groundwater samples collected at CdV-16-2(i)r are provided in Table 1.2-1. A TOC concentration of 0.6 milligrams of carbon per liter was measured in a groundwater sample collected on September 9, 2005. Perchlorate was note detected in the three groundwater samples.

Table 1.2-1. Hydrochemistry of Groundwater Samples Collected from the Perched Intermediate Zone at CdV-16-2(i)-r (filtered samples)

Sample Number	**EU0507162iR01**	**EU0507162iR02**	**EU0509162iR01**
Sample Type	**Near the end of drilling**	**After well development**	**After aquifer performance test**
Depth (ft bgs)	**838.08**	**859.6**	**856.7**
Geologic Unit	**Puye Formation**	**Puye Formation**	**Puye Formation**
Date Sampled	**07/18/05**	**08/22/05**	**09/10/05**
Charge Balance (%)	+10.14	-2.09	-0.08
pH (Lab)	7.32	7.42	7.219
Alkalinity (ppm $CaCO_3$/L)	50.9	62.7	60.6
Al (ppm)	0.043	0.0076	0.008
Sb (ppm)	[0.001], U	[0.001], U	[0.001], U
As (ppm)	0.0004	0.0016	0.0015
B (ppm)	0.013	0.023	0.024
Ba (ppm)	0.0017	0.004	0.006
Be (ppm)	[0.001], U	[0.001], U	0.001], U
HCO_3 (ppm)	62.1	76.5	73.9
Br (ppm)	0.08	0.08	0.07
Cd (ppm)	[0.001], U	[0.001], U	[0.001], U
Ca (ppm)	5.11	7.67	6.27
Cl (ppm)	3.24	2.32	2.31
ClO_4 (ppm) (IC)	[0.005], U	[0.0005], U	[0.0005], U
Cr (ppm)	[0.001], U	[0.001], U	[0.001], U
Co (ppm)	[0.001], U	[0.001, U	[0.001], U
Cu (ppm)	0.0024	0.0018	[0.001], U
F (ppm)	0.19	0.14	0.15
Fe (ppm)	0.03	[0.01], U	[0.01], U
Pb (ppm)	[0.0002], U	[0.0002], U	[0.0002], U
Mg (ppm)	1.46	1.97	1.64
Mn (ppm)	0.026	0.015	0.015
Hg (ppm)	[0.00005], U	0.00011	[0.00005], U
Mo (ppm)	0.0018	0.0027	0.0027
Ni (ppm)	[0.001], U	[0.001], U	0.0015
NO_3 (ppm) (as N)	0.78	0.52	0.57
NO_2 (ppm) (as N)	0.009	0.003	[0.02], U
C_2O_4 (ppm) (oxalate)	[0.01], U	[0.01], U	[0.01], U
PO_4 (ppm)	0.05	0.06	0.11
K (ppm)	1.16	0.44	0.46
Se (ppm)	[0.001], U	[0.001], U	[0.001], U
Ag (ppm)	[0.001], U	[0.001], U	[0.001], U
Na (ppm)	26.3	20.3	22.3
SiO_2 (ppm)	61.8	60.6	57.7
Sr (ppm)	0.035	0.053	0.046
SO_4 (ppm)	4.24	7.87	6.89
Tl (ppm)	[0.001], U	[0.001], U	[0.001], U
U (ppm)	[0.0002], U	0.0005	0.0003
V (ppm)	0.002	0.001	0.001
Zn (ppm)	0.022	0.81	0.61
TDS (calculated)	169	181	175

Note: U = not detected. Silica concentrations were calculated from measured silicon (ICPOES). Bicarbonate concentrations were calculated from measured alkalinity. IC means ion chromatography.

Appendix C

Borehole Video Log

Borehole Video is included with the hard copy of the report as a separate DVD.

TO VIEW THE VIDEO THAT ACCOMPANIES THIS DOCUMENT, PLEASE CALL THE HAZARDOUS WASTE BUREAU AT 505-476-6000 TO MAKE AN APPOINTMENT

Appendix D

Aquifer Testing Report

CdV-16-2(i)r Aquifer Test Analysis

INTRODUCTION

This section describes the analysis of constant-rate pumping tests conducted in September 2005 on well CdV-16-2(i)r on the mesa top above Cañon de Valle within TA-16. The primary objective of the analysis was to determine the hydraulic properties of the perched zone sediments screened in CdV-16-2(i)r.

CdV-16-2(i)r is completed with a single 10-foot-long screen from 850 to 860 feet (ft) below ground surface (bgs) in a saturated perched zone near the top of the Puye Formation. The static water level lies above the top of the well screen, at approximately 838 ft bgs.

This well replaced well CdV-16-2(i) in which video logs showed water entering the open borehole at 827 ft bgs and accumulating with depth, suggesting water contribution over an interval, rather than at a discrete point. That well turned out to be dry after completion. It was assumed that the screen installed in it had breached the perching horizon, allowing perched water to continuously bypass the perching layer and flow into the underlying vadose zone. In the tested replacement well, it was assumed that water was contributed throughout the saturated thickness from the static water level of 838 ft bgs to the bottom of the well screen at 860 ft bgs. It was further assumed that the perching layer was not far below the bottom of the well.

On September 7, the well was initially pumped to fill the drop pipe and to attempt to stabilize the discharge rate. This was followed be two trial tests intended to provide “snapshots” of drawdown and recovery. The first trial began at 4:52 p.m. and continued for 85 minutes until 6:17 p.m. The discharge rate began at 1 gallon per minute (gpm) but declined erratically to around 0.6 gpm by the end of the test. Recovery data were recorded until 7:50 p.m. The second trial began at 7:50 p.m. and continued at a rate of 0.67 gpm for 40 minutes until 8:30 p.m. This was followed by nearly 42 hours of recovery until 2:25 p.m. on September 9. This recovery period was intended to provide background data for the test as well.

Two constant-rate tests were conducted on consecutive days, September 9 and 10. Test 1 was started at 2:25 p.m. and continued for 181 minutes until 5:26 p.m. The discharge rate was 0.45 gpm initially, but declined to about 0.36 gpm toward the end of the test. The discharge rate was less than desired, but rather than adjust the rate significantly during the test, the decision was made to obtain a clean recovery data set and run a second, separate test the next day. Test 2 began at 7:46 a.m. on September 10 and continued for 12 hours until 7:46 p.m. Following pump shutoff, recovery was measured for about 40 hours until 11:57 a.m. on September 12.

During all of the trials and constant-rate tests, it was extremely difficult to maintain a constant discharge rate. The pump used for the testing produced a driving head hundreds of pounds per square inch greater than needed to hydraulically lift the water to ground surface, so it was necessary to operate the pump against nearly-closed valves. The combination of great hydraulic pressure against the valves and low discharge rates vis-à-vis the size of the valves likely contributed to the chaotic flow rates. This forced a reliance on the recovery data for most of the aquifer parameter interpretation. In future tests of low-flow wells, it would be advisable to use

smaller diameter valves to obtain better discharge rate control. It also may be beneficial to size the pump to operate against less shut-in head to put less stress on the valve components.

The tests were conducted with an inflatable packer above the well screen to try to eliminate the effects of casing storage. Indeed, the initial pumping event that was performed to fill the drop pipe produced substantial vacuum, suggesting successful elimination of entrained air beneath the packer. Figure 1 shows the measured head over the transducer during the first couple of pumping cycles at the outset of testing. The lowest absolute pressure measured was a little more than 7 ft of head, nearly 20 ft less than atmospheric pressure. Nevertheless, as discussed below, the pumping-test data showed significant storage effects. It is possible that, at some point, the water level may have been pulled into the well screen, breaking the suction that had been established. Alternatively, and more likely, it is possible that the filter pack outside the screen and casing drained during the test. Filter pack drainage can cause the same kind of storage effect as water standing in the well casing.

BACKGROUND DATA

The background water-level data collected in conjunction with running the pumping tests 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-16-2(i) r tests were compared to barometric pressure data from the area to determine if a correlation existed.

Previous pumping tests demonstrated a 90 to 100% barometric efficiency for most wells. Barometric efficiency is the ratio of water-level change to barometric pressure change, expressed as a percentage. In the initial pumping tests, down-hole pressure was monitored with a *vented* transducer. This equipment measures the *difference* between the total pressure applied to the transducer and the barometric pressure, this difference being the true height of water above the transducer.

Most subsequent pumping tests, including the CdV-16-2(i)r tests, used a *nonvented* transducer. This device simply records the total pressure on the transducer; that is, the sum of the water height plus the barometric pressure. This results in an attenuated “apparent” hydrograph, rather than a true hydrograph, in a barometrically efficient well. Take as an example a 90 percent barometrically efficient well. When monitored with 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 nonvented 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.

Barometric pressure data were obtained from the Los Alamos National Laboratory TA-54 tower site from Environmental Division Meteorology and Air Quality. The TA-54 measurement location is at 6548 ft above mean sea level (amsl), whereas the wellhead elevation was 7457 ft amsl. Furthermore, the static water level in CdV-16-2(i)r was about 838 ft bgs, making the water-table elevation approximately 6619 ft 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-16-2(i)r.

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-16-2(i)r
P_{TA54} = barometric pressure measured at TA-54
g = acceleration of gravity, in meters (m)/second (sec)^2 (9.80665 m/sec^2)
R = gas constant, in Joules (J)/kilogram (Kg)/degrees Kelvin (°K) (287.04 J/Kg/°K)
E_{CdV} = land surface elevation at CdV-16-2(i)r, in ft (7457 ft)
E_{TA54} = elevation of barometric pressure measuring point at TA-54, in ft (6548 ft)
T_{TA54} = air temperature near TA-54, in °K (assigned a value of 64.3 degrees Fahrenheit (°F), or 291.1 °K)
E_{WT} = elevation of the water level in CdV-16-2(i)r, in ft (6619 ft)
T_{WELL} = air temperature inside CdV-16-2(i)r, in °K (assigned a value of 60 °F, or 288.7 °K)

This formula is an adaptation of an equation provided by Environmental Division 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 water-level hydrograph to discern the correlation between the two.

Casing Storage

In most pumping tests, when a packer is not used to prevent drainage and refilling of the well casing, casing storage effects dominate the early-time data, rendering these early data unusable in the analysis. Therefore, it is necessary to screen out the data affected by casing storage prior to analysis. 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 or recovery observed in pumped well at time t_c, in ft

Drainage and refilling of the filter pack also can cause a storage effect. The above formula can be modified to account solely for filter pack storage, as follows:

$$t_c = \frac{0.6 S_y \left(B^2 - D_O^2\right)}{\frac{Q}{s}},$$

where

t_c = duration of filter pack storage effect, in minutes
S_y = short term specific yield of filter pack
B = diameter of borehole, in inches
D_O = outside diameter of well casing, in inches
Q = discharge rate, in gpm
s = drawdown or recovery observed in pumped well at time t_c, in ft

To apply this equation, it is necessary to estimate the short-term drainable porosity of the filter pack, S_y. This parameter likely ranges from about 0.1 to 0.2 for most filter packs used in monitoring wells. In the analysis below, an estimated value of 0.15 was used.

This latter equation was used to quantify the duration of the invalid portion of the time-drawdown and recovery graphs obtained from CdV-16-2(i)r. It is important to note that the calculated storage duration is fairly conservative. In many cases, the actual effective storage duration is as little as about half the calculated value. Therefore, in most instances, it is worthwhile to consider a range of possible storage durations between 50 and 100% of the computed estimate.

Time-Drawdown Methods

Time-drawdown data can be analyzed using a variety of methods. Among them is the Cooper-Jacob method (Cooper and Jacob 1946), a simplification of the Theis equation (Theis 1935) that is mathematically equivalent to the Theis equation for pumped well data. The Cooper-Jacob equation describes drawdown around a pumping well, as follows:

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

where

s = drawdown, in ft

Q = discharge rate, in gpm
T = transmissivity, in gallons per day (gpd)/ft
t = pumping time, in days
r = distance from center of pumpage, in ft
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, where u is defined as follows:

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

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

According to the Cooper-Jacob method of analysis, 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 ft

Recovery Methods

Recovery data are generally analyzed by a semi-log analysis method similar 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.

Specific Capacity Method

The specific capacity of the pumped well can be used to obtain a lower-bound value of hydraulic conductivity. The hydraulic conductivity is computed using formulas that are based on the assumption that the pumped well is 100% efficient. The resulting hydraulic conductivity is the value required to sustain the observed specific capacity. If the actual well is less than 100% 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 solved for the lower-bound hydraulic conductivity. The equation is rewritten, solving for *T*, as follows:

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

Note that *T* appears on both sides of the equation and, thus, an iterative procedure is used to arrive at a solution.

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 for cases where the well screen only partially penetrates the permeable sediments, it is necessary to use a computation algorithm that includes the effects of partial penetration. One such approach was introduced by Brons and Marting (Brons and Marting 1961) and augmented by Bradbury and Rothchild (Bradbury and Rothchild 1985).

Brons and Marting introduced a dimensionless drawdown correction factor, s_P, 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 ft. 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 either the Cooper-Jacob method or the Brons and Marting method, a storage coefficient value, *S*, must be assigned. Storage coefficient values for unconfined aquifers typically range from a few percent to 20% or more, with the majority of the values falling between approximately 5 and 15%. Thus, in the absence of site-specific storage coefficient data, a value of 0.1 is deemed to be a reasonable choice for performing the calculations for unconfined

conditions. When confined conditions are encountered, the storage coefficient can be expected to range from about 10^{-5} to 10^{-3}, depending on aquifer thickness (the thicker the aquifer, the greater the storage coefficient). Typically, a value of 5×10^{-4} may be assigned for most calculation purposes. 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. Because the water table in CdV-16-2(i)r lies within the Puye Formation, unconfined conditions were assumed, and a storage coefficient value of 0.1 was applied.

The analysis also requires assigning a value for the saturated formation thickness, *b*. The perched zone was assumed to be approximately 22-ft thick, from the static water level of 838 ft to the bottom of the well screen at 860 ft. This value could only be considered approximate because there was no definitive information identifying the tops and bottoms of the permeable zone or zones.

CdV-16-2(i)r Data Analysis

This section presents the data obtained from the CdV-16-2(i)r pump testing and the results of the analytical interpretations. Analyses were applied to time-drawdown and recovery data for the trials and constant-rate tests. There also is a discussion of the background data recorded as part of the data collection effort.

Background Data

Figure 2 shows a comparison of the apparent hydrograph and the barometric pressure corrected to conditions at the elevation of the water level inside CdV-16-2(i)r. A cursory examination of the graph showed that the apparent hydrograph exhibited little correlation to the barometric pressure curve. Because the apparent hydrograph is the sum of the actual water level over the transducer and the barometric pressure, this result means that in an open well (no inflatable packer), the actual water level would rise and fall in step with changes in barometric pressure. This implies a barometric efficiency for CdV-16-2(i)r of nearly 100%, consistent with most of the other deep wells on the Pajarito Plateau.

Also of note on Figure 2 is that following each pumping event the water level recovered to a progressively lower elevation. This suggested that the saturated perched zone was severely limited in areal extent, rather than areally extensive.

Trial 1

Trial 1 was started at 4:52 p.m. on September 7 and continued for 85 minutes until 6:17 p.m. The discharge rate began at 1 gpm and varied significantly during the test, averaging about 0.6 gpm toward the end of the pumping period. Following shutdown, recovery data were recorded until 7:50 p.m.

Time-Drawdown Analysis

Because of the erratic discharge rate, the time-drawdown data were not used in the analysis.

Recovery Analysis

Figure 3 shows recovery data from Trial 1, while Figure 4 shows an expanded-scale view of the data for easier interpretation. The multiple slopes observed on the graph were likely the result of filter pack storage effects. The storage duration, t_c, corresponding to filter pack effects was computed to identify the portion of the test data that could not be used for hydraulic analysis. The t/t' values corresponding to t_c (conservative) and $t_c/2$ (less conservative) are shown on the graph. The location of these points is consistent with the slope changes observed in the data trace. The primary steep slope on the graph is largely storage-affected and of no value in determining hydraulic properties.

The transmissivity computed from the late recovery data following the storage-affected data was 320 gpd/ft, or about 43 ft^2/day. Based on a saturated thickness of 22 ft, the corresponding average hydraulic conductivity is about 2.0 ft per day for the simplified assumption of uniform conditions. In all likelihood, however, the conductivity is variable throughout the saturated thickness, consisting of more permeable and less permeable zones.

At late recovery time, the extrapolated water-level trend on Figures 3 and 4 fell well below the initial static water level, even though only 68 gallons of water had been pumped from the well. This suggests a severely limited/bounded saturated perched zone rather than a laterally extensive one.

Note that a cursory examination of the graphs on Figures 3 and 4 could lead to the interpretation that the steep slope reflects the formation transmissivity and that the subsequent flattening is a result of either recharge or delayed yield. However, the transmissivity calculation corresponding to the steep portion of the curve yields an impossibly low value, conflicting with the lower-bound values computed based on the specific capacity of the well, discussed later.

Finally, it is important to note that the computed transmissivity could be an underestimate of the actual value. If the actual effective filter pack storage duration is better represented by t_c than by $t_c/2$, then most of the recovery data on which the analysis has been based would be invalid – still part of the filter pack storage curve. This results in a slightly exaggerated slope and would be expected to yield a transmissivity value smaller than the true value.

Trial 2

Trial 2 was started at 7:50 p.m. on September 7 and continued at 0.67 gpm for 40 minutes until 8:30 p.m. Following shutdown, recovery data were recorded for nearly 42 hours until 2:25 p.m. on September 9.

Time-Drawdown Analysis

Figure 5 shows the time-drawdown data for Trial 2. Filter pack storage affected essentially all of the data, with the computed storage duration being greater than the duration of the test. Also, late in the test, some minor flow-rate changes occurred. As a result, the time-drawdown data were not used to compute formation transmissivity.

Recovery Analysis

Figure 6 shows the recovery data from trial 2, while Figure 7 shows an expanded-scale view for ease of analysis. As with the Trial 1 recovery graph, the computed filter-pack storage times appeared consistent with the observed slope changes. The calculated transmissivity from Trial 2 was 290 gpd/ft. Also, note again that this value could be an underestimate of transmissivity if t_c accurately represents the duration of filter pack storage, as this would mean that primarily storage-affected data had been used to determine transmissivity (and the subsequent data may have been affected by the negative boundary).

The large increase in the slope of the recovery graph at late recovery time provided further indication of the negative boundary, i.e., a severe lateral limit to the saturated perched zone.

Test 1

Test 1 was started at 2:25 p.m. on September 9 and continued for 181 minutes until 5:26 p.m. The discharge rate began at 0.45 gpm and declined gradually to about 0.36 gpm toward the end of the pumping period. As discussed earlier, it was not possible to maintain a constant rate with the available valves. Following shutdown, recovery data were recorded until 7:46 a.m. on September 10.

Time-Drawdown Analysis

Figure 8 shows time-drawdown data from Test 1, yielding a transmissivity value of 260 gpd/ft. Because of the variable discharge rate, the reliability of this value was in question and greater reliance was placed in the recovery calculations.

Recovery Analysis

Figure 9 shows recovery data from Test 1, while Figure 10 shows an expanded-scale view of the data for easier interpretation. As in the trial tests, the multiple slopes observed on the graph showed storage effects and the indication of lateral limits to the saturated perched zone. The computed filter pack storage times were consistent with the observed slopes on the graph.

The transmissivity computed from the portion of the recovery curve between storage effects and boundary effects was 410 gpd/ft, or about 55 ft^2/day. Based on a saturated thickness of 22 ft, the corresponding average hydraulic conductivity was estimated to be about 2.5 ft/day for the simplified assumption of uniform conditions. As stated earlier, however, the conductivity is probably variable throughout the saturated interval, with some zones having greater permeability and others having less than this.

Test 2

Test 2 was started at 7:46 a.m. on September 10 and continued at an average pumping rate of 1 gpm for 12 hours until 7:46 p.m. Following shutdown, recovery data were recorded for over 40 hours until 11:57 a.m. on September 12.

Time-Drawdown Analysis

Figure 11 shows the time-drawdown data for Test 2. It is apparent that the discharge rate varied erratically throughout the test despite best efforts to continually adjust the valves in an attempt to maintain the rate at a constant level. The transmissivity computed from the straight line of best fit shown on the graph was 230 gpd/ft, although the reliability of the calculation is questionable because of the erratic time-drawdown data and also because the late data probably would have been affected by negative boundary conditions.

Recovery Analysis

Figure 12 shows the recovery data from Test 2, while Figure 13 shows an expanded-scale view. As with previous tests, the computed filter pack storage values appeared to be consistent with the observed slopes on the graph. The transmissivity computed from the selected straight line of best fit was 570 gpd/ft, or 76 ft^2/day. The corresponding average hydraulic conductivity of the 22-ft-thick saturated zone computed to 3.5 ft/day, assuming homogeneous conditions.

The increase in the slope of the recovery graph at late recovery time provided additional confirmation of the lateral limits of the saturated perched zone.

Specific Capacity Data

During trial 2, CdV-16-2(i)r produced about 0.67 gpm with 4.6 ft of drawdown after 40 minutes of pumping, making the specific capacity 0.146 gpm/ft. This information was used along with well and formation geometry data to establish a lower bound value for hydraulic conductivity. Other input values used in the calculations included a well screen length of 10 ft, an assumed storage coefficient of 0.1, a saturated thickness of 22 ft and a borehole radius of 0.51 ft. Applying the Brons and Marting method yielded a lower bound transmissivity of 153 gpd/ft, or 20.5 ft^2/day and a hydraulic conductivity of 0.93 ft/day.

Similarly, during Test 1, the well produced 0.36 gpm with 2.76 ft of drawdown after 181 minutes, making the specific capacity 0.13 gpm/ft. Applying the Brons and Marting method to these data yielded a lower bound transmissivity of 160 gpd/ft, or 21.4 ft^2/day and a hydraulic conductivity of 0.97 ft/day.

Finally, during test 2, the well produced 1 gpm with 7.32 ft of drawdown after 720 minutes, making the specific capacity 0.137 gpm/ft. Applying the Brons and Marting method to these data yielded a lower bound transmissivity of 193 gpd/ft, or 25.7 ft^2/day and a hydraulic conductivity of 1.2 ft per day.

In each calculation, the drawdown was exaggerated by successive failures of the water level to return to the original static level following the previous tests. Thus, this contributed to the lower bound transmissivity estimates being even lower than what would have been calculated had the saturated zone been more laterally extensive. Further, the drawdown values measured at the end of each pumping period would have included negative boundary effects not factored into the Brons and Marting analysis. This would further exaggerate the drawdown values used in the calculations. Thus, the true lower bound parameter values could have been somewhat greater than presented here. Nevertheless, the computed lower bound values were consistent with the

transmissivity values computed from the pumping tests. For example, the lower bound transmissivity of 193 gpd/ft from Test 2 was 34 percent of the transmissivity value of 570 gpd/ft from the Test 2 recovery graph. This would imply approximately a 34% efficient well. Likewise, it was 47 percent of the transmissivity value of 410 gpd/ft obtained from the Test 1 recovery graph, implying roughly a 47% efficient well. Either result would be considered reasonable, thus implying that the lower-bound values are consistent with the test results, rather than contradictory.

SUMMARY

The following information summarizes the results of the pumping and recovery tests on CdV-16-2(i)r:

1. The CdV-16-2(i)r pumping tests investigated the hydraulic properties of a perched saturated zone near the top of the Puye Formation.
2. Water level changes in CdV-16-2(i)r were nearly identical to barometric pressure changes, implying essentially a 100% barometrically efficient saturated perched zone.
3. Use of the inflatable packer successfully eliminated casing storage effects, but could not prevent filter pack draining and refilling (storage effects) from invalidating the early pumping and recovery data.
4. The combination of pump capacity and valve size made it impossible to control the discharge rate during the tests, placing a greater reliance on recovery data for determining formation parameter values.
5. Testing showed transmissivities ranging from 230 to 570 gpd/ft. The most reliable values were 410 gpd/ft and 570 gpd/ft, producing and average estimate of 490 gpd/ft, or 66 ft^2/day. Based on an assumed saturated thickness of 22 ft, the average hydraulic conductivity was 3.0 ft/day, although probable heterogeneous conditions likely imply zones of both greater and lesser conductivity.
6. The specific capacity data from CdV-16-2(i)r implied a lower bound transmissivity value of around 200 gpd/ft, not in conflict with the pumping tests estimates.
7. All of the observed data showed strong boundary effects, suggesting that the pumped zone was severely limited in areal extent rather than laterally extensive.

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Figure 1. Well CDV-16-2(I)-r Initial Purging

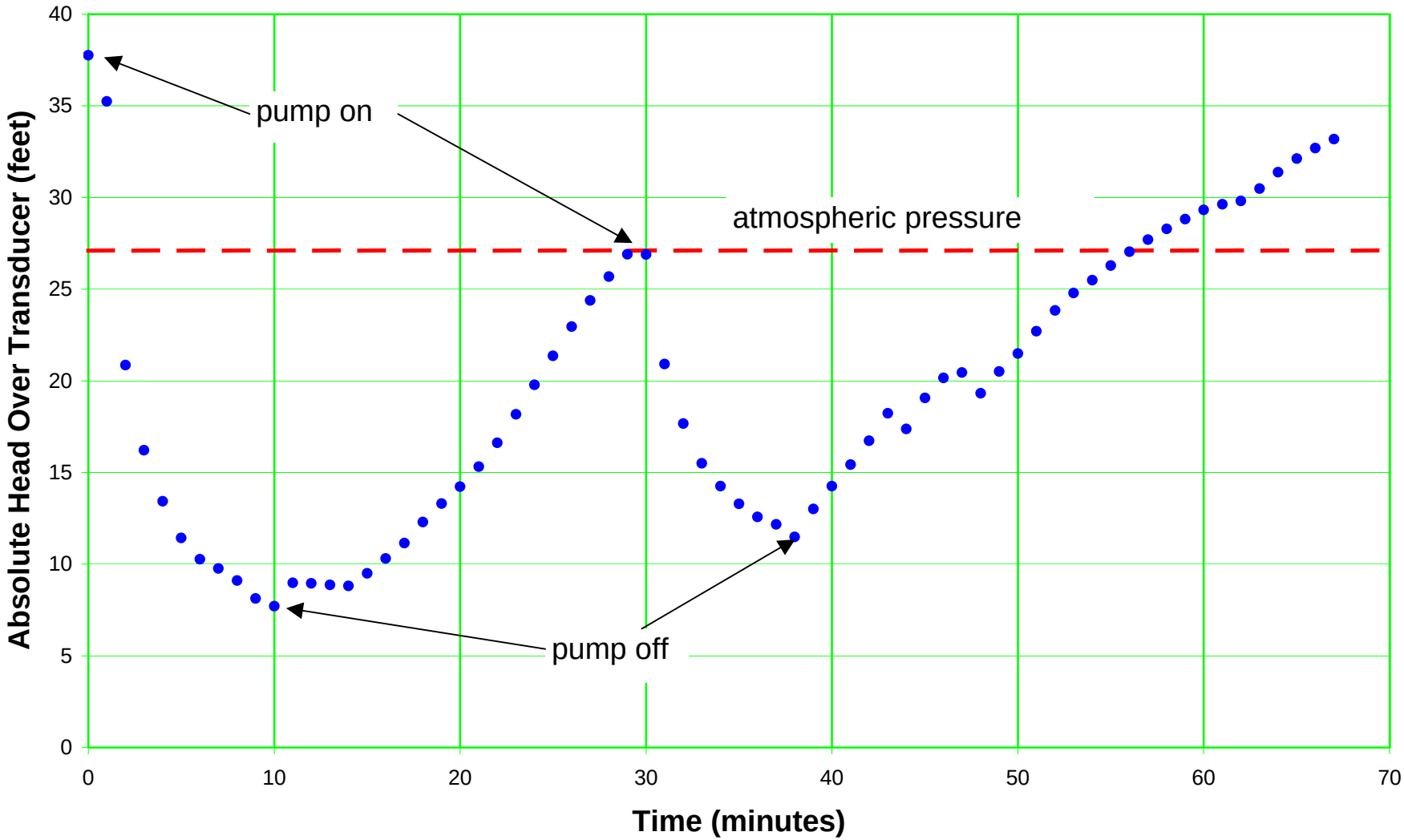


Figure 2. Comparison of CDV-16-2(I)-r Hydrograph and TA-54 Adjusted Barometric Pressure

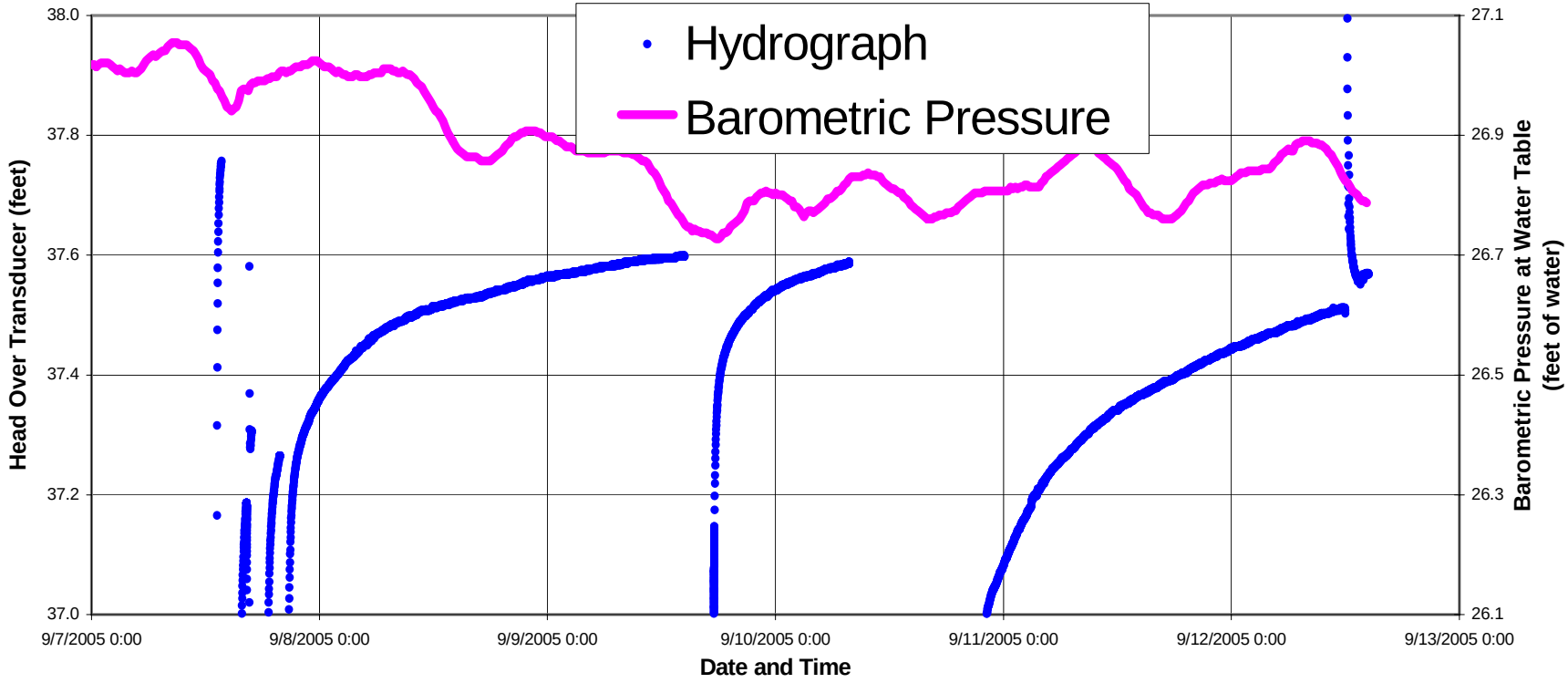


Figure 3. Well CDV-16-2(I)-r Trial 1 Recovery

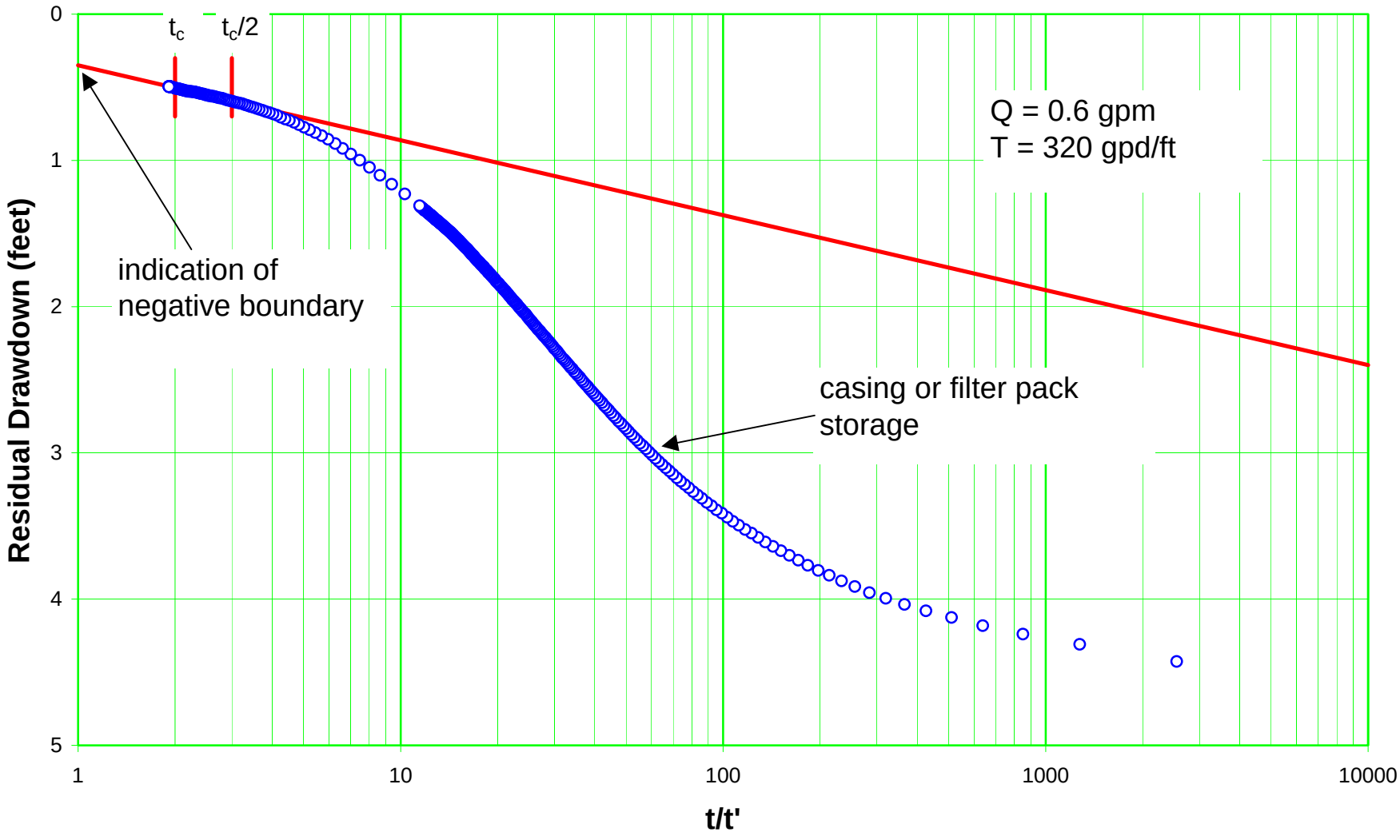


Figure 4. Well CDV-16-2(I)-r Trial 1 Recovery - Expanded Scale

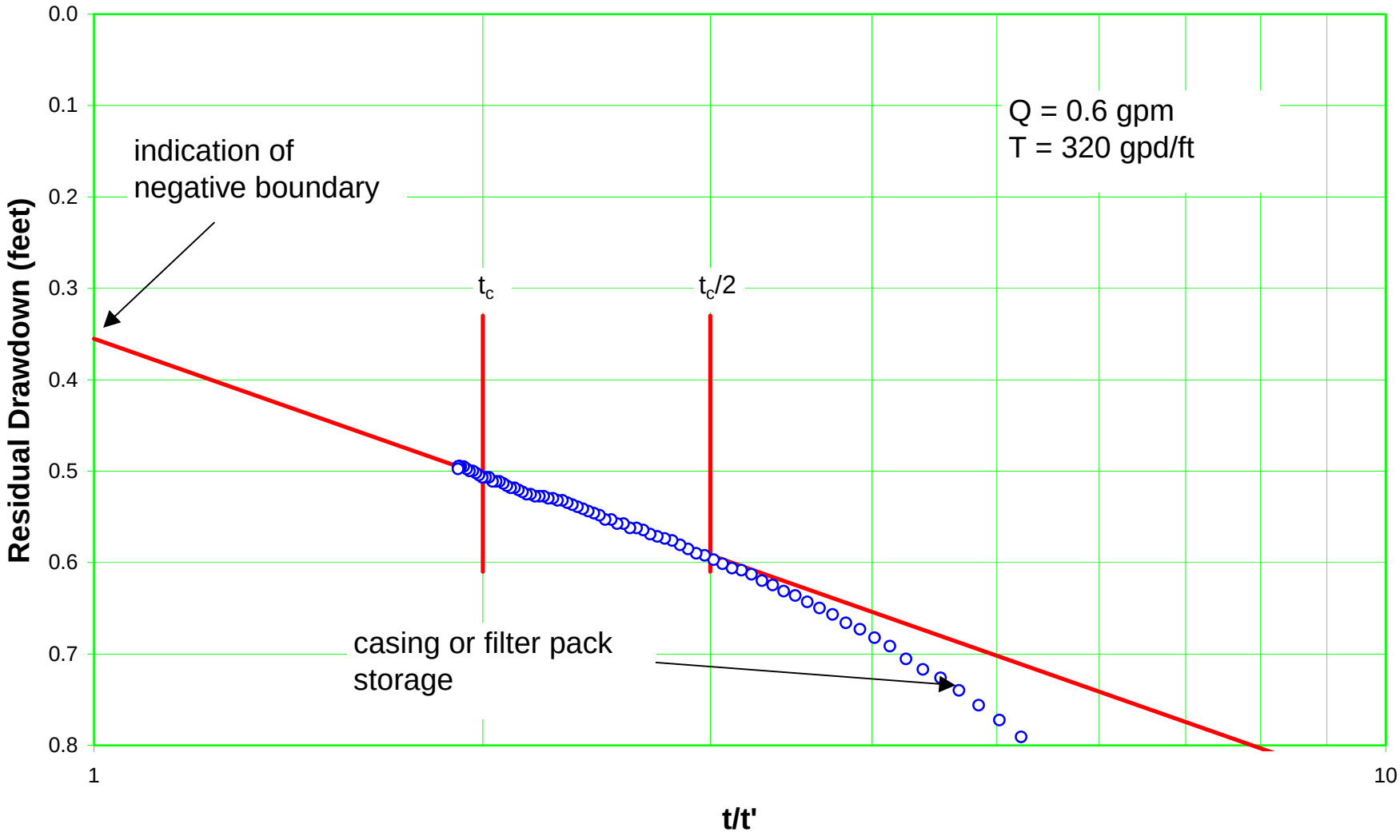


Figure 5. Well CDV-16-2(I)-r Trial 2 Drawdown

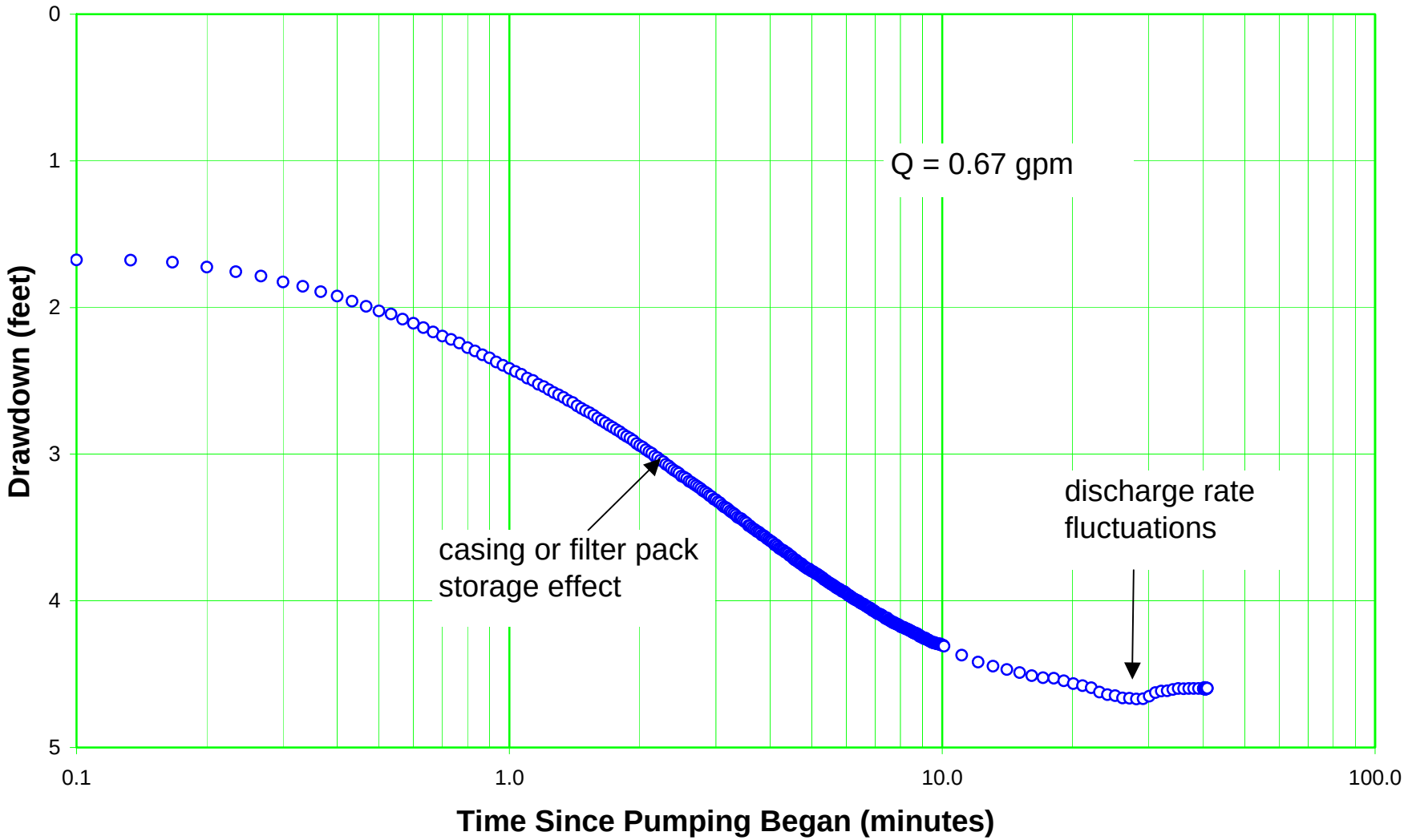


Figure 6. Well CDV-16-2(I)-r Trial 2 Recovery

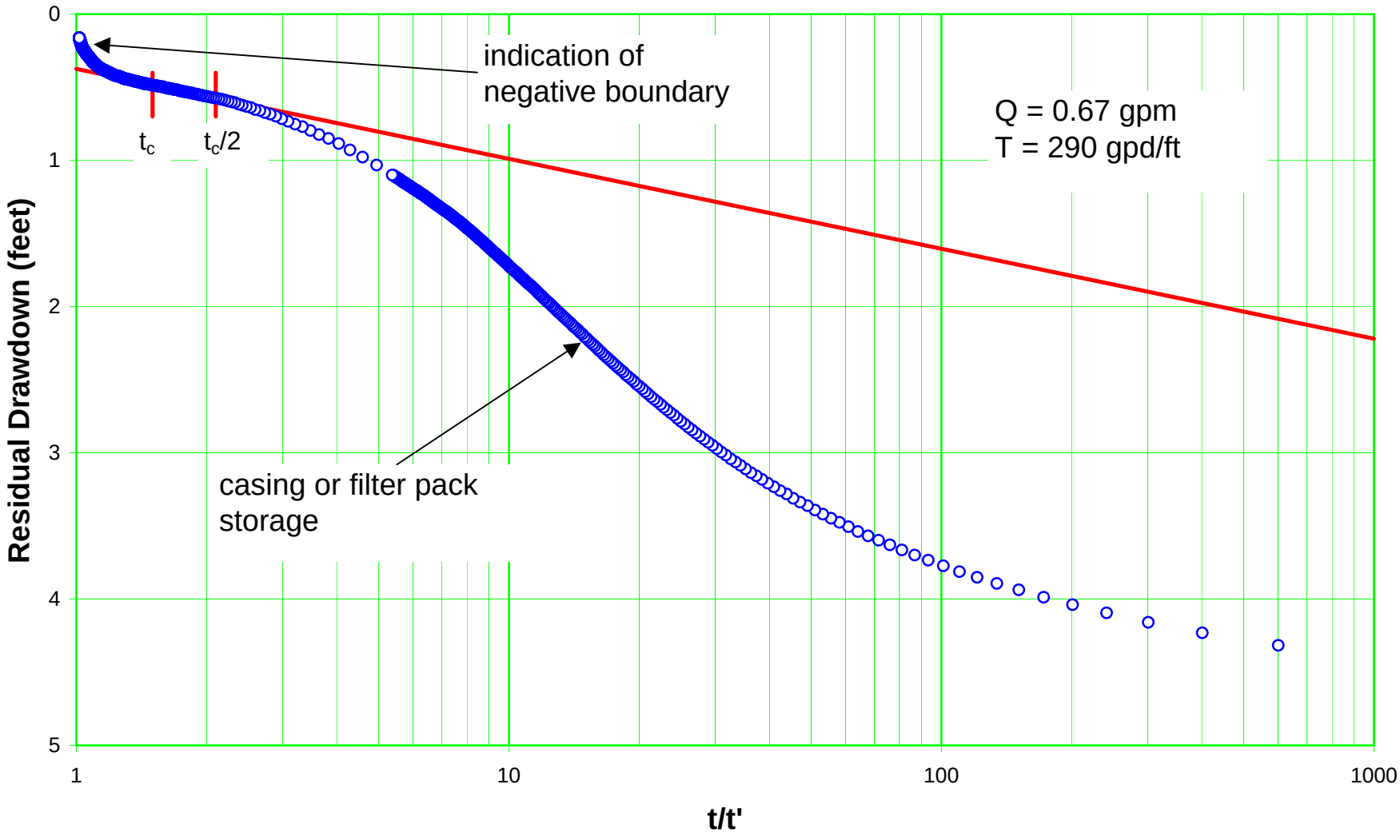


Figure 7. Well CDV-16-2(I)-r Trial 2 Recovery - Expanded Scale

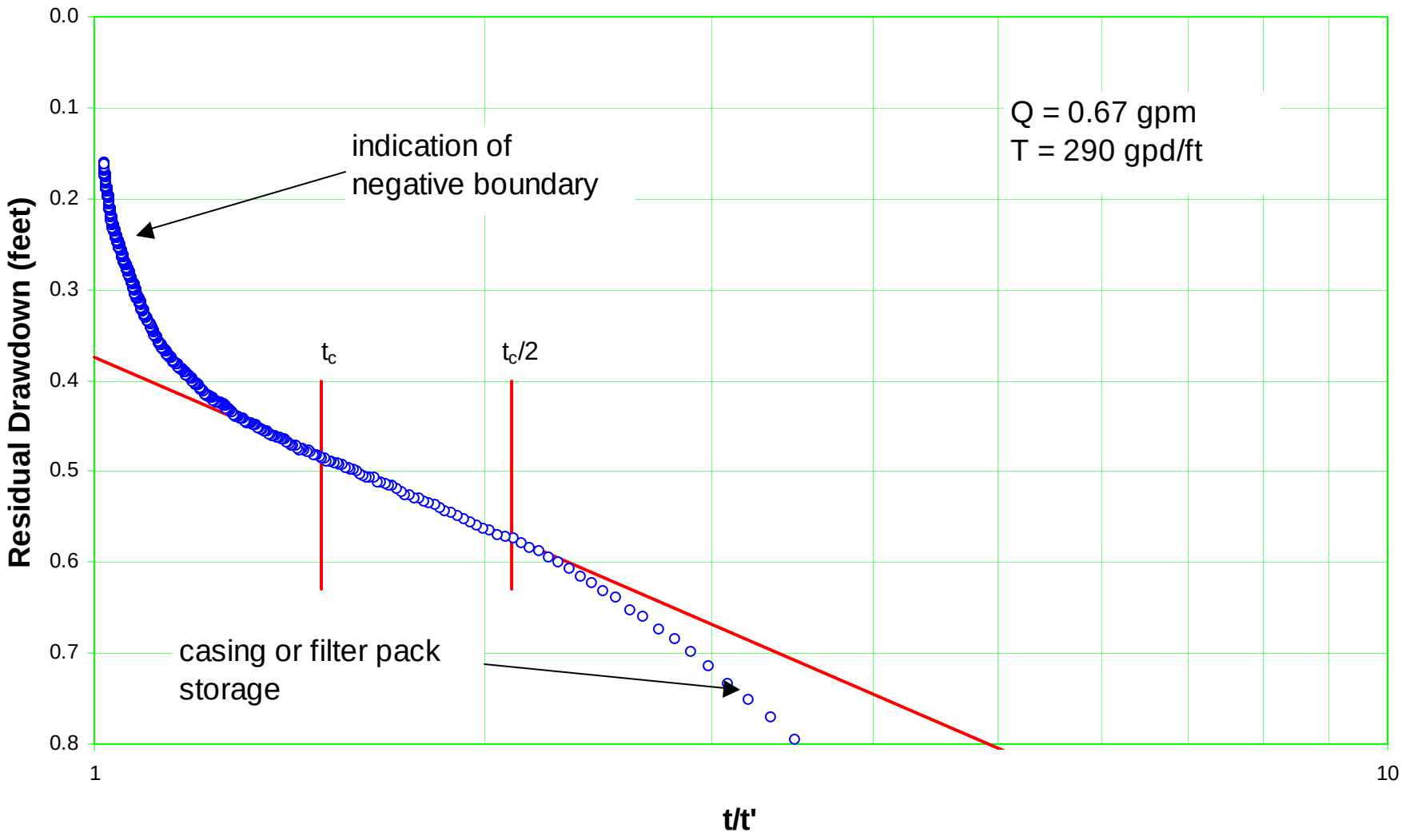


Figure 8. Well CDV-16-2(I)-r Test 1 Drawdown

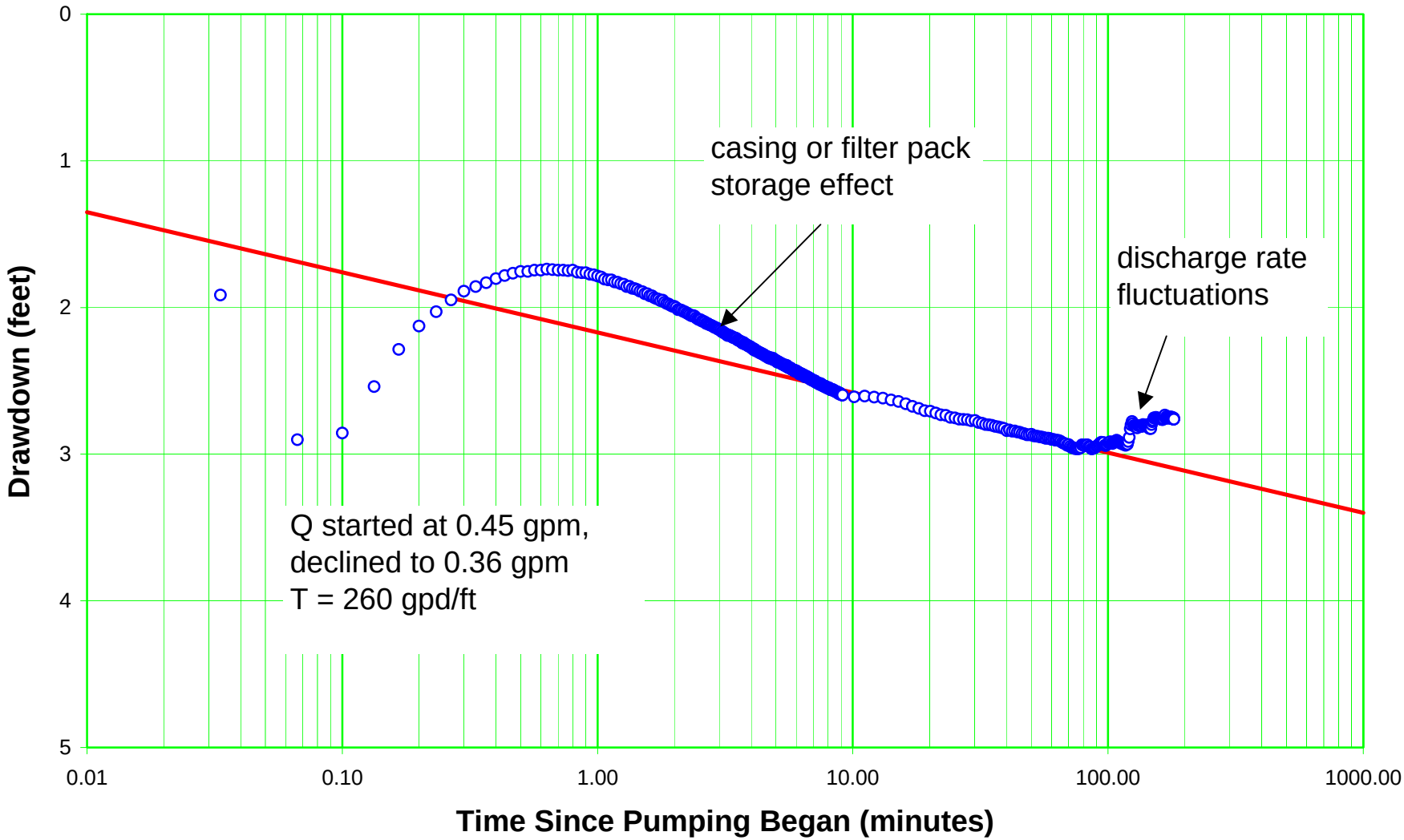


Figure 9. Well CDV-16-2(I)-r Test 1 Recovery

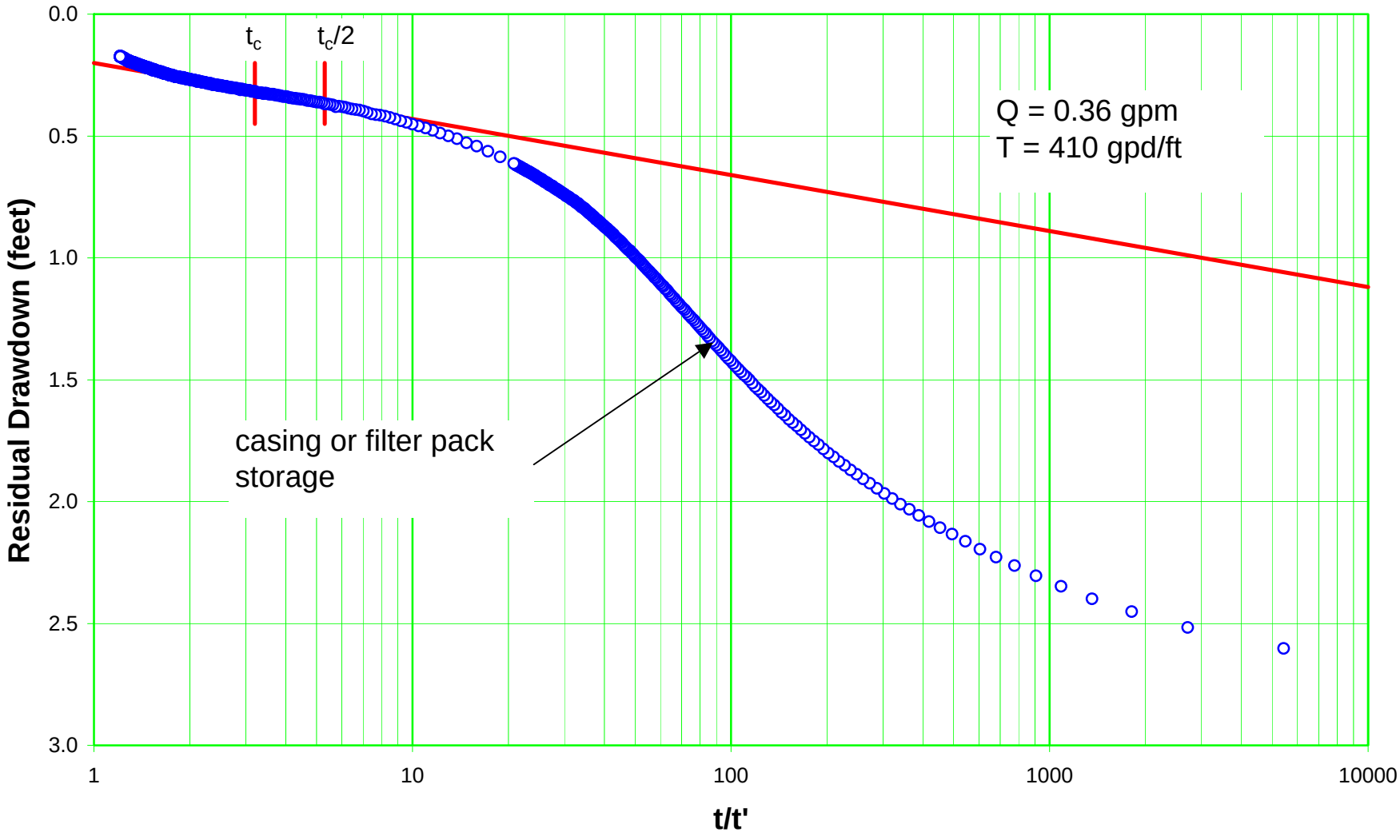


Figure 10. Well CDV-16-2(I)-r Test 1 Recovery - Expanded Scale

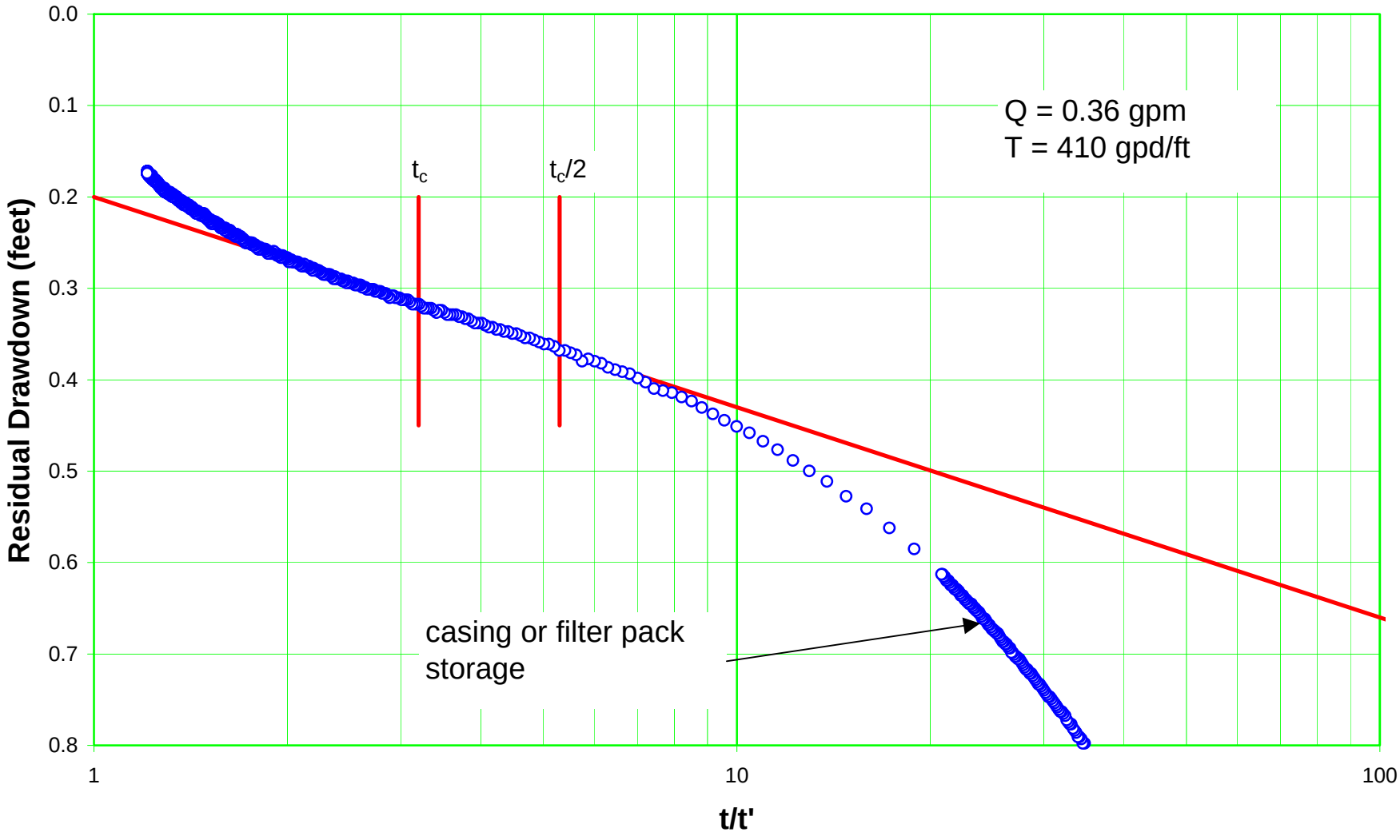


Figure 11. Well CDV-16-2(I)-r Test 2 Drawdown

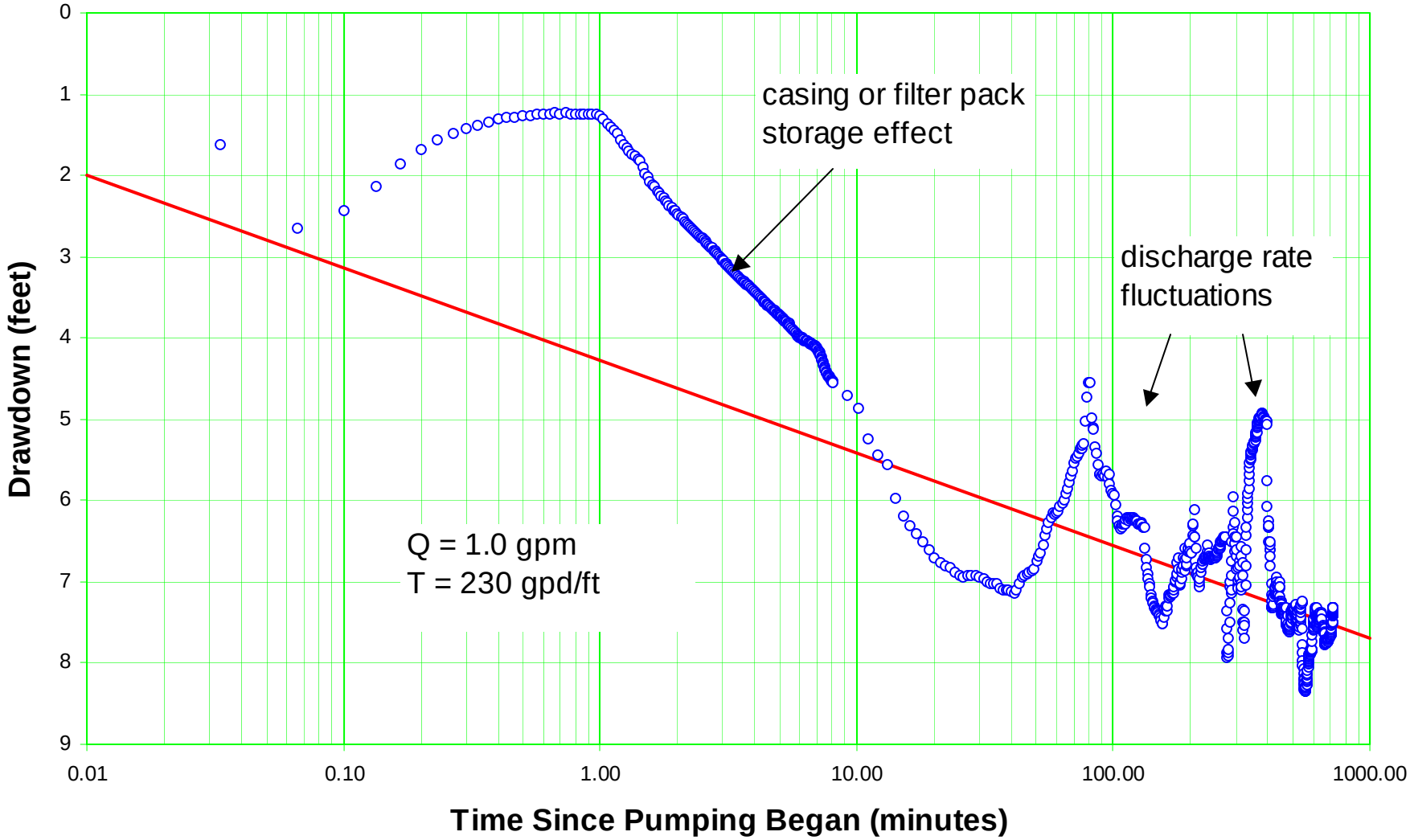


Figure 12. Well CDV-16-2(I)-r Test 2 Recovery

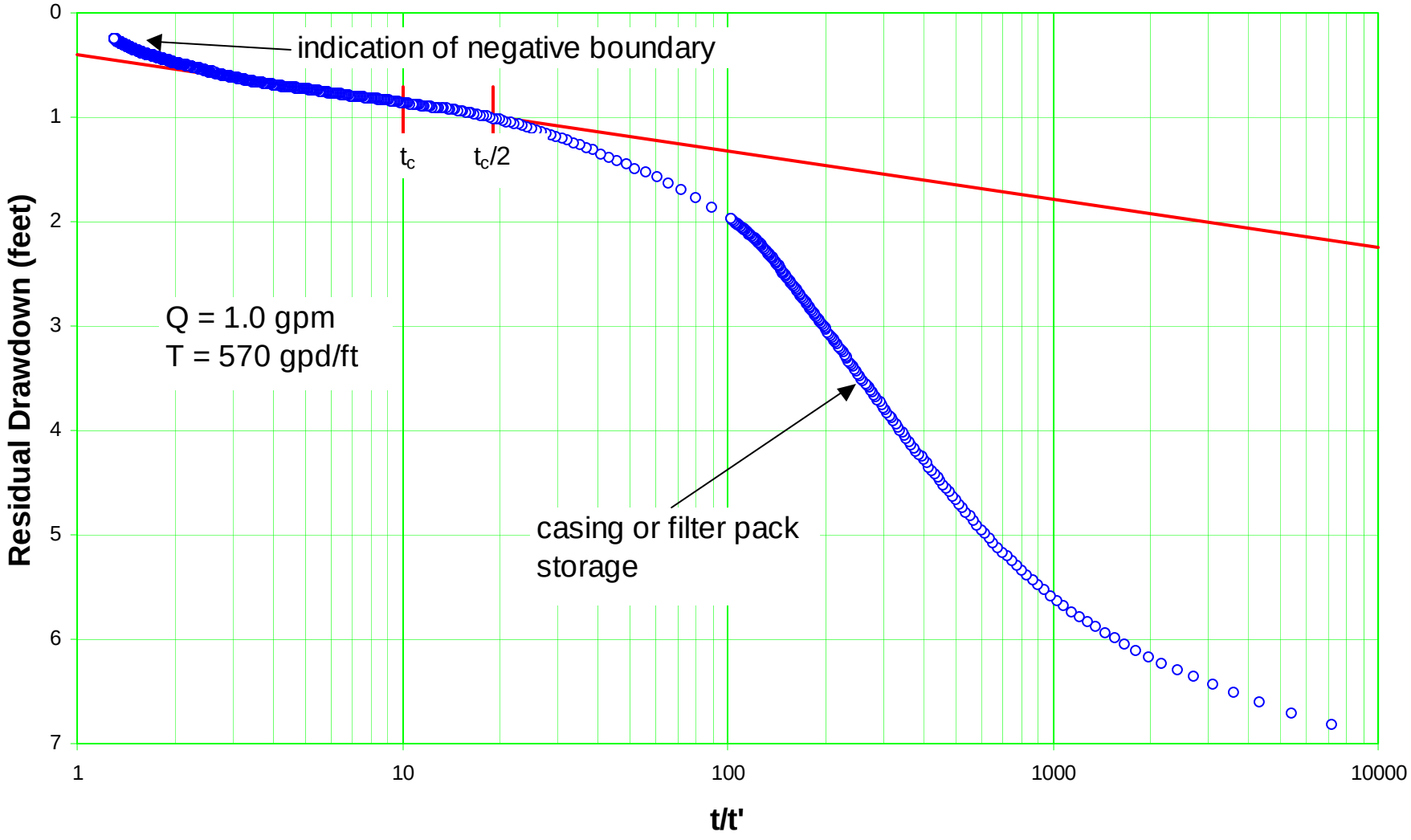
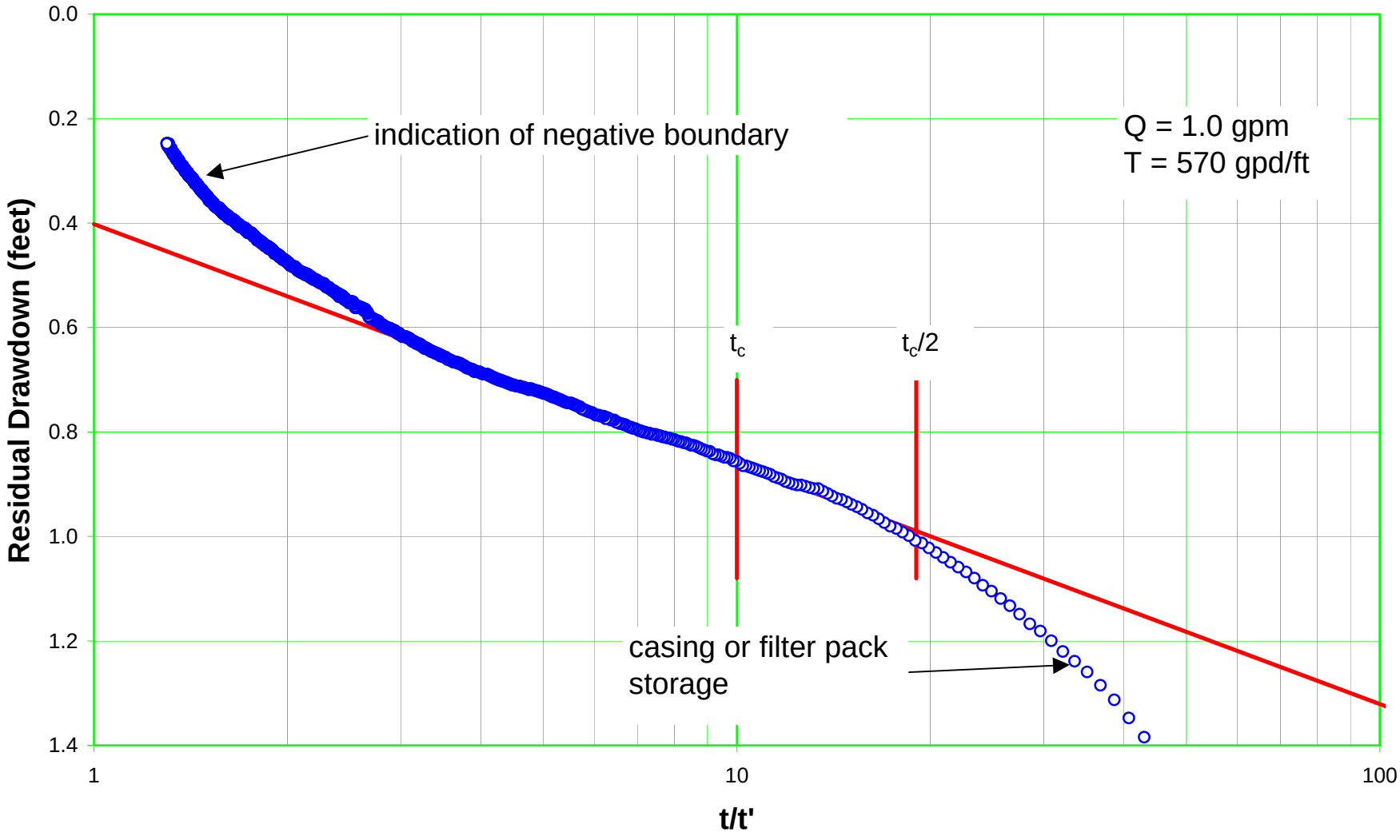


Figure 13. Well CDV-16-2(I)-r Test 2 Recovery - Expanded Scale



Appendix E

Deviations

Activity	Addendum to CMS Plan for PRS 16-021 (c) (LANL 2003)	Scope of Services for CdV-16-2 (i) GSA Task Order 9T3N163PG	Drilling Work Plan for CdV-16-2(i)r (Kleinfelder 2005c)	CdV-16-2 (i)r Actual Work
Planned Depth	Approximately 800 ft – 1000 ft bgs or into the top of the deep perched zone, where present.	Planned TD of 900 ft bgs, approximately 50 ft below the anticipated perched water zone, assumed to be at 850 ft bgs.	Target TD of 900 ft bgs.	CdV-16-2 (i)r was drilled to 874.4 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.	Drilled with air-rotary or fluid-assisted air rotary.	CdV-16-2 (i)r drilled using fluid-assisted, open-hole, air- rotary methods.
Amount of Core	10% of the borehole.	No coring was required in the Scope of Services for CdV-16-2 (i).	No coring required.	No coring was performed at CdV-16-2 (i)r.
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.	Because a lithologic log was prepared for CdV-16-2 (i), no log was required for CdV-16-2(i)r.	Not prepared.
Number of Water Samples Collected for Contaminant Analysis	Not specified.	If perched water is encountered in the unsaturated zone, groundwater samples are to be collected from each perched zones for screening analysis.	If perched water is encountered in the unsaturated zone, groundwater samples are to be collected from each perched zones for screening analysis.	A screening groundwater sample was collected from the open borehole, and a final groundwater sample was collected after development.
Water Sample Analysis	HE, metals, anions (nitrates, sulfate, perchlorate), fluoride, chloride, bromide, HCO_3 (bicarbonate), volatile organic compounds, and gross alpha and gross beta.	Analytes not specified in the Scope of Services.	Radionuclides, explosives, dissolved metals, total metals, and anions.	Sample paperwork from LANL RRES-WQH proscribed EES anions, metals, and perchlorate.
Number of Core/Cuttings Samples Collected for Contaminant Analysis	Not specified.	No coring was required in the Scope of Services for CdV-16-2 (i).	None required.	No core/cuttings samples were collected for contaminant analysis.
Laboratory Hydraulic-Property Tests	Physical properties analyses will be conducted on five core samples.	Not specified in the Scope of Services.	None required.	No Laboratory Hydraulic-Property Tests were performed.

Activity	Addendum to CMS Plan for PRS 16-021 (c) (LANL 2003)	Scope of Services for CdV-16-2 (i) GSA Task Order 9T3N163PG	Drilling Work Plan for CdV-16-2(i)r (Kleinfelder 2005c)	CdV-16-2 (i)r Actual Work
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.	None required; collected during drilling of CdV-16-2(i).	Not collected
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, and elemental capture spectrometer.	Natural gamma and induction array called for. Full suite of Schlumberger logs collected at CdV-16-2(i).	Natural gamma and induction array conducted.
Water-Level Measurements	Not specified.	Water levels will be determined for each saturated zone by water-level meter or by pressure transducer.	Water levels will be determined for each saturated zone by water-level meter or down-hole camera.	Electric water-level meter and down-hole camera used to measure zones of perched saturation.
Field Hydraulic-Property Tests	Not specified.	Slug or pumping tests may be conducted in saturated intervals once the well is completed.	Constant rate pumping test or slug test.	Pumping tests were conducted at CdV-16-2(i)r.
Surface Casing	Approximately 16-inch (in.) outer diameter (OD) extends from land surface to 10-ft depth in underlying competent layer and grouted in place.	Not specified.	Either temporary or permanent surface casing.	13⅜-in. OD steel casing was installed to 9.6 ft bgs and subsequently removed during CdV-16-2(i)r well construction.
Minimum Well Casing Size	5.56-in. OD	4-in. diameter, 304 grade stainless steel casing.	5.0-in. OD A304 stainless steel casing.	5-in. OD A304 stainless steel casing with external couplings.

Activity	Addendum to CMS Plan for PRS 16-021 (c) (LANL 2003)	Scope of Services for CdV-16-2 (i) GSA Task Order 9T3N163PG	Drilling Work Plan for CdV-16-2(i)r (Kleinfelder 2005c)	CdV-16-2 (i)r Actual Work
Well Screen	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.	4-in. diameter, 304 grade stainless steel well screen, estimated to be 20-ft long.	4-in. diameter, 304 grade stainless steel well screen 10-ft long.
Sump	Stainless-steel casing with an end cap	Not specified.		Sump constructed of 5-in. OD stainless steel casing, 21.9-ft long, with end cap.