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FINAL
I WELLS COMPLETION REPORT
2004-05 MORTANDAD CANYON
DRILLING PROGRAM
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

April 2006

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ABSTRACT

This completion report summarizes the drilling, well construction, well development, aquifer testing, and related activities for Intermediate Wells I-1, I-4, I-5, I-6, I-8, and I-10. Kleinfelder, Inc. (Kleinfelder), under contract to the U.S. Army Corps of Engineers (USACE), was responsible for executing the drilling, installation, testing, and sampling activities. The wells were installed in accordance with the "Mortandad Canyon Groundwater Work Plan, Revision 1" (LANL 2004), as part of the Risk Reduction and Environmental Stewardship-Remediation Services (RRES-RS) project at Los Alamos National Laboratory (LANL). The wells were drilled within and adjacent to Mortandad Canyon on LANL property to determine if contaminant releases have impacted the quality of intermediate-depth perched groundwater. The U.S. Department of Energy (DOE), with technical assistance from LANL, contracted and directed the activities associated with this work.

Mortandad Canyon begins near Diamond Drive in Technical Area (TA)-3 and extends 9.8 miles east-southeast to the Rio Grande. I-1 is located in TA-35 within Mortandad Canyon. I-4, I-5, I-6, and I-8 are located in Mortandad Canyon within TA-5. I-10 is located in TA-5 on the mesa top south of Mortandad Canyon, approximately 3,500 feet east of Pajarito Mesa Well Number 5.

Data from intermediate wells will be used to improve the conceptual model of the geology, hydrogeology, and hydrochemistry of the area and to provide data for numerical models that address contaminant migration in the vadose (unsaturated) zone and perched aquifers. This information will in turn be used to facilitate decision-making with regard to regulatory compliance, risk assessment, and remediation.

The majority of the fieldwork was conducted from October 14, 2004 through February 10, 2005. I-1, I-6, I-8, and I-10 were initially cored using a Deltabase 540 multipurpose drilling rig (DB540) to 843.2, 498.2, 522.8 and 727.3 feet (ft) below ground surface (bgs) respectively. A corehole was not advanced at I-4 or I-5.

A Speedstar 50K or a Speedstar 90K drilling rig was used to advance boreholes I-4, I-5, I-6, I-8, and I-10. Boreholes were advanced using conventional fluid-assisted, air rotary drilling methods. The I-4 and I-5 boreholes were advanced to depths of 540 and 717 ft bgs, respectively. The I-6, I-8, and I-10 boreholes were advanced to depths of 720, 745, and 1050 ft bgs, respectively. A borehole was not advanced at I-1. Samples of drill cuttings and/or cores were collected at regular intervals for stratigraphic, petrographic, and geochemical analysis.

Quaternary alluvium was observed in the core and cuttings of boreholes I-4, I-5, I-6, and I-8. Below the Quaternary alluvium, the general stratigraphy observed in the boreholes included (in descending order): the Tshirege Member of the Bandelier Tuff, the Cerro Toledo interval, ash-flow tuffs of the Otowi Member of the Bandelier Tuff, the Guaje Pumice Bed of the Otowi Member, the upper Puye Formation, the Cerros del Rio basalt, and the lower Puye Formation. The Tsankawi Pumice Bed occurs at the base of the Tshirege Member in I-1, I-5, I-8 and I-10. The Tsankawi Pumice Bed was not discernable within the cuttings at I-5, though the unit was noted in the adjacent R-15 corehole. The Tshirege Member was not encountered in I-4 or I-6. Wells I-4, I-5, and I-6 penetrated into the Cerros del Rio basaltic lavas. Wells I-8 and I-10 penetrated through these lavas into the lower Puye Formation. I-1 differs from the other I wells in that it penetrated a thick sequence of dacitic lavas, probably related to the Tschicoma Dacite.

Each of the intermediate wells was constructed with a single-screened interval. Well I-1 was constructed within the corehole using nominal 1-inch (in.) outside diameter (OD) stainless steel casing with a 0.8-in. inner diameter (ID)/1.4 OD pre-pack screen. The screened interval was placed from 815.5 to 825.5 ft bgs within dacitic flow-base breccias. Water has not accumulated in this well and well development, aquifer testing, and pump installation were not performed.

Wells I-4, I-5, I-6, and I-8 were constructed using 4.5-in. ID/5.0-in. OD stainless steel casing and screen. The screened interval in I-4 was placed at 499 to 522 ft bgs across the geologic contact between the upper Puye Formation and the underlying Cerros del Rio basalt. One groundwater-screening sample was collected during drilling, and one groundwater sample was collected after well installation. These samples were submitted to LANL for analysis. The depth to water following well installation, development, and recovery was 520.41 ft bgs. A constant-rate aquifer test was not conducted due to the low recharge rate in the intermediate perched zone; however a slug test was performed.

The screened interval of I-5 was completed within the Cerros del Rio basalt from 689 to 699 ft bgs. One groundwater-screening sample was collected during drilling, and one groundwater sample was collected after well installation. These samples were submitted to LANL for analysis. Well yield was not sufficient to perform a conventional constant-rate pumping test. Hydrologic testing consisted of a series of pump-to-evacuation tests. The DTW following well installation, development, aquifer testing, and recovery was 687.30 ft bgs.

I-6 is screened from 686 to 709 ft bgs, near the base of the Cerros del Rio basalt. One groundwater-screening sample was collected during drilling, and one groundwater sample was collected after well installation. These samples were submitted to LANL for analysis. Additionally, a constant-rate aquifer test was performed to determine the aquifer properties of the screened interval. The DTW following well installation, development, aquifer testing, and recovery was 662.07 ft bgs.

Well I-8 was completed in the Cerros del Rio basalt with a single well screen from 665 to 675 ft bgs. One groundwater-screening sample was collected during drilling and submitted to LANL for analysis. Well yield was not sufficient to perform a conventional constant-rate pumping test and hydrologic testing consisted of a series of pump-to-evacuation tests. The DTW following well installation, development, aquifer testing, and recovery was 675.02 ft bgs.

The I-10 borehole was advanced 76 ft beneath the Cerros del Rio lavas into the Puye Formation to a total depth of 1050 ft bgs. Groundwater was not present and the borehole was plugged and abandoned on February 10, 2005.

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, New Mexico office. Copies will be submitted to the LANL Records Processing Facility. Further analysis and interpretation of geologic, geochemical, and aquifer data will be included in separate technical documents to be prepared by LANL.

FINAL
COMPLETION REPORT
INTERMEDIATE WELL I-1
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

April 2006

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A Corehole Video Log
B Lithologic Log

LIST OF ACRONYMS AND ABBREVIATIONS

ags	above ground surface
amsl	above mean sea level
bgs	below ground surface
BMPs	best management practices
DOE	United States Department of Energy
DTHH	down-the-hole hammer
DTW	depth to water
FSF	Field Support Facility
ft	foot/feet
ft^3	cubic feet
hr/hrs	hour/hours
ID	inner diameter
in.	inch/inches
Kleinfelder	Kleinfelder, Inc.
LANL	Los Alamos National Laboratory
min.	minute/minutes
NM	not measured
OD	outer diameter
PVC	polyvinyl chloride
RCT	radiation control technician
SMO	Sample Management Office
TA	Technical Area
TD	total depth
US	United States

ABSTRACT

Intermediate well I-1 was installed as part of the Risk Reduction and Environmental Stewardship-Remediation Services project at Los Alamos National Laboratory (LANL) in accordance with the "Mortandad Canyon Groundwater Work Plan, Revision 1" (LANL 2004) and the "Final Drill Plan for Intermediate Wells, Mortandad Canyon, Los Alamos National Laboratory" (Kleinfelder 2004b). The United States (US) Department of Energy (DOE) with technical assistance from LANL contracted and directed the installation of this well.

Data from I-1 will be used in conjunction with data from other wells in Mortandad Canyon to improve the conceptual model of the geology, hydrogeology, and hydrochemistry of the area to provide data for numerical models that address contaminant migration in the vadose (unsaturated) zone. This information will be used to facilitate decision-making with regard to regulatory compliance, risk assessment, and remediation.

The majority of the fieldwork for I-1 was conducted from November 23, 2004, to January 9, 2005. A corehole was advanced to 843.2 feet (ft) below ground surface (bgs). Core was collected from 75 to 843.2 ft bgs. As groundwater was not encountered during coring, a borehole was not drilled. Video and geophysical logging was performed in the open I-1 corehole to help delineate the hydrostratigraphy and to facilitate well design. The stratigraphic units encountered during coring include, in descending order, Tshirege Member of the Bandelier Tuff, Tsankawi Pumice Bed, Cerro Toledo interval, Otowi Member of the Bandelier Tuff, Guaje Pumice Bed, upper Puye Formation, Tschicoma Dacite, and lower Puye Formation.

A well was installed in the dry corehole to provide a means to further assess the vadose zone. A single-screened interval from 815.0 to 825.5 ft bgs is located within the Tschicoma Dacite flow-base rubble. The total depth (TD) of the well is 825.6 ft bgs. Groundwater has not been detected in the well.

1.0 INTRODUCTION

This completion report summarizes the site preparation, coring, well installation, and related activities for intermediate well I-1. Kleinfelder, Inc. (Kleinfelder), under contract to the United States (US) Army Corps of Engineers, was responsible for coring, installing, testing, and sampling activities. The US Department of Energy (DOE) with technical assistance from Los Alamos National Laboratory (LANL) contracted and directed this work.

Intermediate well I-1 is located in Technical Area (TA) 35 of LANL in Mortandad Canyon, approximately 0.5 miles east of the TA-50 outfall (Figure 1.0-1). It was installed to determine if contaminant releases have affected the quality of intermediate perched groundwater between the TA-50 outfall and Test Well 8 (LANL 2004). The data quality objectives are provided in the "Mortandad Canyon Groundwater Work Plan, Revision 1" (LANL 2004) and the "Final Drilling Plan for Intermediate Wells, Mortandad Canyon, Los Alamos National Laboratory" (Kleinfelder 2004b). Geochemical data, aquifer characteristics, and geologic information obtained from I-1 will augment the conceptual model and knowledge of contaminant distribution in the intermediate perched zone of the Mortandad Canyon system.

The objectives of the coring activities were to collect core from the encountered geologic formations, to collect groundwater samples from perched intermediate groundwater (if present), and to install a single-screened characterization well in the Guaje Pumice Bed or lava flows. A corehole and separate borehole were originally planned; the projected total depth (TD) of the corehole was 550 ft and the projected TD of the borehole was 800 ft bgs. The I-1 corehole was advanced to 843.2 ft bgs. The borehole was not drilled because groundwater was not encountered in the corehole. The corehole was completed as a well with a single screened interval from 815.0 to 825.5 ft bgs to further assess the vadose zone.

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, New Mexico office and LANL's Record Processing Facility. Further analyses and interpretation of geologic, geochemical, and aquifer data will be included in separate technical documents to be prepared by LANL.

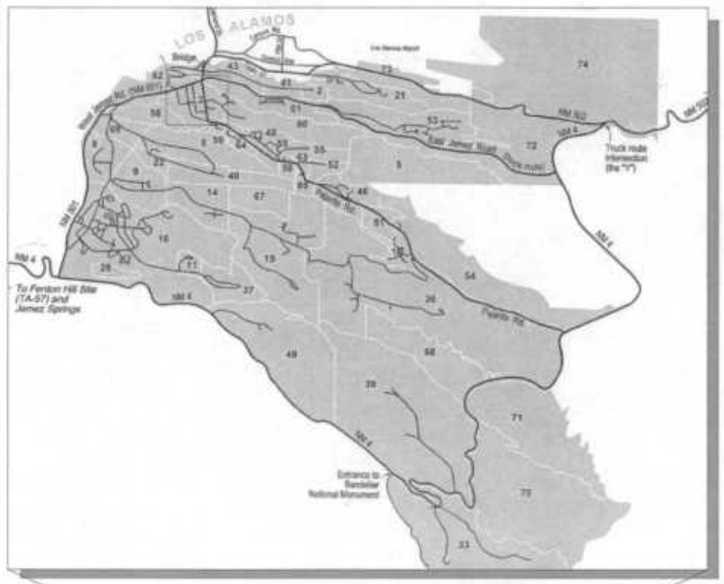
2.0 CORING ACTIVITIES

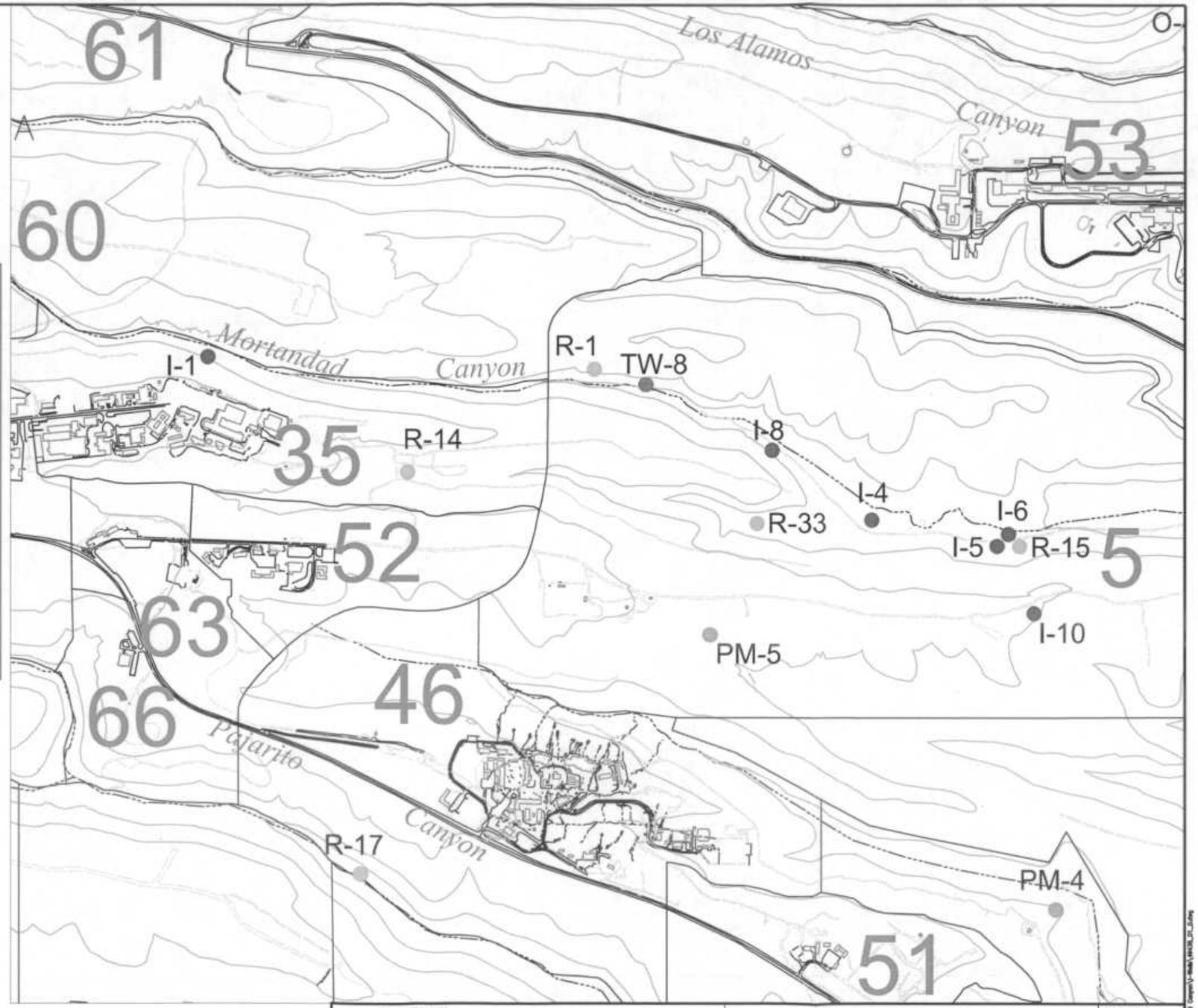
Site preparation consisted of establishing bermed zones for cuttings collection, placement of straw bales to prevent erosion and runoff from the drill site, and setting up the exclusion zone. Best management practices, also known as BMPs, were installed as specified in the "Storm Water Pollution Prevention Plan, Mortandad Canyon Ground Water Work Plan, Los Alamos National Laboratory" (Kleinfelder 2004a). EnviroWorks, Inc. completed these tasks from November 19 through November 23, 2004. A radiation control technician (RCT) from LANL's Health, Safety, and Radiation Protection Group-1 screened the site before site preparation activities. Generators and safety lighting equipment were moved to the site during the subsequent mobilization of coring equipment.

Coring activities occurred from November 23 to December 17, 2004. Well installation continued through January 9, 2005. The I-1 corehole was advanced by Spectrum Exploration, Inc.

Legend

- = Intermediate perched zone wells (proposed)
- = Regional aquifer wells installed since 1998
- = Older test wells
- = Water supply wells
- 58 = Technical area identification
- = 100-ft contours





1000 0 500 1000

SCALE: 1 inch = 1000 ft

KLEINFELDER

Drawn By: C. Landon	Date: April 2006
Project No.: 49436	Filename: 49436_01_0.dwg
Scale: 1" = 1000'	Revision: –

SITE LOCATION MAP
Intermediate Wells I-1, I-4, I-5, I-6, I-8, I-10
Mortandad Canyon
Los Alamos National Laboratory
Los Alamos, New Mexico

FIGURE
1.0-1

to a depth of 843.2 ft bgs to characterize contaminant profiles in the vadose zone and to investigate for perched water-bearing zones.

Coring activities were generally performed in one 12-hour (hr) shift per day, seven days per week, by the drill crew and two site geologists.

A Delta Base DB540 equipped with HQ3 Coring Geobarrel®, 115-millimeter Tubex drilling systems, air compressors, and support equipment was used to conduct the coring. The upper 75 ft of the corehole were drilled using a 7⅜-inch (in.) outer diameter (OD) Tubex down-the-hole hammer (DTHH) system. I-1 was cored using air-rotary drilling techniques. Drilling fluids were not introduced into the corehole. Because I-1 is situated on a mesa ledge overlooking Mortandad Canyon, continuous-core sampling was not required above the approximate elevation of the Canyon floor (75 ft).

On November 23, 2004, mobilization of drilling equipment and supplies to the I-1 site was completed and drilling began using a 7⅜-in. OD Tubex under-reamer system to install temporary 6⅝-in. OD Tubex casing to 75 ft bgs. Coring was not performed.

On November 24, a 4.38-in. OD Geobarrel® core bit was used to advance the corehole to 132.5 ft bgs. Inspection of the core revealed a wet zone at 127.5 ft bgs. The drill crew went on days off.

On November 29, the drill crew returned from days off. The depth to water (DTW) was measured and the corehole was determined to be dry. The corehole was advanced from 132.5 to 152.5 ft bgs.

On November 30, the DTW reading was dry. The corehole was advanced from 152.5 to 225 ft bgs. Air circulation was lost, and efforts to further advance the corehole were unsuccessful.

On December 1, the DTW reading was dry. The 6⅝-in. OD Tubex casing was advanced using a 7⅜-in. OD under-reamer to 220 ft bgs.

On December 2, DTW was again dry and the corehole was advanced from 225 to 232.5 ft bgs. Air circulation was lost at 232.5 ft bgs. Efforts to telescope 5½-in. OD Tubex through the 6⅝-in. OD casing using a 6-in. OD under-reamer bit began. Casing was advanced to 230 ft bgs. The DTW was measured at the end of the shift and the corehole was dry.

On December 3, the DTW was measured and the corehole remained dry. The casing was advanced to 260 ft bgs. Coring resumed and the corehole was advanced to 412.5 ft bgs.

On December 4, coring continued following a DTW measurement (dry). At 517.5 ft bgs, the drill bit could not be further advanced into the dense dacitic lavas.

On December 5, the drill string was tripped out of the hole and the bit was replaced. Coring resumed using a 3.895-in. HQ3 core bit. The corehole was advanced to 536.3 ft bgs.

On December 6, the corehole was advanced from 536.3 to 575.6 ft bgs.

On December 7, DTW was measured (dry) and coring continued from 575.6 to 626.3 ft bgs. Core was wet from approximately 594.1 to 597.1 ft bgs. After monitoring for approximately one hr, the corehole was dry. Coring resumed. Core collected from the interval of 612.1 to 616.3 ft bgs appeared saturated; however, no standing water was detected in the corehole after monitoring approximately 45 minutes (min.). Coring resumed to 626.3 ft bgs.

On December 8, the DTW was measured and the corehole was dry. Coring continued from 626.3 to 680.8 ft bgs. The drill crews went on days off.

On December 15, drill crews returned from days off. DTW was measured, the corehole was dry. The corehole was advanced to 721.1 ft bgs.

On December 16, the DTW was measured and the corehole remained dry. The corehole was advance to 797.0 ft bgs.

On December 17, a DTW reading indicated the corehole was dry. The corehole was advance to the TD of 843.2 ft bgs. Field geologists noted possible water encountered at approximately 812 ft bgs.

On December 18, following a DTW measurement (dry), a Kleinfelder representative conducted video and gamma and induction array logging. Near the base of the corehole (approximately 826 ft bgs), a nominal flow of fluids was observed. The video camera could not pass through a narrow portion of the corehole at 827 ft bgs and the video was terminated. Observations from the video and geophysical logging are located in Section 4.0. The corehole video log is located on the DVD in Appendix A.

On December 19, DTW measurements indicated moisture on the corehole walls from approximately 810 to 818 ft bgs. The DTW meter did not indicate moisture or accumulations of fluids below this level. A bailer was used to attempt to sample corehole fluids. Attempts to collect a groundwater sample were conducted for two hrs; however, a water sample could not be obtained.

On December 20, DTW measurements indicated that water had not accumulated in the corehole. Indications of wet formation material along the corehole walls were noted from approximately 809 to 818 ft bgs. The approved design for a nominal 1-in. OD well was received.

On January 6, 2005, DTW measurements indicated that the corehole was dry. The bottom of the corehole was measured at 828.5 ft bgs, indicating that approximately 14.7 ft of formation material had entered the hole since reaching TD on December 17, 2004.

From January 6 through 9, 2005, a well was installed in the I-1 corehole. The single-screened interval was placed from 815.0 to 825.5 ft bgs. Annular fill materials for the well screen were installed as the Tubex casings were removed. The drill rig was demobilized on January 11, 2005. Details of the well construction are located in Section 6.0.

3.0 SAMPLING ACTIVITIES

Core and waste characterization samples were collected at I-1 in accordance with the drilling plan (Kleinfelder 2004b). Deviations are noted in Section 9.0.

3.1 Core Sampling

Core was collected below 75 ft bgs using a Lexan™ tube-lined or stainless steel core barrel. Selected core was sampled and analyzed for anions, moisture content, tritium, and stable isotopes (Table 3.1-1). The remaining core was placed in lay-flat plastic or Lexan™ tubing, labeled, and stored in standard LANL Environmental Restoration core boxes, which were transported to the Field Support Facility (FSF) for archiving and storage.

LANL RCTs screened the core prior to its removal from the drill site.

Table 3.1-1
Core Samples Collected and Analyzed

Core Samples Location ID MO-24233			ANALYSES						
Sample ID	Sample interval (ft)	Date/Time	moisture	tritium H3	anions/cations	N14N15	D2H O18O16	ARS (DOT screening)	Notes
CAMO-05-56912	75.8-77.5	11/24/2004 7:51	x	x	x	x	x	x	
CAMO-05-56913	86.1-87.8	11/24/2004 9:45	x	x	x	x		x	
CAMO-05-56914	95.8-97.4	11/24/2004 9:55	x	x	x	x		x	
CAMO-05-56915	102.5-103.8	11/24/2004 10:05	x	x	x	x		x	
CAMO-05-56916	115.5-117.1	11/24/2004 10:35	x	x	x	x		x	
CAMO-05-56917	129.3-127.5	11/24/2004 12:54	x	x	x	x	x	x	
CAMO-05-56918	134-135.5	11/29/2004 15:50	x	x	x	x		x	
CAMO-05-56919	144-145.5	11/29/2004 16:30	x	x	x	x		x	
CAMO-05-56920	153.5-155	11/30/2004 8:45	x		x	x		x	poor recovery, no N isotopes
CAMO-05-56921	163.5-165	11/30/2004 10:50	x	x	x	x		x	
CAMO-05-56922	174.5-176.5	11/30/2004 11:10	x	x	x	x	x	x	
CAMO-05-56923	262.5-263.7	12/3/2004 11:00	x	x	x	x		x	
CAMO-05-56924	272.5-273.3	12/3/2004 11:16	x	x	x	x	x	x	
CAMO-05-56925	324-326	12/3/2004 0:00	x	x	x	x	x	x	
CAMO-05-56926	372.5-374.5	12/3/2004 15:45	x	x	x	x	x	x	
CAMO-05-56927	423-425	12/4/2004 0:00	x	x	x	x	x	x	
CAMO-05-56928	473.4-475.4	12/4/2004 11:40	x	x	x	x	x	x	

3.2 Groundwater Sampling

Wet or saturated zones were noted from approximately 594 to 616 ft bgs, approximately 810 to 818 ft bgs, and at 826 ft bgs. However, groundwater did not accumulate in either the open corehole or completed well; thus, groundwater samples were not collected.

3.3 Waste Characterization Sampling

The investigation-derived waste consisted of drilling cuttings and decon water. Drilling fluids were not used or produced at I-1. The waste streams were sampled in April 2005. The cuttings were submitted to Hall Environment Analysis Laboratory in Albuquerque, New Mexico and analyzed for polychlorinated biphenyls, volatile organic compounds, semi-volatile organic compounds, metals, mercury, perchlorate, explosives, tritium, and radionuclides. The drummed decon water was sampled by LANL personnel for laboratory analysis for total dissolved solids, volatile organic compounds, metals, perchlorate, radionuclides, tritium, explosives, nitrate, and sulfate. Disposition of both waste streams is addressed in Section 8.3.

4.0 COREHOLE LOGGING

Kleinfelder ran video and geophysical logging equipment in the I-1 corehole prior to well installation. These visual observations and geophysical data help characterize corehole conditions and hydrostratigraphy, facilitating project personnel in proper well design. Table 4.0-1 summarizes the video and geophysical logs that were run in the I-1 corehole.

Table 4.0-1
Corehole Logging

Operator	Date	Cased Footage (ft bgs)	Open-Hole Interval (ft bgs)	Logged Interval (ft bgs)	Remarks	Tools
Kleinfelder	12/18/04	0-322	322-843.2 (slough to 838)	0-827	Casing unthreaded, dropped to 322 ft bgs. At 826 ft bgs and below, water observed flowing on borehole wall. At 827 ft, camera was unable advance further.	Video camera
Kleinfelder	12/18/14	0-322	322-843.2 (slough to 838)	0-838	Casing unthreaded, dropped to 322 ft bgs	Natural gamma
Kleinfelder	12/18/04	0-322	322-843.2 (slough to 838)	322-833	Casing unthreaded, dropped to 322 ft bgs	Array induction

4.1 Video Logging

Kleinfelder personnel performed video logging of the corehole on December 18, 2004, to assess for evidence of perched groundwater (Table 4.0-1). The video counter displayed discrepancies of reported depths to actual depths at other I-Well locations. The manufactured accuracy of the Kleinfelder-owned GeoVISION™ Junior video camera counter is +/- 2%. Because the logging record did not include a key marker such as a static water level or corehole TD to correlate the video counter to an actual depth, the log presents general corehole conditions and approximate depths. The video log showed that the lower section of the 5½-in. OD Tubex casing had unthreaded at approximately 83 ft bgs, dropping 62 ft such that the lower edge of the casing was at 322 ft bgs. Potential groundwater-bearing zones identified at approximately 594 to 616 ft bgs during coring were dry as was the remainder of the hole above approximately 824 ft bgs where moist cuttings appeared to be adhering to the corehole walls. A small volume of flowing water was observed at approximately 826 ft bgs and continued to approximately 827 ft bgs. The video camera was unable to advance below 827 ft bgs as the camera could not pass between a narrow section within the corehole. No standing water was observed in the corehole. Appendix A contains a DVD of the video log.

4.2 Geophysical Logging

On December 18, 2004, Kleinfelder used a Mount Sopris MGXII geophysical console equipped with the LANL-owned array induction and natural gamma geophysical tools to conduct geophysical logging on the I-1 corehole. Natural gamma logging was conducted from 0 to approximately 838 ft bgs and was used primarily to evaluate the geology and locate geologic contacts; array induction logging was conducted from 322 to 833 ft bgs and was used primarily to evaluate the presence of perched water. The natural gamma and array induction (conductivity) logs are shown in Figure 4.2-1.

5.0 HYDROGEOLOGY

LANL's Earth and Environmental Sciences Group 6 staff provided preliminary interpretation of geologic contacts based on core. Potential groundwater occurrence was interpreted from drilling observations, open-hole video logging, and geophysical logging.

5.1 Geology

Visual examination of core, the open-hole video log, and geophysical logs were used to determine the stratigraphy at I-1 (Figure 5.1-1). In descending order, the stratigraphic units encountered during drilling of the I-1 corehole are Tshirege Member of the Bandelier Tuff, Tsankawi Pumice Bed, Cerro Toledo interval, Otowi Member of the Bandelier Tuff, Guaje Pumice Bed, upper Puye Formation, Tschicoma Dacite, and lower Puye Formation. The lithologic log is presented in Appendix B.

5.2 Groundwater Occurrence and Characteristics

Saturated or moist core was encountered from the interval of approximately 594 to 616 ft bgs, within the Tschicoma Dacite (dacitic lava). During coring, the sample interval from 594.1 to 597.1 ft bgs appeared wet. Coring stopped at 600.3 ft bgs for DTW monitoring. DTW readings initially indicated groundwater accumulating in the corehole. However, following approximately

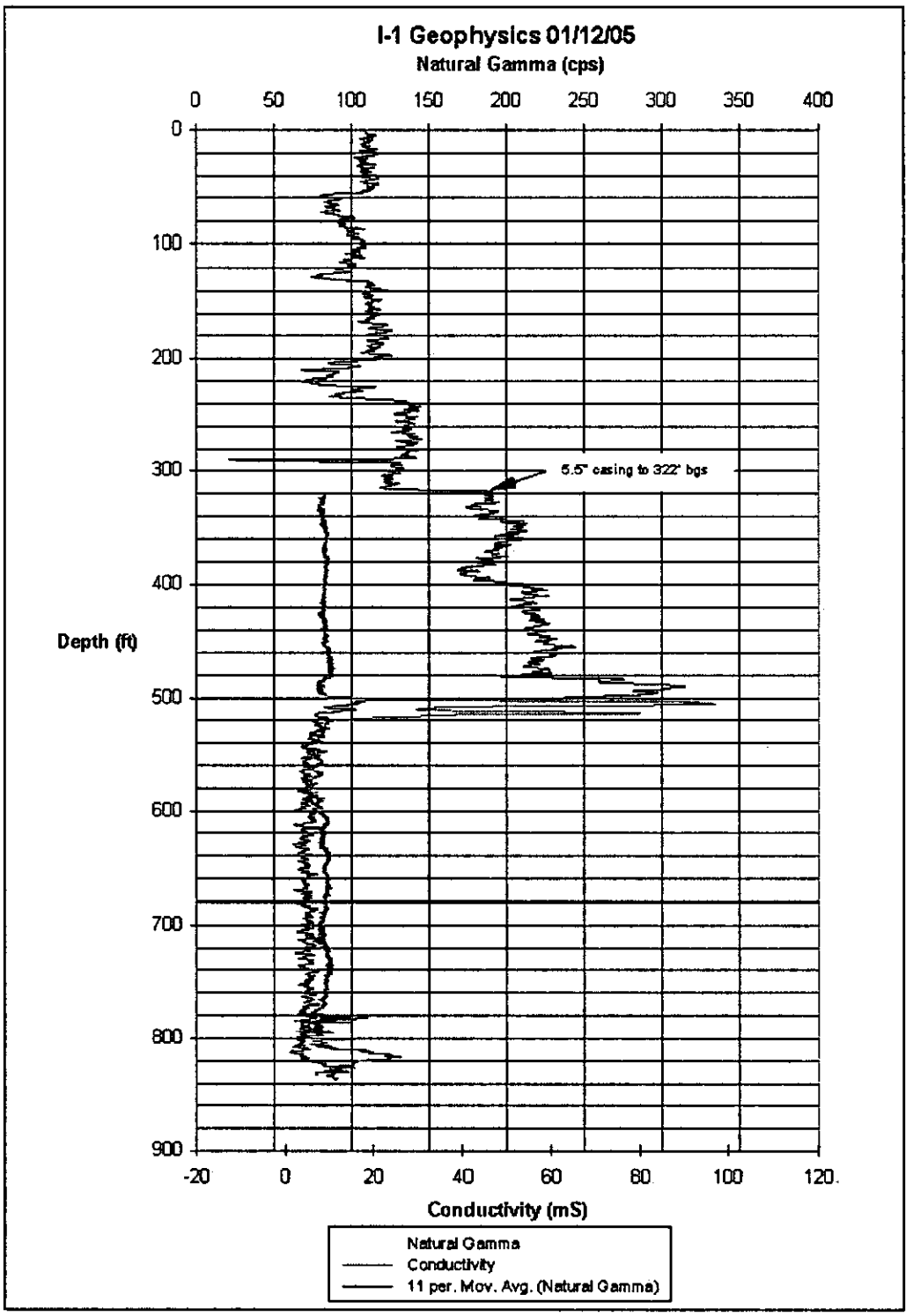
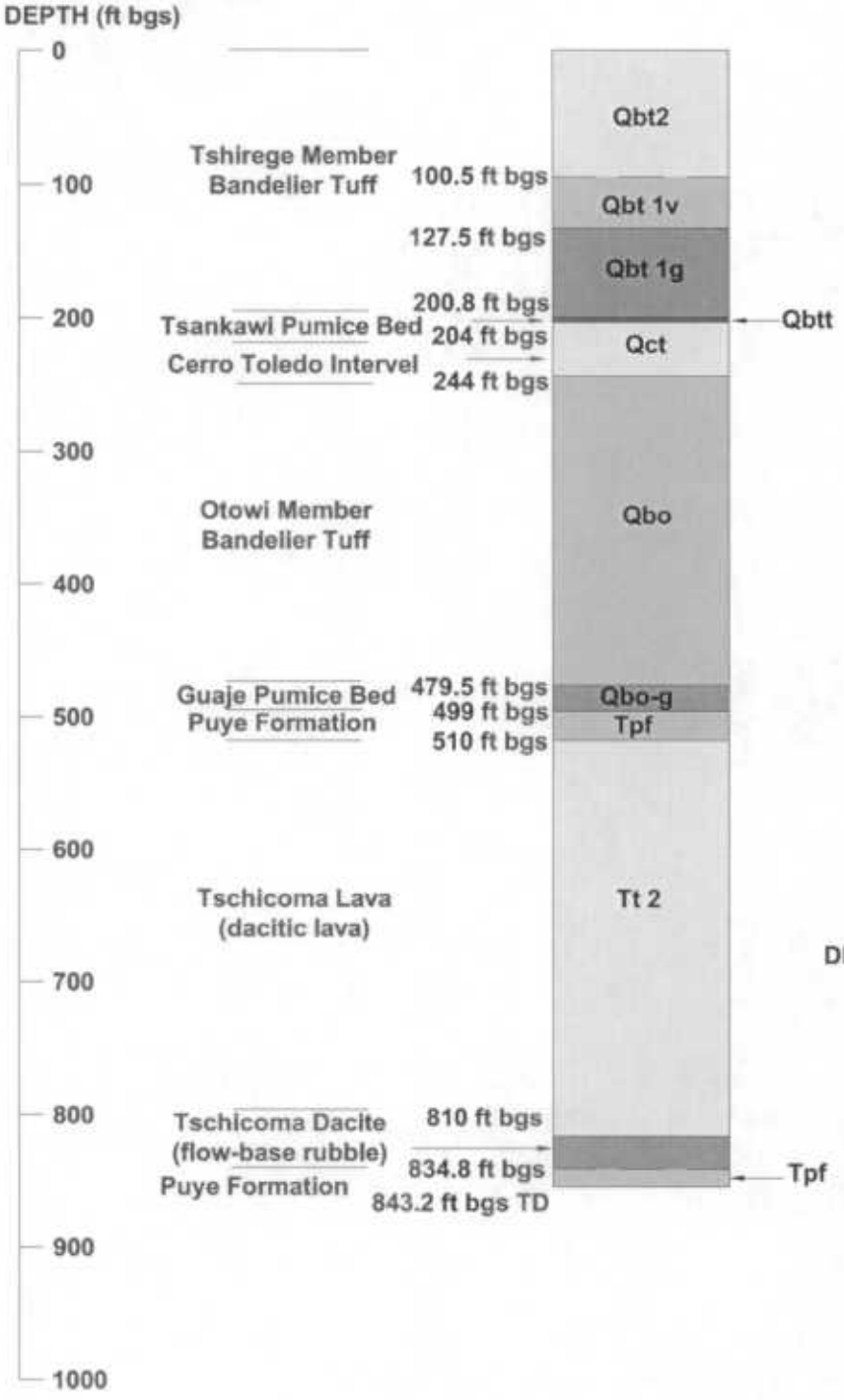


Figure 4.2-1. Natural Gamma and Induction Array Geophysical Logs



DRILLING INFORMATION

DRILLING COMPANY/PERSONNEL

Spectrum Exploration
Steve Jager, Brian Anderson

DRILL RIG DB 540

DRILLING METHOD

☒ CORING

DRILLING BEGAN

DATE 11/23/04 TIME 12:45

DRILLING END

DATE 12/17/04 TIME 14:29

DRILLING FLUID TYPE

☒ AIR

Notes:
1. Geologic contacts are preliminary and subject to change.
2. Geologist noted wet/saturated zone in Tt2 from approximately 594 to 616 ft bgs.
3. Saturated zone observed beginning at 812 ft bgs.
4. Groundwater did not accumulate in the open corehole.

KLEINFELDER

Drawn By: C. Bhongir	Date: April 2006
Project No.: 49436	Filename: 49436_01_0.dwg
Scale: As referenced	Revision: –

COREHOLE SUMMARY DATA SHEET
I-1
Mortandad Canyon
Los Alamos National Laboratory
Los Alamos, New Mexico

FIGURE
5.1-1

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one hr of monitoring, the measurements were dry. Coring resumed to a depth of 616.3 ft bgs where the core again appeared saturated. Initial DTW measurements also indicated a potential for groundwater to accumulate in the corehole. There were no indications of standing water in the corehole following monitoring DTW for 45 min.. The video log also showed these intervals to be dry.

The corehole was advanced to approximately 812 ft bgs where field observations reported potential groundwater. The corehole was advanced to 843.2 ft bgs and a video log was conducted. The video log showed a slight flow of water along the corehole walls at approximately 826 ft bgs. The manufacturer-reported accuracy of the video camera counter is +/- 2%. The counter has previously exhibited a tendency to record depths greater than actual depths, thus there is uncertainty as to the actual depth where flowing water was observed. DTW measurements subsequent to video logging indicated a potentially moist interval from approximately 810 to 818 ft bgs. However, no water accumulated in the open corehole.

6.0 WELL DESIGN AND CONSTRUCTION

On December 20, 2004, Kleinfelder received DOE and LANL approved well construction specifications. Because minor formation material had sloughed into the corehole during extended days-off, the design was modified by DOE on January 6, 2005. The well was constructed between January 6 and 9, 2005.

6.1 Well Design

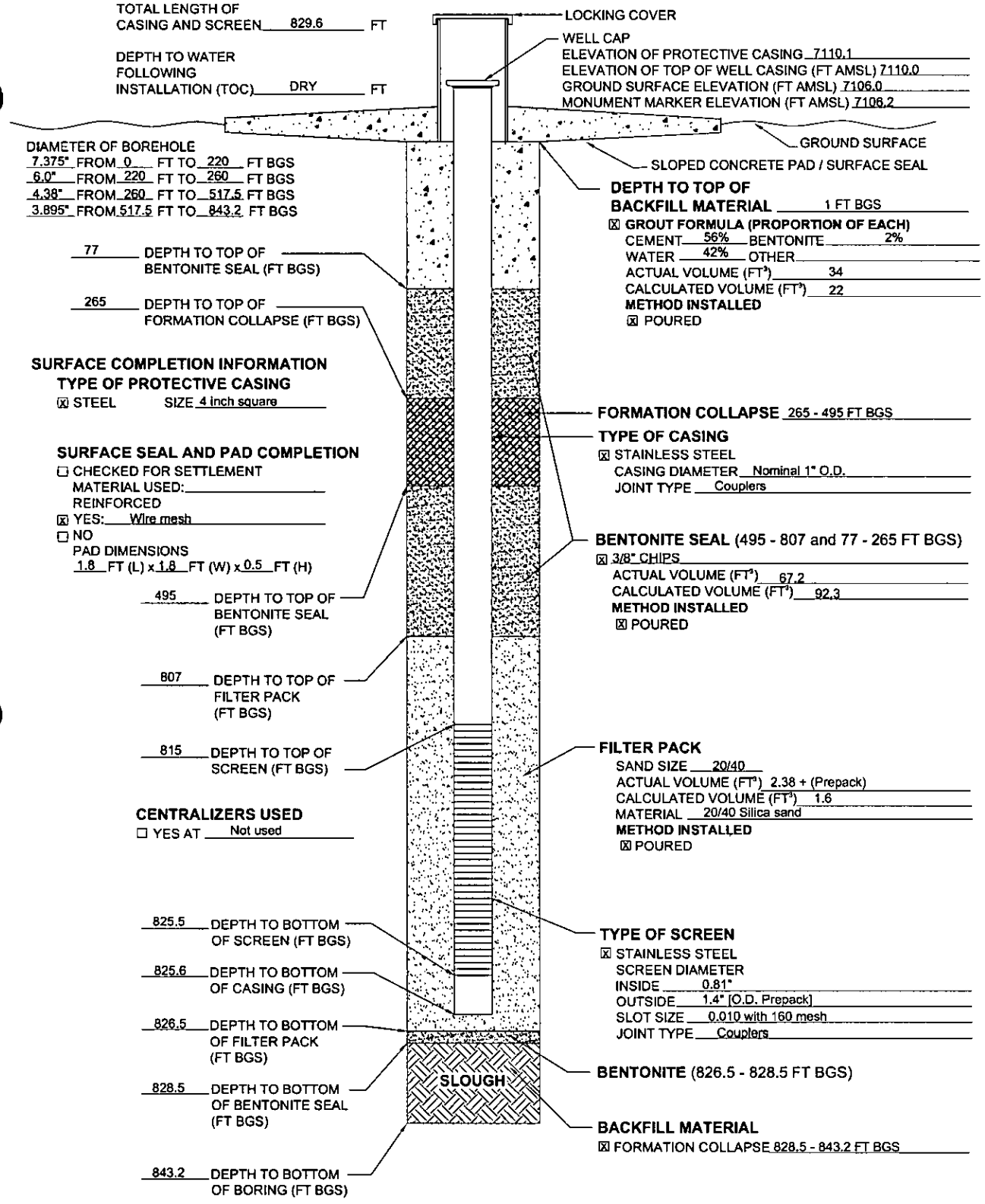
The "Mortandad Canyon Groundwater Work Plan, Revision 1" (LANL 2004) called for a single-screened interval in the Guaje Pumice Bed or dacite flows. The placement of the screened interval within the dacitic flow-base rubble was based on evaluation of corehole logs, core samples, and field observations.

6.2 Well Construction

Decontamination of the stainless-steel components was performed prior to well construction using a high-pressure hot water washer.

I-1 was constructed in general accordance with LANL's "Environmental Restoration Project Standard Operating Procedures for Well Construction, Revision 3", ER-SOP-05.01 (LANL 2001) using nominal 1-in. OD stainless-steel casing obtained from the LANL FSF. Two 5-ft screens were coupled to provide a single 10-ft section of stainless steel, 0.010-in. slot size, perforated wire-wrapped well screen. The screen was pre-packed with 20/40 silica sand that was contained within an inner and outer stainless-steel 160 mesh surrounding the screened interval. The screen inner diameter (ID) is 0.81-in.; the OD of the pre-pack is 1.4-in. The screen was installed from 815.0 to 825.5 ft bgs (Figure 6.2-1)

Prior to installation of the well casing, the bottom of the corehole was tagged at 828.5 ft bgs, indicating that 14.7 ft of formation material had accumulated in the bottom of the corehole. Annular fill materials were poured from the ground surface through the Tubex casing. Bentonite chips (⅜-in. size) were emplaced to 827 ft bgs. The well casing and screen were then installed. Following installation, the top of the bentonite was measured at 826.5 ft bgs, possibly due to swelling of the bentonite. In addition to the pre-packed well screen, a primary filter pack comprised of 20/40 silica sand was placed in the corehole annular space from 826.5 to 807 ft



KLEINFELDER

Drawn By: C. Bhongir	Date: April 2006
Project No.: 49436	Filename: 49436_02_0.dwg
Scale: Not-to-scale	Revision: -

WELL SCHEMATIC
I-1
Mortandad Canyon
Los Alamos National Laboratory
Los Alamos, New Mexico

FIGURE
6.2-1

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bgs. Bentonite chips were placed from 807 to 495 ft bgs. Due to caving of the formation, formation material filled the annulus from 495 to approximately 265 ft bgs. The Tubex casing was pulled in stages as additional bentonite chips were placed in the annulus to a depth of 77 ft bgs. The primary filter pack and bentonite were installed by pouring the materials between the outside of the well casing and the inside of the surface casing. Cement grout with bentonite (2% bentonite calculated as dry weight bentonite to dry weight cement plus bentonite) was placed in the corehole from 77 ft bgs to near ground surface. In order to remove the temporary casing, the stainless-steel well casing was cut to approximately 1 ft above ground surface (ags). The casing was augmented with an approximately 3.3 ft section of polyvinyl chloride (PVC) casing to provide adequate height to the casing once the protective well monument was placed. Table 6.2-1 summarizes the volumes of annular fill materials used to complete I-1.

Table 6.2-1

Annular Fill Materials Used in Well Construction

Material	Volume
Grout seal: cement with 2% bentonite	34 ft^3
Bentonite seal: bentonite chips	67.2 ft^3
Filter sand: 20/40 silica sand	2.38 ft^3
Collapsed formation material	19.6 ft^3

7.0 WELL DEVELOPMENT, AQUIFER TESTING, AND PUMP INSTALLATION

The well has not produced any water following installation; thus, well development, aquifer testing, and pump installation have not been performed.

8.0 WELLHEAD COMPLETION, SURVEY, AND SITE RESTORATION

8.1 Wellhead Completion

Wellhead completion activities consisted of the installation of the protective well monument, surface seal, and pad. On March 2, 2005, a 4-in. square, steel well monument with locking lid was installed from approximately 1 ft bgs to 4 ft ags to protect the well riser. Concurrent with the placement of the monument and surface seal using concrete backfill, the reinforced concrete pad, 1.8-ft long by 1.8-ft wide by 6-in. thick, was installed around the well casing to provide long-term structural integrity for the well. A brass survey cap was embedded in the northwest corner of the pad. The pad is slightly elevated and sloped away from the well casing to promote runoff. Due to the remote location of the site, bollards were not installed.

8.2 Geodetic Survey

On March 24, 2005, the ground surface, well casing, and brass cap at the I-1 wellhead were surveyed by ASTS, Inc. of Albuquerque, New Mexico. The survey data are presented in Table 8.2-1.

Table 8.2-1
Geodetic Data

Description	Northing	Easting	Elevation*
Ground surface	1769958.20	1628044.06	7106.0
Brass cap in I-1 pad	1769957.39	1628044.51	7106.2
Top of PVC casing	1769956.54	1628044.66	7110.0
Top of protective well monument casing[1]	NM[2]	NM	7110.1

* Measured in ft above mean sea level (amsl) relative to the National Geodetic Vertical Datum of 1929, accurate to +/- 0.1 foot

[1]Measured using geodetic survey points and a staff and level

[2]NM – not measured

8.3 Site Restoration Activities

Cuttings and decon water produced during coring have been sampled, containerized, and removed from the site. The waste streams were sampled in April 2005. Results have been received and reviewed. The draft summary of the analytical results for the cuttings has been submitted to a LANL representative for review and verification. Kleinfelder will coordinate with LANL and DOE for the final disposition of the cuttings waste stream. The wastewater results were received and submitted to DOE and LANL. The waste determination by LANL indicates the liquid is Low-Level Radioactive Waste. In coordination with LANL, the water will be disposed of at LANL's liquid waste facility (TA-50).

The site has been restored and native growth re-established. Temporary materials emplaced for BMPs have been removed.

9.0 DEVIATIONS FROM THE FINAL DRILLING PLAN

In general, drilling, sampling, and well construction at I-1 was performed in accordance with the "Final Drilling Plan for Intermediate Wells, Mortandad Canyon, Los Alamos National Laboratory" (Kleinfelder 2004b). Deviations from planned activities were as follows:

- The drill plan called for a corehole to 500 ft bgs and a borehole to 800 ft bgs. The corehole was advance to 843.2 ft bgs as directed by DOE. The corehole was dry, therefore, a borehole was not drilled.
- The drill plan calls out specific sampling intervals and analyses of collected core. During intervals of poor recovery, sampling intervals and analyses were adjusted as needed.
- Analytical samples were not collected at the corehole TD as specified in the drill plan.
- Collected core materials were not analyzed for cations or radionuclide suite.
- I-1 was dry. A nominal 1-in. well was installed to provide a means to further access the vadose zone, rather than a 5-in. OD well as indicated in the drilling plan.

- The stainless-steel casing was cut too low for proper monument installation. A section of PVC pipe was added to the casing to provide appropriate height within the monument.
- No well development or hydrologic testing was performed due to lack of accumulated groundwater.
- A 1.8-ft long by 1.8-ft wide by 6-in. thick concrete pad, rather than the specified 5-ft long by 5-ft wide by 6-in. thick concrete pad, was installed due to smaller well diameter.
- Bollards were not installed due to the remote site location.

10.0 ACKNOWLEDGEMENTS

ASTS, Inc. conducted the final geodetic survey of finished well components.

EnviroWorks, Inc. provided site preparation services.

Hall Environmental Analysis Laboratory conducted laboratory analysis for cuttings waste characterization samples.

Spectrum Exploration, Inc. provided drilling services.

11.0 REFERENCES

Kleinfelder, Inc., 2004a. "Storm Water Pollution Prevention Plan, Mortandad Canyon Ground Water Work Plan, Los Alamos National Laboratory," Los Alamos, New Mexico, Project Number 49436, August 2004.

Kleinfelder, 2004b. "Final Drilling Plan for Intermediate Wells, Mortandad Canyon, Los Alamos National Laboratory," Los Alamos, New Mexico, Project No. 49436, October 2004.

Los Alamos National Laboratory, 2001. "Environmental Restoration Project Standard Operating Procedures for Well Construction, Revision 3," ER-SOP-5.01, April 2001.

Los Alamos National Laboratory, 2004. "Mortandad Canyon Groundwater Work Plan, Revision 1," Los Alamos National Laboratory report LA-UR-0165, Los Alamos, New Mexico, January 2004.

Appendix A

Borehole Video Log

Appendix B

Lithologic Log

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
	Note: Casing was advanced from 0 to 75 feet (ft) below ground surface (bgs); coring was not attempted. Drill core was collected from the interval of 75 ft to 843.2 ft bgs. Descriptions presented in this lithologic log are primarily based on those made during visual examination of drill core. Stratigraphic contacts are based on available information from review of drill core and limited geophysical logs. Unrecovered and/or sampled core in sections of less than 5 ft are not noted unless relevant to lithologic description.	0-75	7106.0-7031.0
Qbt 2, Tshirege Member of the Bandelier Tuff	Tuff, pale red (10YR 6/2) to grayish orange pink (10YR 8/2), moderately welded. Ash matrix; felsic crystal rich with 8% coarse to very coarse felsic crystals; 1-2% fine to medium oxidized mafic crystals, yellow/red in color; 8-10% devitrified brown, purple, and light gray pumice, up to 20 mm long and 10 mm wide, relic fibrous structure and sugary texture, occasional felsic phenocrysts.	75-86	7031.0-7020.0
	Tuff, grayish orange pink (5 YR 7/2), moderately welded. Ash matrix; 12-15% medium to coarse felsic crystals; 0-1% oxidized medium mafic crystals; 20% gray, purple, and olive gray devitrified pumice with sugary texture; pumice up to 12 mm long by 6 mm wide.	86-92	7020.0-7014.0
	Tuff, as above; pumice up to 30 mm long by 25 mm wide, pumice contain 5% very coarse felsic phenocrysts, relic fibrous structure and sugary texture.	92-94	7014.0-7012.0
	As above; 20% devitrified pumice with sugary texture, pumice is light purple gray up to 45 mm long, pumice contain 3-5% felsic phenocrysts.	94-97.5	7012.0-7008.5
	As above, smaller pumice, up to 10 mm long by 5 mm wide, pumice light purple gray to brown with relic fibrous structure and sugary texture. Note: horizontal fracturing of core at 100.5 feet.	97.5-100.5	7008.5-7005.5
Qbt 1v, Tshirege Member of the Bandelier Tuff	Tuff, pinkish gray (5YR 8/1), poorly welded. Ash matrix; 15% coarse to very coarse felsic crystals; 25-30% devitrified pumice with relic fibrous structure and sugary texture, up to 22 mm, grayish brown. **Note: the contact of Unit 2 of the Tshirege Member of the Bandelier Tuff (Qbt 2) and the contact with the underlying Unit 1v of the Tshirege Member of the Bandelier Tuff (Qbt 1v) is interpreted to be at 100.5 ft bgs.**	100.5-102.5	7005.5-7003.5
	No recovery and/or available core sampled. Core unavailable for examination.	102.5 - 107.5	7003.5-6998.5
	As above; slight decrease in welding; pumice up to 22 mm long by 15 mm wide, contain very coarse bipyramidal quartz phenocrysts; possible rhyolitic lithic fragment to 10mm.	107.5-117.5	6998.5-6988.5
	Tuff, pinkish gray (10YR 8/2), poorly welded. Ash matrix; 10-12% coarse to very coarse felsic crystals; 3% light gray to gray lithic fragments to 5 mm - possible rhyolite; 20% brown devitrified pumice with relic fibrous structure, up to 10 mm long.	117.5-120	6988.5-6986.0
	As above; pumice increase to 45%, up to 50 mm long by 20 mm wide with 5% very coarse felsic phenocrysts.	120-123	6986.0-6983.0

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Qbt 1g, Tshirege Member of the Bandelier Tuff	Tuff, light brown (5YR 5/6); Ash matrix; 15% coarse to very coarse felsic crystals; 3% gray lithic fragments to 2mm; 12-15% brown devitrified pumice, up to 10 mm long, sugary texture and minor relic fibrous structure; matrix moist and clayey - possible weathering surface.	123-127.5	6983.0-6978.5
	Tuff, light brown (5YR 5/6). Ash matrix; 20-25% coarse to very coarse felsic crystals; 5% dark gray lithic fragments to 20 mm, fine grained - possible dacite; 10% white pumice to 10 mm, very soft; moist and very clayey. **Note: the base of Qbt 1v and the contact with the underlying Unit 1g of the Tshirege Member of the Bandelier Tuff (Qbt 1g) is interpreted to be at 127.5 ft bgs.**	127.5-129	6978.5-6977.0
	As above; decrease in clay; pumice vitric with fibrous texture and 5-8% felsic phenocrysts.	129-131	6977.0-6975.0
	As above; pumice increase to 40-45%.	131-137.5	6975.0-6968.5
	Tuff, grayish orange (10YR 7/4), poorly welded. Ash matrix; 8-10% medium to very coarse felsic crystals; 50% white vitric pumice with fibrous texture and 10% felsic phenocrysts, up to 30 mm wide by 35 mm long.	137.5-144	6968.5-6962.0
	As above; color change to very pale orange (10YR 8/2).	144-149	6962.0-6957.0
	Tuff, very pale orange (10YR 8/2). Ash matrix; 8-10% medium to very coarse felsic crystals; 2% red to gray lithic fragments to 5 mm; 30% white vitric pumice, occasional brown alteration, fibrous texture, up to 20 mm long by 10 mm wide.	149-159	6957.0-6947.0
	Tuff, very pale orange (10YR 8/2), poorly welded. Ash matrix; 8% medium to coarse felsic crystals; 1-2% dark gray lithic fragments to 3 mm; 35% white vitric pumice, 5% very coarse felsic phenocrysts, fibrous texture, up to 30 mm long.	159-172.5	6947.0-6933.5
	As above; decrease in crystal content in ash matrix to 5-6% medium to coarse felsic crystals; decrease in pumice to 15%, pumice up to 12 mm long by 8 mm wide.	172.5-177.5	6933.5-6928.5
	Tuff, very pale orange (10YR 8/2), poorly welded. Ash matrix; 8% medium to coarse felsic crystals; 1-2% dark gray lithic fragments, up to 3 mm; 45-50% white to tan vitric pumice with fibrous texture and 10% very coarse felsic phenocrysts.	177.5-184	6928.5-6922.0
	As above; 1% yellowish oxidized mafic crystals.	184-195	6922.0-6911.0
	Tuff, very pale orange (10YR 8/2), poorly welded. Ash matrix; 10% medium to coarse felsic crystals; 2-3% dark gray lithic fragments, up to 5 mm, possible dacite; 30% white vitric pumice with fibrous texture and 5-7% coarse to very coarse felsic phenocrysts.	195-199.5	6911.0-6906.5
	Tuff, yellowish orange (5Y 8/1). Ash matrix; 15% coarse to very coarse felsic crystals; 1-2% yellowish oxidized mafic crystals; 10% white vitric pumice, up to 8 mm long.	199.5-200.8	6906.5-6905.2
Qbtt, Tsankawi Pumice Bed of the Tshirege Member of the Bandelier Tuff	Pumice Bed, yellowish orange (5Y 8/1). 85% coarse to very coarse felsic crystals; 2% coarse to very coarse mafic crystals; 13% white vitric pumice up to 10 mm with 1% fine mafic phenocrysts. **Note: the base of Qbt 1g and the contact with the underlying Tsankawi Pumice Bed (Qbtt) is interpreted to be at 200.8 ft bgs.**	200.8-204	6905.2-6902.0

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Qct, Cerro Toledo interval	Volcaniclastic sediments, gravelly sand with fines, light brown (5YR 5/6). Poorly sorted (15-20% gravel, 60-70% sand, 15-20% fines); very fine to very coarse grained sand composed predominately subangular felsic crystals (fine to medium grain size) and pumice with lesser amounts lithic clasts; gravels moderately sorted, predominately white vitric pumice, fine to medium grain size; moist. **Note: the base of the Tsankawi Pumice Bed (Qbtt) and the contact with the underlying Cerro Toledo interval (Qct) is interpreted to be at 204 ft bgs.**	204-205	6902.0-6901.0
	No recovery and/or available core sampled. Core unavailable for examination.	205-207.5	6901.0-6898.5
	Volcaniclastic sediments, yellowish brown (5Y 8/1); predominantly white vitric pumice up to 10 mm, subangular; 5-7% medium felsic crystals in matrix; 3% red to gray lithic fragments to 5 mm.	207.5-208.5	6898.5-6897.5
	Volcaniclastic sediments, silt with trace sand, light brown (5YR 5/6). Silt and clayey matrix with 3% fine to medium sand grain size felsic crystals, 5% white vitric pumice (trace gravel size up to 5 mm), and 1% fine black mafic crystals; at 209.1ft bgs, 1 cm dusky yellowish brown (10YR 2/2) silt/organic layer; moist.	208.5-209.5	6897.5-6896.5
	No recovery and/or available core sampled. Core unavailable for examination.	209.5-212.5	6896.5-6893.5
	Volcaniclastic sediments, (pumiceous) gravelly sand with minor fines, grayish orange (10YR 7/4). Poorly sorted (20% gravel, 60% sand, 15-20% silt/clay); Sands composed of equal amounts of felsic crystals, lithics, pumice, rounded to subangular, felsic crystals very fine to medium; gravel up to 10mm, composed of white vitric pumice and intermediate composition volcanics and possible rhyolite, subrounded.	212.5-214.2	6893.5-6891.8
	No recovery and/or available core sampled. Core unavailable for examination.	214.2-217.5	6891.8-6888.5
	Volcaniclastic sediments, gravelly sand, dark yellowish orange (10YR 6/6). Poorly sorted sand, very fine to very coarse grain size, composed of 30-40% very small felsic crystals, angular to subrounded, 30-40% very fine to coarse lithics, and 25% pumice; well sorted gravel composed of fine to medium grain size intermediate composition volcanic lithics, trace pumice, rounded to subangular; dry.	217.5-220	6888.5-6886.0
	Very poor recovery, lithic fragments to 30 mm, intermediate volcanic composition.	220-222.5	6886.0-6883.5
	Core not sampled. Small volumes of cuttings collected at air discharge line from 222.5 ft to 260 ft bgs.	222.5-230	6883.5-6876.0
	As described at 217.5 feet; sandy gravel with fines. Core not sampled. Small volumes of cuttings periodically collected at air discharge line from 222.5 ft to 260 ft bgs.	230-234	6876.0-6872.0

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Qct, Cerro Toledo interval	Volcaniclastic sediments, gravelly sand with silt, dark yellowish orange (10YR 6/6). Poorly sorted (30-40% gravel, 40-50% sand, 10-15% fines); poorly sorted sand composed of predominately lithic and very fine to medium grained felsic crystals with lesser amounts of vitric pumice, rounded to angular; gravel composed of intermediate composition volcanic clasts up to 1 cm, angular to rounded, with lesser amounts of vitric pumice up to 0.5 cm; dry. Core not sampled. Small volumes of cuttings collected at air discharge line from 222.5 ft to 260 ft bgs.	234-239	6872.0-6867.0
	Volcaniclastic sediments, sandy silt with minor gravel, grayish orange (10YR 7/4). Moderately sorted (5-10% gravel, 15-20% sand, 65-70% fines); well sorted sand (very fine to fine) felsic crystals with minor amounts of lithic clasts, rounded to subangular; gravel composed of white vitric pumice up to 8 mm; dry. Core not sampled. Small volumes of cuttings collected at air discharge line from 222.5 ft to 260 ft bgs.	239-244	6867.0-6862.0
Qbo, Otowi Member of the Bandelier Tuff	Tuff, moderate orange pink (5YR 8/4); ash matrix with 8-10% medium to very coarse felsic crystals; 2% gray lithic fragments to 4 mm; 15% white to tan vitric pumice with fibrous texture. Core not sampled. Small volumes of cuttings collected at air discharge line from 222.5 ft to 260 ft bgs. **Note: the base of the Cerro Toledo interval (Qct) and the contact with the underlying Otowi Member of the Bandelier Tuff (Qbo) is interpreted to be at 244 ft bgs.**	244-254	6862.0-6852.0
	As above; pumice up to 15 mm with 15% very coarse felsic phenocrysts. Core not sampled. Small volumes of cuttings collected at air discharge line from 222.5 ft to 260 ft bgs.	254-260	6852.0-6846.0
	Tuff, dark yellowish orange (10YR 6/6), poorly welded, coarse felsic crystals; 25% subrounded gray lithic fragments up to 40 mm by 20 mm, 15% white vitric pumice with fibrous texture.	260-262.5	6846.0-6843.5
	No recovery and/or available core sampled. Core unavailable for examination.	262.5-277.5	6843.5-6828.5
	Tuff, grayish orange (10YR 7/4), poorly welded. Ash matrix; 5% felsic crystals; 3% gray lithic fragments up to 5 mm; 15% yellowish altered pumice with 10% very coarse felsic phenocrysts.	277.5-282.5	6828.5-6823.5
	As above; 10% pumice, up to 7 mm; gray dacite fragment 40 mm by 30 mm, subangular.	282.5-288.5	6823.5-6817.5
	Tuff, grayish orange (10YR 7/4), poorly welded. Ash matrix; 6-8% medium to very coarse felsic crystals; 3% gray lithic fragments, up to 4 mm; 12-15% yellow altered pumice, up to 15 mm.	288.5-298	6817.5-6808.0
	Tuff, grayish orange (10YR 7/4), poorly welded. Ash matrix; 8-10% medium to coarse felsic crystals; 20% gray dacite fragments, up to 20 mm; 10% yellowish pumice, 5% felsic phenocrysts, up to 10 mm.	298-318	6808.0-6788.0
	As above; more indurated; increase in coarse to very coarse felsic crystals.	318-319	6788.0-6787.0
	Tuff, very pale orange (10YR 8/2), poorly welded. Ash matrix; 8-10% medium to very coarse felsic crystals; 2-3% gray lithic fragments, up to 5 mm; 12-15% yellow altered pumice, 5% felsic phenocrysts, up to 15 mm.	319-344	6787.0-6762.0

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Qbo, Otowi Member of the Bandelier Tuff	As above; occasional gray dacite fragment up to 20 mm.	344-365	6762.0-6741.0
	Tuff, pale yellowish brown (10YR 6/2), poorly welded. Ash matrix; 3-5% medium to very coarse felsic crystals; 1% red to gray lithic fragments to 20 mm; 10% white vitric pumice with fibrous texture, up to 10 mm.	365-400	6741.0-6706.0
	Tuff, very pale orange (10YR 8/2), poorly welded. Ash matrix; 5% coarse to very coarse felsic crystals; 2-3% red to gray subrounded lithic fragments, up to 10 mm; 5% yellow to tan vitric pumice with 10% very coarse felsic phenocrysts, up to 10 mm.	400-419	6706.0-6687.0
	As above; white to yellow vitric pumice up to 15 mm with 10% very coarse felsic phenocrysts.	419-435	6687.0-6671.0
	Tuff, very pale orange (10YR 8/2). Ash matrix; 5% medium to coarse felsic crystals; 5% gray lithic fragments, up to 10 mm, subangular to subrounded, occasional angular fragments to 20 mm; 10% yellowish to white vitric pumice.	435-464	6671.0-6642.0
	As above; increase in pumice content to 10-12%; pumice up to 30 mm.	464-472	6642.0-6634.0
	Tuff, very pale gray (10YR 8/2) to yellowish gray (5Y 8/1), poorly welded - slight increase in welding from above. Ash matrix; 5% medium to very coarse felsic crystals; 5% gray lithic fragments up to 3 mm; 10% white vitric pumice up to 20 mm.	472-477.5	6634.0-6628.5
Qbog, Guaje Pumice Bed of the Otowi Member of the Bandelier Tuff	Pumice Bed, very pale orange (10YR 8/2) to yellowish gray (5Y 8/1). Minor ash; 50-80% white vitric pumice; 10% medium to very coarse felsic crystals; 20-25% gray lithic fragments up to 5 mm. **Note: the base of the Otowi Member of the Bandelier Tuff (Qbo) and the contact with the underlying Guaje Pumice Bed (Qbog) is interpreted to be at 477.5 ft bgs.**	477.5-479.5	6628.5-6626.5
	As above, color change to very light gray (N8)	479.5-482	6626.5-6624.0
	As above, increase in pumice to 80% white, vitric, up to 20 mm, fibrous texture.	482-484	6624.0-6622.0
	As above, increase in gray lithic fragments to 8%.	484-490	6622.0-6616.0
	As above, yellowish brown lithic fragment to 10 mm.	490-494	6616.0-6612.0
	As above, increase in yellowish brown lithic fragments to 10-15%, up to 30 mm, subangular.	494-498.8	6612.0-6607.2
Tpf, silty horizon, assigned to Puye Formation	Silty Horizon, clayey silt with fine sand, core disturbed-intermixing with overlying pumice, moderate yellowish brown (10YR 5/4); moderately sorted, low to medium plasticity; trace subrounded dark clasts up to 1.5 cm; vitric pumice, up to large 5 cm; moist. **Note: The base of the Guaje Pumice Bed (Qbog) and the contact with the underlying Puye Formation (Tpf) is interpreted to be at 498.8 ft bgs.**	498.8-499.3	6607.2-6606.7
	No recovery and/or available core sampled. Core unavailable for examination.	499.3-502.5	6606.7-6603.5
Tt2, Tschicoma Dacite (Dacitic Lava)	Lava flow, poor recovery, dark gray (N3), massive. Poor recovery, several broken fragments up to 6 cm, aphanitic groundmass; ferromagnesian phenocrysts, pyroxene, very small (<1 mm), varied colored including greenish black, yellow brown, yellowish green; trace feldspar phenocrysts; trace vesicles; occasional weathered and subrounded surfaces. **Note: The base of the overlying Puye Formation (Tpf) and the contact with the underlying Tschicoma Dacite (Tt2) is poorly defined due to lack of recovery and is interpreted to be 502.5 ft bgs.**	502.5-502.7	6603.5-6603.3

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Tt2, Tschicoma Dacite (Dacitic Lava)	No recovery and/or available core sampled. Core unavailable for examination.	502.7-517.5	6603.3-6588.5
	As above, possible fracture with minor yellow weathering.	517.5-518.5	6588.5-6587.5
	As above; 1% ferromagnesian phenocrysts (pyroxene), irregular shape, <1 mm, pale green.	518.5-526	6587.5-6580.0
	Lava flow, dark gray (N3), massive. Aphanitic groundmass; trace ferromagnesian (pyroxene) phenocrysts, varied colored including dark green, dark brownish green, pale yellowish brown, irregular shaped, < 1 mm; feldspar phenocrysts <1%, white, rectangular, strong cleavage, some alteration along rims.	526-530	6580.0-6576.0
	Lava flow, dark gray (N3), massive with trace vesicles. 0-1% phenocrysts, ferromagnesian phenocrysts green to dark brownish green, rounded to irregular shapes.	530-543.6	6576.0-6562.4
	As above, trace feldspar phenocryst.	543.6-546	6562.4-6560.0
	Lava flow, very dusky red (10R 2/2); massive, increase in vesicles. Aphanitic groundmass; 0-1% ferromagnesian and feldspar phenocrysts; secondary crystal growths in vesicles, white to very light gray, very small (<1 mm).	546-548	6560.0-6558.0
	As above, color change to dark gray (N3), variable concentration of vesicles and secondary crystal growths.	548-555.4	6558.0-6550.6
	Lava flow, dark gray (N3), massive. 0-1% greenish ferromagnesian phenocrysts, irregular to rounded; trace feldspar phenocrysts, irregular to rounded.	555.4-563.5	6550.6-6542.5
	Lava flow, medium dark gray (N4), massive. Aphanitic groundmass; very weakly porphyritic, <1% phenocrysts ferromagnesian (pyroxene), dark olive green.	563.5-574	6542.5-6532.0
	As above; trace vesicles with secondary white crystal growths, very small.	574-575.3	6532.0-6530.7
	Lava flow, medium dark gray (N4), massive. Aphanitic groundmass; very weakly porphyritic, <1% phenocrysts ferromagnesian (pyroxene), dark olive green. Lava flow structures at 575.3 and 580.1 ft bgs.	575.3-585	6530.7-6521.0
	Lava flow, medium dark gray (N4), massive. 1% ferromagnesian (pyroxene) phenocrysts, varied colored including dark yellow, greenish brown, blackish brown; feldspar phenocrysts rare; secondary crystal growths infill vesicles; minor reddish brown staining.	585-590	6521.0-6516.0
	Lava flow, brownish gray (5YR 4/1), massive with trace vesicles possibly aligned to flow. Trace ferromagnesian phenocrysts (pyroxene), dark colored, irregular to subrounded surfaces; secondary white/light gray crystal growths, <1 mm. Core appears wet at 594.1 ft bgs.	590-600	6516.0-6506.0
	As above, color change to greenish (5GY 2/1). Core dry from 600 to 607 ft bgs.	600-610	6506.0-6496.0
	Lava flow, brownish gray (5YR 4/1), massive to moderately vesicular. Aphanitic groundmass; very weakly porphyritic, 0-1% dark green to blackish green ferromagnesian phenocrysts (pyroxene), <1 mm. Core wet from 607 to 616.3 ft bgs; damp from 616.3 to 621.3 ft bgs. Damp beginning at 631.3 ft bgs.	610-634	6496.0-6472.0

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Tt2, Tschicoma Dacite (Dacitic Lava)	Lava flow, brownish gray (5YR 4/1); massive with trace vesicles; <1% dark blackish green ferromagnesian phenocrysts, pyroxene. Damp.	634-640	6472.0-6466.0
	As above, medium dark gray (N4), increase vesicles up to 1 cm.	640-644	6466.0-6462.0
	Lava flow, medium dark gray (N4), massive, trace vesicles. Aphanitic groundmass; trace ferromagnesian (pyroxene) phenocrysts, dark blackish green, <1 mm; secondary crystal growths include white/light gray growths, pale green prismatic needle-like growths, and fine dark colored blade-like crystals (possibly hematite). Damp to wet.	644-660	6462.0-6446.0
	Lava flow, dark gray (N3), massive, non-vesicular to weakly vesicular. Aphanitic groundmass; very weakly porphyritic with ferromagnesian phenocrysts up to 20 mm; secondary crystal growths as described above; horizontal to sub-horizontal fractures stained with iron oxide at 670 ft bgs; small rounded fragments at 666 ft bgs. Dry beginning at 665.8 ft bgs.	660-675	6446.0-6431.0
	Lava flow, medium gray (N5), massive, non-vesicular. Aphanitic groundmass; <1% ferromagnesian phenocrysts (pyroxene), <1 mm, dark blackish brownish green; very fine secondary crystal growths, white; iron oxide stained fractures at 685 ft bgs.	675-690.5	6431.0-6415.5
	As above, trace vesicles; fracture zone, near horizontal and near vertical, iron oxide staining on fracture surfaces, clay in near vertical fracture. Damp.	690.5-701.5	6415.5-6404.5
	Lava flow, medium gray (N5) to brownish gray (5YR 4/1); aphanitic; massive with trace vesicles; subvertical fractures; iron oxide with clay fracture surfaces; secondary crystal growths - white, <1 mm, and <1 mm brown blades (possible hematite); phenocryst poor, occasional dark greenish brown ferromagnesian crystal.	701.5-720	6404.5-6386.0
	As above; mottled medium gray (N5) with brownish gray (5YR 4/1), phenocryst poor.	720-725	6386.0-6381.0
	Lava flow, light gray (N7) to medium gray (N5), massive. Aphanitic groundmass; phenocryst poor; secondary white and brown crystal growths, up to 30-40% of core surface (patch-like appearance); possible fracture (wet) at 736 ft bgs.	725-749	6381.0-6357.0
	As above, core lacks secondary crystal growths. Dry.	749-754	6357.0-6352.0
	Lava flow, light gray (N7), massive, fractured. Aphanitic groundmass; rare ferromagnesian phenocrysts; fractured zone, core appears as frequent horizontal separations with Fe/Mn staining on surfaces from 754 - 759 ft bgs; clay accumulation on fracture surfaces at 758 ft bgs. Wet beginning at 766.1 ft bgs.	754-770.6	6352.0-6335.4
	Lava flow with minor silt/clay, moderate brown (5YR 4/4) to medium light gray (N6), massive, fractured. Aphanitic groundmass, core is less dense, gritty texture; trace ferromagnesian phenocryst and clear feldspar phenocrysts; highly fractured, altered, moderate brown silt/clay. Wet to 771.1 ft bgs.	770.6-772	6335.4-6334.0
	As above, rubble zone, several near vertical fractures, altered.	772-774	6334.0-6332.0
	As above, fractured massive lava flow with minor silt/clay, moderate brown (5YR 4/4) to medium light gray (N6).	774-780	6332.0-6326.0
	As above, rubble zone. Slightly wet.	780-782	6326.0-6324.0

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Tt2, Tschicoma Dacite (Dacitic Lava)	Lava flow, medium light gray (N6), massive, fractured. Aphanitic with rare ferromagnesian phenocrysts, dark olive green; fractured, possible clay accumulation on fracture surfaces.	782-793.1	6324.0-6312.9
	As above, rubble zone.	793.1-795.5	6312.9-6310.5
	As above.	795.5-797	6310.5-6309.0
	Lava flow rubble zone, moderate brown (5YR 3/4). Rubbilized breccia with silt and sand; poorly-sorted, angular (with occasional subangular) clasts, clasts include large fragments of massive lava flows as above, smaller clasts of moderate reddish brown and black aphanitic groundmass with rare ferromagnesian and feldspar phenocrysts; occasional large clasts within rubble or brecciated zone from 800 to 801 ft bgs, grayish brown (5YR 3/2), massive with trace vesicles, aphanitic groundmass with trace ferromagnesian phenocrysts; 5-10% fines.	797-810	6309.0-6296.0
Tt2, Tschicoma Dacite (Flow Base Rubble)	Flow base rubble, breccia with silt/clay, poorly to moderately indurated, varicolored. Generally aphyric clasts predominately as from above lava flow; clay, grayish orange (10YR 7/4), waxy appearance, clay common between clasts. Possible water from 812.3 to 817.3 ft bgs.	810-817.3	6296.0-6288.7
	Flow base rubble, varied colored clasts (predominately gray). Varied clasts including slightly prophyritic lava flow clasts as described above, and aphanitic clasts with frequent phenocrysts of feldspar and ferromagnesian phenocrysts; angular, trace subrounded clasts; minor sand/fines; thin clay zone with laminar bedding at approx 817.3 ft bgs.	817.3-822	6288.7-6284.0
	Flow base rubble, non-indurated, large clast (1.3 ft), microcrystalline groundmass with 1% feldspar phenocrysts, trace ferromagnesian phenocrysts.	822-823.3	6284.0-6282.7
	Flow base rubble, non-indurated, varied colored. Poorly-sorted clasts of varying size (up to 0.5 ft), moderately to strongly porphyritic, angular to subangular, generally dark colored (grey to black), 5-10% feldspar phenocrysts, up to 5mm, trace rimmed phenocrysts; occasional clast mottled pink/gray with 2-3% ferromagnesian and 2-3% feldspar phenocrysts; trace silt and fine sand.	823.3-834.8	6282.7-6271.2
Tpf, Puye Formation (fanglomer-ate)	Volcaniclastic sediments, gravel, non-indurated, moderately-sorted (gravel to cobble size) with trace fines. Porphyritic dacite clasts of varied lithologies, angular to subrounded surfaces. **Note: The above Tschicoma Dacite (Tt2) and the contact with the underlying Puye Formation (Tpf) is interpreted to be 834.8 ft bgs.**	834.8-843.2	6271.2-6262.8
	TOTAL BOREHOLE DEPTH (TD) IS AT 843.2 FT BGS.		

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)

NOTES:

Drill core was collected from the interval of 75 ft to 843.2 ft bgs. Descriptions presented in this lithologic log are primarily based on those made during visual examination of drill core.

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

Descriptions of drill core from sedimentary units such as the Quaternary Alluvium, Cerro Toledo Interval and the Puye Formation utilized principles outlined in Petrology of Sedimentary Rocks by Robert L. Folk. Color Descriptions were determined using The Geological Society of America, Rock-Color Chart.

Fractures were visually inspected for an approximate orientation. The angle of the fracture surface is approximated from vertical.

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

REFERENCES:

Folk, Robert L., 1980, Petrology of Sedimentary Rocks, Hemphill Publishing Company.

The Geological Society of America, 1991, Rock-Color Chart.

FINAL
COMPLETION REPORT
INTERMEDIATE WELL I-4
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

April 2006

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LIST OF ACRONYMS AND ABBREVIATIONS

ags	above ground surface
amsl	above mean sea level
ASTM	American Society for Testing and Materials
bgs	below ground surface
BMPs	best management practices
DOE	United States Department of Energy
DTW	depth to water
DTHH	down-the-hole hammer
EnviroWorks	EnviroWorks, LLC
ft	foot/feet
ft^3	cubic feet
gal.	gallon/gallons
hr	hour
ID	inner diameter
in.	inch/inches
Kleinfelder	Kleinfelder, Inc.
LANL	Los Alamos National Laboratory
lb	pound/pounds
NM	not measured
NMED	New Mexico Environment Department
OD	outer diameter
ppm	parts per million
psi	pounds per square inch
RCT	radiation control technician
SSLs	Soil Screening Levels
SMO	Sample Management Office
Technical Area	TA
TD	total depth
TKN	total Kjeldahl nitrogen
TOC	total organic carbon
US	United States

ABSTRACT

Intermediate well I-4 was installed as part of the Risk Reduction and Environmental Stewardship-Remediation Services project at Los Alamos National Laboratory (LANL) in accordance with the "Mortandad Canyon Groundwater Work Plan, Revision 1" (LANL 2004) and the "Final Drilling Plan for Intermediate Wells, Mortandad Canyon, Los Alamos National Laboratory" (Kleinfelder 2004b). The United States (US) Department of Energy (DOE), with technical assistance from LANL, contracted and directed the installation of this well.

Data from I-4 will be used in conjunction with data from other wells in Mortandad Canyon to improve the conceptual model of the geology, hydrogeology, and hydrochemistry of the area to provide data for numerical models that address contaminant migration in the vadose (unsaturated) zone. This information will be used to facilitate decision-making with regard to regulatory compliance, risk assessment, and remediation.

The majority of the fieldwork was conducted from October 24, 2004 to November 9, 2004. The I-4 well was installed to further isolate a perched zone encountered during the drilling of MCOBT-4.4 (LANL 2002). The borehole was drilled to a total depth (TD) of 540 feet (ft) below ground surface (bgs) using air-rotary and fluid-assisted air-rotary drilling methods. Samples of drill cuttings were collected at regular intervals for potential stratigraphic, petrographic, and geochemical analysis. Geophysical logging was performed in the open borehole to help delineate the hydrostratigraphy and to facilitate proper well design. The stratigraphy encountered during borehole drilling included, in descending order, alluvium, Cerro Toledo interval, Otowi Member of the Bandelier Tuff, Guaje Pumice Bed, upper Puye Formation, and Cerros del Rio basalt.

The I-4 borehole was completed as a characterization well with a screened interval from 499.0 to 522.0 ft bgs. The screened interval straddles the geologic contact between the upper Puye Formation and the underlying Cerros del Rio basalt. The TD of the well is 525.7 ft bgs The depth to water following well installation, development and extended recovery was 520.41 ft bgs.

1.0 INTRODUCTION

This completion report summarizes the site preparation, drilling, well completion, and related activities for intermediate well I-4. Kleinfelder, Inc. (Kleinfelder), under contract to the United States (US) Army Corps of Engineers, was responsible for executing drilling, installing, testing, and sampling activities. The US Department of Energy (DOE) with technical assistance from Los Alamos National Laboratory (LANL), contracted and directed the installation of this well.

Well I-4 is located in Technical Area (TA) 5, Mortandad Canyon (Figure 1.0-1), approximately 72 ft west of characterization well MCOBT-4.4 (LANL 2002). I-4 replaces well MCOBT-4.4. The screened interval in MCOBT-4.4 is believed to include the zone of production as well as an interval where groundwater is draining back into the formation. The I-4 well further isolates the perched groundwater zone. Information from I-4 will be used to evaluate the effect of releases from TA-50 and TA-35 of LANL on perched intermediate zone groundwater quality. Data quality objectives are provided in the "Mortandad Canyon Groundwater Work Plan, Revision 1" (LANL 2004) and the "Final Drilling Plan for Intermediate Wells, Mortandad Canyon, Los Alamos National Laboratory" (Kleinfelder 2004b). Water quality, geochemical data, aquifer characteristics, and geologic information obtained from I-4 will augment the conceptual model and knowledge of contaminant distribution in the intermediate perched zone in the Mortandad Canyon system.

The objectives of the drilling activities were to collect groundwater samples from perched intermediate groundwater zones and to install a single-screened monitoring well in the upper Puye Formation. Lithologic information is available from the adjacent MCOBT-4.4 drilling effort; however, cuttings collection was added to the I-4 program to ensure a complete assessment of the borehole. The projected total depth (TD) of the borehole was 517 feet (ft) below ground surface (bgs). The actual TD of the I-4 borehole was 540 ft bgs. The I-4 borehole was completed as a characterization well with a single-screened interval from 499.0 to 522.0 ft bgs. Due to the proximity of the MCOBT-4.4 coring location, a corehole was not drilled.

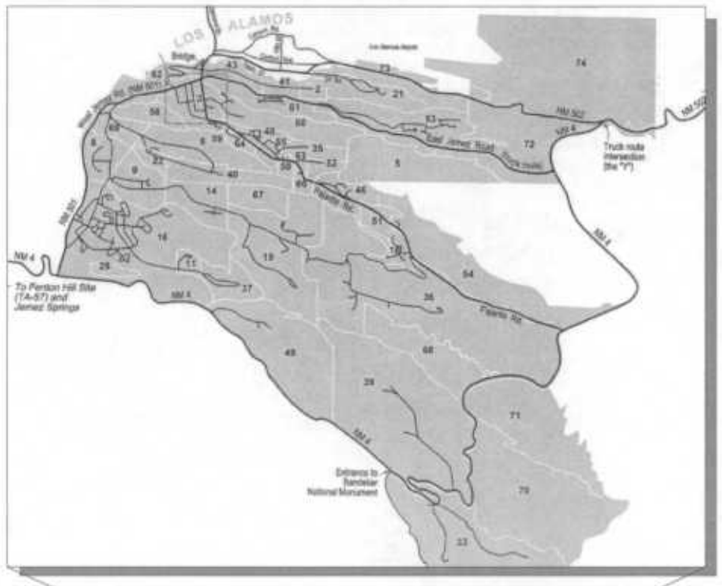
The information presented in this report was compiled from field reports and activity summaries generated by Kleinfelder, LANL, and subcontractor personnel. Original records, including field reports, field logs and survey records, are on file in Kleinfelder's Albuquerque, New Mexico office and in LANL's Records Processing Facility. Further analysis and interpretation of geologic, geochemical, and aquifer data will be included in separate technical documents to be prepared by LANL.

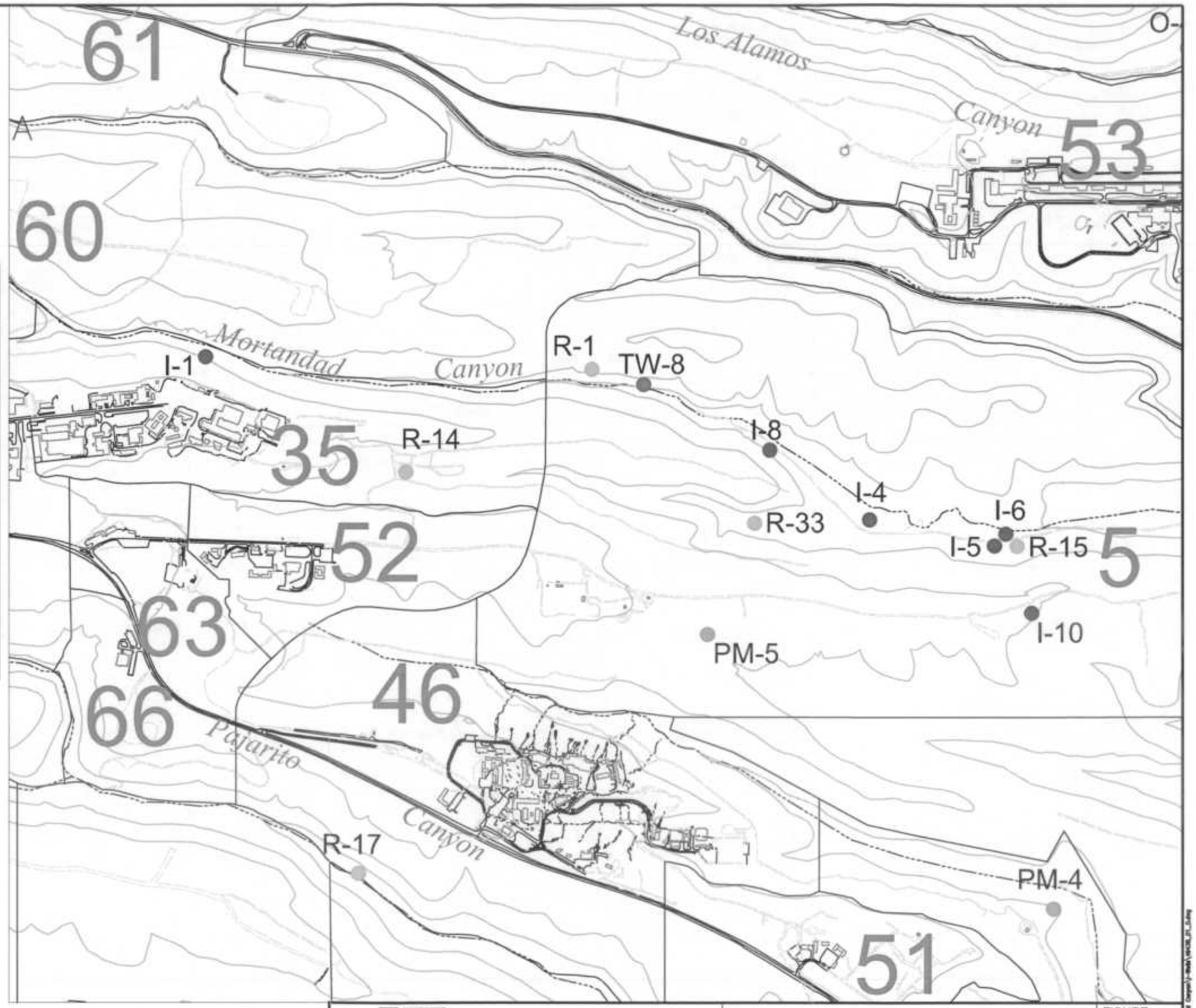
2.0 SITE PREPARATION AND DRILLING ACTIVITIES

Site preparation consisted of constructing and lining the cuttings pit, erecting silt fencing to prevent erosion and runoff from the drill site, and setting up the exclusion zone. Best management practices, also known as BMPs, were installed as specified in the "Storm Water Pollution Prevention Plan, Mortandad Canyon Ground Water Work Plan, Los Alamos National Laboratory" (Kleinfelder 2004a). EnviroWorks, LLC (EnviroWorks) completed these tasks from October 20 through October 26, 2004. A radiation control technician (RCT) from LANL's Health, Safety, and Radiation Protection Group-1 screened the site before site preparation activities. A geology trailer, generator, compressor, and safety lighting equipment were moved to the site during the subsequent mobilization of drilling equipment.

Legend

- = Intermediate perched zone wells (proposed)
- = Regional aquifer wells installed since 1998
- = Older test wells
- = Water supply wells
- 58 = Technical area identification
- = 100-ft contours





1000 0 500 1000

SCALE: 1 inch = 1000 ft

KLEINFELDER

Drawn By: C. Landon	Date: April 2006
Project No.: 49436	Filename: 49436_01_0.dwg
Scale: 1" = 1000'	Revision: –

SITE LOCATION MAP
Intermediate Wells I-1, I-4, I-5, I-6, I-8, I-10
Mortandad Canyon
Los Alamos National Laboratory
Los Alamos, New Mexico

FIGURE
1.0-1

Drilling activities occurred from October 24 to November 2, 2004. Well installation continued through November 9, 2004. Site activities were generally conducted in one 12-hour (hr) shift per day, seven days per week, by the drill crew and two site geologists.

WDC Exploration & Wells drilled I-4 using air-rotary drilling techniques. The borehole was advanced using a GEFCO Speedstar 90K drill rig equipped with conventional drilling rods and drill collars, tricone and down-the-hole hammer (DTHH) bits, air compressors, and support equipment. Drilling fluids, consisting of a mixture of municipal water with QUIK-FOAM® surfactant, were used as needed to improve borehole stability and facilitate cuttings removal from the borehole. An approximate tally of the total drilling fluids introduced into the borehole, as well as the total fluids recovered, is presented in Table 2.0-1.

Table 2.0-1
Introduced and Recovered Fluids

Material		Volume (gallons)
Introduced	QUIK-FOAM®	35
	Potable water (air-rotary drilling)	1,266
	Total introduced fluids[1]	1,301
Recovered	Total recovered fluids[2]	1,820

[1]Represents the fluids introduced during drilling
[2]Represents the estimated fluid volume recovered during drilling and well development

Mobilization of drilling equipment and supplies to the I-4 site was completed on October 24, 2004. Drilling began using a 12¼-inch (in.) diameter tricone bit, which was advanced to 80 ft bgs. Concurrently, 13⅜-in. surface casing was advanced to 76 ft bgs. The borehole was drilled with air only and the cuttings were collected in a portable hopper. Minor amounts of potable water were used for dust suppression. A thin alluvial groundwater zone was encountered at approximately 59 ft bgs. This groundwater zone is monitored by alluvial well A-2 located approximately 55 ft north of the I-4 well (Kleinfelder 2005).

On October 25, the cuttings pit liner had not arrived and drilling activities were suspended until after liner installation.

On October 26, EnviroWorks installed the liner in the cuttings pit, and drilling resumed. The 13⅜-in. surface casing was advanced to 79 ft bgs. The drill string (bit and drill rods) was removed (tripped out) to measure depth to water (DTW); the borehole was dry, indicating the alluvial groundwater was successfully sealed off by the surface casing. The borehole was advanced from 80 to 505 ft bgs using a 12¼ in. tricone bit. Fluid-assist, air-rotary drilling methods (air, water and QUIKFOAM®) were used. It was suspected that the tricone bit became plugged at the end of the shift.

On October 27, the drill string was tripped out to measure DTW, check the drill bit, and to allow for borehole video logging. DTW measurements did not indicate the presence of water in the borehole.

On October 28, a borehole video log was run to a TD of 495 ft bgs using Kleinfelder equipment (formation material filled the hole from 505 to 495 ft bgs). Perched groundwater was not observed. The final borehole video log is located on the DVD in Appendix A.

On November 1, DTW measurements indicated that the borehole was dry. LANL and DOE representatives provided instruction to advance the borehole to 520 ft bgs. Using the 12¼-in. diameter tricone bit, the borehole was advanced from 505 to 519 ft bgs where basalt was encountered. The drill string was tripped out to measure DTW. Fluid was detected in the borehole at 512.1 ft bgs.

On November 2, a borehole video log was run to approximately 513 ft bgs using Kleinfelder equipment. During the video logging, moisture was observed along the borehole wall below 504 ft bgs. Standing water was encountered at 513 ft bgs. Based on measurements taken following the video logging, this was also the approximate TD of borehole. DOE representatives provided instruction to advance the borehole to 540 ft bgs. The tricone drill bit was replaced with a 12¼-in. DTHH bit, and the borehole was advanced from 519 to 540 ft bgs. The drill string was removed from the borehole. DTW was measured at 536.28 ft bgs.

On November 3, DTW was measured at 532.75 ft bgs, after which a borehole video log was conducted. Fluids were detected at the base of the borehole. Water was not visibly entering the borehole; however, damp walls were noted at the lower portion of the borehole. A groundwater sample of the borehole fluids was collected using disposable bailers (details presented in Section 3.2, Groundwater Sampling). Natural gamma and induction logs were then run to 537 ft bgs, the approximate borehole TD.

On November 4, the DTW was 528.70 ft bgs, and the borehole bottom was tagged at 535 ft bgs. The well design was approved and installation began. A lower bentonite and sand seal was applied to the bottom of the borehole to prevent groundwater leakage through the basalt. The well casing and screen were installed and the filter pack was applied. The screened interval was swabbed. Details of the well construction are presented in Section 6.0.

On November 5, 2004, the fine-sand transition collar was applied and the annular space was backfilled with bentonite chips up to 84 ft bgs. The 13⅜-in. surface casing was retracted from 79 to 59 ft bgs.

On November 6, 2004, DTW was measured in the completed well at 499.44 ft bgs. The remaining 60 ft of 13⅜-in. surface casing was removed. A LANL RCT screened the site equipment, and demobilizing of equipment and supplies from the site began.

On November 7, DTW was 499.35 ft bgs in the I-4 well.

On November 9, the annular space from 84 ft to 1.6 ft bgs was filled with cement slurry. Demobilization from the drill site was completed.

3.0 SAMPLING ACTIVITIES

Cuttings, groundwater screening samples, and waste characterization samples were collected at I-4. Sampling activities were conducted in accordance with the drilling plan (Kleinfelder 2004b). Deviations are noted in Section 9.0.

3.1 Sampling of Borehole Drill Cuttings

The drilling plan did not include borehole cuttings collection because lithologic information is available from the adjacent MCOBT-4.4 borehole. I-4 cuttings collection was added to the I-4 program to ensure a complete assessment of the borehole.

As drilling conditions permitted, sufficient quantities of cuttings were collected at approximately 5 to 10-ft intervals from the borehole discharge line. Portions of the cuttings, both sieved (using >#10 and >#35 mesh) and unsieved, were placed in chip trays and examined to determine lithologic characteristics and to prepare the lithologic log presented in Appendix B.

An additional aliquot of the >#10 fraction of cuttings was prepared for all intervals where sufficient returns were available. The sieved fractions were placed in labeled plastic bags and submitted to LANL for potential mineralogic, petrographic, and geochemical analyses. The remaining cuttings were sealed in Ziploc® bags, labeled, and archived in core boxes. With the exception of waste characterization, drill cuttings were not submitted for chemical analyses.

All cuttings were screened by an RCT prior to removal from the site.

3.2 Groundwater Sampling

During drilling, one groundwater sample (split into samples CAMO-05-56778 and CAMO-05-56783 after sampling) was collected from the open I-4 borehole. The DTW prior to sampling was 532.75 ft bgs, the borehole TD was estimated at 537 ft bgs. Within this interval, the zone of groundwater contribution is not known. The samples were submitted to LANL's Sample Management Office (SMO) for perchlorate, anion, metals, radionuclides, tritium, total Kjeldahl nitrogen (TKN), and stable isotopes analyses.

On January 10, 2005, a groundwater sample (CAMO-05-56779) was collected from I-4 during well development and submitted to the SMO for radionuclides, tritium, TKN, and stable isotope analyses.

3.3 Waste Characterization Sampling

Samples of drill cuttings, decon water, recovered drilling fluids, and groundwater generated during well development were collected for waste characterization on December 15, 2004 and February 9, 2005. These samples were submitted to Hall Environmental Analysis Laboratory in Albuquerque, New Mexico, for anions, polychlorinated biphenyls, volatile organic compounds, semi-volatile organic compounds, metals, mercury, perchlorate, radionuclides, tritium, and explosives analyses. The analytical results were received from HEAL on January 10 and March 4, 2005, and submitted to DOE and LANL for review.

4.0 BOREHOLE LOGGING

Kleinfelder logged the I-4 borehole prior to well installation to acquire visual observations and geophysical data to help characterize borehole conditions and hydrostratigraphy. Project personnel used this information to facilitate proper well design. Table 4.0-1 summarizes the video and geophysical logs that were run in the I-4 borehole.

Table 4.0-1
Borehole Logging Conducted

Operator	Date	Cased Footage (ft bgs)	Open-Hole Interval (ft bgs)	Logged Interval (ft bgs)	Remarks	Tools
Kleinfelder	10/28/04	0-79	79-505 (slough to 495)	0-495	Dry	Video camera
Kleinfelder	11/02/04	0-79	79-519 (slough to 513)	0-507[1]	Moisture at approx 500 ft bgs; standing water at base of borehole; DTW tagged prior to video at 506.91 ft bgs	Video camera
Kleinfelder	11/03/04	0-79	79-540 (minor slough to 537)	0- 532[1]	No visible water entering borehole, small volume of fluid at base of borehole; DTW tagged at 532.75 ft bgs prior to running video	Video camera
Kleinfelder	11/03/04	0-79	79-540 (minor slough to 537)	0-537	None	Gamma and Induction

[1] **video counter discrepancy, depth based on DTW measurements**

4.1 Video Logging

Kleinfelder personnel ran borehole video logs on October 28, November 2, and November 3, 2004, to assess for groundwater-bearing zones (Table 4.0-1). The November 3, 2004, video provided a log of the borehole upon reaching TD. The video indicates moisture on the lower portion of the borehole walls below approximately 505 ft bgs. A small volume of standing water was noted at the base of the borehole. No flowing groundwater was observed. The video counter indicates a bottom depth of 541 ft bgs at the top of the standing water. Prior to conducting the video log, the DTW was measured at 532.75 ft bgs. Thus, the counter presents a discrepancy of approximately 8 ft in the lower portions of the borehole. The manufactured accuracy of the Kleinfelder-owned GeoVISION™ Junior video camera counter is +/-2%. The final video log (November 3, 2004) is attached as a DVD in Appendix A.

4.2 Geophysical Logging

Geophysical logging was conducted to identify geologic and hydrogeologic units, with an emphasis on gathering moisture distribution data, identifying water-bearing zones, and obtaining lithologic data. On November 3, Kleinfelder used a Mount Sopris MGXII geophysical console to run LANL-owned array induction and natural gamma geophysical tools to approximately 537 ft bgs the current borehole TD. Figure 4.2-1 presents the natural gamma and array induction (conductivity) logs.

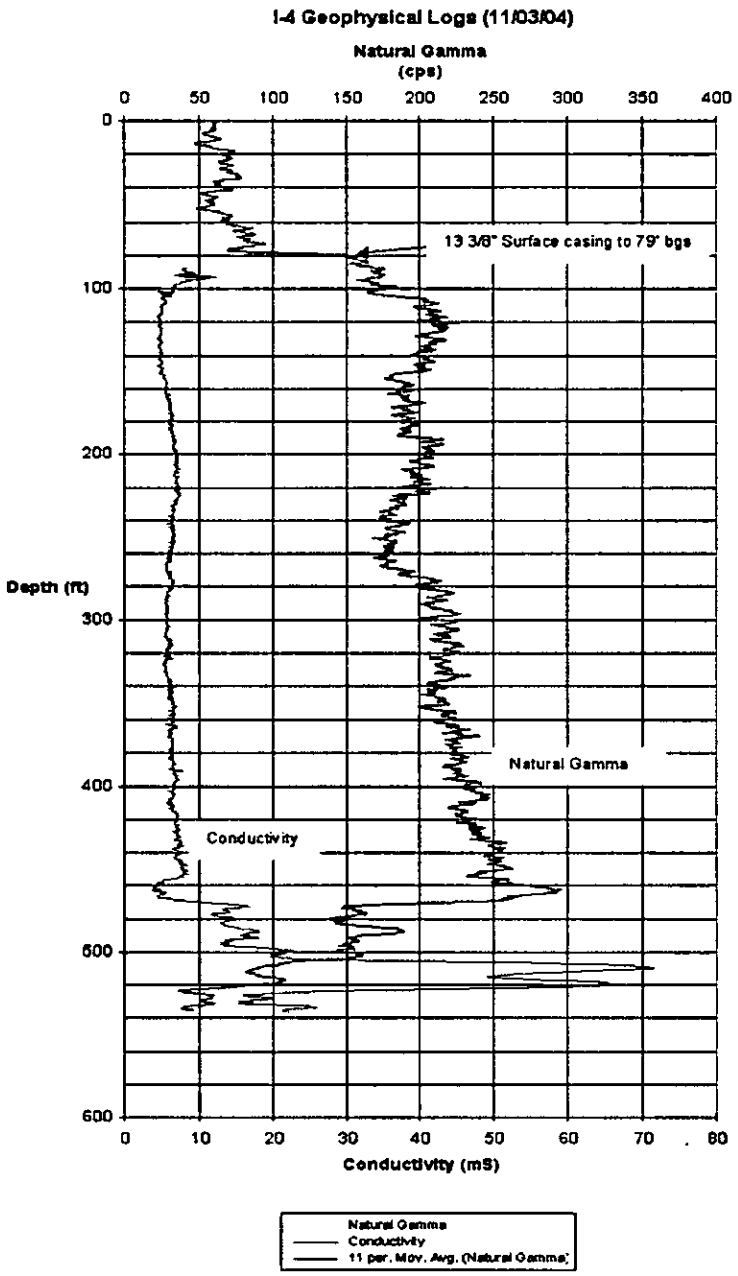


Figure 4.2-1 Natural Gamma and Induction Array Geophysical Logs

5.0 HYDROGEOLOGY

LANL Earth and Environmental Sciences 6 staff provided preliminary interpretation of geologic contacts based on cuttings. Groundwater occurrence is interpreted from drilling observations, open-hole video logging, geophysical logging, and water-level measurements.

5.1 Geology

Visual examination of borehole drill cuttings, open-hole video logs, and preliminary geophysical logs were used to determine the stratigraphy at I-4 (Figure 5.1-1). In descending order, the stratigraphic units encountered during drilling of the I-4 borehole are alluvium, Cerro Toledo interval, Otowi Member of the Bandelier Tuff, Guaje Pumice Bed, upper Puye Formation, and Cerros del Rio basalt. Appendix B contains the lithologic log for I-4 based on visual examination of the drill cuttings.

5.2 Groundwater Occurrence and Characteristics

Based on data from well MCOBT-4.4, an intermediate perched aquifer was anticipated along the contact between the Puye Formation and the underlying Cerros del Rio basalt at approximately 520 ft bgs (LANL 2004). Borehole video logs were run on two occasions while drilling and once after reaching the borehole TD of 540 ft bgs. Groundwater was not observed entering the borehole.

Prior to well construction and emplacement of the lower bentonite seal, the open-hole DTW was 528.70 ft bgs. On November 7, 2004, immediately following well completion, the DTW in the well was 499.35 ft bgs. The elevated water level is likely due to potable water used to place the filter pack during well construction. Prior to well development, the DTW was approximately 504 ft bgs and, following initial development activities, water levels slowly recharged to approximately 509 ft bgs. Subsequent bailing the well "dry" followed by extended recovery intervals produced further decline in water levels to approximately 518 ft bgs. On April 1, 2005, following approximately three months of inactivity, the DTW was 520.41 ft bgs.

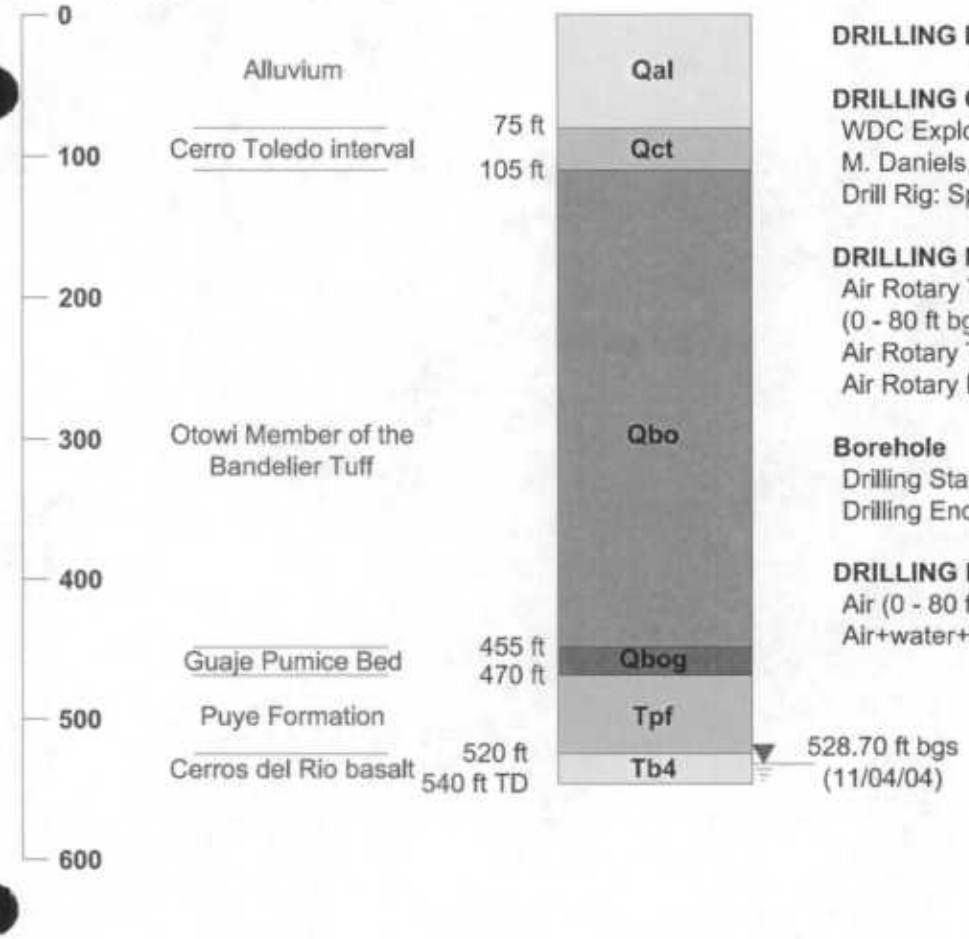
A slug test was performed between April 7 and April 14, 2006. Details of the slug test provide additional information on the nature of the saturated zone (Section 7.2 and Appendix C).

6.0 WELL DESIGN AND CONSTRUCTION

Kleinfelder received the well construction specification on November 4, 2004, after approval from DOE, LANL, and the New Mexico Environment Department (NMED). The well was installed from November 4 through November 9, 2004.

6.1 Well Design

The "Mortandad Canyon Groundwater Work Plan" (LANL 2004) called for a single screened interval between the upper Puye Formation and underlying Cerros del Rio basalt. Final placement of the screened interval from 499.0 to 522.0 ft bgs was determined from geophysical logs, borehole cuttings, water level measurements, and field observations.



DRILLING INFORMATION

DRILLING COMPANY/PERSONNEL
WDC Exploration
M. Daniels, C. Matthews, C. Bufkin, R. Price
Drill Rig: Speedstar 90k

DRILLING METHOD
Air Rotary Tri-cone bit with casing hammer (0 - 80 ft bgs)
Air Rotary Tri-cone bit (80 - 519 ft bgs)
Air Rotary Downhole hammer (519 - 540 ft bgs)

Borehole
Drilling Start Date: 10/24/04 Time: 16:50
Drilling End Date: 11/02/04 Time: 17:30

DRILLING FLUID TYPE
Air (0 - 80 ft bgs)
Air+water+QUIK-FOAM® (80 - 540 ft bgs)

Notes:
1. Geologic contacts are preliminary and subject to change.
2. Perched water at 59 ft bgs. Zone sealed off by surface casing.
3. Video survey indicated borehole wall moist below 504 ft bgs.
4. Groundwater level at 528.70 ft bgs in open hole after reaching TD of 540 ft bgs

KLEINFELDER

Drawn By: C. Bhongir	Date: April 2006
Project No.: 49436	Filename: 49436_01_0.dwg
Scale: not – to – scale	Revision: –

BOREHOLE SUMMARY DATA SHEET
I-4
Mortandad Canyon
Los Alamos National Laboratory
Los Alamos, New Mexico

FIGURE
5.1-1

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6.2 Well Construction

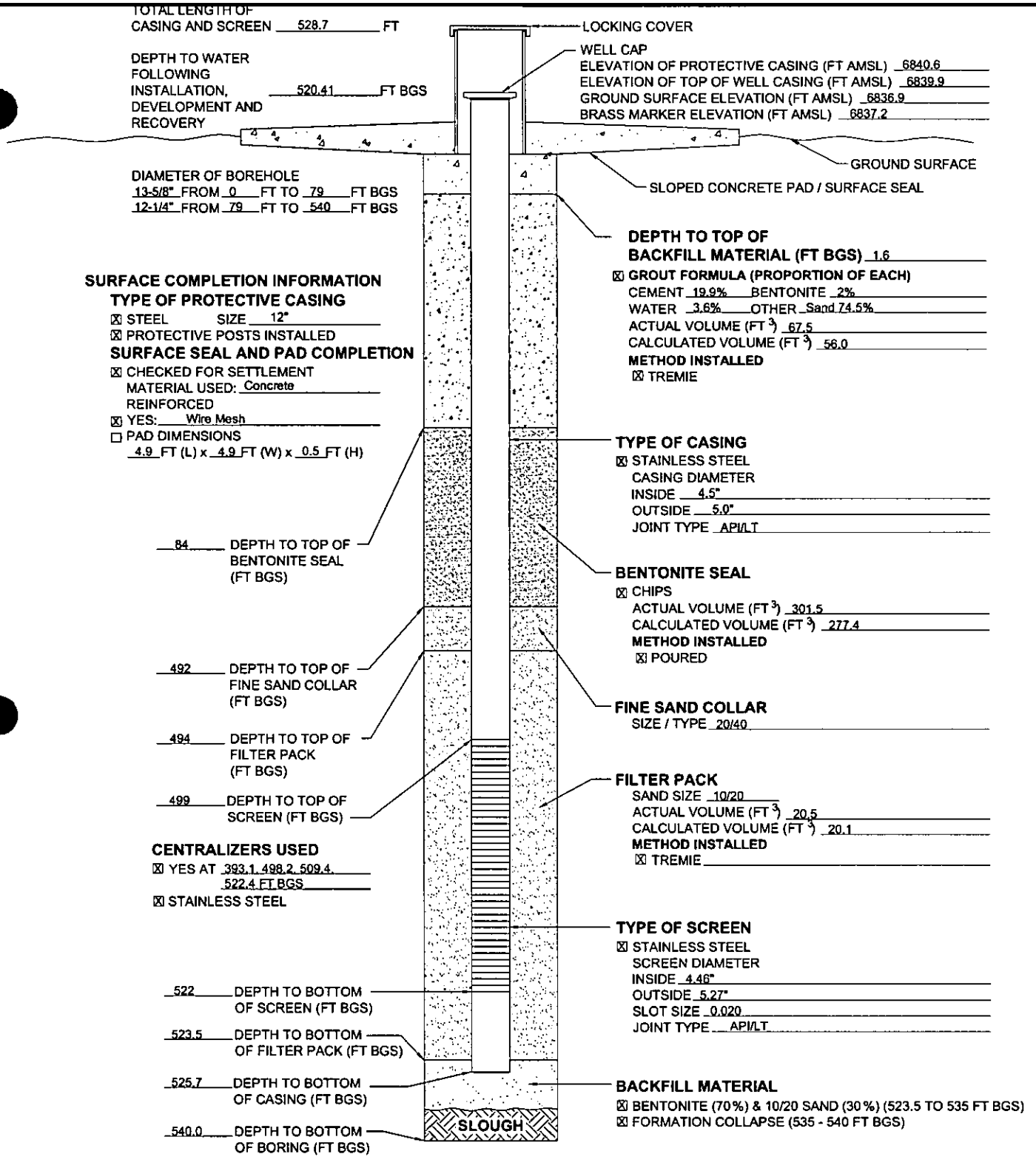
The casing and screen were factory-cleaned before shipment and delivery to the site. The stainless-steel components were additionally decontaminated on site prior to well construction using a high-pressure steam cleaner.

I-4 was constructed in accordance with LANL's "Environmental Restoration Standard Operating Procedures for Well Construction, Revision 3" ER-SOP-05.01 (LANL 2001) using 4.5-in. inner diameter (ID)/5.0-in. outer diameter (OD), type A304, stainless-steel casing fabricated to standards in American Society for Testing and Materials (ASTM) A312-05, "Standard Specification for Seamless, Welded, and Heavily Cold Worked Austenitic Stainless Steel Pipes." External couplers, also of type A304 stainless steel, were used to connect individual casing and screen joints. Two nominal 12-ft lengths of 5.27-in. OD, rod-based, 0.020-in. slot size, wire-wrapped well screen were coupled to construct the screen interval. The combined length of the lower screen weld ring and the well end-piece provide a 3.7-ft stainless-steel sump (Figure 6.2-1).

Prior to running the well casing into the hole, the bottom of the borehole was tagged at 535 ft bgs, indicating that 5 ft of formation material (slough) had accumulated. A mixture of 70% bentonite and 30% 10/20 silica sand was emplaced at the bottom of the borehole up to 526.0 ft bgs to provide a lower seal to the borehole. The well casing and screen were installed and the screen interval set from 499.0 to 522.0 ft bgs. The lower bentonite seal was then tagged at 523.5 ft bgs, likely due to swelling of the hydrated bentonite, possible formation material sloughing into the borehole during casing installation, and displacement of the bentonite by the well sump. A primary filter pack of 10/20 silica sand was placed across the screened interval from 523.5 to 494 ft bgs using 2-in. OD steel tremie pipe. After placement of the primary filter pack, the screened interval was swabbed 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 494 to 492 ft bgs. Following placement of the fine sand collar, a seal of bentonite chips was placed from 492 to 84 ft bgs. The 13⅜-in. surface casing was removed, and a cement grout was placed from 84 to 1.6 ft bgs. The cement grout consisted of a 3000 pounds per square inch (psi) cement/sand slurry blended with powdered bentonite (9.4% bentonite, calculated as dry weight bentonite to dry weight cement plus bentonite). Table 6.2-1 summarizes the volumes of annular fill materials used to complete I-4.

Table 6.2-1
Annular Fill Materials Used in Well Construction

Material	Volume
Grout seal: cement slurry	67.5 ft^3
Bentonite seal: bentonite chips	301.5 ft^3
Fine sand collar: 20/40 silica sand	1.5 ft^3
Primary filter: 10/20 silica sand	20.5 ft^3
Lower bentonite: sand seal	4 ft^3:1.3 ft^3
Potable water	2,320 gal.



WELL COMPLETION BEGAN
DATE 11/4/04 TIME 10:10
WELL COMPLETION FINISHED
DATE 11/09/04 TIME 11:55

WELL DEVELOPMENT INFORMATION
DEVELOPMENT METHOD
☒ SWABBING ☒ BAILING
TOTAL PURGE VOLUME 120 GALLONS

KLEINFELDER

Drawn By: C. Bhongir	Date: April 2006
Project No.: 49436	Filename: 49436_02_0.dwg
Scale: Not-to-scale	Revision: –

WELL SCHEMATIC
Characterization Well I-4
Mortandad Canyon
Los Alamos National Laboratory
Los Alamos, New Mexico

FIGURE
6.2-1

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7.0 WELL DEVELOPMENT, AQUIFER TESTING, AND SAMPLING SYSTEM INSTALLATION

Development activities at I-4 began on November 15, 2004 and continued through January 11, 2005. Well development procedures to date include bailing and swabbing the well screen.

7.1 Well Development

I-4 development began by bailing and swabbing the screened interval to enhance filter-pack settling and to remove drilling fluids and sediment that were introduced into the well during drilling and installation. Fluids were removed using a stainless-steel bailer. Swabbing was conducted by repeatedly drawing a swabbing tool across the screened interval. Because of the low recharge rate, a pump was not used to complete I-4 development.

Approximately 120 gal of water were removed during development. Due to the slow recharge of the perched zone, bailing was conducted for six days over a two-month period (November 15, 2004 to January 11, 2005). Groundwater parameters were not collected. The analytical result of a total organic carbon (TOC) sample collected upon completion of well development activities was 10.3 parts per million (ppm). Near the completion of development activities, a groundwater sample (CAMO-05-56779) was collected and submitted to the SMO for analysis (Section 3.2 Groundwater Sampling).

7.2 Aquifer Testing

Constant-rate pumping and recovery aquifer tests were not conducted due to slow recharge; however, a slug test was performed between April 7 and April 14, 2006. A solid slug and transducer were lowered into the well in the afternoon of April 7, creating a rise in the water level of 0.41 ft. The equipment was left in place until the morning of April 14. A full analysis of the aquifer test data is presented in Appendix C.

The following information summarizes the results of the slug test on I-4:

- The pressure transducer produced a spurious response in the form of instantaneous water level "jump" of about 0.1 ft.
- The hydrograph data record showed an ostensibly impossible response compared to barometric pressure (decreasing when barometric pressure increased, and vice-versa), possibly another indication of transducer malfunction.
- Despite the obvious and apparent data anomalies, certain aspects of the transducer output appeared reasonable, such as transducer submergence and retrieval effects, water level decay following slug submergence, and the overall magnitudes of the observed heads – both atmospheric and submerged.
- Slug test analysis of the water level decay data following slug submergence yielded an average lower-bound hydraulic conductivity for the 2.14-ft saturated screen zone of 0.12 ft per day.

7.3 Dedicated Sampling System Installation

A dedicated sampling system will be purchased for I-4 to be used as needed by LANL staff. The sampling device will be suitable for low-yield aquifers.

8.0 WELLHEAD COMPLETION, SURVEY, AND SITE RESTORATION

8.1 Wellhead Completion

Wellhead completion consisted of the installation of the protective well monument, surface seal, and pad. A 12-in. OD, steel well monument with locking lid was installed from approximately 1.3 ft bgs to 3.7 ft above ground surface (ags) to protect the well riser. Concurrent with the placement of the monument and surface seal using concrete backfill, a reinforced concrete pad, 4.9-ft wide by 4.9-ft long by 0.5-ft thick, was installed around the well casing to provide long-term structural integrity for the well. A brass survey cap was embedded in the northwest corner of the pad. The pad is slightly elevated and sloped away from the well casing to promote runoff. Four bollards are placed around the perimeter of the pad to protect against vehicular damage.

8.2 Geodetic Survey

The ground surface, well casing, and brass cap at the I-4 wellhead were surveyed by ASTS, Inc. on March 10, 2005. The survey data are presented in Table 8.2-1.

Table 8.2-1
Geodetic Data

Description	Northing	Easting	Elevation*
Ground Surface	1768543.22	1634128.07	6836.9
Brass cap in I-4 pad	1768542.01	1634128.53	6837.2
Top of well casing	1768539.96	1634129.99	6839.9
Top of protective well monument casing[1]	NM[2]	NM	6840.6

* Measured in feet above mean sea level (amsl) relative to the National Geodetic Vertical Datum of 1929, accurate to +/-0.1 foot

[1] Measured from the geodetic surveyed brass cap using level and staff

[2] NM – not measured

8.3 Site Restoration Activities

Cuttings and fluids produced during drilling and development were containerized and sampled on December 15, 2004, and February 9, 2005, in accordance with the October 13, 2004, Waste Characterization Strategy Form prepared for the drilling and installation of boreholes and wells in Mortandad Canyon (Appendix C in Kleinfelder 2004b). Analytical results were received on January 10, 2005, and March 4, 2005, and submitted to DOE and LANL for review. Fluid sample results were compared to the State of New Mexico Water Quality Control Commission Regulation 3103 groundwater standards. Water generated during drilling, development and aquifer testing was land applied in accordance with the Workplan Notice of Intent Decision Tree, revised July 15, 2002, and in coordination with NMED. Cuttings sample results were compared

to local geochemical background values and soil screening levels (SSLs) from NMED Soil Screening Levels, Revision 2.0, February 2004, and submitted to DOE for approval to use as site restoration fill.

Site restoration activities included removing the water from the containment area and applying it back to the land, removing the polyethylene liner and cuttings from the containment area, removing the containment berms, backfilling and grading the containment area, and disposing of the containment liner. Remaining cuttings not utilized to backfill the containment area were thinly spread over the site. The site has been reseeded using LANL Seed Mix, applied at a rate of 20 pounds (lb)/acre. Biosol® organic fertilizer was utilized (800 lb/acre) to support re-vegetation. Temporary materials emplaced for BMPs have been removed.

9.0 DEVIATIONS FROM THE WORKPLAN

In general, drilling, sampling, and well construction at I-4 was performed in accordance with the "Final Drill Plan for Intermediate Wells, Mortandad Canyon, Los Alamos National Laboratory"(Kleinfelder 2004b). Deviations are summarized as follows:

- The projected depth called for I-4 was 517 ft bgs; the actual TD of the I-4 borehole was 540 ft bgs.
- The geology from MCOBT-4.4 was to be utilized in lieu of collecting cuttings. Cuttings were collected during drilling, and a lithologic log of the I-4 borehole was prepared.
- Water quality parameters were not collected during well development. The groundwater sample collected at the completion of well development was not analyzed for perchlorate, metals, or anions.
- A post-slug test groundwater sample was not collected.
- Geophysical logging was not planned; logs from MCOBT-4.4 were supplemented with I-4 gamma and induction logging to assess for perched water and stratigraphic contacts.

10.0 ACKNOWLEDGEMENTS

ASTS, Inc. conducted the final geodetic survey of finished well components.

Duratek Federal Services, Inc. performed a review of the analytical results of the drill cuttings for waste determinations.

EnviroWorks, LLC provided site preparation and restoration services.

Hall Environmental Analysis Laboratory conducted laboratory analysis for waste characterization samples

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

WDC Exploration & Wells provided rotary drilling and well development services.

11.0 REFERENCES

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Appendix A

Borehole Video Log

Appendix B

Lithologic Log

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Qal, alluvium	Unconsolidated alluvial sediments, sand with silt, pale yellowish brown (10YR 6/2). WR (whole rock, unsieved): 0-1% gravel, 90-95% well-sorted, medium to coarse sand composed of euhedral to broken felsic (quartz and/or sanidine, unless otherwise noted) crystals; 5-10% fines; 10+F (i.e. plus No. 10 sieve-size fraction): predominantly medium to coarse sand grain size returns of felsic crystals, frequent bipyramidal quartz; 2-3% subrounded to subangular varied intermediate composition volcanic clasts, up to 0.5 cm with trace clasts up to 1 cm; 5% subrounded tuff fragments up to 4 mm with trace devitrified felsic phenocryst-rich pumice; 5% subrounded to subangular quartzite clasts up to 0.5 cm decreasing across interval, possible surface pad construction material; poor returns from 10-20' bgs. 35+F (i.e. plus No. 35 sieve-size fraction): 95-98% euhedral to rounded felsic crystals with frosted surfaces, frequent bipyramidal quartz; trace tuff fragments. **Note: samples of drill cuttings were collected in the interv**	0-20	6836.9-6816.9
	Unconsolidated alluvial sediments, silty sand to sandy silt , pale yellowish brown (10YR 6/2) to light brown (5YR 5/6). WR: 0-5% gravel; 45-50% poorly-sorted sand including felsic crystals, frequent bipyramidal quartz; 40-50% fines. 10+F (variable recovery 20-30'): 60% felsic crystals, frequent bipyramidal quartz, frequent frosted surfaces; 40% subrounded tuff fragments up to 0.5 cm with devitrified pumice; trace subrounded lithic fragments. 10+F (no returns 30-35', sparse returns 35-40'): predominantly subangular to subrounded tuff fragments, vitrified pumice, minor felsic crystals, and trace lithic fragments. 35+F: 90-95% felsic crystals with minor tuff and lithic fragments; decreased felsic crystal content at 35' to 80%.	20-40	6816.9-6796.9
	Unconsolidated alluvial sediments, silty sand with gravel, light brown (5YR 6/4). WR: 5-10% gravel; 50-70% poorly-sorted sand; 30-50% fines; fine to medium grain size gravel. 10+F (40-50'): 50-60% rounded, crystal-rich tuff up to 1 cm; 15-20% felsic crystals with frequent frosted surfaces, frequent bipyramidal quartz; 5-10% subrounded lithic fragments to 0.5 cm, 5% vitric pumice fragments. 10+F (50-60'): poor returns. 35+F: 80-85% subrounded to subangular felsic crystals; 5-10% subrounded to angular pumice and tuff fragments; 5% lithic fragments.	40-60	6796.9-6776.9
	Unconsolidated alluvial sediments, sandy silt, light brown (5YR 6/4) to light brown (5YR 5/6). WR: 40-50% poorly-sorted sand; 10-15% moderately-sorted gravel, composed of felsic crystals, trace pumice, tuff fragments and lithic clasts. 10+F (sparse returns): 30-40% white, vitric, rounded tuff and pumice fragments, pumice increases at 70'; 30-35% subrounded intermediate composition volcanic lithic fragments to 0.5 cm; 20-35% free felsic crystals. 35+F: 70-90% felsic crystals; 5-20% white pumice and tuff fragments; 5-10% lithic fragments.	60-75	6776.9-6761.9

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Qct, Cerro Toledo interval	No cuttings returned; no sample available for examination. **Note: The base of the alluvium (Qal) and the contact with the underlying Cerro Toledo interval (Qct) is interpreted to be at 75 ft bgs, based on data from MCOBT-4.4.**	75-90	6761.9-6746.9
	Volcaniclastic sediments, sandy silt to silty sand, very pale orange (10YR 8/2). WR: 5% gravel; 40-60% poorly-sorted sand, increasing across interval; 35-60% fines, decreasing across interval. 10+F: 70% (decreasing across the interval to 25%) subrounded to angular intermediate composition volcanic lithic fragments, frequent hornblende-rich dacite fragments, up to 1.5 cm; 30% (increasing across the interval to 75%) white, vitric, rounded to angular pumice with 1-2% hornblende phenocrysts, trace felsic phenocrysts. 35+F: 30-35% pumice; 30-35% lithic fragments; 30-35% felsic crystals; trace obsidian.	90-105	6746.9-6731.9
Qbo, Otowi Member of the Bandelier Tuff	Tuff, moderate orange pink (5 YR 8/4) to moderate reddish orange (10YR 6/6), poorly welded. WR: 5-40% fine ash with variable percentages of pumice; 5-10% lithic fragments; no free felsic crystals noted. 10+F: 75-95% subrounded to angular, moderate orange pink, vitric pumice with fibrous texture, up to 2 cm, 1-2% felsic phenocrysts and frequent surficial manganese/iron (Mn/Fe) oxide specks; 1-25% subangular to angular intermediate composition volcanic lithic fragments, up to 1 cm, dacite and trace vitrophyre noted; 0-1% felsic crystals. 35+F: 70-80% pumice fragments and lithic fragments as described for 10+F; 20-25% felsic crystals. **Note: The base of the Cerro Toledo interval (Qct) and the contact with the underlying Otowi Member (Qbo) is interpreted to be at 105 ft bgs, based on gamma log.**	105-130	6731.9-6706.9
	Tuff, moderate orange pink (5YR 8/4) to moderate reddish orange (10YR 6/6), poorly welded. WR: 90% fine ash; 5% pumice fragments; 5% lithic fragments; trace felsic crystals. 10+F: 80-85% rounded to angular, moderate reddish orange, vitric pumice with fibrous texture, weathered appearance, up to 1.5 cm, frequent surficial Mn/Fe oxide specks, 1-2% felsic phenocrysts; 15-20% subrounded to angular, very weakly porphyritic to aphyric intermediate composition volcanic lithic fragments; sparse free felsic crystals. 35+F: 50-60% lithic fragments; 40% pumice fragments; 5-10% felsic crystals; constituents as described for 10+F.	130-145	6706.9-6691.9
	No cuttings returned; no sample available for examination.	145-170	6691.9-6666.9
	Tuff, very pale orange (10YR 8/2), poorly welded. WR: predominantly fine ash with 5-30% pumice, 2-5% lithic fragments, trace felsic crystals. 10+F: 45-55% white to moderate orange pink, vitric pumice with fibrous texture, minor surficial Mn/Fe oxide staining, 1-2% felsic phenocrysts, rare mafic phenocrysts; 45-55% very weakly porphyritic to aphyric intermediate composition volcanic lithic fragments; 0-1% felsic crystals. 35+F: 60-75% pumice; 20-35% felsic crystals; 5-10% lithic fragments; constituents as described for 10+F. **Note: drill cuttings from 180-410 ft bgs were collected on a 10 ft interval rather than a 5 ft interval as normally collected.**	170-190	6666.9-6646.9

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Qbo, Otowi Member of the Bandelier Tuff	Tuff, very pale orange (10YR 8/2), poorly welded. WR: predominantly fine ash with 15-25% pumice, 5-10% lithic fragments, and 2-5% free felsic crystals. 10+F: 40-70% white, vitric pumice with fibrous texture, 1-2% felsic phenocrysts, rare mafic phenocrysts, trace surficial Mn/Fe oxide specks; 30-60% subrounded to angular, very weakly porphyritic to aphyric intermediate composition volcanic lithic fragments, biotite dacite noted; trace free felsic crystals; 35+F: 60% felsic crystals, 30% pumice, 10% lithic fragments; constituents as described for 10+F.	190-220	6646.9-6616.9
	Tuff, very pale orange (10YR 8/2), poorly welded. WR: fine ash with 25-40% pumices, 5% lithic fragments, trace felsic crystals. 10+F: 50-60% white to yellow brown, vitric pumice with fibrous texture, trace felsic phenocrysts, surficial Mn/Fe oxide specks and Mn/Fe oxide staining; 40-50% weakly porphyritic to aphyric intermediate composition volcanic lithic fragments; trace felsic crystals. 35+F: 70-75% felsic crystals; 15-25% pumice; 5-10% lithic fragments; constituents as described for 10+F.	220-250	6616.9-6586.9
	Tuff, very pale orange (10YR 8/2), poorly welded. WR: fine ash with varying percentages of pumice and lithic fragments and trace felsic crystals. 10+F: predominately varying percentages of pumice and lithics across interval with trace felsic crystals throughout interval; pumice are white, yellow brown, and olive green, vitric with fibrous texture, up to 2.5 cm, trace felsic phenocrysts, rare mafic phenocrysts, trace Mn/Fe oxide staining (dendritic); lithics are subrounded to angular intermediate composition volcanics, up to 1.5 cm, trace staining. 35+F: 70-75% felsic crystals; 20-25% pumice; 5-10% lithic fragments; constituents as described for 10+F.	250-280	6586.9-6556.9
	Tuff, very pale orange (10YR 8/2), poorly welded. WR: fine ash with 25% pumice fragments, 3-5% felsic crystals, 2-3% lithic fragments. 10+F: 60-80% white, pale yellowish orange, and moderate orange, pumice, vitric, up to 1.5 cm, trace felsic phenocrysts, Mn/Fe oxide staining (dendritic); 20-40% subrounded to subangular, weakly porphyritic to aphyric intermediate composition volcanic lithic fragments, up to 1 cm, Mn/Fe oxide staining, occasionally pitted; trace free felsic crystals. 35+F: 35-60% felsic crystals; 35% pumice fragments; 5% lithic fragments; constituents as described for 10+F.	280-310	6556.9-6526.9
	Tuff, very pale orange (10YR 8/2), poorly welded. WR: fine ash with 30-40% pumice and minor amounts of felsic crystals and lithic fragments. 10+F (variable percentages of pumice and lithics across interval): 40-70% white to pale orange, vitric pumice with trace felsic phenocrysts, frequent surficial Mn/Fe oxide specks occasionally altered to dendritic pattern; intermediate composition volcanic lithics, including andesite, up to 2.5cm, angular. 35+F: 20-25% white, vitric pumice; 70-80% felsic crystals, broken fragments; 5% lithics.	310-330	6526.9-6506.9

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Qbo, Otowi Member of the Bandelier Tuff	Tuff, very pale orange (10YR 8/2), poorly welded. WR: fine ash with 15-20% pumice, 2-3% lithics, trace free felsic crystals. 10+F: 40-60% pumice, white, vitric, generally <0.5cm, minor Mn/Fe oxide specks; 40-60% lithics, intermediate composition volcanics, weakly porphyritic to aphyric, frequently pitted surfaces; trace free felsic crystals. 35+F: 30-50% white, vitric pumice; 50-60% felsic crystals, broken fragments; 5-10% lithics.	330-360	6506.9-6476.9
	Tuff, very pale orange (10YR 8/2), poorly welded. WR: fine ash with 25-30% pumice fragments; minor lithic fragments and felsic crystals. 10+F: 50-80% white to very pale orange, vitric pumice with trace felsic phenocrysts, minor surficial Mn/Fe oxide specks; 30-50% subrounded to subangular intermediate composition volcanic lithic fragments, up to 1.5 cm; trace felsic crystals. 35+F: 60% pumice; 30-45% felsic crystals; 5% lithic fragments; constituents as described for 10+F.	360-390	6476.9-6446.9
	Tuff, very pale orange (10YR 8/2), poorly welded. WR: fine ash with 25-30% pumice fragments; minor lithic fragments and felsic crystals; trace obsidian. 10+F: 75-80% white to very pale orange, vitric pumice, up to 2cm, trace felsic phenocrysts, minor surficial Mn/Fe oxide specks; 20-25% subrounded to subangular intermediate composition volcanic lithic fragments, up to 0.5 cm, weakly porphyritic to aphyric; trace free felsic crystals. 35+F: 55-65% pumice; 35-40% felsic crystals; 5% lithic fragments; constituents as described for 10+F. **Note: Resumed collecting cuttings on a 5ft interval at 410 ft bgs.**	390-415	6446.9-6421.9
	Tuff, very pale orange (10YR 8/2), poorly welded. WR: fine ash with up to 80% pumice fragments; minor lithic fragments and felsic crystals. 10+F: 75-100% white to very pale orange, vitric pumice up to 1 cm, trace felsic phenocrysts, minor Mn/Fe oxide surficial specks; 0-25% subrounded to subangular intermediate composition volcanic lithic fragments including dacite, up to 0.5 cm. 35+F: 40-70% pumice; 30-55% broken felsic crystal fragments; 5-10% lithic fragments; constituents as described for 10+F.	415-435	6421.9-6401.9
	Tuff, very pale orange (10YR 8/2), poorly welded. WR: fine ash with 15-20% pumice fragments; trace lithic fragments and felsic crystals. 10+F: 90-95% white to very pale orange, vitric pumice with fibrous texture, trace felsic phenocrysts, pumice becomes very light gray 450-455'; 5-10% subrounded lithic fragments, up to 0.5 cm, frequent pitted surfaces. 35+F: 60-65% broken felsic crystals; 30-35% pumice; 5% lithic fragments; constituents as described for 10+F.	435-455	6401.9-6381.9

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Qbog, Guaje Pumice Bed of the Otowi Member of the Bandelier Tuff	Tuff, very pale orange (10YR 8/2) to very light gray (N8). WR: fine ash with 35% pumice fragments; trace lithic fragments and felsic crystals. 10+F (455-460'): 95% fresh pumice fragments. 10+F (460-465'): 65% subangular intermediate composition volcanic lithic fragments up to 2 cm; 35% white to very light gray, vitric pumice with fibrous texture, trace felsic phenocrysts. 35+F: 65% pumice; 30% felsic crystals; 5% lithic fragments; constituents as described for 10+F. **Note: The base of the Otowi Member (Qbo) and the contact with the underlying Guaje Pumice Bed (Qbog) is interpreted to be at 455 ft bgs.**	455-465	6381.9-6371.9
	No cuttings returned; no sample available for examination.	465-470	6371.9-6366.9
Tpf, Puye Formation (fanglomerate)	Volcaniclastic sediments, intermixing of cuttings with overlying formation, very pale orange (10YR 8/2) to white (N9). WR: 80-90% pumice; trace ash. 10+F: 90% vitric, clear to white pumice with fibrous texture, trace felsic phenocrysts, rare Mn/Fe oxide surficial specks; 10% subrounded to angular lithic fragments up to 0.5 cm. 35+F: 70% white pumice fragments; 20% broken felsic crystals; 5% lithic fragments; constituents as described for 10+F. **Note: The base of the Guaje Pumice Bed (Qbog) and the contact with the underlying Puye Formation (Tpf) is interpreted to be at 470 ft bgs.**	470-480	6366.9-6356.9
	Volcaniclastic sediments, intermixing of cuttings with overlying formation, sandy silt, grayish orange (10YR 7/4) to very pale orange (10YR 8/2). WR: fine ash (silt fraction) with poorly-sorted sand grains of pumice, felsic crystals, and lithic fragments; minor gravel fraction of subangular to angular lithic fragments. 10+F: 50% rounded to subangular, white, vitric pumice; 50% intermediate composition volcanic lithic fragments, angular, numerous subrounded clasts, up to 1.5 cm. 35+F: 60% pumice; 20% lithic fragments; 20% felsic crystals; constituents as described for 10+F.	480-485	6356.9-6351.9
	Volcaniclastic sediment, gravel with sand , varied colored, medium light gray (N6) to light brownish gray (5YR 6/1). WR: moderately-sorted gravel, up to 2 cm, angular to subrounded; poorly-sorted sand; sand and gravel of intermediate composition volcanic fragments. 10+F: predominantly gray, subrounded to angular intermediate composition volcanic lithic fragments up to 2 cm, generally weakly porphyritic with aphanitic groundmass, rare oxide staining, dacite and andesite noted. 35+F: finer fraction as described for 10+F with trace pumice and felsic crystals.	485-500	6351.9-6336.9
	Volcaniclastic sediment, moderately-sorted gravel with sand. WR: gravel up to 1cm, subrounded. 10+F: predominantly gray, subrounded to angular intermediate composition volcanic lithic fragments, up to 1 cm, generally weakly porphyritic, aphanitic groundmass, rare oxide staining, dacite and andesite noted. 35+F: finer fraction as described for 10+F with trace pumice and felsic crystals.	500-505	6336.9-6331.9

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Tpf, Puye Formation (fanglomerate)	Volcaniclastic sediment, sandy gravel. WR: 80-85% moderately-sorted (up to 1.5 cm) gravel of intermediate composition volcanic clasts and sandstone/siltstone fragments, subrounded to angular; 10-15% sand; 5-10% fines. 10+F: 30% sandstone/siltstone/clay fragments increasing to 70% from 510-515 ft bgs, trace laminar bedding, fragments up to 2 cm, angular; 30-70% subrounded intermediate composition volcanic lithic fragments, up to 1 cm, predominantly very weakly porphyritic to aphyric, dacite noted and rare rhyolitic composition clast. 35+F: finer fraction as described for 10+F, trace pumice and felsic crystals.	505-520	6331.9-6316.9
Tb4, Cerros del Rio Basalt	Poor returns: mixed cuttings of volcaniclastic sediments as described for 505-520' with minor vesicular basalt fragments. **Note: The base of the Puye Formation (Tpf) and the contact with the underlying Cerros del Rio Basalt (Tb4) is interpreted to be at 520 ft bgs.**	520-525	6316.9-6311.9
	Basalt, grayish black (N2) with remnants of fines from volcaniclastic sediments as described for 505-520 ft bgs; volcaniclastic sediments and sandstone fragments decrease across interval. WR: vesicular basalt chips up to 2.5cm with coating of fines. 10+F: 70-99% vesicular basalt chips with 1-2% olivine phenocrysts, oxide staining, clay infilling in vesicles frequent from 525-535 ft bgs; 30% subrounded intermediate composition volcanic lithic fragments (remnant from overlying formation), decrease to 1% at 530 ft bgs. 35+F: basalt chips and intermediate composition volcanic fragments as described for 10+F; sandstone fragments.	525-540	6311.9-6296.9
	TOTAL BOREHOLE DEPTH (TD) IS AT 540 FT BGS.		

NOTES:
Stratigraphic contacts are based on available information from review of drill cuttings and geophysical logs.

REFERENCES:
Folk, Robert L., 1980, Petrology of Sedimentary Rocks, Hemphill Publishing Company.
The Geological Society of America, 1991, Rock-Color Chart.

Appendix C

Slug Test Analysis

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I-4 SLUG TEST ANALYSIS

INTRODUCTION

This section describes the analysis of hydraulic testing conducted in April 2006 on intermediate well I-4, located in Mortandad Canyon. The primary objective of the testing and analysis reported here was to estimate the hydraulic conductivity of the saturated perched zone screened in I-4. Because of the limited saturated height of water standing in the well and the negligible production capacity, I-4 was tested by slug testing.

I-4 is completed with a single screen, 23 feet (ft) long between the depths of 499 and 522 ft, straddling the Puye Formation and Cerros del Rio basalt. The contact between the Puye and Cerros del Rio is at a depth of 520 ft. At the time of testing, the static water level measured in I-4 was 519.86 ft below ground surface, essentially at the top of the Cerros del Rio. It is not known whether the observed water in the well represents saturated Cerros del Rio basalt or simply a thin (just a few inches) Puye Formation saturated zone resulting from water perching on top of the basalt.

Testing was performed from April 7 to 14, 2006. Testing consisted of strapping a pressure transducer near the bottom of a 2-inch (in.) diameter, 5-foot (ft) long solid slug and performing a "slug-in" test by rapidly pushing the slug assembly into the water. The screen was underlain by a 3-ft sump, so there was just enough room to immerse the slug. Forcing the slug into the water raised the level in the screen and filter pack based on the volume displaced by the slug. The subsequent decay of the water level was used to obtain a lower-bound hydraulic conductivity for the short screened interval.

SLUG TEST METHODS

A common method used to analyze slug tests is the Bouwer & Rice method (1976). This procedure analyzes recovery data following a sudden raising or lowering of the water level in the well. The theoretical basis for this technique is based on the water level in the well being lowered "instantaneously." For exceedingly tight sediments, the method is valid, even when it takes a finite amount of time to install the slug and raise the water level in the well. In this instance, the water level recovery rate was exceedingly sluggish (hours) compared to the duration of installing the slug (just a couple of minutes), making the slug test analytical procedure applicable to the data.

When water levels equilibrate back toward the static level following a slug event, the observed water levels can be used to estimate a lower-bound value for hydraulic conductivity based on the rate of water level recovery. The following formula, in mixed units, can be applied to perform the calculation according to the Bouwer & Rice procedure:

$$K = \frac{1.25}{tL} \ln\frac{y_1}{y_2} \ln\frac{R}{r_w}\left[\left(576r_w^2 - D_O^2\right)S_y + D_I^2\right]$$

where,

K = hydraulic conductivity, in feet per day
y_1, y_2 = measurements of the water level change from static conditions, in feet
t = elapsed time between measurements, in minutes
R = effective radius of influence, in feet
r_w = borehole radius, in feet (0.51 ft)
D_O = outside diameter of well casing, in inches (5.0 in.)
D_I = inside diameter of well casing, in inches (4.5 in.)
S_y = short-term specific yield of filter pack (approximately 25 percent)

The computed K value is considered a lower-bound estimate of the true formation conductivity. This is because the water level equalization rate is a function of both the conductivity and the well efficiency whereas the Bouwer & Rice equation is based on the assumption of a 100 percent efficient well. If the actual well is less than 100 percent efficient, the water level equalization rate will be slowed compared to theoretical expectations and, thus, will cause the K value to be underestimated.

The Bouwer & Rice formula is specifically crafted to account for water refilling both the well casing and the surrounding filter packed annulus during recovery. The volume of water refilling the filter pack is related to the term S_y, the short-term specific yield of the pack. This parameter generally must be estimated.

The term, R, referred to as an effective radius of influence, is actually an empirical parameter evaluated as part of the Bouwer & Rice procedure that is computed to take into account partial penetration of the saturated zone. Its value is determined as a function of the geometry of the well and static water level, as well as the depth of the saturated zone beneath the well screen. For the calculations presented below, an arbitrary saturated thickness of 10 ft was used. Once the selected thickness is chosen to significantly exceed the saturated screen length, the calculations are insensitive to this arbitrary value, because the presence or absence of saturated materials well below the screen has little effect on hydraulic response. Therefore, it was only necessary to select a saturated thickness (10 ft in this case) greater than the saturated screen length (2.14 ft).

I-4 DATA ANALYSIS

The solid slug was run into I-4 and lowered into the sump at 4:30 pm on April 7. Manual water level measurements made before and after slug placement showed that the water level rise caused by the slug placement was approximately 0.41 ft. The equipment was left in place until 9:48 am on April 14, at which time it was pulled from the well.

BACKGROUND DATA

Figure 1 shows the data set recorded in I-4 over the week-long observation period along with the barometric pressure recorded during the same period. Curiously, to get the peaks and valleys on the curves to coincide, it was necessary to adjust the time variable for a 4-hour (hr) lag in the hydrograph data compared to the barometric pressure data.

On the left side of the graph, the "spike" associated with slug placement can be seen followed by a steep decline as water levels recovered during the afternoon and evening of April 7. These early data were used to evaluate the hydraulic conductivity of the saturated screened interval.

Unfortunately, the transducer appeared to produce spurious data. There are two examples of this. First, there were several instances where the recorded head measurements changed instantaneously by about 0.1 ft on April 8 and 9. Figure 2 shows an expanded-scale plot of the data from the afternoon and evening of April 8 that makes it easier to see this effect. The observed jumps in apparent water level reflect equipment problems rather than true water level changes.

Also evident on Figure 1 is that when the barometric pressure increased, the formation pressure *decreased*, and vice-versa – the opposite of the expected response. Normally, when barometric pressure increases (or decreases), the formation pressure also increases (or decreases) by a fraction of the barometric change, where the fraction equals 100 percent minus the barometric efficiency of the well. The observed response on Figure 1 is ostensibly impossible and, therefore, the transducer may have produced erroneous data. If the transducer data are correct, however, it would indicate some kind of unusual elastic effect, perhaps similar to reverse water level fluctuations sometimes observed in piezometers near pumping wells.

The transducer manufacturer, In-Situ, Inc., reviewed the I-4 data set and concluded that the transducer had malfunctioned and produced erroneous data.

Despite the unusual reported transducer response compared to barometric pressure, other aspects of the data set look reasonable. For example, prior to submergence and following retrieval, the transducer reported pressure readings near atmospheric pressure. Also, when the transducer was submerged into five ft of water, the measured head rise appeared normal, as did the head decline over the next several hours. Finally, when the transducer was retrieved, the measured head dropped as expected. In other words, much of the observed response looked legitimate.

SLUG TEST ANALYSIS

The recovery data following initial slug submergence were plotted on a semilog graph with head change on the logarithmic scale and time on the linear scale. Figure 3 shows the resulting data plot and the selected line of best fit. The concave-upward shape of the data plot agreed with theoretical expectations for slug test response. Applying the Bouwer & Rice equation to the data yielded an average lower-bound hydraulic conductivity value of 0.12 ft per day for the upper 2.14 ft of saturated material penetrated by I-4.

The corresponding lower-bound transmissivity of the saturated screen zone is 2.14 x 0.12 = 0.26 square ft per day. This could represent the lower-bound transmissivity of the upper two ft of the Cerros do Rio basalt. If the basalt is impermeable at this location, however, this figure could represent the properties of a very thin layer of saturated Puye just above the basalt. From the available data it is not possible to distinguish between these two scenarios.

SUMMARY

The following information summarizes the results of the slug test conducted on I-4:

1. The pressure transducer produced spurious response in the form of instantaneous water level "jump" of about 0.1 ft.
2. The hydrograph data record showed an ostensibly impossible response compared to barometric pressure (decreasing when barometric pressure increased, and vice-versa), possibly another indication of transducer malfunction.
3. Despite the obvious and apparent data anomalies, certain aspects of the transducer output appeared reasonable, such as transducer submergence and retrieval effects, water level decay following slug submergence, and the overall magnitudes of the observed heads – both atmospheric and submerged.
4. Slug test analysis of the water level decay data following slug submergence yielded an average lower-bound hydraulic conductivity for the 2.14-ft saturated screen zone of 0.12 ft per day.

REFERENCES

Bouwer, Herman and Rice, R. C., 1976. A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers With Completely or Partially Penetrating Wells, Water Resources Research, vol. 12, no. 3, pp. 423-428.

Figure 1. Comparison of I-4 Apparent Hydrograph and TA-54 Adjusted Barometric Pressure

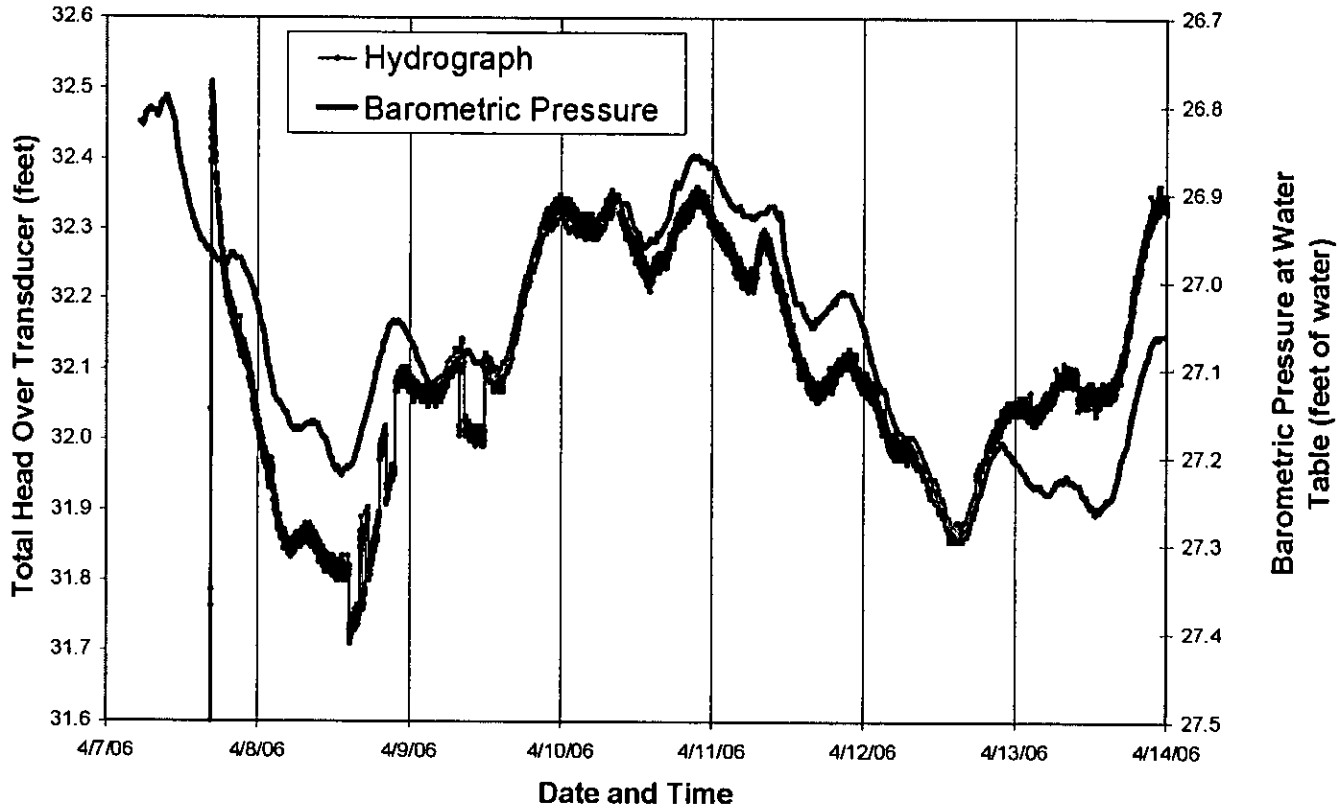


Figure 2. Expanded View Showing Transducer Malfunction

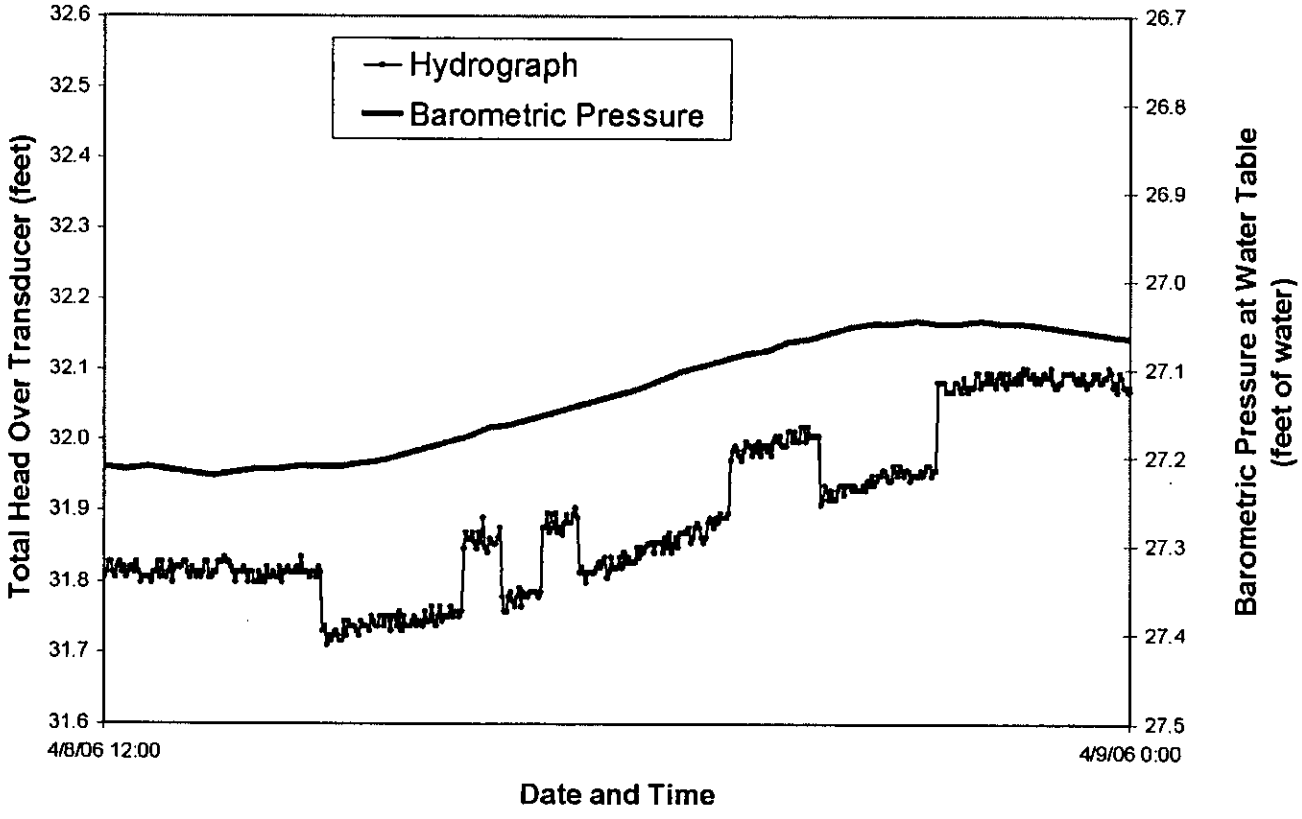
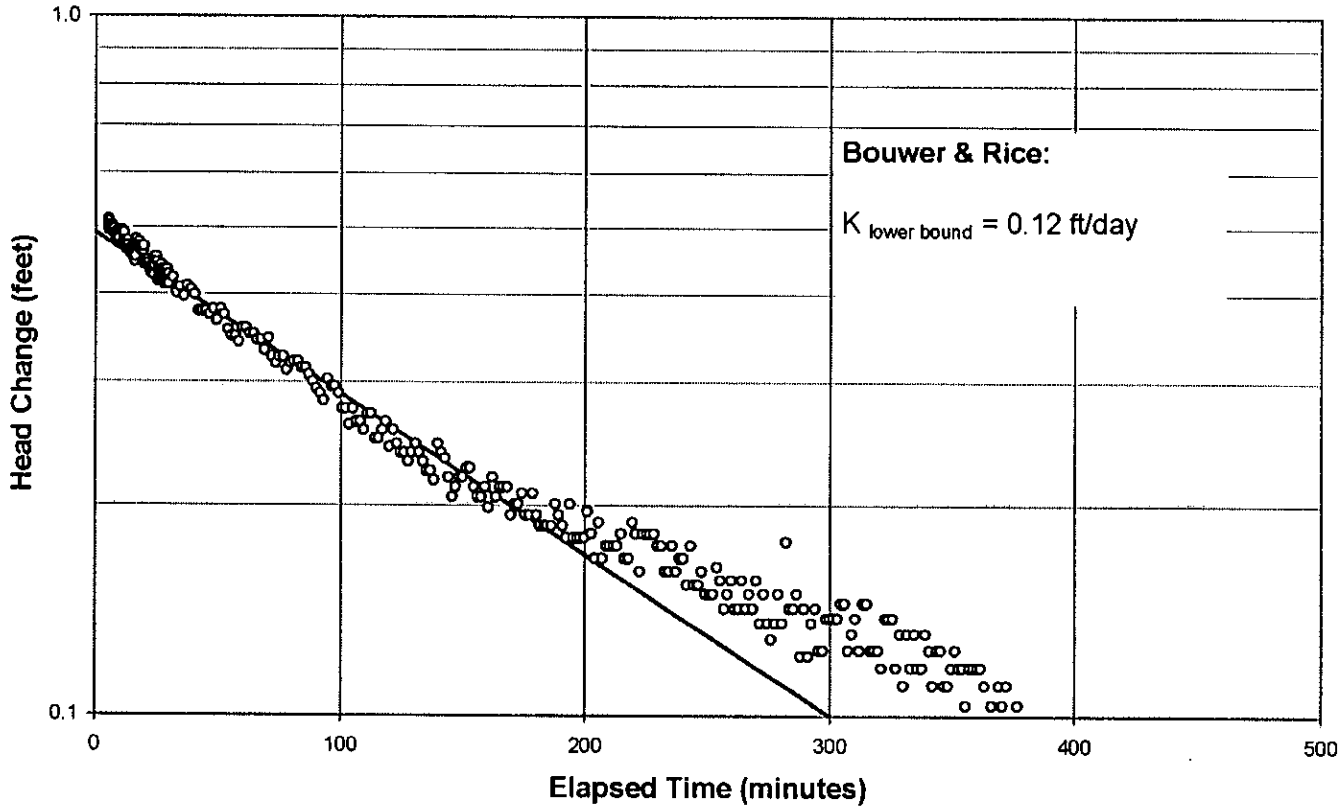


Figure 3. Bouwer and Rice Slug Test Analysis for I-4



FINAL
COMPLETION REPORT
INTERMEDIATE WELL I-5
LOS ALAMOS NATIONAL LABORATORY
LOS ALAMOS, NEW MEXICO
PROJECT NO. 49436

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Prepared by:

KLEINFELDER

8300 Jefferson NE, Suite B
Albuquerque, New Mexico 87113

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LIST OF ACRONYMS AND ABBREVIATIONS

ags	above ground surface
amsl	above mean sea level
ASTM	American Society for Testing and Materials
bgs	below ground surface
BMPs	best management practices
°C	degrees Celsius
DOE	United States Department of Energy
DTW	depth to water
DTHH	down-the-hole hammer
FSF	Field Support Facility
ft	foot/feet
ft^3	cubic feet
gal.	gallon/gallons
gpm	gallons per minute
hp	horsepower
hr	hour/hours
ID	inner diameter
in.	inch/inches
Kleinfelder	Kleinfelder, Inc.
LANL	Los Alamos National Laboratory
lb	pound/pounds
µS/cm	microSiemens per centimeter
NM	not measured
NMED	New Mexico Environment Department
NTUs	nephelometric turbidity units
OD	outer diameter
pH	potential of hydrogen ions
ppm	parts per million
psi	pounds per square inch
RCT	radiation control technician
SC	Specific Conductance
SMO	Sample Management Office
SSLs	Soil Screening Levels
S_y	specific yield
TA	Technical Area
TD	total depth
TKN	total Kjeldahl nitrogen
US	United States
WDC	WDC Exploration and Wells

ABSTRACT

Intermediate well I-5 was installed as part of the Risk Reduction and Environmental Stewardship-Remediation Services project at Los Alamos National Laboratory (LANL) in accordance with the "Mortandad Canyon Groundwater Work Plan, Revision 1" (LANL 2004) and the "Final Drilling Plan for Intermediate Wells Mortandad Canyon, Los Alamos National Laboratory" (Kleinfelder 2004b). The United States (US) Department of Energy (DOE) with technical assistance from LANL contracted and directed the installation of this well.

Data from I-5 will be used in conjunction with data from other wells in Mortandad Canyon to improve the conceptual model of the geology, hydrogeology, and hydrochemistry of the area to provide data for numerical models that address contaminant migration in the vadose (unsaturated) zone. This information will be used to facilitate decision-making with regard to regulatory compliance, risk assessment, and remediation.

The majority of the fieldwork was conducted from October 14 through October 25, 2004. The I-5 borehole was drilled to a depth of 717 feet (ft) below ground surface (bgs) using air-rotary and fluid-assisted air-rotary drilling methods. Samples of drill cuttings were collected at regular intervals for potential stratigraphic, petrographic, and geochemical analysis. Geophysical and video logging was performed in the open borehole to help delineate the hydrostratigraphy and to facilitate proper well design. The stratigraphic units encountered during drilling include, in descending order, alluvium, Tshirege Member of the Bandelier Tuff, Cerro Toledo interval, Otowi Member of the Bandelier Tuff, the Guaje Pumice Bed, the Puye Formation, and Cerros del Rio basalt. The Tsankawi Pumice Bed was noted from 65 to 66 ft bgs in the adjacent R-15 corehole (LANL 2001b).

The I-5 borehole was completed as a characterization well with a single-screened interval from 689.0 to 699.0 ft bgs within the Cerros del Rio basalt. The total depth (TD) of the well is 702.7 ft bgs. The depth to water (DTW) after well installation, development, aquifer test, and recovery was 687.30 ft bgs.

1.0 INTRODUCTION

This completion report summarizes the site preparation, drilling, testing, and related activities for intermediate well I-5. Kleinfelder, Inc. (Kleinfelder), under contract to the United States (US) Army Corps of Engineers, was responsible for executing drilling, installing, testing, and sampling activities. The US Department of Energy (DOE) with technical assistance from Los Alamos National Laboratory (LANL) contracted and directed this work.

Intermediate well I-5 is located in Technical Area (TA) 5 in Mortandad Canyon, approximately 66 feet (ft) west of characterization well R-15 (Figure 1.0-1). I-5 was installed to assess intermediate perched groundwater within the Cerros del Rio basalt, down-gradient from waste outfalls at TA-35 and TA-50 and to provide additional data on the perched groundwater encountered during the drilling of R-15 (LANL 2001b). The data quality objectives are provided in the "Mortandad Canyon Groundwater Work Plan, Revision 1" (LANL 2004) and the "Final Drilling Plan for Intermediate Wells, Mortandad Canyon, Los Alamos National Laboratory" (Kleinfelder 2004b). Water quality, geochemical data, aquifer characteristics, and geologic information obtained from I-5 will augment the conceptual model and knowledge of contaminant distribution in the intermediate perched zone in the Mortandad Canyon system.

The objectives of the drilling activities were to collect cuttings of geologic formations, to collect groundwater samples from perched intermediate groundwater zones, and to install a single-screen characterization well in the base of the Cerros del Rio basalt. The projected total depth (TD) of the borehole was 760 ft below ground surface (bgs); the actual TD of the I-5 borehole was 717 ft bgs. The I-5 borehole was completed as a characterization well with a single-screened interval from 689.0 to 699.0 ft bgs. Due to the proximity to the R-15 coring location, a corehole was not drilled.

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, New Mexico office and LANL's Records Processing Facility. Further analysis and interpretation of geologic, geochemical, and aquifer data will be included in separate technical documents to be prepared by LANL.

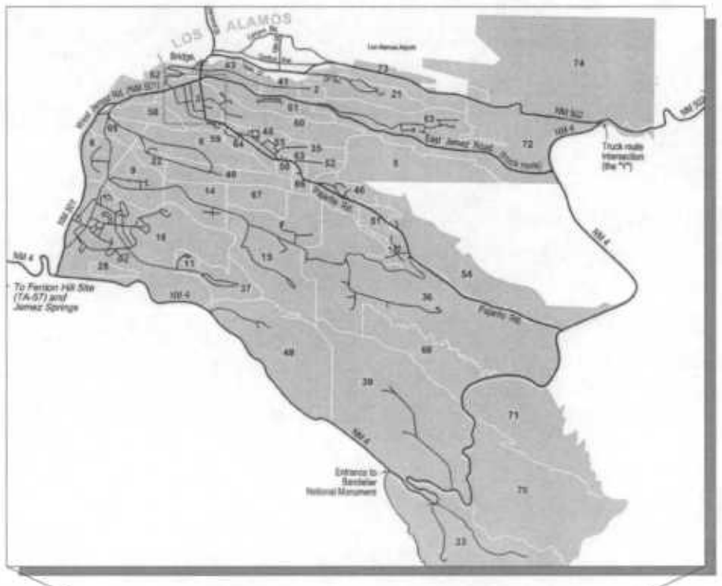
2.0 SITE PREPARATION AND DRILLING ACTIVITIES

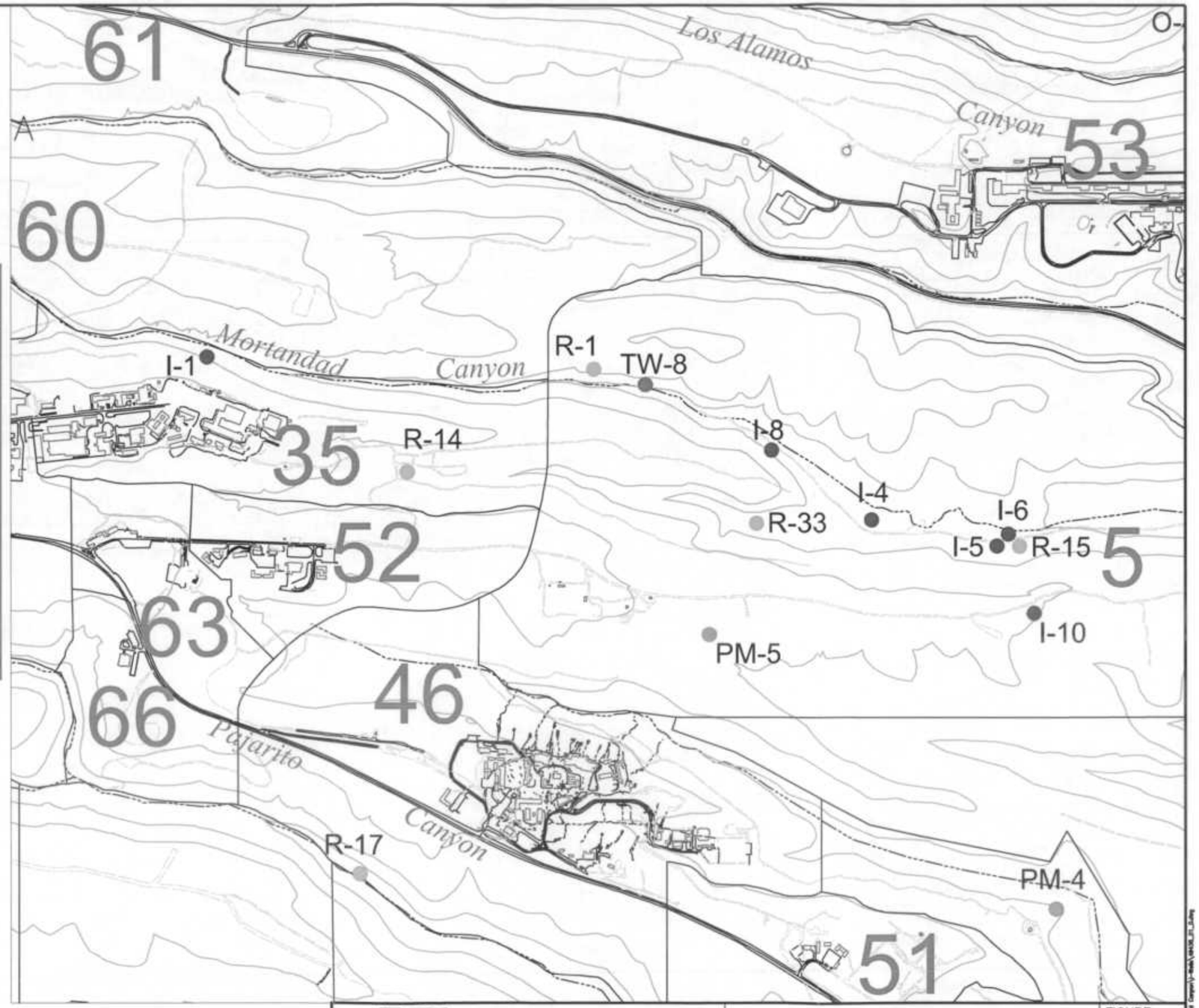
Site preparation consisted of constructing and lining the cuttings pit, erecting silt fencing to prevent erosion and runoff from the drill site, and setting up the exclusion zone. Best management practices, also known as BMPs, were installed as specified in the "Storm Water Pollution Prevention Plan, Mortandad Canyon Ground Water Work Plan, Los Alamos National Laboratory" (Kleinfelder 2004a). EnviroWorks, Inc. completed these tasks from September 29 through October 11, 2004. A radiation control technician (RCT) from LANL's Health, Safety, and Radiation Protection Group-1 screened the site before site preparation activities. A geology trailer, generator, compressor, and safety lighting equipment were moved to the site during the subsequent mobilization of drilling equipment.

Drilling activities occurred between October 14 and October 18, 2004. Well installation continued through October 25, 2004. The borehole was drilled to a TD of 717 ft bgs, and the well was completed with one screened interval near the base of the Cerros del Rio basalt from

Legend

- = Intermediate perched zone wells (proposed)
- = Regional aquifer wells installed since 1998
- = Older test wells
- = Water supply wells
- 58 = Technical area identification
- = 100-ft contours





1000 0 500 1000

SCALE: 1 inch = 1000 ft

KLEINFELDER	
Drawn By: C. Landon	Date: April 2006
Project No.: 49436	Filename: 49436_01_0.dwg
Scale: 1" = 1000'	Revision: –

SITE LOCATION MAP
Intermediate Wells I-1, I-4, I-5, I-6, I-8, I-10
Mortandad Canyon
Los Alamos National Laboratory
Los Alamos, New Mexico

FIGURE
1.0-1

689.0 to 699.0 ft bgs. Drilling activities were performed generally in one 12-hour (hr) shift per day, 7 days per week, by the drill crew and two site geologists.

WDC Exploration & Wells (WDC) drilled I-5 using direct air-rotary drilling techniques. They used a GEFCO Speedstar 50K drill rig equipped with conventional drilling rods and drill collars, tricone and down-the-hole hammer (DTHH) bits, air compressors, and support equipment. Drilling fluids, consisting of a mixture of municipal water with QUIK-FOAM® surfactant, were used as needed to improve borehole stability and facilitate cuttings removal from the borehole. An approximate tally of the total drilling fluids introduced into the borehole, as well as the total fluids recovered, is presented in Table 2.0-1.

Table 2.0-1

Introduced and Recovered Fluids

Material		Volume (gallons)
Introduced	QUIK-FOAM®	55
	Potable water	2,900
	Total introduced fluids[1]	2,955
Recovered	Total recovered fluids[2]	2,170

[2]Represents fluids that were introduced during drilling
[3]Represents the estimated fluid volume recovered during drilling, well development, and hydrologic testing

On October 14, 2004, mobilization of drilling equipment and supplies to the I-5 drill pad was initiated. Final site preparations were completed.

On October 15, drilling began using a 12¼-inch (in.) tricone bit that was advanced to 62.8 ft bgs using air-only drilling methods. Concurrently, $13^{3}/_{8}$-in. outside diameter (OD) surface casing was installed to a depth of 59 ft bgs.

On October 16, drilling resumed using the tricone bit and the borehole was advanced to 482 ft bgs. Potable water was used as a drilling additive beginning at 62.8 ft bgs. Beginning at 108 ft bgs, QUIK-FOAM® was used in addition to water. Upon reaching 482 ft bgs, the drill string was removed from the borehole (tripped out) in preparation for geophysical logging.

On October 17, depth to water (DTW) measurements indicated the borehole was dry with minor formation material (slough) having accumulated. Natural gamma and induction array geophysical logging was conducted by Kleinfelder. WDC replaced the tricone bit with a DTHH bit. The borehole was advanced from 482 to 570 ft bgs.

On October 18, the borehole was advanced to 717 ft bgs. The drill string was tripped out in preparation for DTW monitoring and geophysical logging.

On October 19, DTW was observed at 687.3 ft bgs, indicating approximately 30 ft of water had accumulated in the borehole. DTW measurements were performed for approximately 6 hr. The final DTW reading was 686.6 ft bgs. Schlumberger began geophysical logging (Section 4.0).

On October 20, geophysical logging was completed, the logs were reviewed, and the well design developed. A groundwater sample (sample set CAMO-05-56736 and CAMO-05-56741) was collected from the open borehole. The DTW prior to sampling was 685.53 ft bgs. Details of the groundwater sampling are presented in Section 3.2.

On October 21, DTW was measured at 685.30 ft bgs using the depth to water sounder. Alpha Southwest, Inc. conducted a video of the borehole. During video logging, moisture was observed on the borehole walls below 600 ft bgs with standing water at 686 ft bgs. The final borehole video log is located on the DVD in Appendix A. Approval of the well design was received and preparations for well construction were initiated. The borehole total depth was measured at 713 ft bgs, indicating 4 ft of formation material had accumulated in the borehole. A lower bentonite seal was emplaced from 713 to 707 ft bgs. Installation of the well casing and screen began. Details of the well construction are presented in Section 6.0.

On October 22, and October 23, the surface of the hydrated bentonite was measured at 706.5 ft bgs. The remaining well casing was installed and the screen was set at 689.0 to 699.0 ft bgs. Annular materials were placed to a depth of 72 ft bgs and the $13^3/_8$-in surface casing was retracted and removed.

On October 24, the drill rig and support equipment were demobilized from the I-5 well site.

On October 25, cement grout was applied to the annular space from 72 ft bgs to 2 ft bgs. The surface pad, the protective casing monument, and remaining 2 ft of annular seal were also installed.

3.0 SAMPLING ACTIVITIES

Cuttings, groundwater screening samples, and waste characterization samples were collected at I-5. Sampling activities were conducted in accordance with the drilling plan (Kleinfelder 2004b). Deviations are noted in Section 9.0.

3.1 Cuttings Sampling

As drilling conditions permitted, cuttings were collected at approximately 5-ft intervals from the borehole discharge line. Portions of the cuttings samples were sieved (using #10 and #35 mesh) and placed in chip trays along with unsieved cuttings. The cuttings were examined to prepare the lithologic log provided in Appendix B.

An additional aliquot of the >#10 fraction of cuttings was prepared for all intervals where sufficient returns were available. The sieved fractions were placed in labeled plastic bags and submitted to LANL for potential mineralogic, petrographic, and geochemical analyses. The results of these analyses will be included in a future LANL investigation report. The remaining cuttings were sealed in Ziploc® bags, labeled, and archived in core boxes at the Field Support Facility (FSF). With the exception of waste characterization, drill cuttings were not submitted for chemical analyses.

LANL RCTs screened the cuttings prior to their removal from the site.

3.2 Groundwater Sampling

On October 20, 2004, a groundwater-screening sample was collected from the I-5 open borehole. Prior to collecting the sample, the DTW was 685.53 ft bgs, the borehole TD was 717 ft bgs. Within this interval, the zone of groundwater contribution is not known. The groundwater-screening sample (sample set CAMO-05-56736 and CAMO-05-56741) was collected using a clean stainless-steel bailer and submitted to LANL's Sample Management Office (SMO) for anions, metals, tritium, stable isotopes, perchlorate, total Kjeldahl nitrogen (TKN), and radionuclide analyses.

The completed well was sampled on January 10, 2005. Sample CAMO-05-56738 was collected near the completion of well development and submitted to the SMO for tritium, stable isotopes, TKN, and radionuclide analyses.

3.3 Waste Characterization Sampling

On January 10 and 11, 2005, samples of drill cuttings, decontamination water, recovered drilling fluids, and groundwater generated during well development/aquifer testing were collected for waste characterization. These samples were submitted to Hall Environmental Analysis Laboratory in Albuquerque, New Mexico, for anions, polychlorinated biphenyls, volatile organic compounds, semi-volatile organic compounds, metals, mercury, radionuclides, perchlorate, tritium, and explosives analyses. Analytical results were received on February 8, 2005, and submitted to DOE and LANL for review.

4.0 BOREHOLE LOGGING

Kleinfelder logged the I-5 borehole prior to well installation to acquire visual observations and geophysical data to help characterize borehole conditions and hydrostratigraphy to facilitate well design. Table 4.0-1 summarizes the video and geophysical logs that were run in the I-5 borehole.

Table 4.0-1
Borehole Logging

Operator	Date	Cased Footage (ft bgs)	Open-Hole Interval (ft bgs)	Logged Interval (ft bgs)	Remarks	Tools
Kleinfelder	10/17/04	0-59	59-482 (slough to 480.5 ft bgs)	65-480	Dry hole based on DTW measurement	Array induction, natural gamma
Schlumberger	10/19/04	0-59	59-717	59-717	Gamma ray re-run for depth correction; formation at high end for array induction tool	Combinable magnetic resonance, compensated neutron, triple detector litho-density, array induction, gamma ray, elemental capture, caliper
Alpha Southwest	10/21/04	0-59	59-717	65-704	Standing water at 686 ft bgs	Video camera

4.1 Video Logging

Alpha Southwest, Inc. conducted a borehole video log on October 21, 2004, to assess for evidence of groundwater-bearing zones. Borehole walls were moist beginning at approximately 600 ft bgs. Standing water was encountered at approximately 686 ft bgs. The video camera continued into the groundwater; however, visibility was poor and the log was terminated. The borehole video log is included as a DVD in Appendix A.

4.2 Geophysical Logging

On October 17, Kleinfelder used a Mount Sopris MGXII geophysical console to run LANL-owned array induction and natural gamma geophysical tools from 65 to 480 ft bgs. Natural gamma logging was used primarily to evaluate the geology and to locate geologic contacts; array induction logging was used primarily to evaluate the presence of perched water. The Mount Sopris natural gamma and array induction (conductivity) logs are shown in Figure 4.2-1.

On October 19, the day after reaching a TD of 717 ft bgs, Schlumberger ran a standard suite of eight geophysical tools. An integrated log analysis, using as many of the processed logs as possible, was performed to model the near-well bore substrate lithology/mineralogy and pore fluids. This analysis was performed using the Elemental Log Analysis program, a petrophysical interpretation program designed for depth-by-depth quantitative formation evaluation from borehole geophysical logs. The report for this logging and a CD containing electronic copies of the geophysical logs are included in Appendix C.

5.0 HYDROGEOLOGY

LANL Earth and Environmental Sciences 6 staff provided a preliminary interpretation of geologic contacts based on borehole cuttings. Groundwater occurrence is interpreted from drilling observations, open-hole video logging, geophysical logging, and water-level measurements.

5.1 Geology

Visual examination of borehole cuttings, open-hole video logs, and geophysical logs were used to determine the stratigraphy of I-5 (Figure 5.1-1). Geophysical logs were integral to interpreting formation contacts because drill cuttings commonly contain material from more than one stratigraphic unit. The stratigraphic units encountered during drilling of the I-5 borehole, in descending order, are alluvium, Tshirege Member of the Bandelier Tuff, Cerro Toledo interval, Otowi Member of the Bandelier Tuff, the Guaje Pumice Bed, Puye Formation, and Cerros del Rio basalt. The Tsankawi Pumice Bed was noted at 65 to 66 ft bgs in the adjacent R-15 corehole (LANL 2001b). Appendix B contains the lithologic log for I-5 based on visual examination of the drill cuttings.

5.2 Groundwater Occurrence and Characteristics

Interpretation of processed geophysical data from October 19, 2004, in the open I-5 borehole indicates that the perched intermediate zone groundwater occurred within the Cerros del Rio basalt at 685 ft bgs. The analysis further indicates that the interval from 685 ft bgs to the bottom of the logging measurements (715 ft bgs) was fully saturated, and above 685 ft bgs no fully saturated zones were indicated.

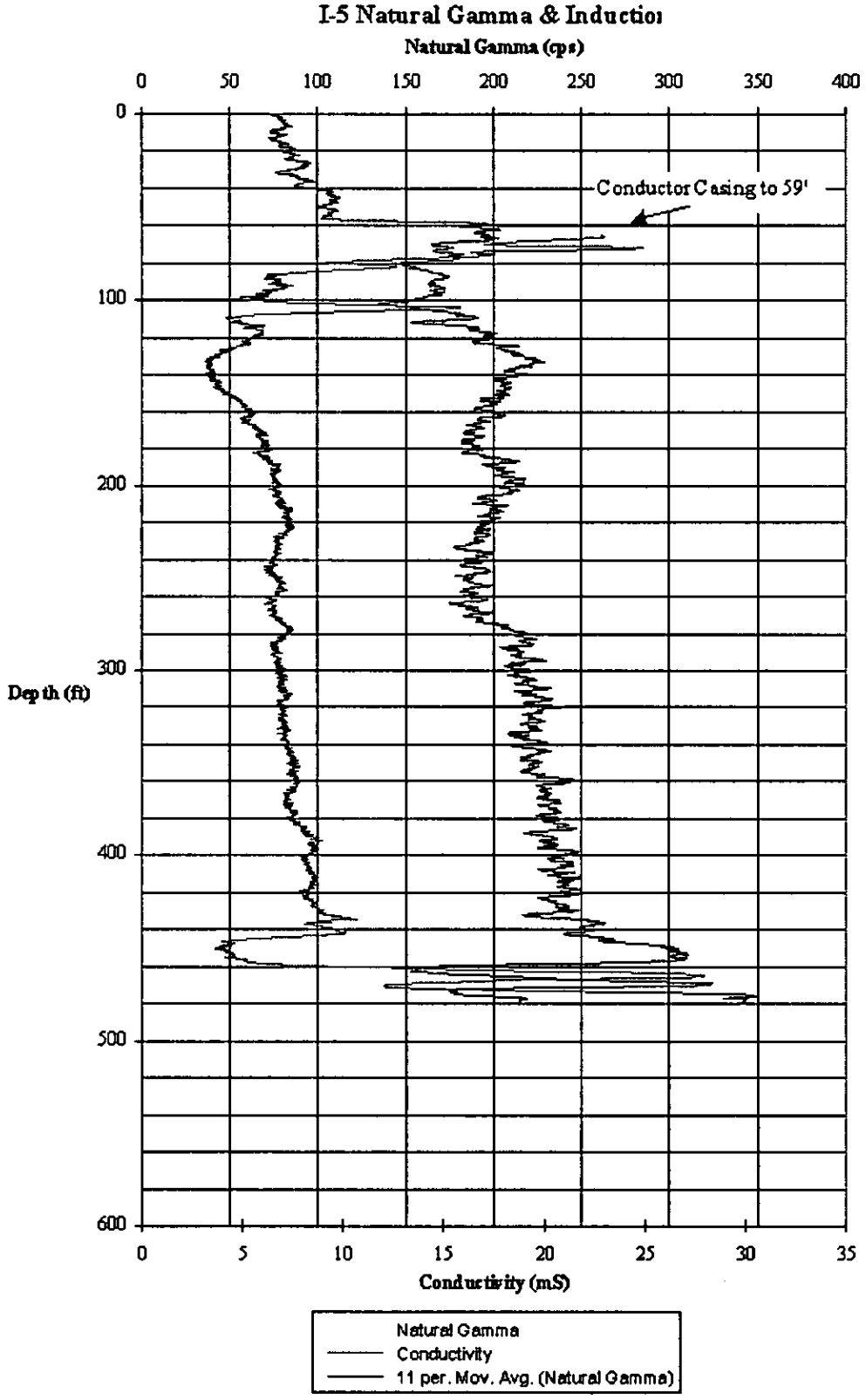
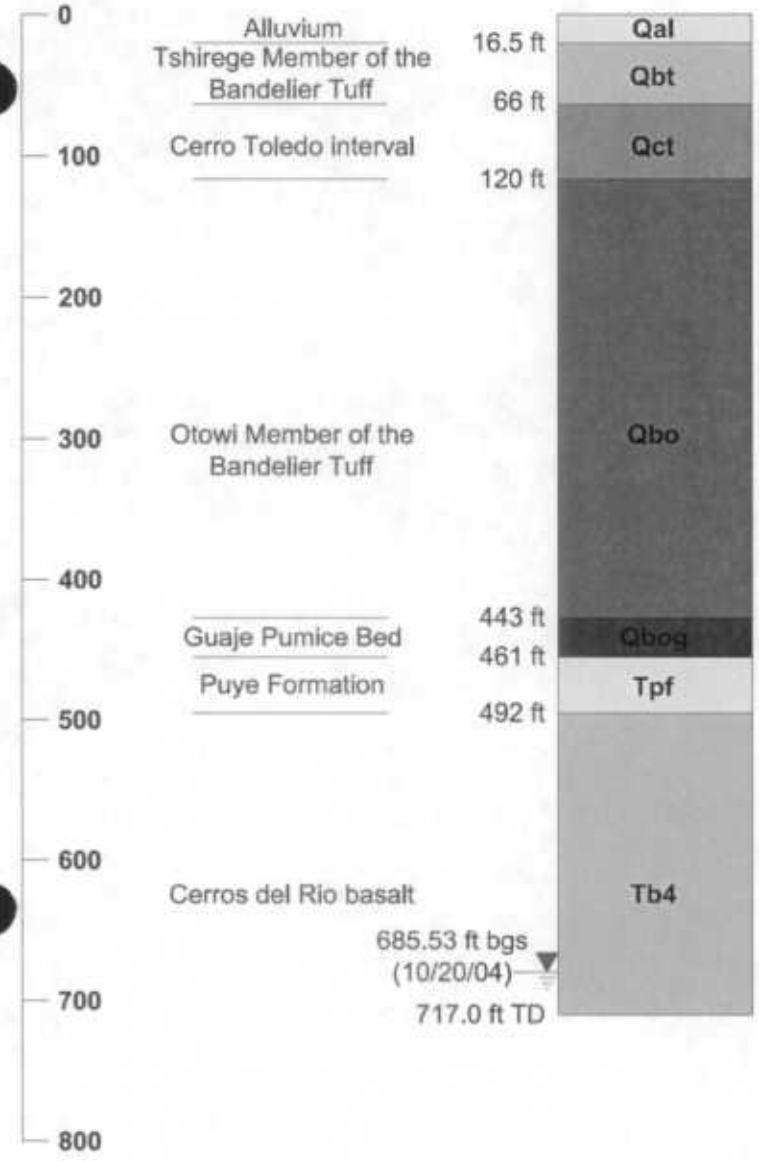


Figure 4.2-1. Natural Gamma and Induction Array Geophysical Logs



DRILLING INFORMATION

DRILLING COMPANY/PERSONNEL
WDC Exploration
M. Daniels, C. Matthews, C. Bufkin, R. Price
Drill Rig: Speedstar 90k

DRILLING METHOD
Air Rotary Tri-cone bit with casing hammer (0 - 59 ft bgs)
Air Rotary Tri-cone bit (59 - 482 ft bgs)
Air Rotary Downhole hammer (482 - 717 ft bgs)

Borehole
Drilling Start Date: 10/15/04 Time: 14:40
Drilling End Date: 10/18/04 Time: 18:32

DRILLING FLUID TYPE
Air (0 - 62.8 ft bgs)
Air+water (62.8 - 108 ft bgs)
Air+water+QUIK-FOAM® (108 - 717 ft bgs)

Notes:
1. Geologic contacts are preliminary and subject to change.
2. No wet/saturated zones noted above approximately 685 ft bgs.
3. Groundwater level in open borehole after reaching TD was 685.53 ft bgs.

KLEINFELDER

Drawn By: C. Landon	Date: April 2006
Project No.: 49436	Filename: 49436_01_0.dwg
Scale: not – to – scale	Revision: –

BOREHOLE SUMMARY DATA SHEET
I-5
Mortandad Canyon
Los Alamos National Laboratory
Los Alamos, New Mexico

FIGURE
5.1-1

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DTW measurements and aquifer testing provide further evidence for a single, low-yielding saturated zone. Upon reaching the total depth of 717 ft bgs, the initial water level in the open hole was 687.3 ft bgs. Since that time, the static water level in the open hole or completed well has generally fluctuated between 688 and 685 ft bgs, although elevation of the water table was sometimes difficult to estimate because the well was slow to recover from bailing and pumping. Approximately one month following the aquifer test, the DTW measurement was 687.30 ft bgs. Details of the aquifer test provide additional information on the nature of the saturated zone (Section 7.2 and Appendix D).

6.0 WELL DESIGN AND CONSTRUCTION

Kleinfelder received well construction specifications on October 21, 2004, after approval by DOE, LANL, and the New Mexico Environment Department (NMED). The well was installed between October 21 and October 25, 2004.

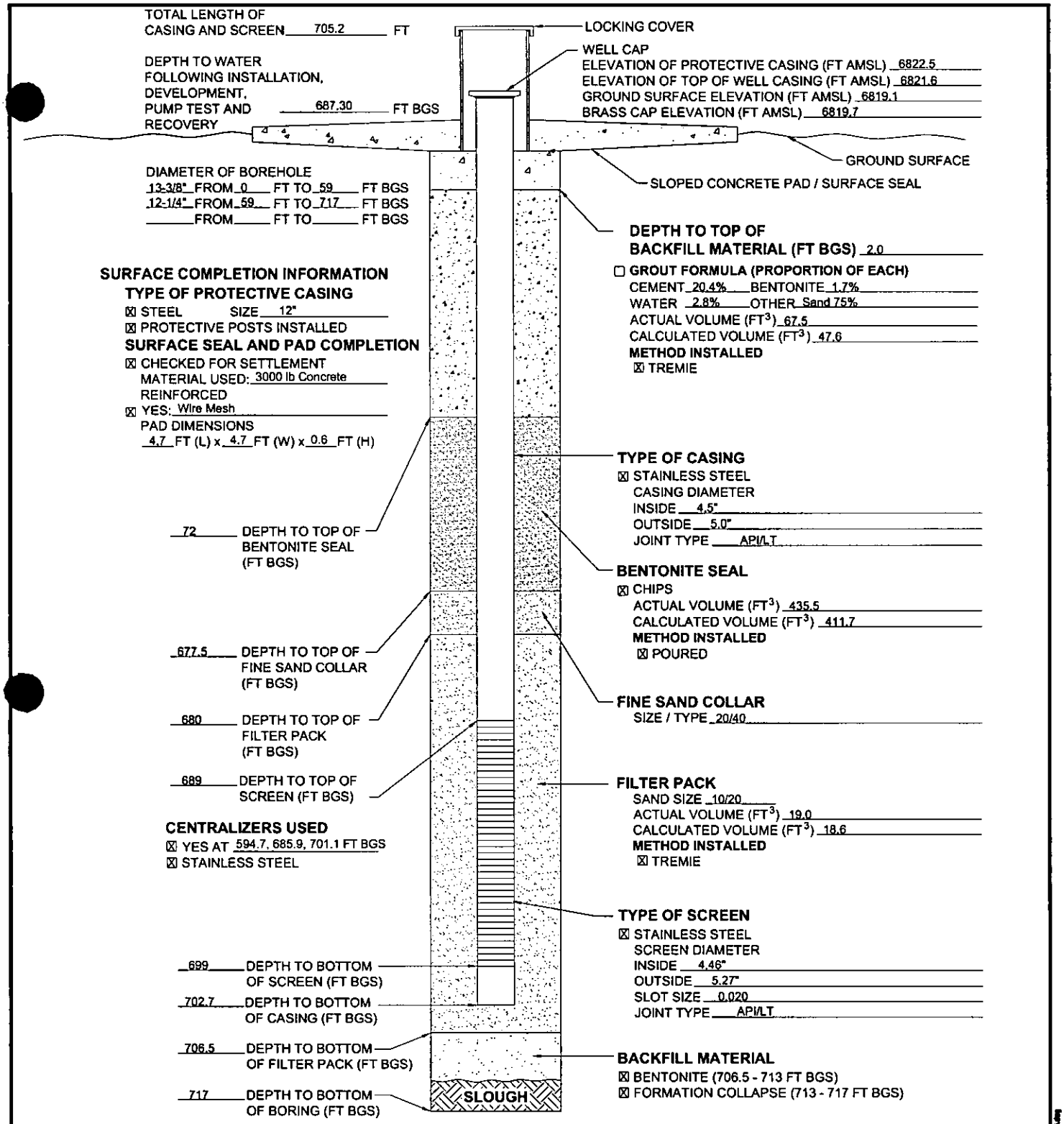
6.1 Well Design

The "Mortandad Canyon Groundwater Work Plan, Revision 1" (LANL 2004) called for a single screened interval at the base of the Cerros del Rio basalt to monitor potential contaminants and groundwater chemistry in the intermediate perched water zone above the regional aquifer. The well was designed with a single screened interval from 689.0 to 699.0 ft bgs based on evaluation of geophysical data, borehole cuttings, water level measurements, and field observations.

6.2 Well Construction

Well I-5 was constructed in accordance with LANL "Environmental Restoration Project Standard Operating Procedure for Well Construction, Revision 3" ER-SOP-05.01 (LANL, 2001a). Well casing and screen were factory-cleaned before shipment and delivery to the site. The stainless-steel components were additionally cleaned on site prior to well construction using a high-pressure hot water cleaner. The well was constructed using 4.5-in. inside diameter (ID)/5.0-in. OD, type A304, stainless-steel casing fabricated to standards in American Society for Testing and Materials (ASTM) A312-05, "Standard Specification for Seamless, Welded, and Heavily Cold Worked Austenitic Stainless Steal Pipes." External couplers, type A304 stainless-steel, were used to connect individual casing and screen joints. A single 10-ft section of 5.27-in. OD, stainless steel, 0.020-in. slot, rod-based, wire-wrapped well screen was installed from 689.0 to 699.0 ft bgs. The combined length of the lower screen weld ring and well end-piece provide a 3.7-ft stainless steel sump (Figure 6.2-1).

Prior to installing the well casing, the bottom of the borehole was tagged at a depth of 713 ft bgs, indicating that 4 ft of formation material (slough) had accumulated. Annular fill materials were generally placed through a 2-in. OD tremie pipe or by pouring directly from ground surface. A lower bentonite seal was emplaced to a depth of 707 ft bgs and installation of the stainless-steel well components began. After allowing the bentonite to hydrate overnight, the seal was measured at 706.5 ft bgs. The remaining well casing was installed and the screen interval was set from 689.0 to 699.0 ft bgs. A primary filter pack of 10/20 silica sand was then placed from 706.5 to 680 ft bgs using 2-in. OD tremie. The screened interval was swabbed 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 680 to 677.5 ft bgs. Bentonite chips were placed above the fine sand collar to 72 ft bgs. The bentonite was hydrated with potable water as it was emplaced. The



WELL COMPLETION BEGAN
DATE 10/21/04 TIME 15:45

WELL COMPLETION FINISHED
DATE 10/25/04 TIME 13:10

WELL DEVELOPMENT INFORMATION

DEVELOPMENT METHOD
☒ SWABBING ☒ BAILING
☒ PUMPING
TOTAL PURGE VOLUME 649.8 GALLONS

FINAL PARAMETER MEASUREMENTS

pH	7.94	
TEMPERATURE	11.3	°C
SPECIFIC CONDUCTANCE	128.6	µS/cm
TURBIDITY	18.9	NTU

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Drawn By: C. London	Date: April 2006
Project No.: 49436	Filename: 49436_02_0.dwg
Scale: Not-to-scale	Revision: --

WELL SCHEMATIC
I-5
Mortandad Canyon
Los Alamos National Laboratory
Los Alamos, New Mexico

FIGURE
6.2-1

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$13^3/_8$- in. surface casing was removed, and a cement grout was placed from 72 to 2 ft bgs. The cement grout consisted of a 3000 pounds per square inch (psi) cement/sand slurry blended with powdered bentonite (1.7% bentonite calculated as dry weight bentonite to dry weight cement plus bentonite). Table 6.2-1 summarizes the volumes of annular fill materials used to complete I-5.

Table 6.2-1

Annular Fill Materials Used in Well Construction

Material	Volume
Surface seal: cement slurry	67.5 ft^3
Upper bentonite seal: bentonite chips	435.5 ft^3
Fine sand collar: 20/40 silica sand	1.5 ft^3
Primary filter: 10/20 silica sand	19.0 ft^3
Lower bentonite seal: bentonite chips	4.7 ft^3
Potable water	3,925 gallons (gal)

7.0 WELL DEVELOPMENT, AQUIFER TESTING, AND SAMPLING SYSTEM INSTALLATION

Well I-5 was developed between November 1, 2004, and January 11, 2005. An aquifer test was attempted from January 22 to 24, 2005, but data were not collected due to transducer malfunction and low sustainable yield of the well. Successful aquifer tests were performed on February 22, 23, and 24, 2005.

7.1 Well Development

Development of I-5 began by bailing and swabbing the screened interval to remove drilling fluids and sediment that were introduced into the formation during drilling and well installation. Prior to initiating well development, DTW was measured at 686.48 ft bgs. Fluids were removed with a stainless-steel bailer. Swabbing was conducted by repeatedly drawing a swabbing tool across the screened interval. Bailing and swabbing were conducted over a two–day period, removing approximately 35 gal. of water from the low yielding aquifer. Water quality parameters were not monitored during the bailing/swabbing process.

A submersible pump was used for the continuation of well development, during which approximately 615 gal. of water were pumped from I-5. Development activities were conducted for 17 days over a three month period as a result of the low recharge rate. Water in the well was completely evacuated after pumping for a short period of time, and several hours were required for the well to recover. Water samples were collected to measure water quality parameters during pumping. Table 7.1-1 summarizes water quality at the end of well development, and Figure 7.1-1 shows the effect of well development on water quality parameters.

Table 7.1-1
Water Quality Parameters
During Well Development and Aquifer Testing

Method	Water Removed (gallons)	pH	Temp-erature (°C)	Specific Conductance (µS/cm)	Turbidity (NTU)	Total Organic Carbon (ppm)
Bailing/Swabbing	35	NM	NM	NM	NM	NM
Pumping	614.8	7.94	11.3	128.6	18.9	2.28

µS/cm - microSiemens per centimeter
NM - not measured
NTU - nephelometric turbidity unit
ppm - parts per million

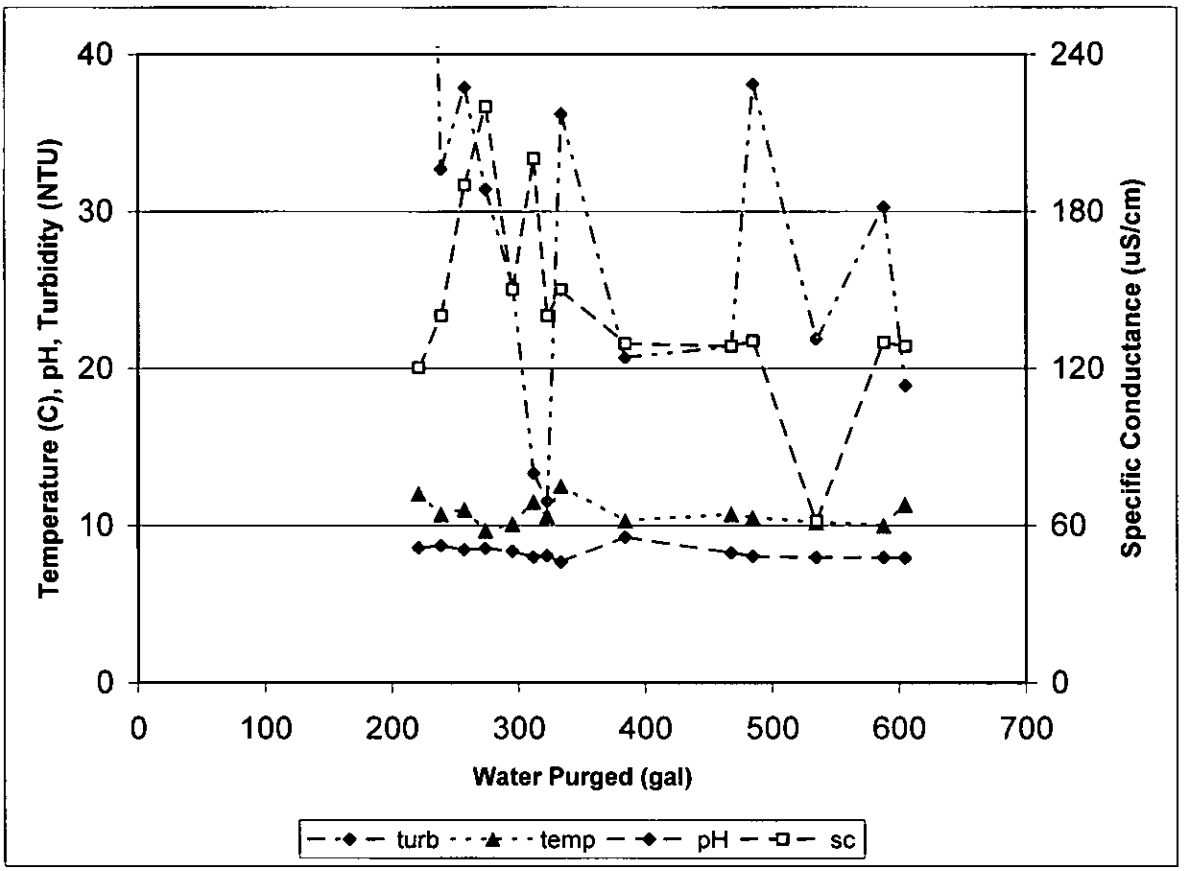

Figure 7.1-1. Selected Water Quality Parameters During Well Development

7.2 Aquifer Testing

Aquifer tests were performed on February 22, 23, and 24, 2005, using a 3 horse power (hp) submersible pump. Flow was not sufficient to perform a conventional constant-rate pumping test. Therefore, testing consisted of a series of four pump-to-evacuation events in which the pump was operated until it broke suction. The pump was then shut off and recovery of the aquifer was

monitored. During each pump-down event, approximately 20 gal. of water were removed over a time period of 4 to 6 minutes. Following pump shut down, recovery data were measured for a period of several hours to overnight. A full analysis of the aquifer test data is presented in Appendix D.

The following information summarizes the results of the pump-to-evacuation tests on I-5:

- Because of the slow recovery response, slug test analysis methods were applicable to the recovery data.
- Bouwer & Rice slug test analysis suggested a lower-bound hydraulic conductivity of about 0.15 ft per day.
- Specific capacity analysis suggested a lower-bound hydraulic conductivity range of about 0.15 to 0.3 ft per day.
- The short-term specific yield, S_y, of the filter pack was estimated to be 23.9%.
- Each test showed an unusual steepening of the data trace at about 2 ft of residual drawdown, likely indicating the response of trapping air in the annulus above the well screen as the water level passed above the top of the screen.

7.3 Sampling System Installation

Upon review of the low aquifer yields and research of available sampling systems, a Bennett Sampling System was purchased for the I-5 dedicated sampling system. The system utilizes compressed gas to operate a reciprocating piston to force groundwater through a Teflon™ tube to the surface. The compressed gas does not come into contact with the sample. The stainless-steel Bennett sample pump (1 gallon per minute (gpm) capacity, model 1800-6, serial number 1806-552) is 1.8-in diameter and 2 ft in length. The pump intake is located from 701.6 to 701.8 ft bgs, approximately 2 ft below the base of the screened interval. The system was installed in I-5 on March 22, 2006, and will be assessed for effectiveness. Should the system prove appropriate, the pump will remain in place to be utilized as needed by LANL staff.

8.0 WELLHEAD COMPLETION, SURVEY, AND SITE RESTORATION

8.1 Wellhead Completion

Wellhead completion consisted of the installation of the protective well monument, surface seal, and pad. A 12-in. OD, steel well monument with locking lid was installed from approximately 1.6 ft bgs to 3.4 ft above ground surface (ags) to protect the well riser. Concurrent with the placement of the monument and surface seal using concrete backfill, a reinforced concrete pad, 4.7-ft wide by 4.7-ft long by 0.6-ft thick, was installed around the well casing to provide long-term structural integrity for the well. A brass survey cap was embedded in the northwest corner of the pad. The pad is slightly elevated and sloped away from the well casing to promote runoff. Four bollards are placed around the perimeter of the pad to protect against vehicular damage.

8.2 Geodetic Survey

The ground surface, well monument, and brass cap at the I-5 wellhead were surveyed by ASTS, Inc., on January 18, 2005 (Table 8.2-1).

Table 8.2-1
Geodetic Data

Description	Northing	Easting	Elevation*
Ground surface	1768301.53	1635246.95	6819.1
Brass cap in I-5 pad	1768300.46	1635247.94	6819.7
Top of stainless-steel well casing[1]	NM[2]	NM	6821.6
Top of protective well monument casing	1768299.13	1635249.28	6822.5

* Measured in ft above mean sea level (amsl) relative to the National Geodetic Vertical Datum of 1929, accurate to +/- 0.1 foot

[1] Measured from geodetic surveyed brass cap using staff and level

[2] NM - not measured

8.3 Site Restoration Activities

Cuttings and fluids produced during drilling and development/aquifer testing were containerized and sampled on January 10 and 11, 2005, in accordance with the October 13, 2004, Waste Characterization Strategy Form prepared for the drilling and installation of boreholes and wells in Mortandad Canyon (Appendix C in Kleinfelder 2004b). Analytical results were received on February 8, 2005, and submitted to DOE and LANL for review. Fluid sample results were compared to the State of New Mexico Water Quality Control Commission Regulation 3103 groundwater standards. Water generated during drilling, development and aquifer testing was land-applied in accordance with the Workplan Notice of Intent Decision Tree, revised July 15, 2002, and in coordination with NMED. Cuttings sample results were compared to local geochemical background values and soil screening levels (SSLs) from NMED Soil Screening Levels, Revision 2.0, February 2004, and submitted to DOE for approval to use as site restoration fill.

Site restoration activities included removing the water from the containment area and applying it back to the land, removing the polyethylene liner and cuttings from the containment area, removing the containment berms, backfilling and grading the containment area, and disposing of the containment liner. Remaining cuttings not utilized to backfill the containment area were thinly spread over the site. The site has been reseeded using LANL Seed Mix, applied at a rate of 20 pounds (lb)/acre. Biosol® organic fertilizer was utilized (800 lb/acre) to support revegetation.

Temporary materials emplaced for BMPs have been removed.

9.0 DEVIATIONS FROM THE FINAL DRILLING PLAN

In general, drilling, sampling, and well construction at I-5 were performed as specified in the "Final Drilling Plan for Intermediate Wells, Mortandad Canyon, Los Alamos National Laboratory" (Kleinfelder 2004b). Deviations from planned activities are as follows:

- The total depth of the borehole was 717 ft bgs rather than 760 ft bgs as noted in the drill plan.
- Due to the very low aquifer yield, well development and aquifer testing were limited.
- A groundwater sample was not collected following aquifer testing, only at the completion of well development. The well completion sample was not submitted for perchlorate, metals or anions analysis.

10.0 ACKNOWLEDGEMENTS

Alpha Southwest, Inc. conducted videologging of the borehole.

ASTS, Inc. conducted the final geodetic survey of finished well components.

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

Duratek Federal Services, Inc. performed a review of the analytical results of the drill cuttings for waste determinations.

EnviroWorks, Inc. provided site preparation services.

Hall Environmental Analysis Laboratory conducted laboratory analysis for waste characterization samples.

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

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

WDC Exploration & Wells provided rotary drilling services.

11.0 REFERENCES

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Appendix A

Borehole Video Log

Appendix B

Lithologic Log

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Qal, alluvium	Unconsolidated sediments, alluvium, sandy silt, light brown (5YR 6/4). WR (whole rock, unsieved): 1-2% pumice; 5-10% felsic (quartz and/or sanidine unless otherwise noted) crystals; 90-95% sand. 10+F (i.e. plus No. 10 sieve-size fraction): trace gravel clast: 50% rounded tuff fragments (pumice poor, felsic crystal rich); 50% felsic crystals, occasional bipyramidal. 35+F (i.e. plus No. 35 sieve-size fraction): 30-40% tuff fragments; 60-70% felsic crystals. **Note: Samples of drill cuttings were collected in the interval from 0 to 717 ft bgs. Descriptions presented in this lith log are primarily based on those made during visual examination of the drill cuttings. Stratigraphic contacts are based on available information from review of drill cuttings and geophysical logs.**	0-15	6819.1-6804.1
Qbt 1g, Tshirege Member of the Bandelier Tuff	Tuff, grayish orange (10YR 7/4), poorly welded. WR: fine ash, sparse felsic crystals. 10+F: 60-65% pumice poor tuff fragments, rounded; 35-40% felsic crystals; 1-2% vitric pumices. 35+F: 25-30% tuff; 70-75% felsic crystals; trace lithics (unless otherwise noted, intermediate composition volcanic xenoliths or volcanic clasts depending on formation) . **Note: The base of the alluivium (Qal) and the contact with the underlying Tshirege Member Unit 1g (Qbt 1g) of the Bandelier Tuff is interpreted to at 16.5 ft bgs.**	15-25	6804.1-6794.1
	Tuff, grayish orange (10YR 7/4), poorly welded. WR: fine ash, sparse felsic crystals. 10+F: Sparse returns; 20-25% tuff fragments; 5% vitric pumice; 60-65 % felsic crystals; trace subrounded lithics. 35+F: 5% pumice; 80-85% felsic crystals; 5-10% lithic tuff fragments.	25-40	6794.1-6779.1
	Tuff, yellowish gray (5Y 8/1) to white (N9), poorly welded. WR: fine ash with 15-20% felsic crystals, 15-20% vitric, white pumice fragments. 10+F: white, fibrous, vitric pumice with felsic phenocrysts, rare mafic phenocrysts, up to 1.5 cm. 35+F: 50% white, vitric pumice; 50% felsic crystals.	40-55	6779.1-6764.1
	Tuff, grayish orange (10YR 7/4). WR: 70% white, vitric pumice, up to 1.2 cm, with trace fines above 60 ft bgs; 25% angular quartz crystals with trace sanidine; 5% lithics, include gray dacite, up to 1.3cm. 10+F: 50% white, vitric pumice; 25% angular to subrounded felsic crystals; 25% lithics, up to 1.3 cm. 35+: 50-60% white, vitric pumice; 20% felsic crystals, trace euhedral, angular to sub-rounded; 20-30% gray hornblende dacite and other intermediate volcanics, subangular to subrounded. **Note: Installation of surface casing to 65 ft bgs was difficult resulting in uncertainties of sample interval. This interval likely extends deeper than 65 ft bgs, as cuttings also reflect representative lithology of the Cerro Toledo Interval (Qct). The Tsankawi Pumice Bed (Qbtt) was noted in R-15 core from 65 to 66 ft bgs. Geologists were unable to identify this unit in the borehole cuttings.**	55-65	6764.1-6754.1
Qct, Cerro Toledo interval	Volcaniclastic sediments, silty sand with gravel, grayish orange pink (5YR 7/2). WR: 10-15% gravels; 60-65% sand; 20-25% fines. 10+F: subrounded pumice up to 1.2 cm; lithics (intermediate composition volcanic clasts) up to 2 cm; trace felsic crystals. 35+F: 50-60% white, vitric pumice with trace subrounded, felsic phenocrysts; 20-25% free felsic crystals; 20-25% lithics, including gray dacite. **Note: The base of the Qbt 1g (Qbtt as noted in R-15 core) and the contact with the underlying Cerro Toledo interval (Qct) is interpreted to be at 66 ft bgs.**	65-85	6754.1-6734.1

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Qct, Cerro Toledo interval	Volcaniclastic sediments, gravelly sand with silt, grayish orange (10YR 7/4). WR: 10-15% gravel; 80-85% sand; 10-15% fines, pale yellow tuff fragments, poor to moderately welded, subangular to subrounded. 10+F: 50% white, vitric pumice with manganese/iron (Mn/Fe) oxide surface staining; 0-1% subrounded free felsic crystal; 50% lithics, angular, intermediate composition volcanic clasts including gray dacite; trace obsidian. 35+F: 30% white, vitric pumice; 40% quartz with trace sanidine crystals, rare hornblende crystals; 30% lithics, including dacite.	85-90	6734.1-6729.1
	Volcaniclastic sediments, sand with gravel, grayish orange (10YR 7/4). WR: 10-15% pumice and intermediate composition volcanic gravels; 80-85% sand; 0-5% fines. 10+F: Sparse returns; 20% pumice; 60% angular to subrounded felsic crystals; 20% lithics (general term for intermediate composition volcanic clasts). 35+F: 35% vitric pumice; 35% angular to subrounded felsic crystals; 30% lithics; trace obsidian.	90-95	6729.1-6724.1
	No Recovery; sample unavailable for examination.	95-105	6724.1-6714.1
	Volcaniclastic sediments, poorly sorted pumiceous sand, grayish orange (10YR 7/4). WR: 100% pumice sand with rare angular to rounded lithics. 10+F: 60% white, vitric pumice with rare mafic phenocrysts and Mn/Fe oxide surface staining; 5% subrounded felsic crystals; 55% lithics, including hornblende dacite and various intermediate composition volcanics. 35+F: subangular to subrounded sand composed of 40% white pumice, 35% felsic crystals; 25% lithics, including dacite.	105-110	6714.1-6709.1
	Volcaniclastic sediments, sandy silt, grayish orange (10YR 7/4). WR: fines with sand and gravel; 0-2% gravels; 35-40% sand; 55-60% fines. 10+F: gravel up to 2 cm, angular to rounded; 10-25% white, vitric pumice with trace felsic phenocrysts; 75-90% lithics composed of intermediate composition aphanitic and dacite with weathered or trace hornblende phenocrysts. 35+F: sand composed of 30-40% white, vitric pumice; 40-60% felsic crystals, angular to subrounded, vitreous to frosted; 10-15% lithics composed of intermediate composition volcanics, including dacite; trace obsidian.	110-120	6709.1-6699.1
Qbo, Otowi Member of the Bandelier Tuff	Tuff, very pale orange (10YR 8/2) to moderate orange pink (5YR 8/4), poorly welded. WR: fine ash with pumice and lithic fragments. 10+F: 30-40% pumice, pale yellow, vitric; 60-70% intermediate composition volcanic lithics, up to 2 cm, angular. 35+F: 40-45% pumice; 40-45% felsic crystals; 15-20% lithics; clay fragments, moderate red (5R 4/6), present at 125 - 130 feet bgs. **Note: The base of the Cerro Toledo interval (Qct) and the contact with the underlying Otowi Member of the Bandelier Tuff (Qbo) is interpreted to be at 120 ft bgs.**	120-130	6699.1-6689.1
	Tuff, moderate orange pink (5YR 8/4), poorly welded. WR: fine ash with 30-40% pumice and lithic fragments. 10+F: 90% pumice, white to yellow, vitric, Mn-Fe oxide staining, felsic phenocrysts; 10% lithics including hornblende dacite, angular to subangular, up to 1.5cm. 35+F: 35% pumice, yellow to trace white; 50% felsic crystals; 15% lithics.	130-135	6689.1-6684.1
	Tuff, moderate orange pink (5YR 8/4), poorly welded. WR: ash with 30-40% pumice, up to 1.5 cm, felsic crystals and trace lithic fragments. 10+F: 90-95% pumice, white to yellow, vitric, fibrous, Mn/Fe oxide surface staining, trace felsic phenocrysts; 2-5% free felsic crystals, angular to subrounded; 2-5% lithics. 35+F: 35-45% pumice, yellow/orange, vitric, fibrous; 35-45% angular felsic crystals; 10-20% lithics including hornblende dacite.	135-145	6684.1-6674.1

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Qbo, Otowi Member of the Bandelier Tuff	Tuff, moderate orange pink (5YR 8/4), poorly welded. WR: 20% ash with pumice up to 0.8 cm; 20% lithics of dacite and intermediate composition volcanics. 10+F: 65% pumice, orange, vitric; 35% gray dacite/rhyodacite lithics with hornblende and felsic phenocrysts. 35+F: 35-40% pumice, orange, vitric; 35-40% angular felsic crystals; 15-20% intermediate composition volcanics including dacite.	145-150	6674.1-6669.1
	Tuff, grayish orange (10YR, 7/4), poorly welded. WR: 60% ash with pumice and lithics of dacite and intermediate composition volcanics. 10+F: 70-80% pumices, vitric, fibrous, Mn/Fe oxide staining, felsic phenocrysts, rare mafic phenocrysts; 20-30% intermediate composition volcanics, up to 5mm, angular to subrounded. 35+F: 35% pumice, orange, vitric, fibrous; 40% felsic crystals, angular/subhedral to subrounded; 15% lithics, dacitic.	150-160	6669.1-6659.1
	Tuff, very pale orange (10YR, 8/2), poorly welded. WR: 70-75% ash with pumice and lithics. 10+F: 70% pumice decreasing to 30% across interval, white to orange, vitric, fibrous, felsic phenocrysts, trace Mn/Fe oxide staining; <2% free felsic crystals; 30% lithics increasing to 70% across interval, composed of gray hornblende dacite and other aphanitic intermediate composition volcanics, up to 2 cm, angular to subrounded. 35+F: 35-45% pumice, white to orange, vitric, fibrous; 35-40% felsic crystals; 5-30% dacitic lithics.	160-180	6659.1-6639.1
	Tuff, very pale orange (10YR 8/2), poorly welded. WR: 50-70% ash with pumices, lithics and felsic crystals. 10+F: 50-70% pumice, white, vitric, fibrous with felsic phenocrysts, trace Mn/Fe oxide staining, trace mafic phenocrysts; 30-50% lithics of aphanitic intermediate composition volcanics, up to 2cm, angular to subangular. 35+F: 30-50% pumice, white to orange, vitric; 30-50% felsic crystals, angular to subrounded; 30-40% lithics composed of aphanitic intermediate composition volcanics.	180-200	6639.1-6619.1
	Tuff, very light gray (N8), poorly welded. WR: 40-70% ash with lithics and pumices. 10+F: 50-70% pumice, white, vitric, felsic phenocrysts, up to 1.7 cm in size, vitreous luster; 30-60% biotite and hornblende dacite, andesite, rhyodacite and gray/red mottled aphanitic clasts, up to 3cm, angular to sub angular. 35+F: 40-60% pumice, vitric to fibrous, vitreous luster, felsic phenocrysts; 25-40% free felsic crystals of quartz with trace sanidine (smoky, yellow, and clear) angular to subrounded; 15-30% lithics composed of gray dacites, varied colored (gray, pale green and gray/red) aphanitic clasts.	200-220	6619.1-6599.1
	Tuff, very light gray (N8) to very pale orange (10YR 8/2), poorly welded. WR: felsic crystals, lithics and pumices. 10+F: 50-65% pumice, white, vitric, vitreous luster, felsic phenocrysts, frequent surficial Mn/Fe oxide specks; 35-50% lithics composed of gray hornblende/biotite dacites and varicolored (red/pale green/gray) aphanitic clasts, up to 2.5 cm, angular to subangular. 35+F: 5-10% pumice; 90-95% felsic crystals; 2-5% lithics; constituents as described for 10+F.	220-240	6599.1-6579.1
	Tuff, light gray (N7) to very pale orange (10YR, 8/2), poorly welded. WR: ash, lithics, pumice and felsic crystals. 10+F: 50-60% pumice, subrounded, up to 1.2 cm, white, vitric, vitreous luster, felsic phenocrysts, frequent surficial Mn/Fe oxide specks; 40-50% lithics including andesite, dacite and varicolored intermediate volcanic aphanitics, up to 2 cm, angular. 35+F: 30-40% pumice, white, vitric; 45-65% felsic crystals; 5-15% lithics, aphanitic.	240-250	6579.1-6569.1

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Qbo, Otowi Member of the Bandelier Tuff	Tuff, moderate yellowish brown (10YR 5/4), poorly welded. WR: ash coated lithics, pumices and felsic crystals. 10+F: 30% pumice, white, vitric, up to 1 cm; 70% lithics, consist of dacite and varicolored intermediate aphanitics, weakly porphyritic, Mn/Fe oxide staining. 35+F: 15% pumice, white, vitric; 60% felsic crystals, angular to subangular; 25% aphanitic lithics, subangular .	250-255	6569.1-6564.1
	Tuff, grayish orange (10YR 7/4), poorly welded. WR: 70-80% ash with lithics, pumices and felsic crystals. 10+F: 40-60% pumice, up to 1.8 cm, white to orange, vitric, vitreous to dull luster, felsic phenocrysts; 40-60% lithics, including biotite/hornblende dacite, andesite and trace rhyolitic composition clasts, up to 2 cm, angular to subrounded. 35+F: 20-30% pumice, white, vitric; 45-60% felsic crystals, subangular to subrounded, trace frosting of surfaces; 25-40% lithics of intermediate composition volcanics.	255-275	6564.1-6544.1
	Tuff, light gray (N7). WR: ash with pumice, lithics and crystals. 10+F: 30-60% pumice, up to 1.4 cm, white, vitric, fibrous, felsic phenocrysts; 40-70% lithics composed of dacites and other intermediate volcanics, aphanitic, up to 1.3 cm, angular to subrounded; trace vesicular dark vitrophyric/aphyric fragment. 35+F: 30-55% pumice, white to orange, vitric to fibrous, vitreous luster; 30-60% felsic crystals, subangular to subrounded; 20-30% intermediate aphanitic lithics.	275-290	6544.1-6529.1
	Tuff, very pale orange (10YR, 8/2), pumice rich, poorly welded. WR: 60-70% ash with pumice, trace lithics, and felsic crystals. 10+F: 80-90% pumice, up to 2.3 cm, white, vitric, felsic phenocrysts, frequent surficial Mn/Fe oxide specks; 10-20% lithics of dacite and varicolored aphanitic intermediate composition volcanics, up to 0.8 cm. 35+F 35-50% pumice, white, vitric, fibrous; 35-50% felsic crystals, subangular to subrounded; 15-30% lithics of varicolored aphanitic intermediate composition volcanics.	290-310	6529.1-6509.1
	Tuff, very pale orange (10YR 8/2), poorly welded. WR: ash coated lithics, pumice and crystals. 10+F: 50-60% pumices, up to 1.8 cm, white, vitric, felsic phenocrysts, frequent surficial Mn/Fe oxide specks; 40-50% lithics consist of hornblende and biotite dacite, and varicolored weakly porphyritic intermediate composition volcanics, up to 2.2 cm, angular to subrounded. 35+F: 30-40% pumices, white, vitric; 30-40% felsic crystals, subangular to subrounded; 15-30% lithics.	310-325	6509.1-6494.1
	Tuff, very pale orange (10YR 8/2) pumice rich tuff, poorly welded. WR: 80-90% ash with pumice and trace lithics. 10+F: 65-80% pumices, , up to 1.1 cm, white, vitric, felsic phenocrysts, frequent surficial Mn/Fe oxide specks; 20-35% lithics, varicolored, weakly porphyritic including andesite, trace vitrophyre, up to 1cm, angular to subangular. 35+F: 30-40% pumices same as above, 40-50% felsic crystals;15-25% lithics.	325-335	6494.1-6484.1
	Tuff, very pale orange (10YR 8/2) poorly welded. WR: 60% ash with lithics, pumice and felsic crystals. 10+F: 50-65% pumice, white, vitric, felsic phenocrysts and rare mafic phenocrysts, frequent surficial Mn/Fe oxide specks; <5% free felsic crystals; 35-50% lithics of predominantly intermediate composition aphanitics, including hornblende dacites, up to 2 cm, angular to subrounded. 35+F: 30-40% pumice, white, vitric; 35-50% felsic crystals, subangular to subrounded; 20-25% lithics composed of varicolored aphanitics.	335-355	6484.1-6464.1

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Qbo, Otowi Member of the Bandelier Tuff	Tuff, very pale orange (10YR 8/2), poorly welded. WR: 40-50% ash with lithics, pumice and felsic crystals. 10+F 65-85% pumice, up to 2.3 cm, white, vitric, felsic phenocrysts, frequent surficial Mn/Fe oxide specks; 15-35% lithics, predominantly intermediate volcanics, including biotite/hornblende dacite, andesite noted, angular to subrounded. 35+F: 40-60% pumice, white, vitric; 20-50% felsic crystals, subangular to subrounded; 10-25% lithics as described in 10+F.	355-375	6464.1-6444.1
	Tuff, very pale orange (10YR 8/2), poorly welded, pumice rich. WR: ash with lithics and pumice. 10+F: 75-90% pumice, white, vitric, up to 1.6 cm, subrounded, felsic phenocrysts, frequent surficial Mn/Fe oxide specks; 10-25% lithics, predominantly varicolored intermediate volcanic aphanitics, hornblende dacite noted, trace vitrophyre, up to 1cm, angular with occasional subrounded surfaces. 35+F: 50-70% pumice, white, vitric; 30-40% felsic crystals, subangular to subrounded; 10-25% lithics composed of varicolored intermediate volcanics, subangular to subrounded.	375-390	6444.1-6429.1
	Tuff, very pale orange (10YR 8/2), poorly welded. WR: ash with lithics and pumice. 10+F: 50% pumice, white, vitric; 50% lithic, intermediate weakly porphyritic aphanitics, hornblende dacite noted, up to 1cm, angular. 35+F: 35% pumice, white, vitric; 45% felsic crystals; 20% lithics as described for 10+F.	390-395	6429.1-6424.1
	Tuff, very pale orange (10YR 8/2) pumice rich tuff, poorly welded. WR: 70% ash with pumice and 5% lithics. 10+F: pumice, up to 1.4 cm, white, vitric, felsic phenocrysts, frequent surficial Mn/Fe oxide specks; 20-20% lithics composed of gray/red intermediate volcanics, porphyritic and nonporphyritic aphanitics, hornblende dacite noted, trace vitrophyre, trace subrounded fragments, up to 1.5 cm. 35+F: 45-55% pumice as described above; 25-35% felsic crystals, subangular to subrounded; 15-20% lithics as described for 10+F.	395-405	6424.1-6414.1
	Tuff, grayish orange pink (5YR 7/2), pumiceous, poorly welded. WR: ash and pumice with lithics and felsic crystals. 10+F: 75-90% pumice, up to 2.3 cm, white, vitric, fibrous, occasional felsic phenocrysts, frequent surficial Mn/Fe oxide specks; 10-25% lithics composed of predominantly aphanitic to weakly porphyritic intermediate volcanics, hornblende dacite noted, trace vitrophyre, angular to occasional subrounded, up to 1cm. 35+F: 40-55% pumice as described above; 25-50% felsic crystals, subangular to subrounded; 15-30% lithics as described for 10+F.	405-420	6414.1-6399.1
	Tuff, grayish orange pink (5YR 7/2), pumiceous, poorly welded. WR: ash and pumice with lithics and felsic crystals. 10+F: 75-90% pumice, up to 2.3 cm, white, fibrous, vitric, occasional felsic phenocrysts, frequent surficial Mn/Fe oxide specks; 10-25% lithics of predominantly intermediate composition volcanics, porphyritic aphanitics including frequent hornblende/biotite dacite, subangular to subrounded, up to 1.6 cm. 35+F: 50-70% pumice as described above; 20-35% felsic crystals; 15-30% lithics as described for 10+F.	420-440	6399.1-6379.1

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Qbog, Guaje Pumice Bed of the Otowi Member of the Bandelier Tuff	Pumice bed, very pale orange (10YR 8/2) to white (N9), poorly welded. WR: ash (60%) with pumice, trace lithics and felsic crystals. 10+F: 50-100% pumice (440-450 ft bgs interval is 100% pumice), up to 2 cm, white, vitric, vitreous luster with felsic and rare mafic phenocrysts; 0-50% lithics at 450-455 ft bgs interval, gray hornblende/biotite dacite, andesite, varicolored (gray/red) intermediate volcanic aphanitics, minor oxidation of mafic phenocrysts, up to 1 cm, angular to subrounded. 35+F: 60-70% pumice as described for 10+F; 20-30% felsic crystals, subangular to subrounded; 5-20% lithics as described for 10+F. **Note: The base of the Otowi Member of the Bandelier Tuff (Qbo) and the contact with the underlying Guaje Pumice Bed (Qbog) is interpreted to be at 443 ft bgs.**	440-460	6379.1-6359.1
Tpf, Puye Formation (fanglomerate)	Volcaniclastic sediments, intermixed with overlying formation, very pale orange (10YR 8/2) to white (N9). WR: pumice, white, vitric, minor ash, up to 2.5 cm. 10+F: 80-85% pumice, white, vitric, vitreous to frosted, up to 1.8 cm, with felsic phenocrysts; 15-20% lithics composed of intermediate aphanitics clasts and trace sandstone fragments, predominantly angular to subrounded with trace rounded clasts. 35+F: 70-80% pumice as described above, 15% felsic crystals, angular to subangular; 5-15% lithics as described for 10+F above, no sandstone clasts. **Note: The base of the Guaje Pumice Bed (Qbog) (base of the Otowi Member and the Bandelier Tuff Formation) and the contact with the underlying fanglomerates of the Puye Formation (Tpf) is interpreted to be at 461 ft bgs.**	460-470	6359.1-6349.1
	Volcaniclastic sediments, gravel with sand and silt, grayish orange (10YR 7/4), well sorted. WR: 70-75% gravel, 15% sand, and 10-15% fines.10+F: gravel, broken, subrounded to round, composed of 85% varicolored intermediate volcanic aphanitics including hornblende dacite,15% sandstone, trace white, vitric pumice. 35+F: 30% sandstone, 30% pumice, 5% felsic crystals, 10% lithics.	470-490	6349.1-6329.1
Tb4, Cerros del Rio Basalt	Basalt intermixed with volcaniclastic sediments from overlying formation, gravel with sand, silt and basalt, medium gray (N5). WR: intermediate composition volcanic clasts and basalt fragments. 10+F: 30-50% dacite and other intermediate aphanitic rounded clasts; 50-75% basalt, weakly vesicular with clay infilling of vesicles, weakly porphyritic (olivine), subrounded to rounded. 35+F: dacite, other intermediate aphanitics and free felsic crystals grading to basalt with dacite, free felsic crystals and trace sandstone fragments. **Note: The base of the Puye Formation (Tpf) and the contact with the underlying Cerros del Rio Basalt (Tb4) is interpreted to be at 492 ft bgs.**	490-505	6329.1-6314.1
	Basalt, medium dark gray (N4) with dusky red (5R 3/4). WR: basalt chips with fines, up to 1.5 cm. 10+F: basalt chips, angular and broken, up to 1.8 cm, weakly vesicular, weakly porphyritic with aphanitic groundmass, 1-2% olivine phenocrysts, occasional tan clay on surfaces or infilling vesicles. 35+F: basalt as described for 10+F; trace white vitric pumice, sandstone fragments, and angular felsic crystals.	505-530	6314.1-6289.1
	No recovery; sample unavailable for examination.	530-535	6289.1-6284.1

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Tb4, Cerros del Rio Basalt	Basalt, medium light gray (N6). WR: basalt chips with fines, up to 1.7 cm. 10+F: basalt chips, up to 1 cm, massive with trace vesicles, weakly porphyritic (olivine phenocrysts), aphanitic groundmass, angular to subrounded, trace clay in vesicles; trace pumice and sandstone fragments. 35+F: 80% basalt as described for 10+F; 10% angular felsic crystals; 10% pumice.	535-540	6284.1-6279.1
	No recovery; sample unavailable for examination.	540-545	6279.1-6274.1
	Basalt, medium light gray (N6). WR: basalt, minor fines, up to 1.7 cm. 10+F: basalt chips, subrounded, up to 1 cm, massive with occasional vesicle, trace olivine phenocrysts in aphanitic groundmass. 35+F: 90% fine basalt as described for 10+F with 10% free felsic crystals, lithics, sandstone and pumice.	545-550	6274.1-6269.1
	Basalt, light gray (N7). WR: basalt coated in fine sand, up to 1.2cm. 10+F: basalt, subangular to subrounded, up to 0.9 cm, massive, aphanitic groundmass with trace olivine phenocrysts; trace lithics composed of sandstone fragments and subrounded, white, vitric, pumice; 35+F: 80% fine basalt chips as described for 10+F; 10% free felsic crystals, subangular to round, glassy to frosted; 10% pumice and trace sandstone fragments.	550-560	6269.1-6259.1
	Basalt, light gray (N7). WR: basalt chips coated in fines, angular to subangular, up to 3.6 cm. 10+F: basalt chips, massive aphanitic groundmass, 3-5% olivine/olivine altered phenocrysts, up to 2.5 cm. 35+F: 75% fine basalt chips as described for 10+F; 15% felsic crystals, occasional faceted surfaces;10% pumice and trace sandstone.	560-580	6259.1-6239.1
	Basalt, medium light gray (N6). WR: basalt chips coated in fines, angular to subangular, up to 1.6 cm. 10+F: basalt chips, up to 1.8 cm, massive, aphanitic groundmass with 2-5% olivine/altered olivine phenocrysts; trace subrounded vesicular chips. 35+F: 90% fine basalt chips as described for 10+F; 10% felsic crystals, pumice, clay chips and vitrophyre.	580-590	6239.1-6229.1
	Basalt, light gray (N7). WR: basalt chips coated in fines, up to 3 cm. 10+F: basalt chips, angular, up to 3 cm, massive, aphanitic groundmass with 2-5% olivine/altered olivine phenocrysts; trace clay coatings on surfaces. 35+F: few returns; 90% fine basalt chips as described for 10+F; 10% felsic crystals (rare faceted surfaces), pumice, trace clay chips.	590-600	6229.1-6219.1
	Basalt, medium gray (N5). WR: Basalt chips coated in fines, up to 1cm. 10+F: basalt, up to 1.2 cm, angular, broken; aphanitic groundmass with 2-8% olivine phenocrysts. 35+F: 90% fine basalt chips as described for 10+F; 10% felsic crystals (broken and rare faceted surfaces), pumice and sandstone/clay.	600-605	6219.1-6214.1
	Basalt, light gray (N7). WR: basalt chips coated in fines, up to 3 cm, massive. 10+F: basalt, angular, up to 3 cm, massive, aphanitic groundmass with 2-5% olivine phenocrysts. 35+F: 80% angular, fine basalt chips as described for 10+F; 20% felsic crystals (broken and rare faceted surfaces, pumice, clay).	605-610	6214.1-6209.1
	Basalt, medium light gray (N6). WR: basalt chips coated in fines, angular, up to 2.5 cm. 10+F: basalt chips, up to 1.8 cm, angular, massive aphanitic groundmass with 1-3% olivine phenocrysts, trace vesicular; occasional clay fragment and clay infilling of vesicles. 35+F: 80-90% basalt, angular, fine basalt chips as described for 10+F; trace pumice, clay, felsic crystal fragments; increasing clay below 620 ft bgs.	610-630	6209.1-6189.1

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Tb4, Cerros del Rio Basalt	Basalt, pale reddish brown (10YR 5/4). WR: basalt chips coated in fines, chips up to 0.8 cm. 10+F: basalt chips, red (75%) and black(25%), massive aphanitic groundmass with 0-1% olivine phenocrysts, minor clay on surfaces; trace clay and sandstone chips. 35+F: basalt chips as described for 10+F (red with minor black) with minor felsic crystals, clay and pumice fragments.	630-635	6189.1-6184.1
	Basalt, pale reddish brown (10YR 5/4). WR: basalt chips coated in fines, chips up to 2.5 cm. 10+F: basalt chips, red (70%) and black (30%), massive, aphanitic groundmass with minor vesicles and trace olivine phenocrysts, chips up to 2 cm, occasional clay filling of voids and on surfaces; trace clay. 35+F: 90% basalt, primarily red with minor black, subangular; 10% pumice, trace sandstone/clay.	635-640	6184.1-6179.1
	Basalt, pale reddish brown (10YR 5/4) and dark gray (N4). WR: fines and basalt chips, chips up to 1cm. 10+F: basalt, red and gray/black, massive, aphanitic groundmass with 1-3% olivine phenocrysts, minor vesicles with occasional clay infilling; trace clay, dacite. 35+F: basalt chips as described for 10+F, angular; 5% felsic crystals, trace faceted surfaces; 5% clay; trace dacite and pumice.	640-650	6179.1-6169.1
	Basalt, medium gray (N5). WR: basalt chips coated in fines, angular, chips up to 2.5 cm. 10+F: basalt, angular, aphanitic groundmass with 1-2% olivine/olivine altered phenocrysts; trace red basalt and vesicular chips, clay on surfaces from 665-670 ft bgs; trace rounded dacite. 35+F: 90% fine basalt chips as described for 10+F; 10% felsic crystals (trace broken and faceted surfaces), pumice, trace sandstone, trace loose olivine crystals, and clay.	650-670	6169.1-6149.1
	Basalt, medium gray (N5). WR: basalt chips coated in fines, angular, chips up to 1.7 cm. 10+F: basalt, angular, aphanitic groundmass with olivine phenocrysts, weakly porphyritic, trace clay. 35+F: 90% basalt as described for 10+F; 10% felsic crystals, subangular to subrounded, frosted to glassy; trace pumice, clay, sandstone and loose olivine crystals.	670-680	6149.1-6139.1
	Basalt, medium light gray (N6). WR: basalt chips coated in fines, chips up to 1.5 cm, angular. 10+F: basalt, angular to subangular, aphanitic groundmass with olivine / altered olivine phenocrysts, clay on surfaces. 35+F: basalt chips as described for 10+F; 10% felsic crystals, angular to subrounded; trace pumice, clay, sandstone and loose olivine crystals.	680-695	6139.1-6124.1
	Basalt, light gray (N7) to medium light gray (N6). WR: basalt chips, chips up to 2.3 cm, coated with silt and fine sand. 10+F: basalt, angular, aphanitic groundmass with olivine/altered olivine phenocrysts; trace clay chips and felsic crystal fragments. 35+F: 60-70% basalt chips as described for 10+F; 10-20% clay, pumice, loose olivine, dacite fragments, felsic crystals.	695-715	6124.1-6104.1
	Basalt, medium light gray (N6). WR: basalt chips, up to 1 cm, subangular, coated with fine sand and silt. 10+F: 70% basalt, aphanitic groundmass with olivine phenocrysts ; 30% pumice, white to orange, subrounded, vitric, felsic phenocrysts. 35+F: basalt chips as described for 10+F; 20% felsic crystals (angular, broken), pumice, clay, trace olivine, trace dacite.	715-717	6104.1-6102.1
	TOTAL BOREHOLE DEPTH (TD) IS 717 FT BGS.		

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)

NOTES:

Samples of drill cuttings were collected in the interval from 0 to 717 ft bgs. Descriptions presented in this lithlog are primarily based on those made during visual examination of the drill cuttings.

Descriptions of drill chips from sedimentary units such as the Quaternary Alluvium, Cerro Toledo Interval and the Puye Formation utilized principles outlined in *Petrology of Sedimentary Rocks* by Robert L. Folk. Color Descriptions were determined using The Geological Society of America, Rock-Color Chart.

Cuttings were collected at nominal 5 or 10-ft intervals and divided into three sample splits: (1) unsieved, or whole rock (WR), sample; (2) 10+F sieved fraction (No. 10 sieve equivalent to 2.0 mm); and (3) 35+F sieved fraction (No. 35 sieve equivalent to 0.5 mm). When cuttings were overall finer grained, then cuttings were divided into a 35+F sieved fraction and a 60+F sieved fraction.

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

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

REFERENCES

Folk, Robert L., 1980, *Petrology of Sedimentary Rocks*, Hemphill Publishing Company.

The Geological Society of America, 1991, Rock-Color Chart

Characterization Well R-15 Completion Report, Los Alamos National Laboratory, LA-13749-MS, Los Alamos, New Mexico, May 2001.

Appendix C

Geophysical Logging Report

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1.0 SUMMARY

This report describes the borehole geophysical logging measurements acquired in characterization well I-5 by Schlumberger, acquired in October 2004 – prior to well completion. The report (1) summarizes the technology, measurements, and procedures employed, and (2) presents the processed results from these measurements and discusses their interpretation. The logging measurements were acquired from 26 feet (ft) to 715 ft below ground surface (bgs), when the borehole was open below 58.5 ft, drilled with a 12.25 inch (in.) diameter bit size to 717 ft, and contained 12.375 in. inner diameter (ID) steel casing above 58.5 ft (as measured by the logs).

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

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

The geophysical log measurements from Well I-5 provide good quality results that are consistent with each other through most of the borehole. The quality of some measurements was degraded across intervals where the borehole contains large washouts. The measurements most affected by the adverse borehole conditions were ones that have a shallow depth of investigation and require close contact to the borehole wall—the bulk density, photoelectric effect, and the porosity measurements. The greatest impact on the log processing was erroneously high air-filled and/or water-filled porosity in the problem zones – as estimated from the logs. Through the integrated analysis and interpretation of all the logs, the individual shortcomings of the specific measurements are reduced. Thus, the results derived from integrated log analysis (e.g., the optimized water-filled porosity log) are the most robust single representation of the geophysical

log measurements—providing a wealth of valuable high resolution information on the geologic and hydrogeologic environment of the I-5 locale.

Important results from the processed geophysical logs in I-5 include the following:

1. The well water level was stable throughout the logging acquisition, remaining between 684 ft and 685 ft bgs during all three logging runs.
2. The processed logs indicate that the intersected geologic section from 685 ft to the bottom of the log interval (715 ft bgs) is fully saturated with water throughout – possibly representing the top of a significant perched water aquifer. The porosity across this interval varies widely from 10% to 50% of the total rock volume, although the zone with highest porosity is in a section of borehole that appears to be very rugged which could be causing elevated porosity log readings. Most of the saturated log interval appears to be porous fractured basalt (porosity greater than 20%) and likely productive – although a low porosity, tight zone appears to exist at 704 ft to 708 ft. The most porous zone is 691 ft to 699 ft – potentially a rubble zone within the basalt.
3. The processed logs do not indicate any significant fully water saturated (perched) zones above 685 ft. Estimated water saturation is mostly below 60%, except in very low porosity basalt zones, where the overall water content is very low anyways.
4. Above the log-inferred perched groundwater level (685 ft bgs) the processed logs show a continuation of the basalt lava flow sequence up to a depth of 493 ft below ground surface. The sequence consists of mostly dense, low porosity basalt rock (total porosity less than 15% of total rock volume) with low water content (less than 10% of total rock volume), but also contains some higher porosity zones with slightly higher water content (maximum 21% of total rock volume). The most significant higher porosity basalt zones are 493 ft to 517 ft, 617 ft to 645 ft and 660 ft to 670 ft.
5. The geophysical log response in the zone 450 ft 461 ft is characteristic of the Guaje Pumice Bed, with extremely high total porosity (63%), relatively high water-filled porosity (20% to 32%) that decreases in the upward direction, and the presence of moveable water (15% to 25%). The pumice bed is overlain by slightly less-porous volcanic tuff (total porosity 54%).
6. A section of heterogeneous alluvium/fanglomerate beds is clearly delineated from the processed logs between the bottom of the Guaje Pumice Bed and the top of the basalt lava flow sequence (461 ft to 493 ft, as delineated from the logs). The zone appears to contain varying, but considerable, amounts of clay.

2.0 INTRODUCTION

Geophysical logging services were performed in characterization well I-5 by Schlumberger in October 2004, prior to initial well completion. The purpose of these services was to acquire in-situ measurements that help characterize the borehole, near-borehole, and abutting geologic formation environment. The primary objective of the geophysical logging was to provide in-situ evaluation of formation properties (hydrogeology and geology) intersected by the well. This

information was (and is) used by scientists, engineers, and project managers in the Los Alamos Characterization and Monitoring Well Project to design the well completion, better understand subsurface site conditions, and assist in overall decision-making.

The primary geophysical logging services performed by Schlumberger in well I-5 were the

- Combinable Magnetic Resonance (CMR*) tool to measure the nuclear magnetic resonance response of the formation, which is used to evaluate total and effective water-filled porosity of the shallow formation and to estimate pore size distribution and in-situ hydraulic conductivity;

- Compensated Neutron Tool (CNT*) to measure volumetric water content of the formation, which is used to evaluate moist/porous zones;

- Triple Detector Litho-Density (TLD*) tool to measure formation bulk density and photoelectric factor, which are used to estimate total porosity and lithology;

- Array Induction Tool (AIT*) to measure formation electrical resistivity at five depths of investigation and borehole fluid resistivity, which is used to evaluate drilling fluid invasion into the formation (a qualitative indicator of permeability and water saturation), presence of moist zones far from the borehole wall, and presence of clay-rich zones;

- Scintillation Gamma Ray Tool (SGT*) tool to measure gross natural gamma which is used to evaluate geology/lithology, particularly the amount of clay and thorium/potassium-bearing minerals;

- Elemental Capture Spectroscopy (ECS*) tool to measure neutron-induced spectral gamma ray activity from which is derived elemental weight percent concentrations of a number of key rock-forming elements, used to characterize geochemistry, mineralogy, and lithology of the formation.

In addition, calibrated gross gamma ray (GR) was recorded with every service for the purpose of depth matching the logging runs to each other. Table 2.1 summarizes the geophysical logging runs performed in I-5.

*Mark of Schlumberger

Table 2.1
Geophysical logging services, their combined tool runs and intervals logged, as performed by Schlumberger in borehole I-5

Date of Logging	Borehole Status	Run #	Tool 1	Tool 2	Tool 3	Depth Interval (ft)
19-Oct-2004	Open hole below 58.5 ft Bit size of 12.25 in. Steel casing above 58.5 ft Casing ID of 12.375 in.	1	TLD	CNT	SGT	26–715 ft
Same	Same	2	AITH	GR		59–710 ft
Same	Same	3	ECS	CMR	GR	28–708 ft

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

3.0 METHODOLOGY

This section describes the methods employed by Schlumberger at Well I-5 for performing geophysical logging services, including the following stages/tasks:

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

3.1 Acquisition Procedure

Once the well drilling project team notified Schlumberger that I-5 was ready for geophysical well logging, the Schlumberger district in Farmington, NM, mobilized a wireline logging truck, the appropriate wireline logging tools and associated equipment, and crew to the job site. Upon arriving at the LANL site, the crew completed site-entry paperwork and received a site-specific safety briefing.

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

- Parking and stabilizing the logging truck in a position relative to the borehole that is best for performing the surveys
- Setting up a lower and an upper sheave wheel (the latter attached to, and hanging above, the borehole from the drilling rig/mast truck)
- Threading the wireline cable through the sheaves
- Attaching to the end of the cable the appropriate sonde(s) for the first run

Next, pre-logging checks and any required calibrations were performed on the logging sondes, and the tool string was lowered into the borehole. If any of the tools required active radioactive sources (in this case a neutron and gamma source for the CNT/ECS and TLD, respectively) the

sources were taken out of their carrying shields and placed in the appropriate tool source-holding locations using special source handling tools – just prior to lowering the tool string. The tool string was lowered to the bottom of the borehole and brought up at the appropriate logging speed as measurements were made. At least two logging runs (one main and one repeat) were made with each tool string.

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

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

Before departure, the logging engineer printed field logs and created a compact disc containing the field log data for onsite distribution and sent the data via satellite to the Schlumberger data archiving center. The Schlumberger data processing center was alerted that the data were ready for post-acquisition processing.

3.2 Log Quality Control and Assessment

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

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

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

In addition, on every logging job, onsite before and after "calibrations" are executed for most Schlumberger tools directly before/after lowering/removing the tool string from the borehole. For most tools, these represent a measurement verification instead of an actual calibration – used

to confirm the validity of the measurements directly before acquisition and to ensure that they have not drifted or been corrupted during the logging job.

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

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

3.3 Processing Procedure

After the geophysical logging job was completed in the field and the data archived, the data were downloaded to the Schlumberger processing center. There the data were processed in the following sequence, to (1) correct the measurements for near-wellbore environmental conditions and redo the raw measurement field processing for certain tools (CMR and ECS) using better processing algorithms, (2) depth match and splice the log curves from different logging runs, and (3) model the near-wellbore substrate lithology/mineralogy and pore fluids through integrated log analysis. Afterwards, an integrated log montage was built to combine and compile all the processed log results.

3.3.1 Environmental Corrections and Raw Measurement Reprocessing

If required, the field log measurements were processed to correct for conditions in the well, including fluid type (water or air), presence of steel casing, and (to a much lesser extent) pressure, temperature, and fluid salinity. Basically, these environmental corrections entail subtracting from the measurement response the known influences of the set of prescribed borehole conditions. In I-5, the log measurements requiring these corrections are the CNT porosity, TLD density, ECS elemental concentrations, and SGT gross gamma ray logs.

Two CNT neutron porosity measurements are available – one that measures thermal ("slow") neutrons and one that measures epithermal ("fast") neutrons. Measurement of epithermal neutrons is required to make neutron porosity measurements in air-filled holes. In water/mud-filled holes, both the CNT epithermal and thermal neutron measurements are valid, but the thermal neutron porosity has better statistical precision. Both epithermal and thermal neutron porosity measurements were made in I-5 since the borehole was partly water-filled (below 686 ft during the CNT logging) and partly air-filled (above 686 ft during the logging). Epithermal neutron porosity was processed at the field site for borehole fluid type (air versus water) and other environmental conditions and didn't require any further processing. The thermal neutron porosity measurement was reprocessed for borehole conditions, although the results were very similar to the field logs. For further processing and analysis (e.g., integrated log analysis), the reprocessed thermal neutron porosity log was used.

The standard open-hole processing algorithm used for the TLD density measurement is influenced by the steel density in cased hole. A cased-hole density algorithm was applied to the raw TLD field measurements obtained in the short cased hole section of the log interval (35 ft to 58.5 ft) to try to eliminate the casing response. While the algorithm can account for the casing per se, it cannot account for air- or water-filled gaps in the annulus between the casing and the formation that cause erroneously low bulk density readings.

The raw ECS elemental yield measurements include the contribution of iron from steel casing and hydrogen from fluid in the borehole. The processing consists of subtracting these unwanted contributions from the raw normalized yields, then performing the normal elemental yields-to-weight fraction processing. The contribution to subtract is a constant baseline amount (or zoned constant values if there are bit/casing size changes), usually determined by comparing the normalized raw yields in zones directly below/above the borehole fluid/casing change. The ECS log from I-5 has a very short cased hole section, but the data in the casing is problematic – even after casing corrections. At the time of the ECS logging in I-5 the borehole water level was 685 ft; no hydrogen correction was required in the air-filled section above 685 ft and the difference between the hydrogen yield above and below this depth was used to determine the baseline borehole hydrogen correction to apply below.

The SGT gross gamma ray is affected by the material (fluid, air, casing) in the borehole because different types and amounts of these materials have different gamma ray shielding properties; the SGT measures incoming gamma rays emitted by radioactive elements in the formation surrounding the borehole. The processing algorithms try to correct for the damping influence of the borehole material. The gross gamma ray log from I-5 was reprocessed to fully account for the environmental effects of the borehole fluid (water below 684 ft and air above), hole size, and casing (the latter above 58.5 ft).

The measurements cannot be fully corrected for borehole washouts or rugosity, nor the annulus material (e.g., bentonite grout) between casing and the formation, since the specific characteristics of these features (e.g., geometry) are unknown and their effects on the measurements are often too significant to account for. Thus, the compromising effects of these conditions on the measurements should be accounted for in the interpretation of the log results.

3.3.2 Depth-Matching and Splicing

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

3.3.3 Integrated Log Analysis

An integrated log analysis, using as many of the processed logs as possible, was performed to model the near-wellbore substrate lithology/mineralogy and pore fluids. This analysis was

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

The logging tool measurements, volume components, and measurement response parameters used in the ELAN analysis for I-5 are provided in Table 3.1. The final results of the analysis – an optimized mineral-fluid volume model – are shown on the integrated log montage (on attached CD), 3rd track from the right (inclusive of the depth track). In addition, the ELAN program provides a direct comparison of the modeled versus the actual measured geophysical logs, as well as a composite log of all of the key ELAN derived results. To make best use of all the measurement data and to perform the analysis across as much of the well interval as possible (27 ft to 715 ft), as many as possible of the processed logs were included in the analysis, with less weighting applied to less robust logs. Not all of the tool measurements shown in Table 3.1 and the ELAN modeled versus measured log display are used for the entire interval analyzed, as not all the measurements are available, or of good quality, across certain sections of the borehole. To accommodate fewer tool measurements certain model constituents are removed from the analysis in some intervals. Most notably, above 62 ft and below 689 ft, many of the minerals had to be removed from the model due to the absence of many of the logs; above 90 ft and below 708 ft capillary bound water had to be removed because no CMR measurement is available (CMR has the only measurement that is independently sensitive to bound water).

The ELAN analysis was performed with as few constraints or prior assumptions as possible. A considerable effort was made to choose a set of minerals or mineral types for the model that is representative of Los Alamos area geology and it's volcanic origins. For the ELAN analysis, the log interval 61 ft to 460.5 ft was assumed to be tuff or pumice, and a mineral suite considered representative of this volcanic tuff was used (primary "minerals" silica glass/cristobalite/tridymite [indistinguishable from the log measurements], quartz, sanidine, and montmorillinite with accessory minerals augite, calcite, and pyrite). The log interval 460.5 ft to 494 ft was assumed to be in the Puye Formation, or fanglomerate/alluvium with similar composition, and the interval 494 ft to 715 ft was assumed to be in the Cerros del Rio basaltic lavas, both with a wide range of possible minerals. In addition, the results of laboratory analyses of Bandelier Tuff and Puye Formation core samples from around the LANL site were used to

*Mark of Schlumberger

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

constrain the proportion of quartz versus the combination of glass/cristobalite/tridymite in the ELAN analysis (as well as to determine the representative primary mineral suites).

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

Table 3.1
Tool measurements, volumes, and respective parameters used in the I-5 ELAN analysis

Volume / Tool Measurement	Air	Capillary Bound Water	Water	Hypersthene	Labradorite	Silica Glass, Cristo., Tridy.	Heavy Mafic Minerals	Augite	Montmorillinite	Pyrite	Orthoclase / Sanidine	Calcite	Quartz
Bulk density (g/cc)	–0.19	1.00	1.00	3.55	2.65	2.33	4.0	3.08	2.02	4.99	2.58 2.56		2.64
Epithermal neutron porosity (ft^3/ft^3)	0	1.00	1.00	0.01	-0.01	0.0	0.02	-0.01	0.5	0.17	-0.01	0.0	-0.047
Thermal neutron poro. (nonlinear) (ft^3/ft^3)	0	1.00	1.00	0.04	-0.01	-0.03	0.07	0.02	0.65	0.01	-0.01	0.0	-0.02
Volumetric photoelectric effect	0	0	0.40	20.2	7	4.2	65	23.8	4.4	82.1	7.3 7.0	14.1	4.8
Total CMR water-filled porosity (ft^3/ft^3)	0	1.0	0.7	0	0	0	0	0	0.5	0	0	0	0
CMR bound fluid volume (ft^3/ft^3)	0	1.0	0	0	0	0	0	0	0.5	0	0	0	0
Resistivity (ohm-m)	Very high	35	35	Very high	Very high	Very high	Very high	Very high	0.58	Very high	Very high	Very high	Very high
Dry weight silicon (lbf / lbf)	0.0	0.0	0.0	0.24	0.24	0.47	0.18	0.23	0.26	0	0.3 0.38	0	0.47
Dry weight calcium (lbf / lbf)	0.0	0.0	0.0	0.0	0.09	0.0	0.0	0.10	0.01	0.0	0.0	0.405	0.0
Dry weight iron (lbf / lbf)	0.0	0.0	0.0	0.20	0.02	0.0	0.22	0.11	0.04	0.47	0.02	0.0	0.0
Dry weight sulfur (lbf / lbf)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.53	0.0	0.0	0.0
Dry weight titanium (lbf / lbf)	0.0	0.0	0.0	0.01	0.0	0.0	0.0	0.048	0.0	0.0	0.0	0.0	0.0
Dry weight aluminum (lbf / lbf)	0.0	0.0	0.0	0.0	0.16	0.0	0.0	0.02	0.11	0.0	0.10	0.0	0.0
Wet weight potassium (lbf / lbf)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.003	0.005	0.0	0.102	0.0	0.0
Weight hydrogen (lbf / lbf)	0.0	0.111	0.111	0.0	0.0	0.01	0.0	0.0	0.025	0.0	0.0	0.0	0.0
Wet weight thorium (ppm)	0.0	0.0	0.0	25	3	2	4	20	24	0	5.5	0.0	2
Clay bound water volume (ft^3/ft^3)	0	0	0	0	0	0	0	0	0.5	0	0		0
Magnetic Field Variation (mT)	0	0	0	0	0	0	2	0	0	0.5	0		0
Gamma Ray (gAPI)	0	0	0	50	50	20	50	30	300	0	255 500	11	25

4.0 RESULTS

Preliminary results from the wireline geophysical logging measurements acquired by Schlumberger in I-5 were generated in the logging truck at the time the geophysical services were performed and were documented in the field logs provided on site. However, the measurements presented in the field results are not fully corrected for undesirable (from a measurement standpoint) borehole and geologic conditions and are provided as separate, individual logs. The field log results have been processed (1) to correct/improve the measurements, as best as possible, for borehole/formation environmental conditions; and (2) to depth-match the logs from different tool runs in the well. Additional logs were generated from integrated analysis of processed measured logs, providing valuable estimates of key geologic and hydrologic properties.

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

Important results from the processed geophysical logs in I-5 are described below.

4.1 Well Water Level

The standing water level in I-5 was stable during the October 19, 2004 logging, remaining between 684 ft and 685 ft below ground surface for all three logging runs.

4.2 Known (Target) Perched Aquifer

The processed geophysical logs indicate a significant increase in water saturation below 685 ft, which is coincident with the well water level at the time of the logging. The estimated pore-volume water saturation (fraction of the total pore volume containing water) computed from the ELAN analysis is very high (mostly 90% to 100%) from 685 ft to the bottom of the log interval (715 ft), compared with 40% to 80% in the interval directly above 685 ft. The estimate is similarly high when computed directly from bulk density and ELAN water-filled porosity for a grain density range of 2.65 g/cc to 3.05 g/cc (for the basalt zone below 493 ft). These results suggest that the water table associated with a perched water "aquifer" zone may reside at 684 ft in this location, with the perched aquifer itself below. However, if the borehole water level is higher than the ground water level in the surrounding geologic formation (e.g., due to confined conditions in the aquifer), the logging measurements could be reading higher water content, and thus water saturation, than actually exists – due to induced saturation of the near-borehole formation, which is the volume that most of the porosity logs are sensitive to. This condition

does not seem likely since the inferred water table does not rise much above the very porous zone (688 ft to 699 ft) showing 100% water saturation.

Water-filled and total porosity[2] varies widely from 10% to 50% across the bottom of the log interval that intersects the apparent perched aquifer (685 ft to 715 ft), although the zone with highest porosity is in a section of borehole that appears to be very rugged, which could be causing elevated porosity log readings. Key hydrogeologic characteristics observed from the logs across this interval are described below (referenced to depth below ground surface):

- **685–691 ft:** This zone is characterized by moderate total and water-filled porosity that increases with depth (20% to 35%). Effective porosity, estimated from the ELAN integrated log analysis (primarily sensitive to the CMR log results), is a significant proportion of the total porosity (ranging 12% to 24%). Total and water-filled porosity generally overlap in this zone and all zones below (indicating 100% water saturation). The ELAN analysis model results indicate that the interval possibly contains minor amounts of clay and other fine-grained material, but is predominantly composed of basaltic rock minerals. The full saturation and high effective porosity is suggestive of productive aquifer material – likely fractured basalt.

- **691–699 ft:** This zone has very high total (water-filled) porosity (35% to 53% of total rock volume), as well as effective porosity (24% to 42%). These log-measured/derived porosity values may be particularly elevated due to rugged borehole conditions, but likely the true formation porosity is high in spite of this. The high estimated moveable water content in this zone is suggestive of productive aquifer material – likely highly fractured basalt.

- **699–706 ft:** Total (water-filled) porosity (18% to 33%), as well as effective porosity (12% to 28%) decreases with depth across this zone. The ELAN results suggest this zone is also composed of basaltic rock, but likely is less fractured than the zone above.

- **706–708 ft:** This thin zone is characterized by a sharp decrease in total (water-filled) and effective porosity (10% and 7%, respectively) from the surrounding section – possibly corresponding to a tight zone that inhibits vertical water movement. The composition of the rock is difficult to discern from the log results since many of the logging tools could not measure this close to the bottom of the borehole. However, the ELAN analysis optimized mineral results are suggestive of a continuation of the basalt sequence from above. If this is true, this zone could be a dense, basalt section with very little fracturing.

- **708–715 ft (bottom of log interval):** Total (water-filled) porosity appears to increase at the bottom of the log interval – from 23% at the top of this zone to 39% at the bottom. No direct information about effective porosity is available from the log

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

measurements since this interval is below the bottom of the CMR log. The composition of the rock is very difficult to discern from the logs since most of the logging tools could not measure this close to the bottom of the borehole.

4.3 Vadose Zone Perched Water

Above 685 ft (the apparent known perched aquifer water table), the processed geophysical logs indicate highly variable total porosity (comprising air and water) and much lower, but also highly variable, water-filled porosity (maximum 32% of total rock volume, but mostly less than 20%) – compared to the likely saturated section below. Water saturation, as estimated from the processed geophysical logs, never surpasses 80% above 685 ft, mostly staying below 60%. Thus, no significant fully water saturated (perched water) zones are evident from the log results above 685 ft (log interval 27 ft to 685 ft). Key hydrogeologic characteristics observed from the logs across the vadose zone log interval are described below, from bottom to top (referenced to depth below ground surface):

- **670–685 ft**: Water saturation (estimated from the ELAN integrated log analysis) varies between 46% and 73% – much lower than the log interval below 685 ft. Water-filled porosity is very low (mostly 6%, reaching 20% at the bottom), as is total porosity (mostly 10%, reaching 27% at the bottom) – both much lower than the saturated interval directly below. Estimated moveable water content ranges zero to 5%. The ELAN model results indicate the presence of variable, minor amounts of clay across the interval.

- **660–670 ft:** This zone has sharply higher water-filled and total porosity (maximum of 19% and 28%, respectively) than the surrounding zones. In addition, estimated moveable water content is higher (3% to 12%), peaking at the bottom. The ELAN model results indicate the presence of clay above 665 ft.

- **645–660 ft:** The processed log results indicate very low water-filled and total porosity (average of about 6% and 12%, respectively), as well as low estimated moveable content (average of about 3%). The ELAN results indicate minor amounts of clay are present throughout the interval.

- **617–645 ft:** Both water-filled and total porosity are much higher than surrounding zones (12% to 21% and 17% to 35%, respectively). Estimated moveable water content varies mostly between 3% and 23%, with the highest value at the bottom. The ELAN model suggests appreciable amounts of clay are present in much of the zone.

- **606–617 ft:** This zone is characterized by very low water-filled and total porosity (3% to 6% and 8% to 15%, respectively), the former decreasing and the latter increasing in the upwards direction. Estimated moveable water content varies from about 2% to 5% (decreasing in the upwards direction). The ELAN results indicate minor amounts of clay are present throughout the interval.

- **602–606 ft:** Based on the bulk density log, a spike in total porosity occurs here (maximum of 43%), but water content remains very low (3%).
- **599–602 ft:** Water-filled and total porosity are very low (3% and 11%, respectively).
- **596–599 ft:** This thin zone is distinguished by another high total porosity anomaly (30%) and very low water content (3%).
- **525–596 ft:** Water-filled and total porosity are very low – increasing in the upwards direction (4% to 11% and 8% to 19%, respectively). Estimated moveable water content varies from about 3% at the bottom to 8% at the top. The ELAN mineral model results indicate a minor amount of clay is present throughout the interval.
- **517–525 ft:** There is a slight increase in total porosity compared to the zone below (average of about 24%), but water-filled porosity and moveable water content are similar (8% to 11% and 0 to 7%, respectively). Negligible clay is present according to the ELAN results.
- **506–517 ft:** This zone is characterized by a very high total porosity anomaly (60% to 64%) that is directly coincident with a large borehole washout. The log derived water-filled porosity is very low (4% to 8%). The log results appear to be significantly affected by the washout, which would cause an elevated measurement response of air since the borehole contained air at this depth.
- **500–506 ft:** Water-filled and total porosity are low (average of about 9% and 20%, respectively) – similar to the zone between 517 ft and 525 ft. Estimated moveable water is about 6%. The ELAN results indicate negligible clay content.
- **461–500 ft:** Total porosity is moderately high (25% to 42%, with a 57% spike at 480 ft where there is a large borehole washout) and water-filled porosity is higher than the zone below (9% to 21%). Estimated moveable water content varies from about 3% to 11% (maximum at the bottom, although the ELAN results indicate a significant amount of clay is present through much of the interval.
- **450–461 ft:** The processed log results are characterized by extremely high total porosity (63%) and higher water-filled porosity and moveable water content than surrounding intervals (20 to 32% and 15 to 25%, respectively). Water saturation is estimated at 35–63%. There is an anomalous sharp decrease in water-filled porosity at 459 ft that is coincident with a sharp washout. The log response, seen in many other Los Alamos wells, is characteristic of the Guaje Pumice Bed.
- **443–450 ft:** Total porosity is very high (54%), although not as high as in the Guaje Pumice Bed below, and water-filled porosity and moveable water content are relatively high (20% and 8 to 14%, respectively), the latter decreasing in the upwards direction.
- **279–443 ft:** Total porosity is high and consistent (46%) throughout this interval and water content decreases slightly in the upwards direction from 19% at 443 ft to 14%

at 279 ft. Moveable water content is steady at 3 to 4%. ELAN estimated moveable water content is notably higher than below, ranging 3–5%. Water saturation decreases (in the upwards direction) from about 42% at 443 ft to 30% at 280 ft.

- **226–279 ft:** The processed log results are characterized by a slight, but distinct, drop in total porosity (43%) compared to zone below. Water-filled porosity and moveable water content are steady at 13% and 3%, respectively.

- **156–226 ft:** Total porosity increases upwards from 43% at 226 ft to 47% at 156 ft. Water-filled porosity (average about 15%) and moveable water content (average about 5%) are also higher than the zone below. This zone does contain significant borehole washouts that could cause elevated porosity log measurements.

- **61–156 ft:** This zone contains significant borehole washouts and the processed log results indicate highly variable total and water-filled porosity (40% to 63% and 5% to 30%, respectively), the latter trending higher in the upwards direction. Likely the log porosity results exceeding 50% are erroneously high due to borehole washouts.

- **27–61 ft (top of processed log interval):** Total porosity from the processed logs is very high (44% to 49%) with two lower porosity anomalies at 39 ft (39%) and 59 ft (34%). Water-filled porosity steadily decreases in the upwards direction from 39% at 61 ft to 3% at 27 ft.

4.4 Geology

The processed geophysical log results clearly delineate the geologic material and most of the formation contacts intersected by I-5. The generalized geologic stratigraphy observed from the logs across the measured interval is as follows (depth below ground surface):

- **27–61 ft (top of processed log interval): Very high porosity material (volcanic tuff or alluvial sediments)** – characterized by very high total porosity (44% to 49% of total rock volume) and high potassium feldspar and silica mineral/glass content, although it is difficult to delineate specific mineralogy or lithology from the limited number of geophysical log in this cased hole section of the well

- **61–98 ft: Very high porosity silicon and calcium rich material (volcanic tuff or alluvial sediments)** – characterized by very high total porosity (41% to 62% of total rock volume), high potassium feldspar and silica mineral/glass content, significant augite (or similar mineral) and calcite (or other calcium-bearing minerals), and minor amounts of pyrite or other sulfur-bearing mineral. It is hard to determine from the processed geophysical logs whether this zone is within or above the top of the volcanic tuff sequence (the latter case would entail that the zone is within alluvial sediments), although most of the log results are similar to those in the known tuffs below.

- **98–113 ft: High porosity silicon rich material containing clay (volcanic tuff or alluvial sediments)** – characterized by high, but variable, total porosity (38% to 60% of total rock volume), high silica glass/tridymite/cristobalite and sanidine content,

significant clay content (especially 98 ft to 103 ft), and minor amounts of augite (or similar minerals) and calcite (or other calcium-bearing minerals)

- **113–156 ft: Very porous volcanic tuff** – characterized by very high total porosity (40% to 52% of total rock volume); high sanidine and silica glass/tridymite/cristobalite content; minor amounts of augite (or similar minerals) and calcite (or other calcium-bearing minerals), and possibly trace amounts of clay

- **156–279 ft: Porous volcanic tuff** – characterized by high total porosity (43% of total rock volume below 181 ft, increasing to about 50% at 156 ft); high silica glass/tridymite/cristobalite and sanidine content; minor amounts of augite (or similar minerals), calcite (or other calcium-bearing minerals), and possibly clay

- **279–443 ft: Very porous volcanic tuff** – characterized by very high total porosity (46% of total rock volume); high sanidine and silica glass/tridymite/cristobalite content; and minor amounts of augite (or similar minerals), calcite (or other calcium-bearing minerals), and possibly clay

- **443–450 ft: Very porous volcanic tuff (possibly pumice-rich)** – characterized by very high total porosity (54% of total rock volume); high sanidine and silica glass/tridymite/cristobalite content; and minor amounts of augite (or similar minerals), calcite (or other calcium-bearing minerals), and possibly pyrite (or other sulfur-bearing mineral)

- **450–461 ft: Extremely porous volcanic pumice bed** – characterized by extremely high total porosity (63% of total rock volume); high sanidine and silica glass/tridymite/cristobalite content; and minor amounts of augite (or similar minerals), calcite (or other calcium-bearing minerals), and possibly pyrite (or other sulfur-bearing mineral). The log response is characteristic of the Guaje Pumice Bed, as seen in many other Los Alamos wells.

- **461–493 ft: Heterogeneous alluvium (possible fanglomerate) containing clay** – characterized by variable total porosity (26% to 42% of total rock volume, except higher in borehole washouts); high silica glass/tridymite/cristobalite content; moderate potassium feldspar content; minor amounts of augite, hypersthene, and/or other heavy mafic minerals; and the presence of varying, but considerable, amounts of clay

- **493–506 ft: Variable porosity basalt lava containing clay (likely altered)** – characterized by variable total porosity (19% of total rock volume at bottom and 40% at top); high plagioclase content; moderate amounts of augite, hypersthene, and/or other heavy mafic minerals; and variable clay content (greatest at the top of the zone)

- **508–517 ft: Extremely high total porosity anomaly (60% to 64%) within basalt lava** – characterized by extremely high total porosity (60% to 64% of total rock volume) that is likely associated with a large borehole washout at this depth; high feldspar and heavy mafic mineral content; moderate amounts of augite and hypersthene; and possible small amounts of clay

- **517–525 ft: Relatively porous basalt lava** – characterized by relatively high total porosity (average of about 24% of total rock volume); high plagioclase content; moderate amounts of hypersthene, augite, and/or other heavy mafic minerals; and small amounts of potassium feldspar

- **525–596 ft: Low porosity, competent basalt lava** – characterized by low total porosity (8% to 19% of total rock volume, average about 14%); high plagioclase content; moderate amounts of hypersthene, augite, and/or other heavy mafic minerals; and possible small amounts of potassium feldspar and clay

- **596–599 ft: High porosity anomaly within basalt lava** – characterized by high total porosity (30% of total rock volume); high plagioclase content; moderate amounts of hypersthene, augite, or other heavy mafic minerals; and possible small amounts of potassium feldspar and/or clay

- **599–602 ft: Low porosity, competent basalt lava** – characterized by low total porosity (11% of total rock volume); high plagioclase content; moderate amounts of hypersthene, augite, or other heavy mafic minerals; and possible small amounts of potassium feldspar and/or clay

- **602–606 ft: High porosity anomaly within basalt lava** – characterized by high total porosity (maximum 43% of total rock volume); high plagioclase content; moderate amounts of hypersthene, augite, and/or other heavy mafic minerals; and possible small amounts of potassium feldspar and/or clay

- **606–617 ft: Low porosity, competent basalt lava** – characterized by low total porosity (8% to 15% of total rock volume); high plagioclase content; moderate amounts of hypersthene, augite, or other heavy mafic minerals; and possible small amounts of potassium feldspar and/or clay

- **617–645 ft: Relatively porous basalt lava (possibly altered)** – characterized by relatively high total porosity (17% to 35% of total rock volume); high plagioclase content; moderate amounts of hypersthene, augite, and/or other heavy mafic minerals; and possible small amounts of potassium feldspar and clay

- **645–660 ft: Low porosity, competent basalt lava** – characterized by low total porosity (12% of total rock volume); high plagioclase content; moderate amounts of hypersthene, augite, or other heavy mafic minerals; and possible small amounts of potassium feldspar and/or clay

- **660–670 ft: Relatively porous basalt lava (possibly altered)** – characterized by relatively high total porosity (maximum 28% of total rock volume); high plagioclase content; moderate amounts of hypersthene, augite, and/or other heavy mafic minerals; and possible small amounts of potassium feldspar and clay

- **670–681 ft: Low porosity, competent basalt lava** – characterized by low total porosity (10% of total rock volume); high plagioclase content; moderate amounts of

hypersthene, augite, or other heavy mafic minerals; and possible small amounts of potassium feldspar and/or clay

- **681–689 ft: Relatively porous basalt lava (possibly altered)** – characterized by relatively high total porosity (20% to 24% of total rock volume); high plagioclase content; moderate amounts of hypersthene, augite, and/or other heavy mafic minerals; and possible small amounts of potassium feldspar and clay

- **689–704 ft: Very porous basalt lava (likely altered, rubble zone)** – characterized by high to very high total porosity (20% to 53% of total rock volume); high amounts of hypersthene, augite, and/or other heavy mafic minerals; moderate plagioclase content; and possible small amounts of potassium feldspar and/or clay

- **704–708 ft: Low porosity, competent material (possibly basalt lava)** – characterized by low total porosity (10% of total rock volume); high plagioclase content; moderate amounts of hypersthene, augite, or other heavy mafic minerals; and possible small amounts of potassium feldspar and/or clay

- **708–715 ft (bottom of log interval): Relatively porous material (rock type difficult to determine from logs)** – characterized by relatively high total porosity (23% to 39% of total rock volume); possibly high augite, hypersthene, hornblende, and/or heavy mafic mineral content; and possibly moderate plagioclase content

4.5 Summary Logs

Three summary log displays have been generated for I-5 to highlight the key hydrogeologic and geologic information provided by the processed geophysical log results:

- Porosity summary log showing continuous hydrogeologic property logs, including total and moveable water content and water saturation, highlights hydrologic information obtained from the integrated log results (Figure 4.1)

- Density and clay content summary showing a continuous logs of formation bulk density and estimated grain density, as well as photoelectric factor (sensitive to mineralogy) and estimated clay volume, highlights key geologic rock matrix information obtained from the log results (Figure 4.2)

- Lithology and mineralogy summary showing a high vertical resolution, continuous volumetric analysis of formation mineral and pore fluid composition (based on an integrated analysis of the logs) and relative dry weight mineral composition, highlights the geologic lithology, mineralogy, and stratigraphy obtained from the log results (Figure 4.3).

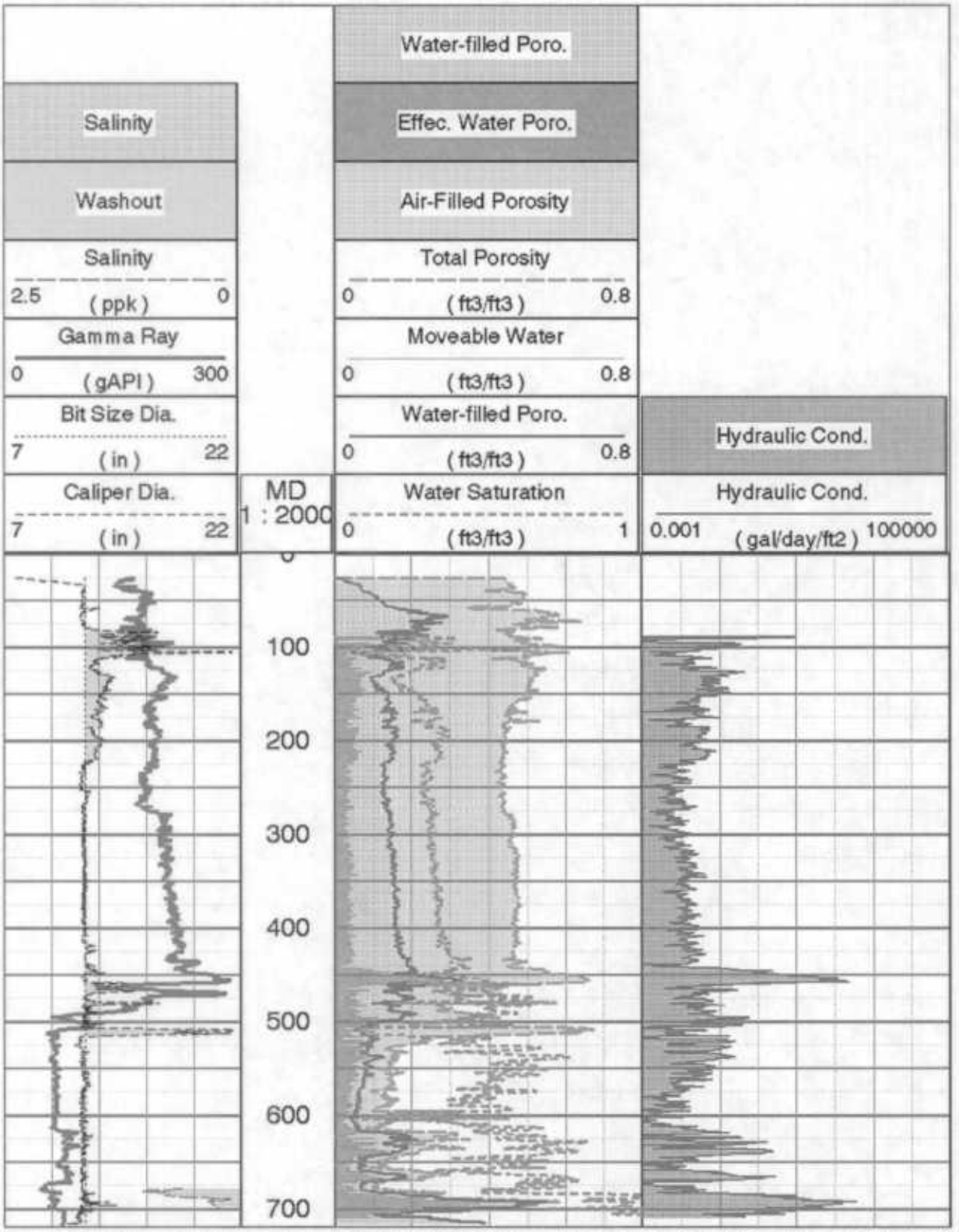

Figure 4.1. **Summary of porosity logs in I-5 borehole from processed geophysical logs, interval of 27 to 715 ft, with caliper, gross gamma, apparent salinity, water saturation, and water hydraulic conductivity logs. Porosity, water saturation, and hydraulic conductivity logs are derived from the ELAN integrated log analysis.**

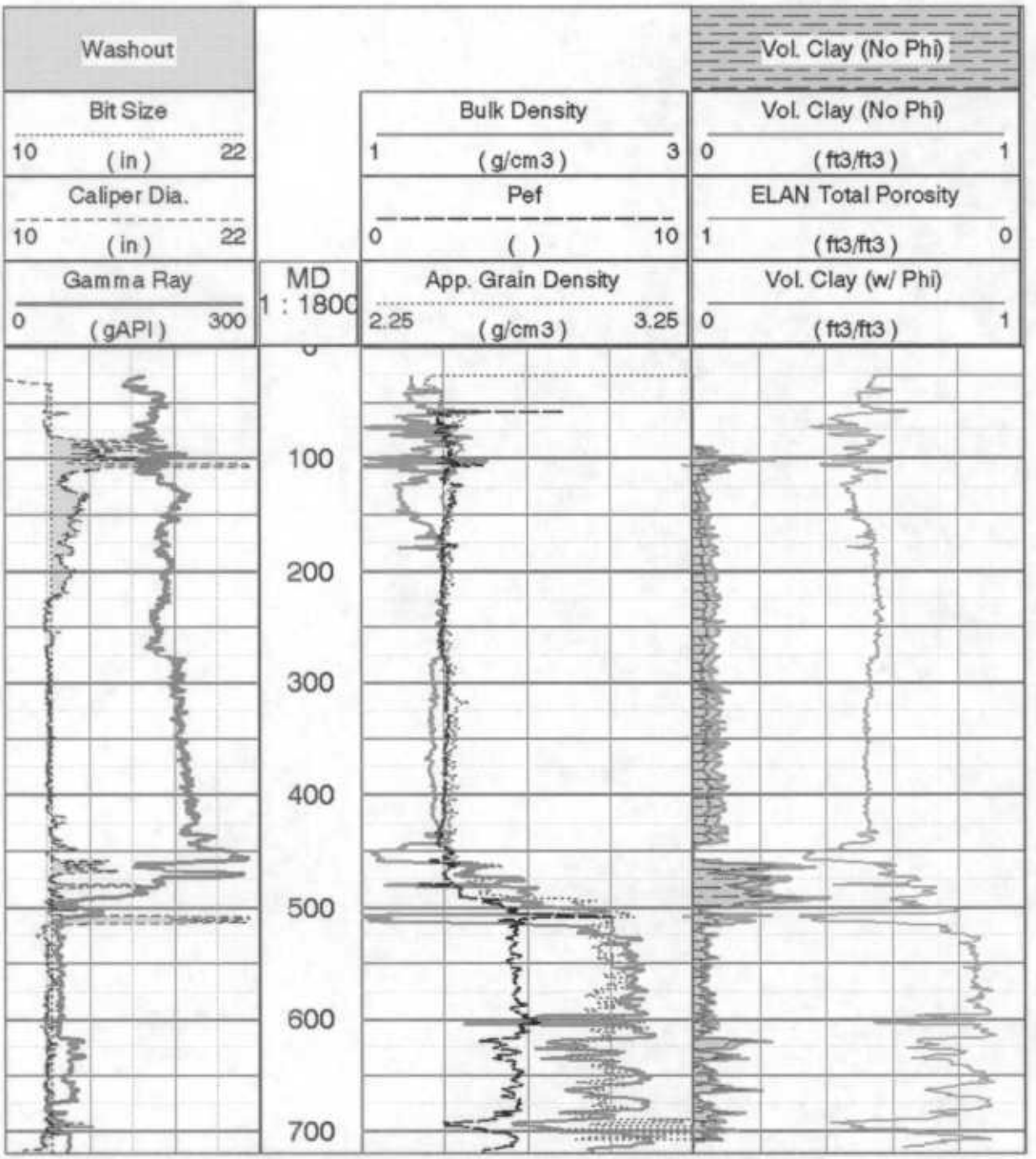

Figure 4.2. **Summary of bulk density and volume clay logs in I-5 borehole from processed geophysical logs, interval of 27 to 715 ft. Also shown are caliper, gross gamma, apparent grain density, and total porosity logs (the latter two derived from the ELAN analysis).**

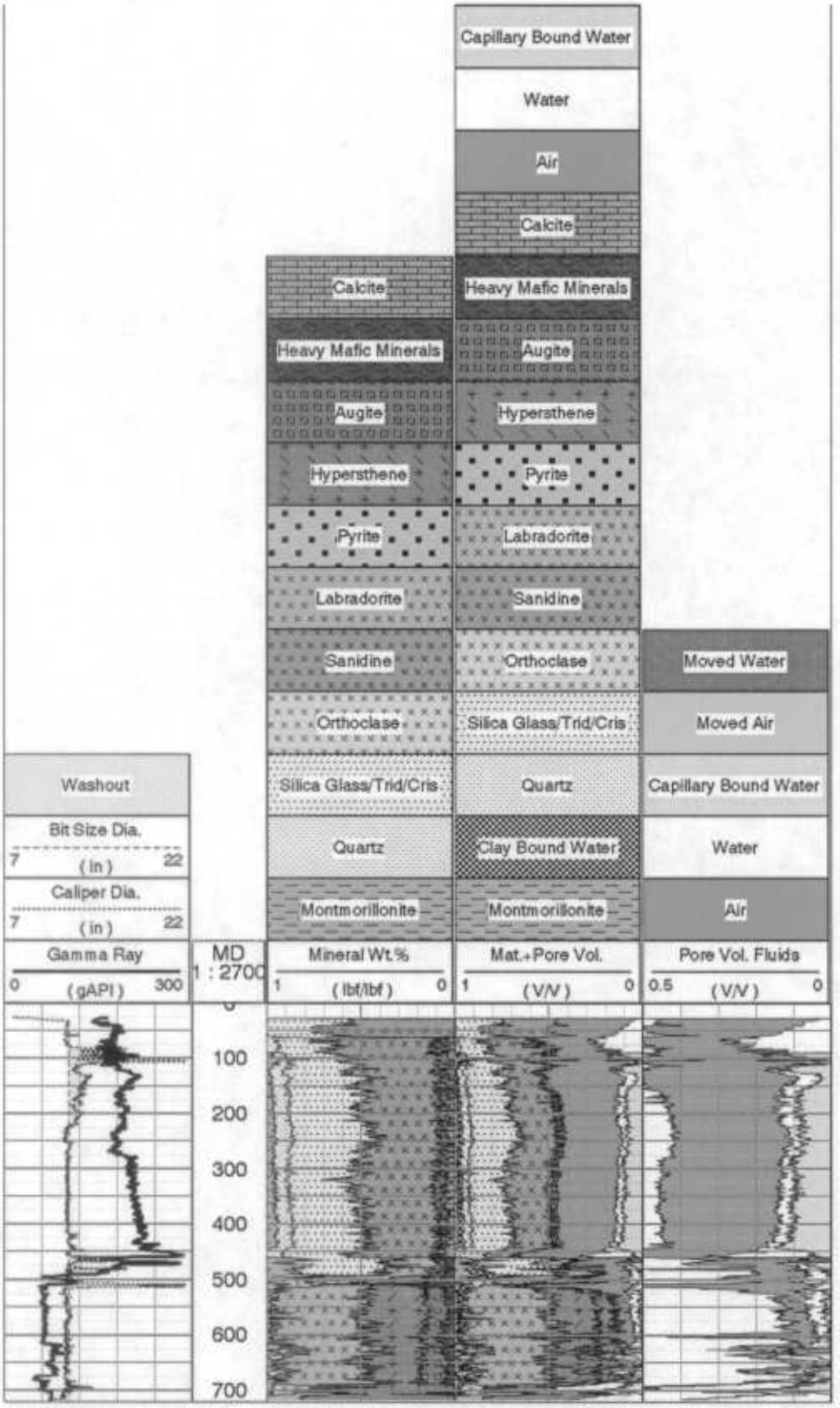

Figure 4.3. **Summary of optimized mineralogy/lithology and pore fluid model volumes derived from the ELAN integrated log analysis for I-5 borehole, interval of 27 to 715 ft. Caliper and gamma ray logs are also shown.**

4.6 Integrated Log Montage

This section summarizes the integrated geophysical log montage for I-5. The montage is provided on the attached CD. A description of each log curve in the montage follows, organized under the heading of each track, starting from track 1 on the left-hand side of the montage. Note that the descriptions in this section focus on what the curves are and how they are displayed; the specific characteristics and interpretations of the I-5 geophysical logs are provided in the previous section.

4.6.1 Track 1–Depth

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

4.6.2 Track 2–Basic Logs

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

- gamma ray (thick black), recorded in API units and displayed on a scale of 0 to 300 API units;
- caliper from the TLD (thin solid pink) with bit size as a reference (dashed-dotted black) to show washout (pink shading), recorded as hole diameter in inches and displayed on a scale of 10 to 25 in.;
- spontaneous potential, or SP (dashed red – valid only below the borehole water level), recorded in millivolts and displayed on a relative scale;
- bulk salinity (dashed green with green shading), recorded in parts per thousand (ppk) and displayed on a scale of 5 to 0 ppk (left to right).

4.6.3 Track 3–Resistivity

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

The six resistivity logs from the AIT that are displayed are

- Borehole fluid resistivity (solid orange curve)–only valid in water-filled hole
- Bulk electrical resistivity at five median depths of investigation–10 in. (black solid), 20 in. (long-dashed blue), 30 in. (short-dashed red), 60 in. (dashed-dotted green), and 90 in. (solid purple)–each having a 2-foot vertical resolution. The logs are only valid (and, thus, only displayed) below the steel casing present at the time of the logging.

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

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

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

4.6.4 Track 4–Porosity

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

- CNT epithermal neutron porosity (solid sky blue curve)–epithermal neutron porosity processed for zoned air-filled and water-filled hole;
- CNT water-filled thermal neutron porosity (solid sky blue curve)–thermal neutron porosity valid only in the water-filled borehole;
- CMR total water-filled porosity (solid black);
- CMR effective water-filled porosity (dashed green);
- CMR bound water porosity (light blue area shading)–representing by the area between the CMR total and effective water-filled porosities;
- Total porosity derived from bulk density and ELAN water-filled porosity using a grain density of 2.65/2.75/3.05 g/cc (dotted red curve), 2.45/2.55/2.65 g/cc (long-dashed red curve), and 2.25/2.35/2.65 g/cc (dashed red curve)–with red shading between the 2.25/2.35/2.65 g/cc and 2.65/2.75/3.05 g/cc porosity curves to show the range (the highest grain density range used across the basalt interval [493 to 715 ft], the middle grain density range used across the fanglomerate/alluvium interval [461 to 493 ft], and the lowest grain density range used across the tuff/pumice interval [27 to 461 ft]); and
- ELAN total water and air-filled porosity (dashed-dotted cyan)–derived from the ELAN integrated analysis of all log curves to estimate optimized matrix and pore volume constituents.

4.6.5 Track 5–Density

The fifth track displays the

- bulk density (thick solid maroon curve) on a scale of 1 to 3 g/cc;
- photoelectric effect Pe (long-dashed black curve) on a scale of 0 to 10 non-dimensional units;

- density correction (dashed orange curve) on a scale of -0.75 to 0.25 g/cc; and
- apparent grain density (dashed-dotted brown curve), derived from the ELAN analysis, on a scale of 2.4 to 3.2 g/cc.

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

4.6.6 Track 6–CMR Porosity

Track 6 displays various CMR water-filled porosities along with measurement quality flags–valid only in the open-hole section. The porosity and measurement quality logs are presented on a scale of 0.5 to 0 volume fraction and discrete blocks originating from the left side, respectively. Specifically, the CMR logs shown in this track are

- Total water-filled porosity (solid black curve)–representing the total water volume fraction measured by the CMR;
- Three millisecond (ms) porosity (short-dashed brown)–representing the water volume fraction corresponding to the portion of the CMR measured T2 distribution that is above 3 ms, a cutoff that is considered to be representative of the break between clay-bound water (less than 3 ms) and all other types of water (greater than 3 ms);
- Effective water-filled, or free-fluid, porosity (solid pink)–representing the water volume fraction that is moveable (can flow), based on a 33 ms T2 distribution cutoff that is considered representative of the break between bound water (less than 33 ms) and moveable water (greater than 33 ms) in clastic rocks;
- Clay-bound water (brown area shading between total and 3 ms porosity logs)–representing the water volume fraction that is bound within clays;
- Capillary-bound water (pink area shading between 3 ms and effective porosity logs)–representing the water volume fraction that is bound within matrix pores by capillary forces;
- CMR magnetic field variation (dotted yellow)–representing the variation in the measured magnetic field versus the baseline magnetic field used for the logging (used as an indicator of the presence of magnetic minerals which requires a lower T2 cutoff)
- CMR wait-time flag (red area shading)–activates when there is significant measurement response at late T2 times, corresponding to large amounts of completely free ("bathtub") water and often associated with washouts or very large pores;
- CMR measurement noise flag (yellow and orange area shading)–activates when there is potentially detrimental amounts of measurement noise detected by the tool, at moderate (yellow) and high (orange) levels.

4.6.7 Track 7–Pore Size Distribution

Track 7 displays the water-filled pore size distribution as determined by the CMR–shown as binned water-filled porosities and valid only in the open-hole section. The binned porosity logs are presented on a scale of 0.5 to 0 volume fraction with colored area shading corresponding to the different bins:

- Clay-bound water–brown area shading
- Micro-pore and small-pore water (the sum comprising capillary-bound water)–gray and blue area shading, respectively
- Medium-pore, large-pore, and late-decay (the sum comprising effective water-filled porosity)–yellow, red, and green area shading, respectively

4.6.8 Track 8–CMR T2 Distribution (Waveforms)

The CMR T2 distribution is displayed in Track 8 as green waveform traces at discrete depths. The horizontal axis, corresponding to relaxation time in milliseconds, is on a logarithmic scale from 0.3 to 3000 ms. Also plotted are the:

- T2 logarithmic mean (solid blue curve) and
- T2 cutoff time used for differentiating between bound and free water (solid red line)–chosen as 12 ms below 495 ft and 33 ms above 495 ft

4.6.9 Track 9–CMR T2 Distribution (Heated Amplitude)

Track 9 displays the T2 distribution in another way–on a heated color scale where progressively "hotter" color (green to yellow to red) corresponds to increasing T2 amplitude. The remaining aspects of the display are the same as in Track 9, except that the T2 logarithmic mean is shown as a solid white curve and the T2 cutoff is displayed as a solid black line.

4.6.10 Track 10–CMR Hydraulic Conductivity

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

- A K-versus-depth estimate derived from using the SDR permeability equation applied to the processed CMR results, converted to hydraulic conductivity (dashed purple curve);
- A K-versus-depth estimate derived from using the Timur-Coates permeability equation with total and moveable water content derived from the ELAN analysis, converted to hydraulic conductivity (solid blue curve); and

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

4.6.11 Tracks 11 to 15–Geochemical Elemental Measurements

The narrow tracks 11 to 15 present the geochemical measurements iron (Fe) and silicon (Si), sulfur (S) and calcium (Ca), estimated aluminum (Al), titanium (Ti) and gadolinium (Gd), and hydrogen (H) and bulk chlorinity (Cl) —from left to right respectively, in units of dry matrix weight fraction (except H wet-weight fraction and Cl in ppk).

4.6.12 Track 16–ELAN Mineralogy Model Results (Dry Weight Fraction)

Track 16 displays the results from the ELAN integrated log analysis (the matrix portion)–presented as dry-weight fraction of mineral types chosen in the model:

- Montmorillonite clay (brown/tan)
- Quartz (yellow with small black dots)
- Silica glass (orange)
- Orthoclase or other potassium feldspar (lavender)
- Sanidine (violet)
- Labradorite or other plagioclase feldspar (pink)
- Hypersthene (purple)
- Hornblende (forest green)
- Augite (maroon)
- Heavy mafic/ultramafic minerals, such as magnetite or olivine (dark green)
- Calcite (cyan)
- Pyrite (cross-hatched red)

4.6.13 Track 17–ELAN Mineralogy and Pore Space Model Results (Wet Volume Fraction)

Track 17 displays the results from the ELAN integrated log analysis–presented as wet mineral and pore fluid volume fractions:

- Montmorillonite clay (brown/tan)
- Clay-bound water (checkered gray-black)
- Quartz (yellow with small black dots)

- Silica glass (yellow with large black dots)
- Orthoclase or other potassium feldspar (lavender)
- Sanidine (violet)
- Labradorite or other plagioclase feldspar (pink)
- Pyrite (tan with large black squares).
- Hypersthene (purple)
- Hornblende (forest green)
- Augite (maroon)
- Heavy mafic minerals, such as magnetite (dark army green)
- Calcite (cyan)
- Air (red)
- Moveable water (white)
- Capillary-bound water (light blue)

4.6.14 Track 18–Summary Logs

Track 18, the second track from the right, displays several summary logs that describe the fluid and air-filled volume measured by the geophysical tools, including water saturation

- Optimized estimate of total volume fraction water from the ELAN analysis (solid dark blue curve and area shading);
- Optimized estimate of moveable volume fraction water (effective porosity in fully saturated conditions) from the ELAN analysis (dashed cyan curve and green area shading);
- Optimized estimate of total volume fraction of air-filled porosity from the ELAN analysis (solid red curve and dotted red area shading);
- Optimized estimate of water saturation (percentage of pore space filled with water) from the ELAN analysis (dashed-dotted purple curve);
- Water saturation as calculated directly from the bulk density and ELAN-estimated porosity using a grain density of 2.65/3.05/2.85 g/cc (dotted light blue curve), 2.45/2.85/2.65 g/cc (long-dashed light blue curve), and 2.25/2.65/2.45 g/cc (dashed light blue curve)–with light blue shading between the 2.25/2.65/2.45 g/cc and 2.65/3.05/2.85 g/cc porosity curves to show the range (the highest grain density range used across the basalt interval [493 to 715 ft], the middle grain density range used

across the fanglomerate/alluvium interval [461 to 493 ft], and the lowest grain density range used across the tuff/pumice interval [27 to 461 ft]);

- Integrated estimated relative water flow from the ELAN water permeability log that mimics a flow meter (spinner) acquired under flowing conditions (solid green line coming from left-hand side at bottom of logged interval);
- Potential for water flow indicator from the CMR log (block cyan coming from the right-hand side of the track).

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

4.6.15 Track 19–Depth

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

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Appendix D

Aquifer Testing Report

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I-5 PUMPING TEST ANALYSIS

INTRODUCTION

This section describes the analysis of hydraulic tests conducted in February 2005 on intermediate well I-5, located in Mortandad Canyon, near regional aquifer well R-15. I-5 was completed to test and sample the intermediate perched zone detected during the drilling of R-15. The primary objective of the analysis reported here was to estimate the hydraulic properties of the sediments screened in I-5.

I-5 is completed with a single screen, 10 feet (ft) long between the depths of 689 and 699 ft, in an interflow zone within the Cerros del Rio formation. The piezometric surface was measured at approximately 688 ft below land surface, i.e., about a foot (ft) above the top of the well screen. Geophysical logs showed dense materials below 702 ft. It was believed that this was an indication of a massive basalt flow – a zone that probably is tight and serves as the perching unit for the thin saturated zone. Based on this information, the water bearing unit was considered to be a 14-ft-thick unconfined zone, extending from the static water level at 688 ft to the top of the perching layer at 702 ft.

The maximum capacity of I-5 was less than ¼ gallons per minute (gpm) and, therefore, it was not possible to sustain steady pumping to conduct a conventional constant-rate pumping test. Therefore, testing consisted of "pump down" events in which the pump was operated until it broke suction and then shut off. Following each pump down event, the well was rested for several hours or overnight to allow water levels to recover.

Testing was performed from February 22 to 24 utilizing four pump down and recovery cycles. During each pump down event, the pump was operated for about 4 to 6 minutes until 20 gallons (gal.) of water had been removed, dewatering the well screen and surrounding filter pack. The first pumping event went from approximately 12:25 pm to 12:30 pm on February 22, followed by recovery until 7:42 pm. The second pumping test went from 7:42 pm to 7:48 pm on February 22, followed by recovery until 9:46 am the next day. The third test lasted from 9:46 am to 9:52 am, followed by recovery until 7:58 pm on February 23. The final test went from 7:58 pm to 8:03 pm on February 23, followed by recovery until 2:34 am on February 24.

SLUG TEST METHODS

One of the methods used to analyze the pump out tests was the Bouwer & Rice slug test method. This procedure analyzes recovery data following a sudden lowering of the water level in the well. The theoretical basis for this technique is based on the water level in the well being lowered "instantaneously" and, thus, the method is not necessarily applicable to wells that have been pumped. For exceedingly tight sediments, however, the method is valid, even when it takes a finite amount of time to lower the water level in the well. In this instance, the water level recovery was exceedingly sluggish (hours) compared to the duration of pumping (just a few minutes), making the slug test analytical procedure applicable to the data.

When water levels equilibrate back toward the static level following a slug event or brief pump out event, the observed water levels can be used to estimate a lower-bound value for transmissivity based on the rate of water level recovery. The following formula, in mixed units, can be applied to perform the calculation according to the Bouwer & Rice procedure:

$$T = \frac{1.25}{t} \ln\frac{y_1}{y_2} \ln\frac{R}{r_w} \left[\left(576 r_w^2 - D_O^2\right) S_y + D_I^2 - d^2\right]$$

where,

T = transmissivity, in ft^2/day
y_1, y_2 = measurements of the water level change from static conditions, in feet
t = elapsed time between measurements, in minutes
R = effective radius of influence, in feet
r_w = borehole radius, in feet (0.51 ft)
D_O = outside diameter of well casing, in inches (5.0 in.)
D_I = inside diameter of well casing, in inches (4.5 in.)
d = outside diameter of drop pipe, in inches (1.315 in.)
S_y = short-term specific yield of filter pack

This formula is specifically crafted to account for water refilling both the well casing and the surrounding filter packed annulus during recovery. The volume of water refilling the filter pack is related to the term S_y, the short-term specific yield of the pack. This parameter must either be estimated or, if sufficient data exist, calculated for the particular well being tested. For I-5, it was possible to calculate S_y using the pump down and recovery data.

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 percent efficient. The resulting hydraulic conductivity is the value required to sustain the observed specific capacity. If the actual well is less than 100 percent efficient, it follows that the actual hydraulic conductivity would have to be greater than calculated to compensate for well inefficiency. Thus, because the efficiency is unknown, the computed hydraulic conductivity value represents a lower bound. The actual conductivity is known to be greater than or equal to the computed value.

Because I-5 could not be pumped continuously, a specific capacity could not be measured directly. Instead, it was determined indirectly by observing the refill rate during early recovery. By estimating the volume of filter pack voids and well casing refilled in a certain time interval, it was possible to determine a "pumping rate", i.e., the rate at which formation water entered the well. Dividing this rate by the average drawdown over the refill interval yielded a specific capacity. The following formula was used to compute the specific capacity:

$$\left(\frac{Q}{s}\right)_{theo} = \frac{(s_1 - s_2)(v_c + V_a S_y)}{(t_2 - t_1)\left(\frac{s_{1COR} + s_{2COR}}{2}\right)}$$

where,

s_1, s_2 = residual drawdown measured at times t_1 and t_2
t_1, t_2 = time since pump down event originally began
v_c = volume per foot of casing between 4.5-in. ID casing and 1.315-in. OD drop pipe (0.755 gallons per ft)
V_a = volume per foot of annulus between 12.25-in. borehole and 5-in. OD well casing (5.102 gallons per ft)
S_y = short-term specific yield of filter pack
s_{1COR} = drawdown s_1 corrected for dewatering
s_{2COR} = drawdown s_2 corrected for dewatering

Note that the drawdown terms in the denominator were corrected for dewatering of the formation and well screen. The following equation was used to provide a realistic estimate of the dewatering effect:

$$s_{COR} = s - \frac{s^2}{2b}$$

where,

s_{COR} = corrected drawdown
s = actual drawdown
b = original saturated thickness

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

$$K = \frac{264}{b}\left(\frac{Q}{s}\right)_{theo}\left(\log\frac{0.3Tt}{r_w^2 S} + \frac{2s_p}{\ln 10}\right)$$

In this equation, the specific capacity must be corrected for dewatering effects and thus is different than the actual specific capacity. Note that the calculations incorporate both dewatering and partial penetrating effects. There is no complete equation that accounts for both of these effects simultaneously, so their combined effect was estimated by applying the dewatering correction and partial penetration corrections separately. While this approach is not exactly and rigorously accurate, it was expected to provide reasonable accuracy and was a pragmatic way to obtain lower-bound estimates for hydraulic conductivity.

To apply the Brons and Marting formula, a storage coefficient value must be assigned. Storage coefficient values for unconfined, unconsolidated sediments, such as the interflow breccias, typically range from a few percent to 20 percent or more, with the majority of the values falling between approximately 5 and 15 percent. Thus, in the absence of site-specific storage coefficient data, a value of 0.1 is often deemed to be a reasonable choice for performing the calculations for unconfined conditions. For the I-5 calculations, however, convergence to a solution could not be achieved for storage coefficient values of 0.1 and even 0.05. Thus, the effective storage coefficient was less than these values. The pumping data used to support the calculations was from early pumping time, about 10 to 15 minutes after pumping began, and thus it was likely that the sediments hadn't had time to drain. This meant that either elastic storage, or a transition storage coefficient value between elastic storage and specific yield, was more appropriate for use in the equations. Calculations were performed for storage coefficient values ranging from 0.001 to 0.02 to provide a range of possible lower-bound hydraulic conductivity values. The calculation result is not especially sensitive to the choice of storage coefficient value, so a rough estimate of the storage coefficient was adequate to support the calculations.

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

I-5 DATA ANALYSIS

Four pump down tests were conducted on I-5, with each episode of pumping removing a total volume of 20 gal. of water from the well. Following pump shut down, recovery data were measured for a period of several hours or overnight. This section presents the data obtained from the I-5 pump down tests and the results of the analytical interpretations.

Slug Test Analysis

The recovery data following each pump down event were analyzed using the Bouwer & Rice method and the equation presented previously. To apply this method it was necessary to assign a

value for the specific yield, S_y, of the filter pack. This, in turn, required estimating the volume of water that gravity drained from the filter pack.

During the few minutes of pumping the well down, water was contributed from casing and filter pack storage, and also from the formation, to produce the known pumped volume of 20 gal. of water for each test. During recovery, water was produced only from the formation and this water corresponded to the rate of refill of the casing and filter pack. These two events were coupled mathematically to develop and equation for the volume of water contributed from the well casing and filter packed annulus per ft of well length, as follows:

$$v = \frac{V_P}{s_{PD} + 2 s_{APD} t_{PD} \dfrac{s_1 - s_2}{(t_2 - t_1)(s_1 + s_2)}}$$

where,

v = volume of water gravity drained from both the well casing and filter packed annulus per foot of well length
V_P = total volume of water pumped from the well during the test (20 gallons)
s_{PD} = the change in head observed between the start of pumping and shutdown
s_{APD} = the time-averaged drawdown during pump operation
t_{PD} = length of time that the pump operated
s_1, s_2 = residual drawdown measured at times t_1 and t_2
t_1, t_2 = time since pump down event began

In this equation, s_1 and s_2 are arbitrarily selected residual drawdown values during the early stages of recovery. To be rigorously correct, the terms s_{APD} and (s_1+s_2) should be corrected for dewatering of the screen and filter pack. However, this would have added complexity to the equation and calculations. Therefore, to keep the analysis as simple as possible, s_1 and s_2 were selected to be similar in magnitude to s_{APD}. In this way, the corrections for each term were similar and offsetting and, thus, omitting the correction procedures did not alter the final results significantly.

Once the drained volume per ft of well length, v, was estimated, it was possible to compute the specific yield of the filter pack, S_y, as follows:

$$S_y = \frac{v - v_c}{V_a}$$

where,

S_y = short-term specific yield of filter pack
v_c = water volume per foot of well casing (0.755 gallons per ft)
v = volume of water gravity drained from the well casing and filter packed annulus per foot of well length

V_a = volume per foot of annulus between 12.25-in. borehole and 5-in. OD well casing (5.102 gallons per ft)

Figure 1 shows the pump down and recovery data from test 1. The maximum drop in water level during pumping was a little less than 10 ft.

Table 1 shows the relevant data used to calculate v and S_y. For example, s_1 and s_2, 7.83 ft and 7.19 ft, respectively, are the arbitrary residual drawdown values corresponding to 10 minutes and 15.5 minutes after pump startup, as indicated in the table. The total head change during pump down was 9.66 ft and the average drawdown during the 5 minutes that the pump was running was 7.58 ft.

These data resulted in a computed value for v of 1.952 gallons per ft of well length (0.755 gallons per ft of well casing [between the 4.5-in. ID well casing and the 1.315-in. OD drop pipe] and, thus, 1.197 gal. of drained water per ft of filter pack). As indicated in Table 1, similar calculations were performed for all four tests and the results were averaged, yielding an average v of 1.975 gallons per ft of well length and a filter pack specific yield of 0.239. This value was used in all of the slug test calculations.

The computed specific yield value of 0.239 seemed a little high for short-term conditions, even for the coarse 10-20 filter sand used in the well completion. It is possible that the specific yield was less than 0.239 and that the borehole through the screened interval was enlarged beyond the nominal diameter of 12.25 in. If this were the case, the larger annular volume and smaller specific yield could produce the same drained volume as the apparent 5.102-gallon annulus and the 0.239 specific yield. Thus, the calculations performed using the apparent values would still be valid.

The straight line of best fit on Figure 1 yielded a calculated transmissivity of 2.20 ft^2/day and hydraulic conductivity of 0.157 ft per day. The data curve showed three other interesting features. First, the initial recovery data showed a steep slope. This suggested that some ongoing filter pack drainage still occurred briefly after pump shutoff. The data trace was plotted on an expanded scale on Figure 2 to make this trend easier to see.

The second unique feature of the graph was the steepening of the curve once the residual drawdown declined to about 2 ft. One explanation for this was that this elevation corresponded to the top of the well screen. If this were the case and if the air in the filter pack above the well screen was trapped by the overlying bentonite seal, once the rising water level reached the top of the well screen, the air in the annulus above the screen would begin to compress. The trapped air would keep the water level in the filter pack from rising as fast as the water level inside the casing. This, in turn, would result in a greater pressure increase per unit volume of inflowing water. This idea was expressed mathematically by deriving an equation for the predicted ratio of the slopes – the residual drawdown slope that would be observed just prior to the water level reaching the top of the well screen and the slope observed just after:

$$S_r = \frac{v_c + v_a}{v_c + v_a \dfrac{D}{D + A}}$$

where,

S_r = the ratio of the final slope to the initial slope
v_c = water volume per foot of well casing (0.755 gallons per ft)
v_a = water volume drained per foot of filter packed annulus (1.22 gallons per ft)
D = distance from top of well screen to bottom of bentonite seal (11.5 ft)
A = atmospheric pressure, in feet of water (approximately 27 ft)

In this equation v_a is computed as follows:

$$v_a = S_y V_a$$

where,

S_y = short term specific yield of filter pack (0.239)
V_a = total volume of annulus between 12.25-in. borehole and 5-in. OD well casing (5.102 gallons)

The resulting predicted slope ratio computed using this analysis was 1.76.

Figure 3 shows a linear plot of the residual drawdown data just before and just after the break in slope. The early slope was 0.0248, while the late slope was 0.0422, yielding a ratio of 1.70. This was consistent with the theoretical prediction of 1.76, reinforcing the idea that the transition in slopes occurred at an elevation corresponding to the top of the well screen. Note that this occurred at about 2 ft of residual drawdown, implying a static water level approximately 2 ft above the top of the well screen. The well construction records showed the top of screen at 689 ft below land surface, while the hand measured static water level was 688 ft below land surface, for a differential of 1 ft rather than 2 ft. Thus, there was an apparent 1-ft discrepancy. This was a minor difference and could be due to a small error in the depth markings on the water level sounder used for hand measuring the water level; a difference in the "land surface" elevation reference used to identify the water level versus that used when the casing was installed; cumulative errors in recorded casing joint makeup lengths during well installation; or a combination of these. At any rate, the residual drawdown slope change suggested that the top of screen was submerged about 2 ft below the static water level. [It should be pointed out that an alternate explanation for the short-lived slope increase is the presence of lower-porosity fill outside the well screen at the elevation where the anomaly occurred. For example, if formation material had caved against the top of the screen at that location, the recovery curve would steepen as the water level passed through the slough zone, creating the slope changes observed in the actual data set. There is no way to know for sure the cause of this anomaly.]

The third distinguishing feature of the data plot on Figure 1 was that it flattened steadily at late time rather than describing a straight line as predicted by Bouwer & Rice. This was expected, as

most slug test response curves exhibit a concave upward shape because of ongoing growth of the cone of depression around the well. The Bouwer & Rice method is based on the assumption of a fixed radius of influence, i.e., a constant cone of depression size. In practice though, the hydraulic response propagates outward from the well bore, and the radius of influence and cone of depression steadily expand. The result is steady flattening of the data trace over time – quite predictable and as it should be.

Figure 4 shows the data plot for test 2. An expanded-scale plot is shown on Figure 5. The lower-bound hydraulic conductivity value computed for test 2 was 0.145 ft per day. As in test 1, the data trace showed 1) rapid recovery for the first couple minutes following pump shutoff, likely an indication of continued filter pack drainage, 2) a slope increase where the residual drawdown approached about 2 ft, presumably at the elevation of the top of the well screen, and 3) a concave upward data trace, i.e., steady flattening.

Figures 6 and 7 show the data for test 3, revealing a lower-bound hydraulic conductivity of 0.143 ft per day and the same data plot characteristics observed in the previous tests.

Figures 8 and 9 show similar information for test 4, revealing a lower-bound hydraulic conductivity of 0.141 ft per day and the same data plot characteristics observed in the other tests.

Specific Capacity Data

Specific capacity data were used to estimate lower-bound values for hydraulic conductivity. The specific capacity values were determined from the rate of refill of the well casing and filter pack at early recovery time.

Table 2 summarizes input data used in the calculations. The values for s_1, s_2, t_1 and t_2 shown in the table were arbitrarily selected. The pumping rates shown were calculated as the volume of casing and filter pack voids refilled divided by the corresponding elapsed time interval. The drawdown, s, shown in the table is the arithmetic average of s_1 and s_2, while $s_{corrected}$ incorporates a mathematical correction for formation and well screen dewatering. Finally, the specific capacity and total elapsed time (t) are the values that were used in the Brons and Marting method for determining lower-bound values of hydraulic conductivity.

Calculations were performed for storage coefficient values ranging from 0.001 to 0.02. Table 3 summarizes the results of the calculations which also are depicted graphically on Figure 10, The results indicated that the lower-bound hydraulic conductivity values fell in the general range of approximately 0.15 to 0.3 ft per day, reasonably consistent with the slug test results.

SUMMARY

The following information summarizes the results of the pump down tests on I-5:

1. Four pump down tests were conducted in I-5 in which the well was pumped for several minutes until 20 gal. of water was removed and then allowed to recover for several hours or overnight.

2. Because of the slow recovery response, slug test analysis methods were applicable to the recovery data.
3. Bouwer & Rice slug test analysis suggested a lower-bound hydraulic conductivity of about 0.15 ft per day.
4. Specific capacity analysis suggested a lower-bound hydraulic conductivity range of about 0.15 to 0.3 ft per day.
5. The short-term specific yield, S_y, of the filter pack was estimated to be 23.9 percent.
6. Each test showed an unusual steepening of the data trace at about 2 ft of residual drawdown, likely indicating the response of trapping air in the annulus above the well screen as the water level passed above the top of the screen.

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Bouwer, Herman and Rice, R. C., 1976. A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers With Completely or Partially Penetrating Wells, Water Resources Research, vol. 12, no. 3, pp. 423-428.

Bradbury, Kenneth R. andRothschild, Edward R., 1985. A Computerized Technique For Estimating the Hydraulic Conductivity of Aquifers From Specific Capacity Data. Ground Water. V. 23, no. 2, pp. 240-246.

Brons, F. and Marting, V. E., 1961. The Effect of Restricted Fluid Entry on Well Productivity. J. Petrol. Technol. V. 13, no. 2, pp. 172-174.

Figure 1. Test 1 Analysis

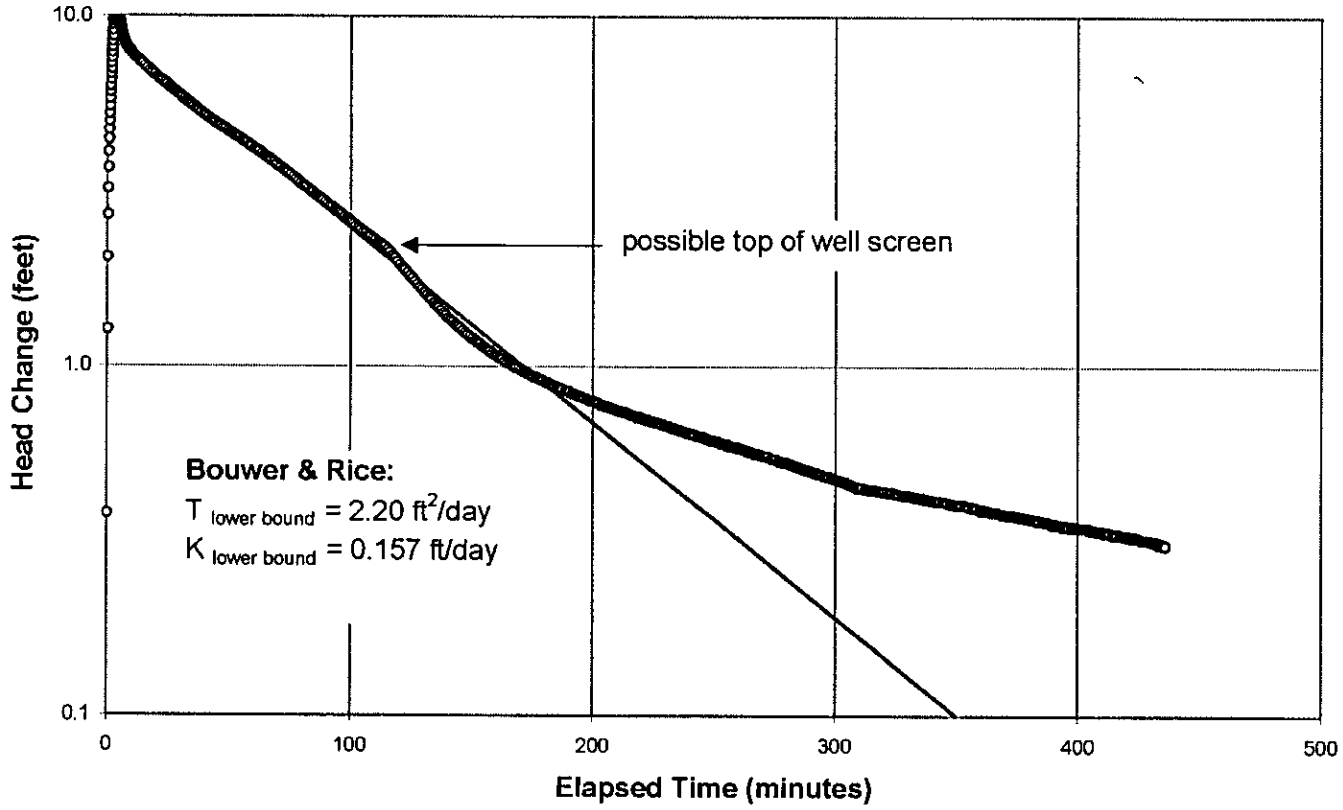


Figure 2. Test 1 Analysis - Expanded Scale

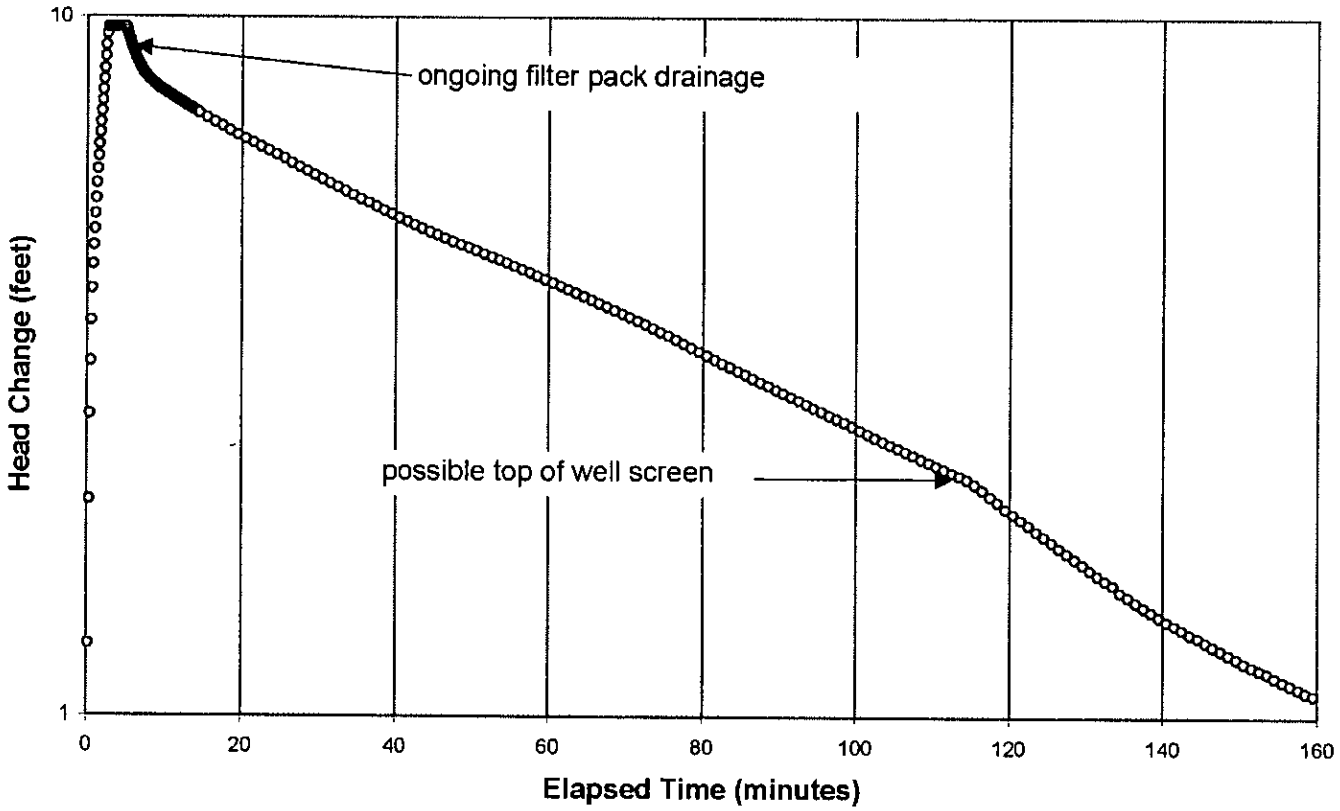


Figure 3. Test 1 Analysis - Linear Scale

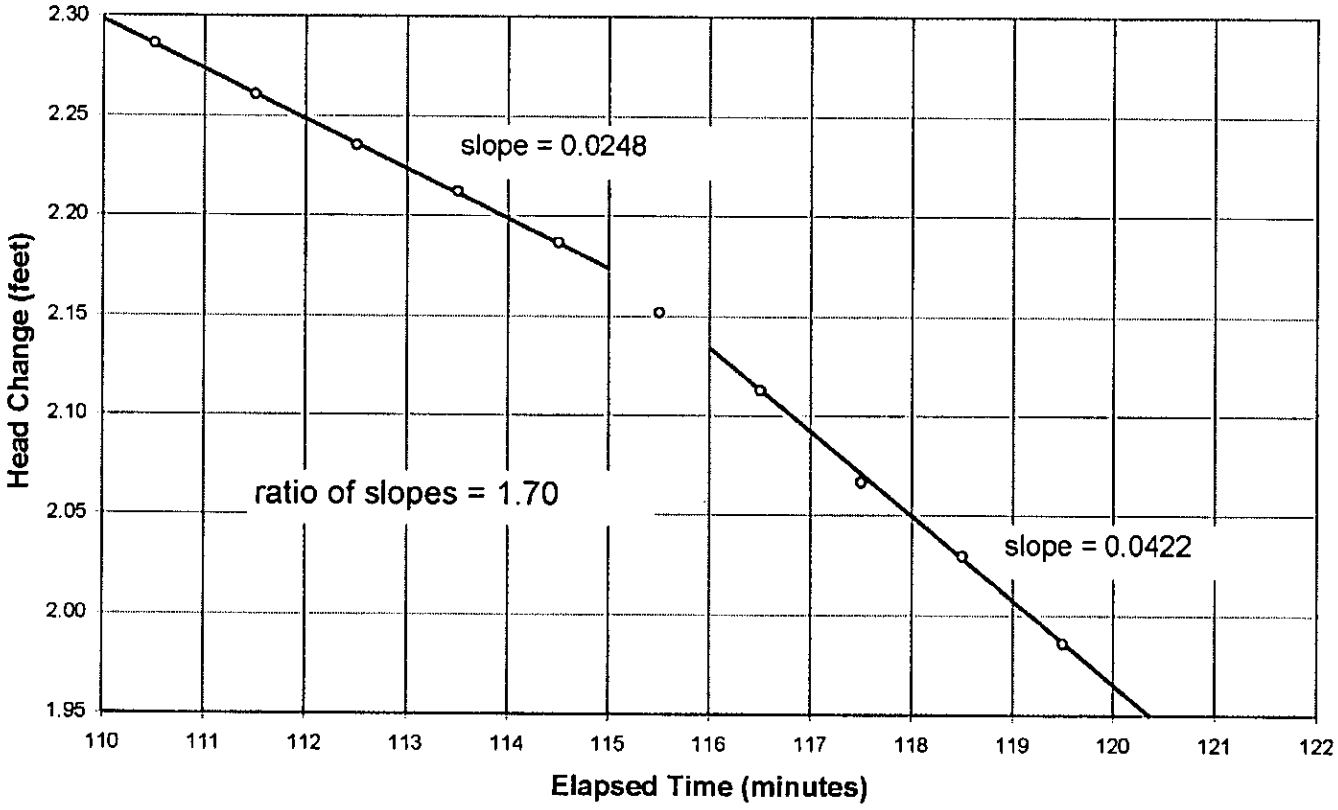


Figure 4. Test 2 Analysis

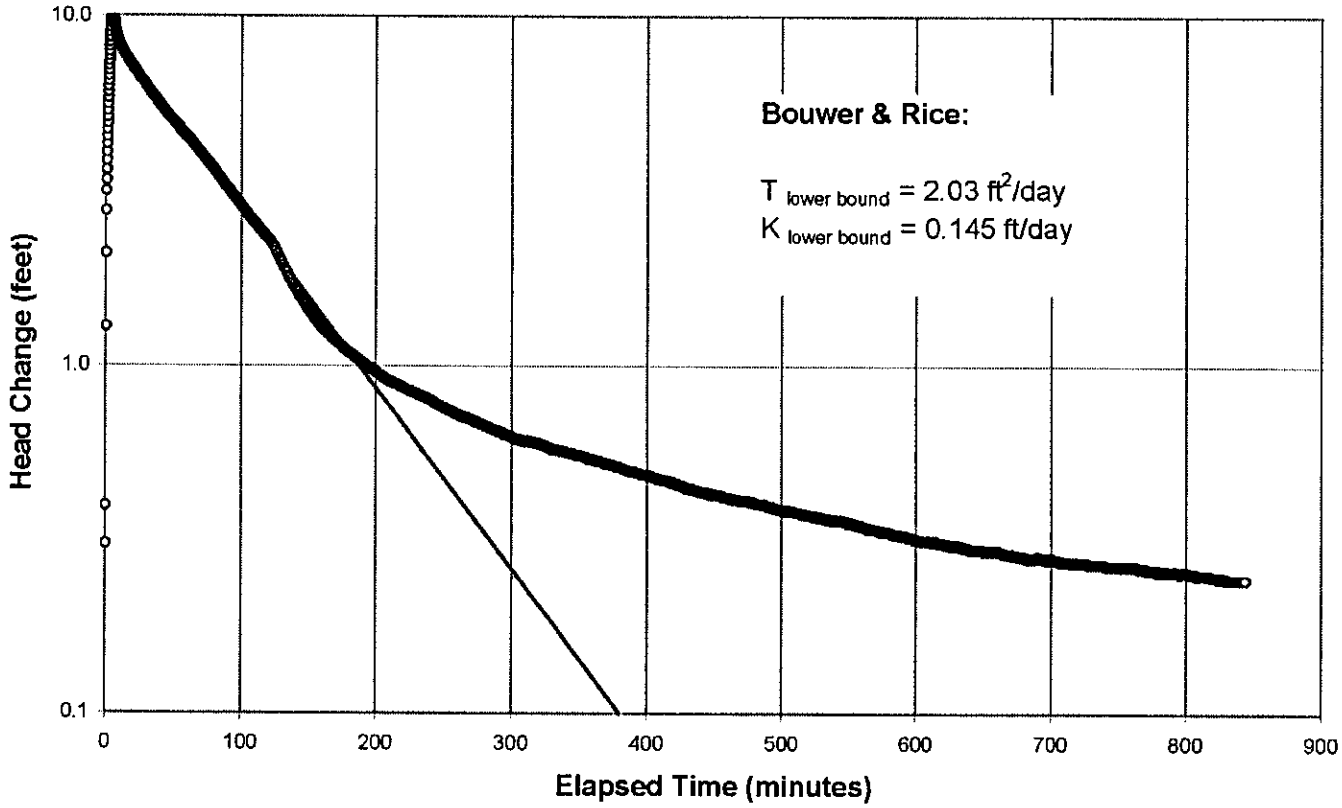


Figure 5. Test 2 Analysis - Expanded Scale

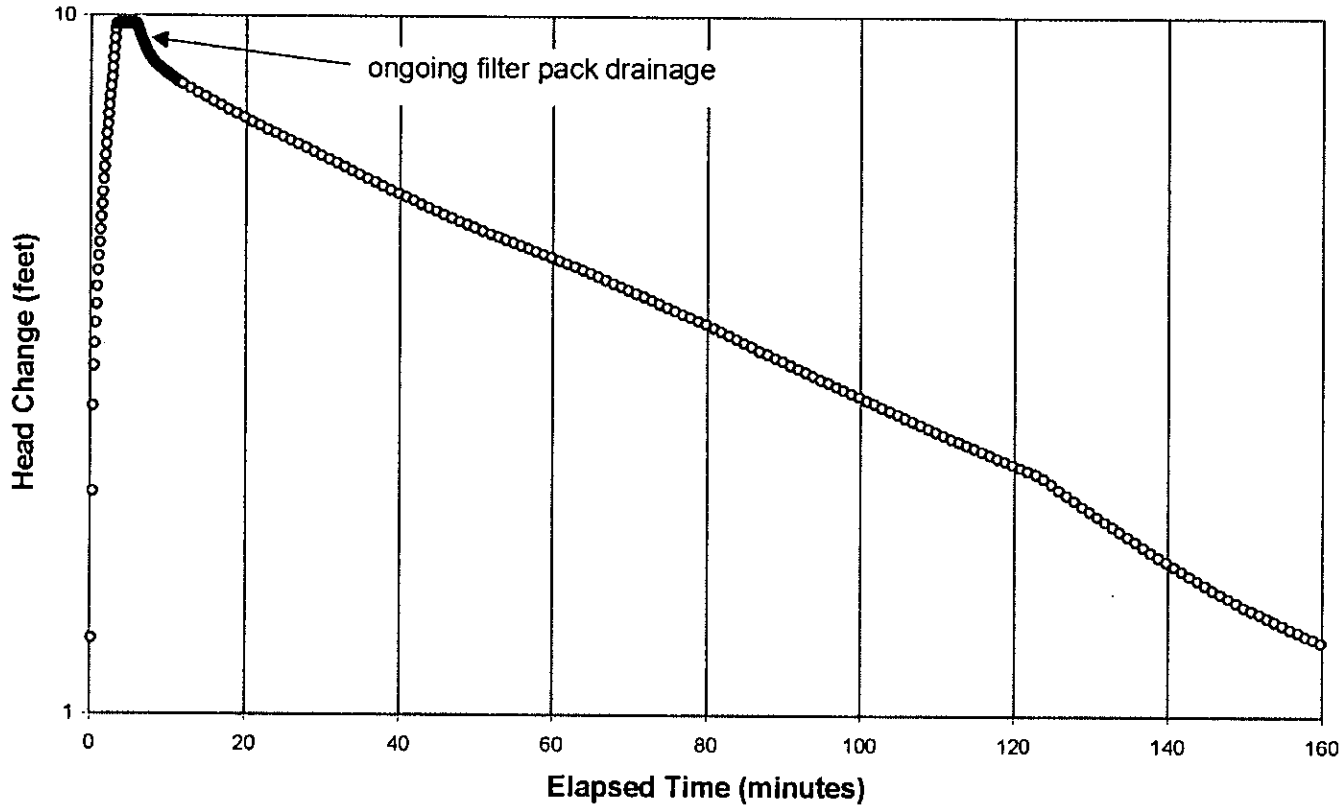


Figure 6. Test 3 Analysis

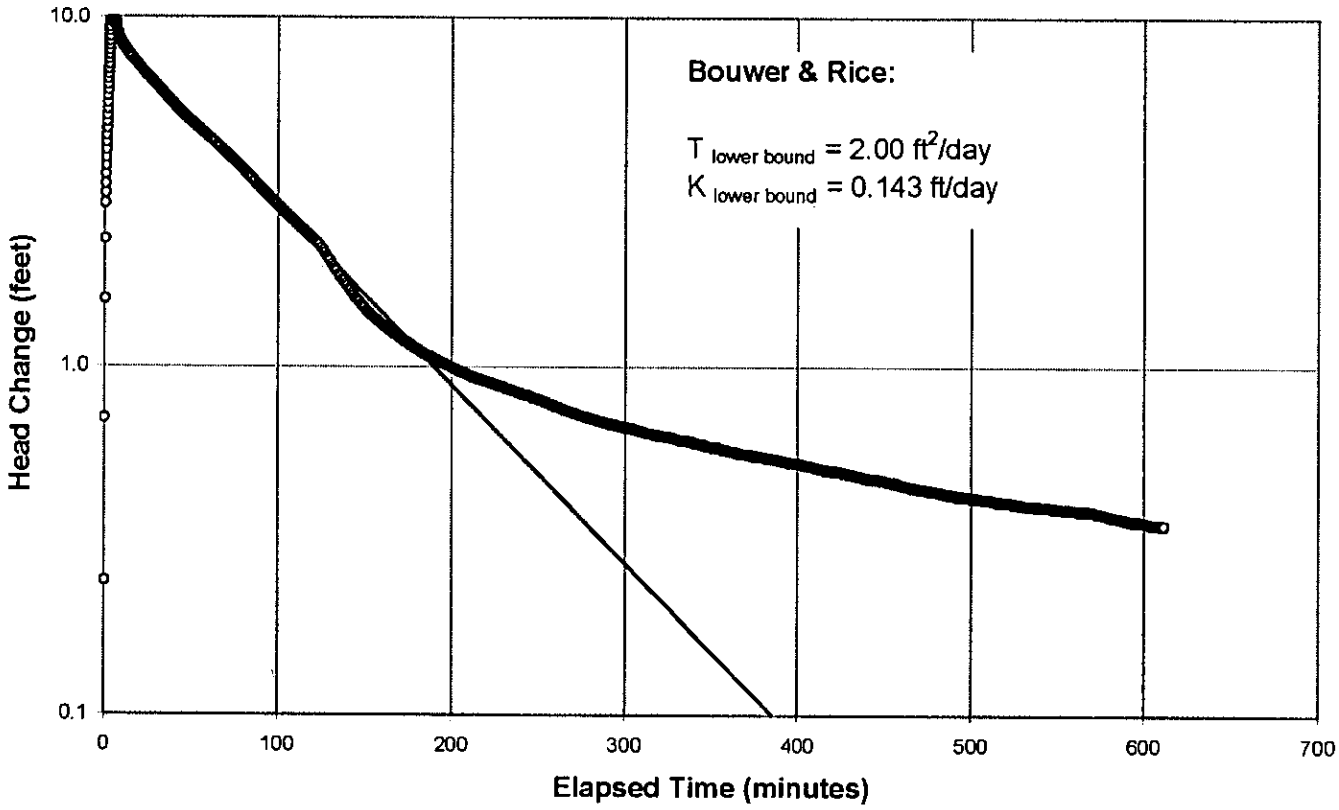


Figure 7. Test 3 Analysis - Expanded Scale

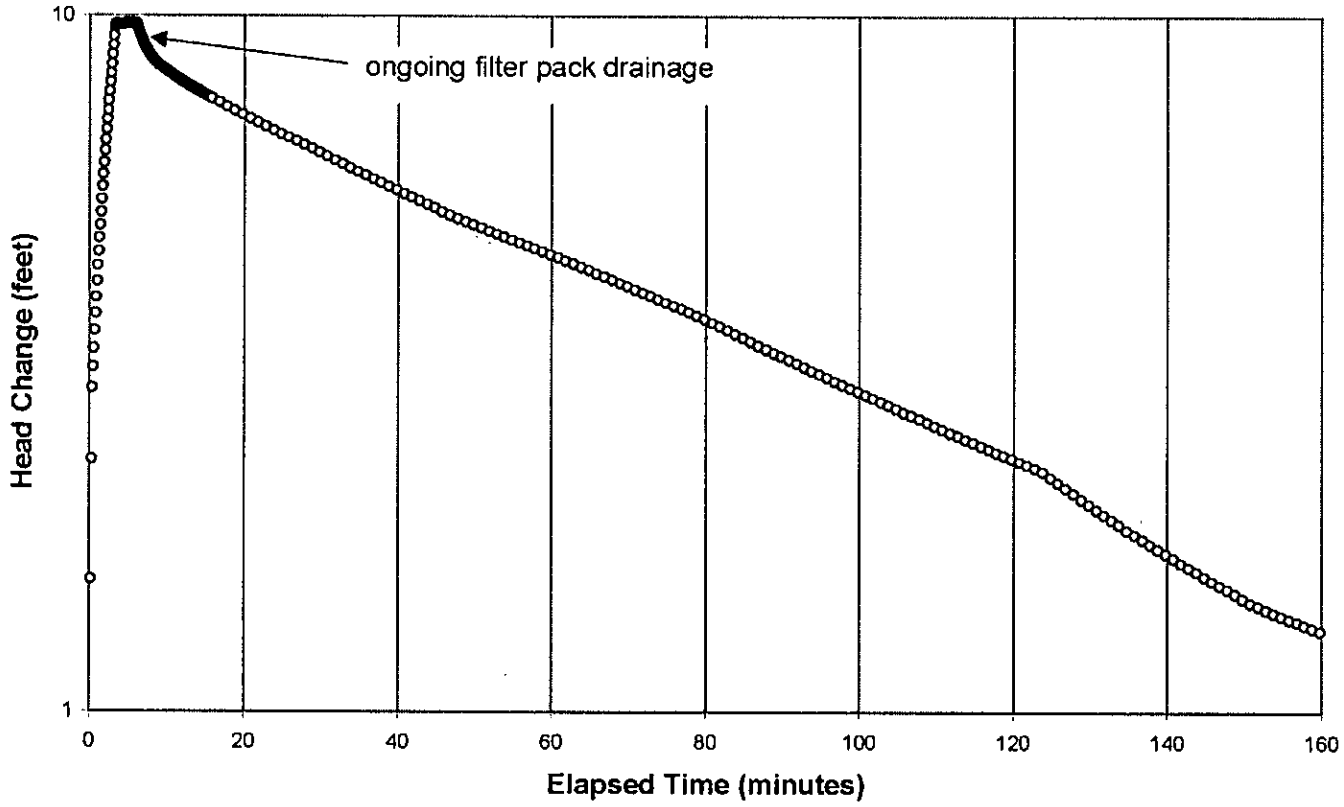


Figure 8. Test 4 Analysis

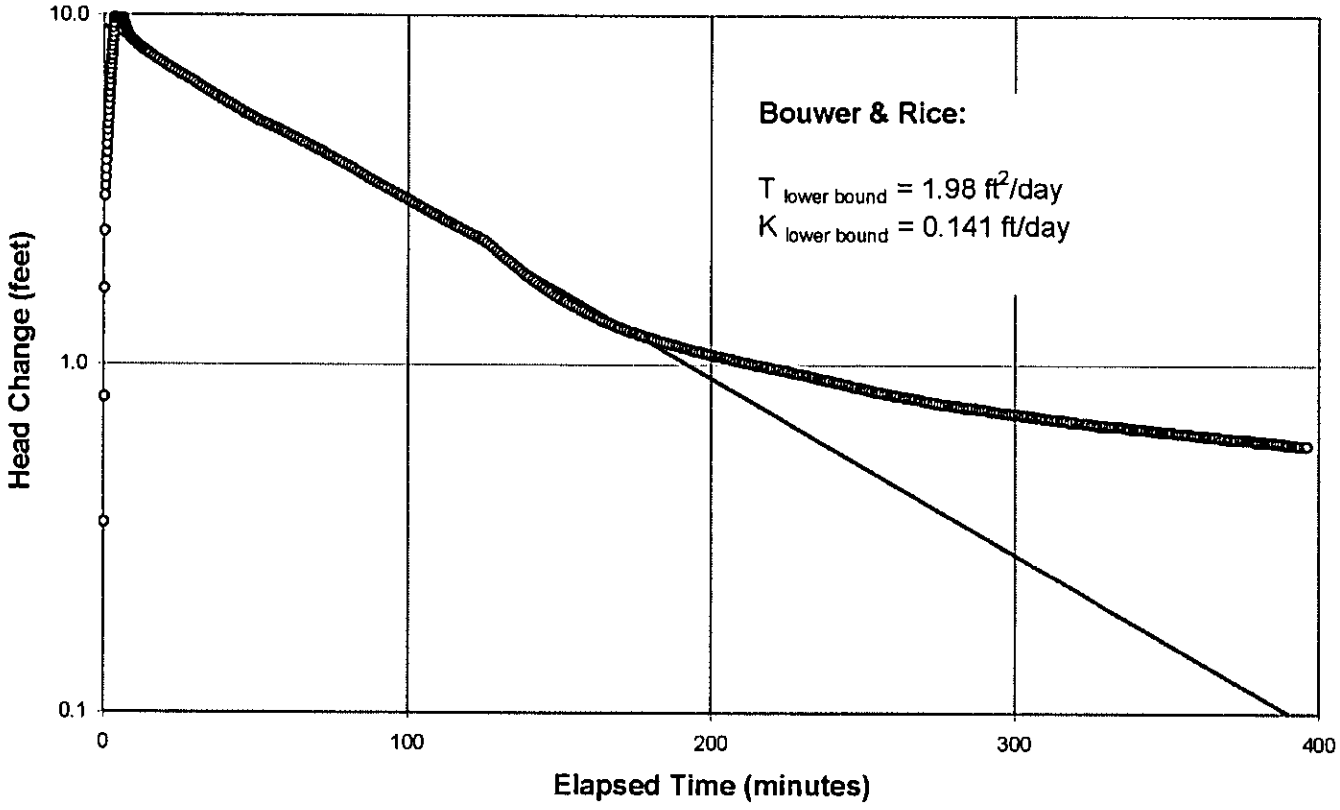


Figure 9. Test 4 Analysis - Expanded Scale

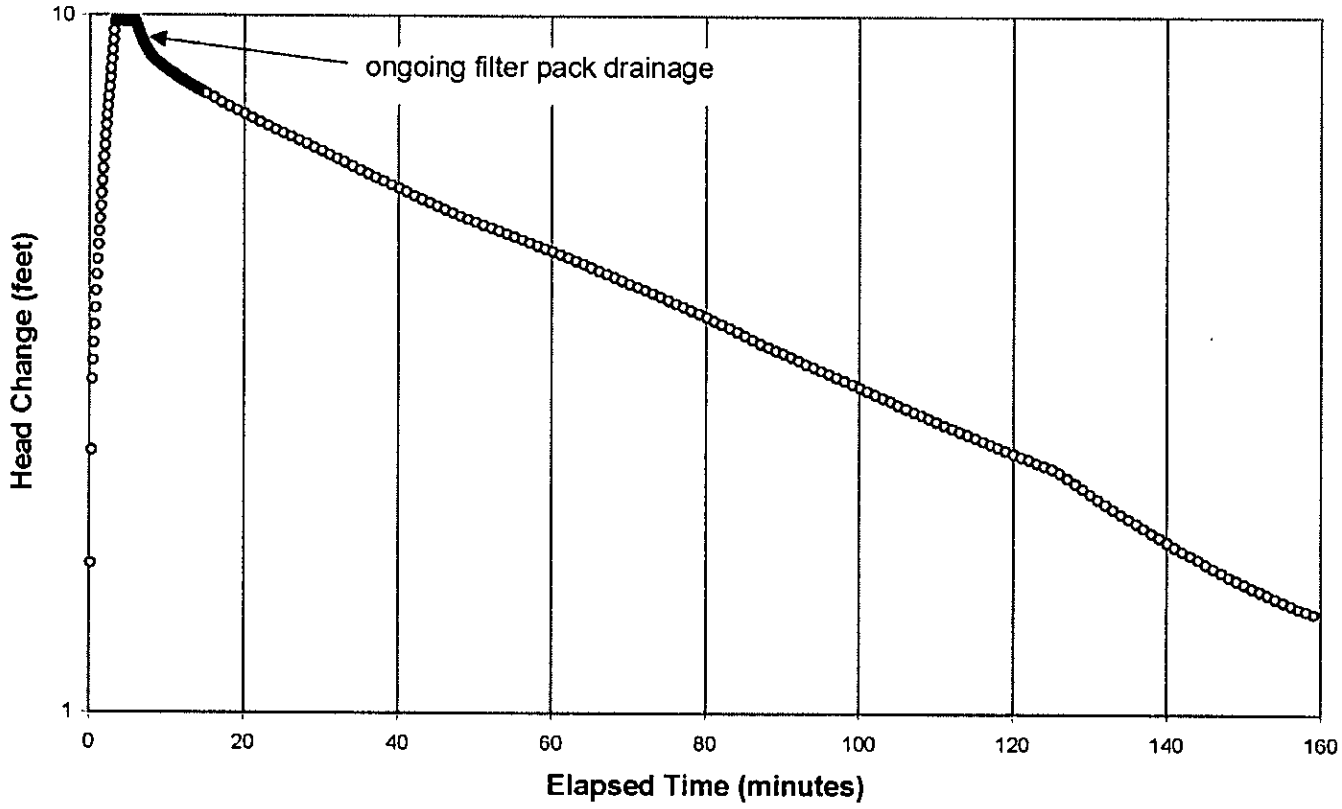
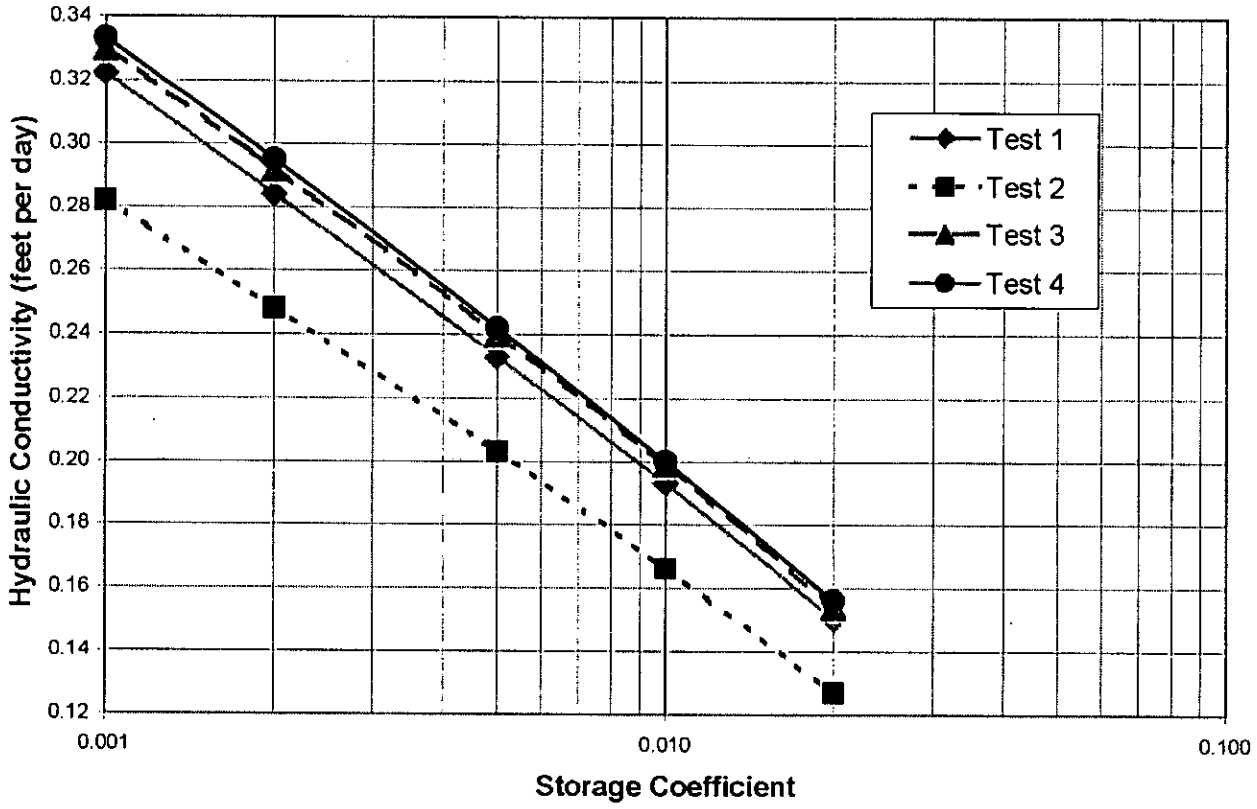


Figure 10. I-5 Lower-Bound Hydraulic Conductivity Estimated From Specific Capacity



FINAL
COMPLETION REPORT
INTERMEDIATE WELL I-6
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

April 2006

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LIST OF ACRONYMS AND ABBREVIATIONS

ags	above ground surface
amsl	above mean sea level
ASTM	American Society for Testing and Materials
bgs	below ground surface
BMPs	best management practices
DOE	United States Department of Energy
DTW	depth to water
DTHH	down-the-hole hammer
FSF	Field Support Facility
ft	foot/feet
ft^3	cubic feet
gal.	gallon/gallons
gpd	gallons per day
gpm	gallons per minute
hr/hrs	hour/hours
in.	inch/inches
Kleinfelder	Kleinfelder, Inc.
LANL	Los Alamos National Laboratory
NM	not measured
NMED	New Mexico Environment Department
OD	outer diameter
psi	pounds per square inch
RCT	radiation control technician
SSLs	Soil Screening Levels
SMO	Sample Management Office
TA	Technical Area
TD	total depth
TKN	total Kjeldahl nitrogen
US	United States

ABSTRACT

Intermediate well I-6 was installed as part of the Risk Reduction and Environmental Stewardship-Remediation Services project at Los Alamos National Laboratory (LANL) in accordance with the "Mortandad Canyon Groundwater Work Plan, Revision 1" (LANL 2004) and the "Final Drilling Plan for Intermediate Wells, Mortandad Canyon, Los Alamos National Laboratory" (Kleinfelder 2004b). The United States (US) Department of Energy (DOE), with technical assistance from LANL, contracted and directed the installation of this well.

Data from I-6 will be used in conjunction with data from other wells in Mortandad Canyon to improve the conceptual model of the geology, hydrogeology, and hydrochemistry of the area to provide data for numerical models that address contaminant migration in the vadose (unsaturated) zone. This information will be used to facilitate decision-making with regard to regulatory compliance, risk assessment, and remediation.

The majority of the fieldwork was completed from October 21, 2004, through January 13, 2005, during which a separate corehole and borehole were drilled. The corehole was drilled to 498.2 feet (ft) below ground surface (bgs), backfilled with bentonite and abandoned. The borehole was drilled to a depth of 720 ft bgs using air-rotary and fluid assisted air-rotary drilling methods. Samples of drill cuttings were collected at regular intervals for potential stratigraphic, petrographic, and geochemical analysis. Geophysical logging was performed in the open borehole to help delineate the hydrostratigraphy and to facilitate proper well design. The stratigraphy encountered during borehole drilling included, in descending order, alluvium, Cerro Toledo interval, Otowi Member of the Bandelier Tuff, Guaje Pumice Bed, Puye Formation, and Cerros del Rio basalt.

The I-6 borehole was completed as a characterization well with a single screened interval from 686.0 to 709.0 ft bgs near the base of the Cerros del Rio basalt. The total depth (TD) of the well is 712.6 ft bgs. The depth to water (DTW) after well installation, development, aquifer test, and recovery was 662.07 ft bgs.

1.0 INTRODUCTION

This completion report summarizes the site preparation, drilling, sampling and related activities for intermediate well I-6. Kleinfelder, Inc. (Kleinfelder), under contract to the United States (US) Army Corps of Engineers, was responsible for drilling, installing, testing, and sampling activities. The US Department of Energy (DOE) with technical assistance from Los Alamos National Laboratory (LANL) contracted and directed this work.

Intermediate well I-6 is located in Technical Area (TA) 5 within Mortandad Canyon at LANL (Figure 1.0-1). The well was installed to assess intermediate perched groundwater within the Cerros del Rio basalt, downgradient from waste outfalls TA-35 and TA-50 of LANL, and to evaluate the lateral extent of the intermediate groundwater encountered in nearby characterization well R-15. The data quality objectives are provided in the "Mortandad Canyon Groundwater Work Plan, Revision 1" (LANL 2004) and the "Final Drilling Plan for Intermediate Wells, Mortandad Canyon, Los Alamos National Laboratory" (Kleinfelder 2004b). Water quality, geochemical data, aquifer characteristics, and geologic information obtained will augment the conceptual model and knowledge of contaminant distribution in the intermediate perched zone in Mortandad Canyon system.

The objectives of the coring and drilling activities were to collect core and cuttings of encountered geologic formations, to collect groundwater samples from the perched intermediate aquifer, and to install a single-screen characterization well near the base of the Cerros del Rio basalt. The corehole was drilled to assess contaminant profiles in the upper 500 feet (ft) of the vadose zone. The actual core collection interval was from 0 to 498.2 ft bgs. The projected total depth (TD) of the borehole was 760 ft bgs (LANL 2004). The actual TD of the I-6 borehole was 720 ft bgs. The I-6 borehole was completed as a characterization well with a single-screened interval from 686.0 to 709.0 ft bgs.

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, New Mexico office and LANL's Records Processing Facility. Further analysis and interpretation of geologic, geochemical, and aquifer data will be included in separate technical documents to be prepared by LANL.

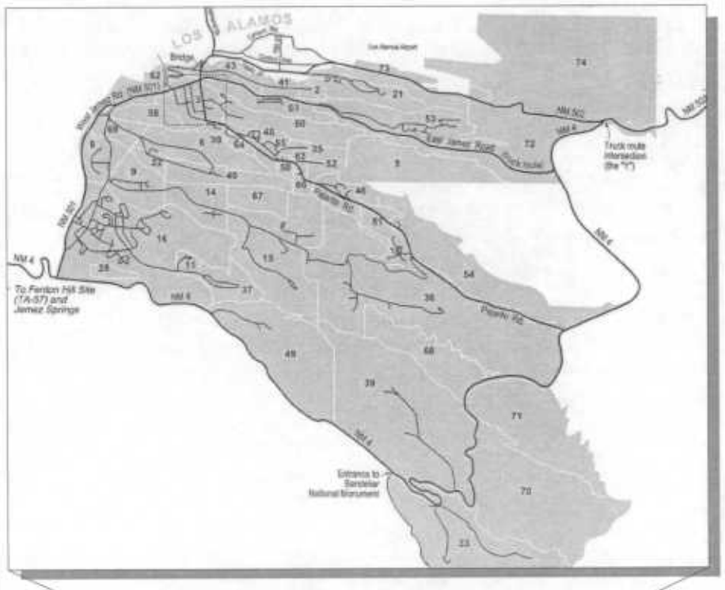
2.0 SITE PREPARATION AND DRILLING ACTIVITIES

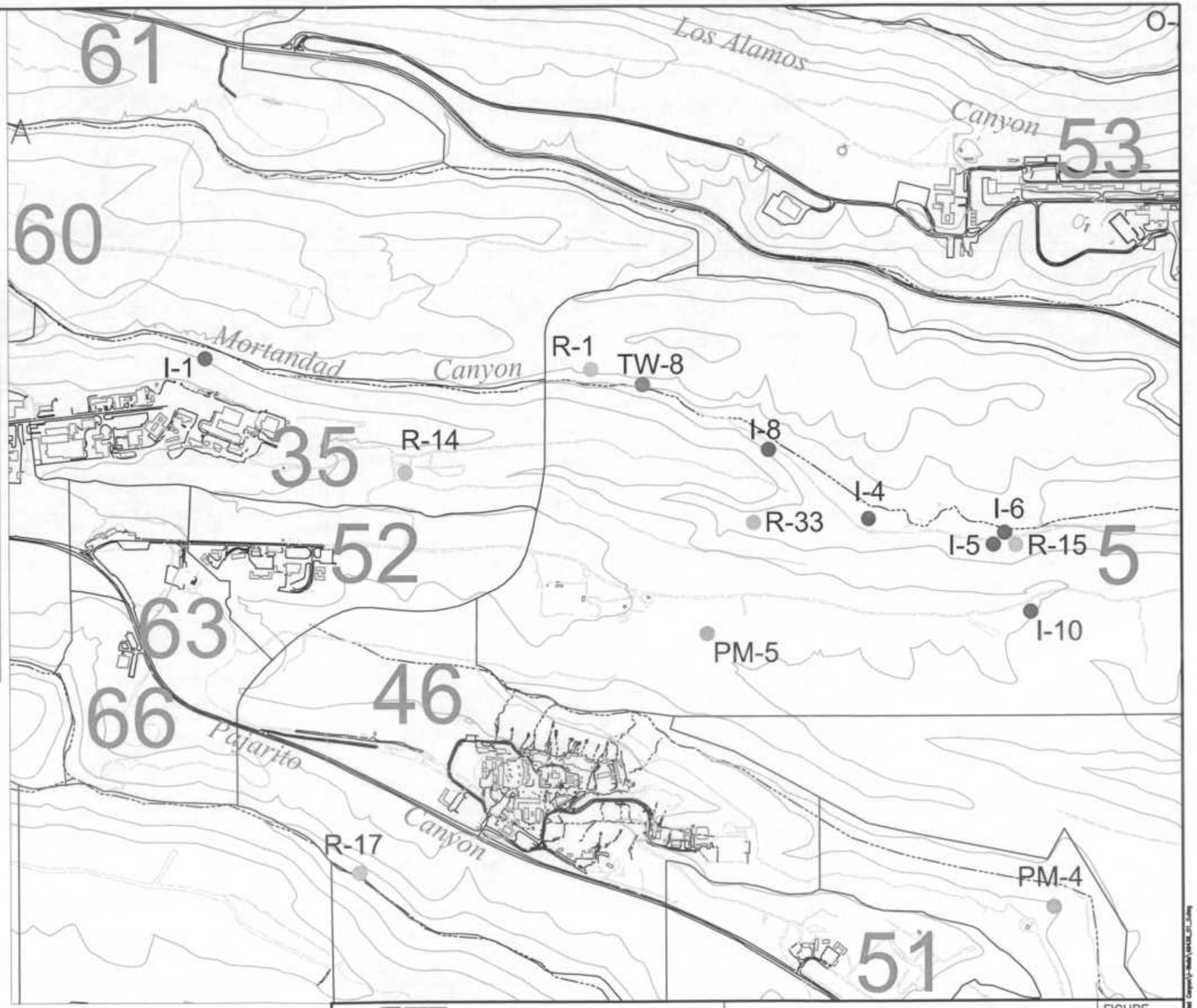
Site preparation consisted of constructing and lining the cuttings pit, erecting silt fencing to prevent erosion and runoff from the drill site, and setting up the exclusion zone. Best management practices, also known as BMPs, were installed as specified in the "Storm Water Pollution Prevention Plan, Mortandad Canyon Ground Water Work Plan, Los Alamos National Laboratory" (Kleinfelder 2004a). EnviroWorks, Inc. completed these tasks from October 15 through October 19, 2004. A radiation control technician (RCT) from LANL's Health, Safety, and Radiation Protection Group-1 screened the site before site preparation activities. A geology trailer, generator, compressor, and safety lighting equipment were moved to the site during the subsequent mobilization of drilling equipment.

The I-6 location was initially cored to characterize vertical contaminant profiles in the vadose zone. From October 21 through October 28, 2004, the I-6 corehole was cored from 0 to 498.2 ft

Legend

- = Intermediate perched zone wells (proposed)
- = Regional aquifer wells installed since 1998
- = Older test wells
- = Water supply wells
- 58 = Technical area identification
- = 100-ft contours





1000 0 500 1000

SCALE: 1 inch = 1000 ft

KLEINFELDER

Drawn By: C. Landon	Date: April 2006
Project No.: 49436	Filename: 49436_01_0.dwg
Scale: 1" = 1000'	Revision: –

SITE LOCATION MAP
Intermediate Wells I-1, I-4, I-5, I-6, I-8, I-10
Mortandad Canyon
Los Alamos National Laboratory
Los Alamos, New Mexico

FIGURE
1.0-1

bgs. The corehole was plugged with bentonite chips and abandoned. A separate borehole was advanced to 720 ft bgs using air-rotary and fluid-assisted, air-rotary drilling methods from January 3 through 6, 2005. A groundwater characterization well was installed in this borehole to 712.6 ft bgs. Well installation activities continued through January 13, 2005. Drilling activities were performed generally in one 12-hour (hr) shift per day, 7 days per week, by the drill crew and two site geologists.

2.1 Coring Activities

Coring operations were performed by Spectrum Exploration, Inc. using a Delta Base DB540 drill rig equipped with split spoon, HQ3 Coring Geobarrel®, and 115-millimeter Tubex drilling systems.

On October 21, 2004, mobilization of coring equipment and supplies to the I-6 site was completed and coring began. Split-spoon sampling was conducted to 15 ft bgs. Continuous-core, air-assisted drilling was conducted from 15 to 498.2 ft bgs using a HQ3 core barrel. Temporary 6⅝-in. outer diameter (OD) surface casing was installed to a depth of 15 ft bgs using a 7⅜-in. Tubex under-reamer system. The casing was later advanced to 105 ft bgs. After reaching 498.2 ft bgs (TD), the corehole was backfilled with bentonite chips to 3 ft bgs. A cement grout seal was then applied to ground surface and the corehole was abandoned.

During drilling, the corehole was monitored for groundwater. A single groundwater-bearing zone was encountered within the alluvium at approximately 57.5 ft bgs. The alluvial zone was cased off before advancing the corehole. Additional groundwater-bearing zones were not encountered during the remainder of the coring effort. Groundwater sampling, core sampling, and analyses are presented in Section 3.0.

2.2 Rotary Drilling Activities

The I-6 borehole was drilled by WDC Exploration & Wells using a GEFCO Speedstar 50K drill rig equipped with conventional drilling rods and drill collars, tricone bits, down-the-hole hammer (DTHH) bits, air compressors, and support equipment. I-6 was drilled using air-rotary and fluid assisted, air-rotary drilling methods.

Drilling fluids, consisting of a mixture of municipal water with QUIK-FOAM® surfactant, were used as needed to improve borehole stability and facilitate cuttings removal. An approximate tally of the total drilling fluids introduced into the borehole, as well as the total fluids recovered, is presented in Table 2.2-1.

Table 2.2-1
Introduced and Recovered Fluids

Material		Amount (gallons)
Introduced	QUIK-FOAM®	90
	Potable water (air rotary drilling)	7,500
	Total introduced fluids[1]	7,590
Recovered	Total recovered fluids[2]	9,704

[1] Represents the fluids introduced during drilling
[2] Represents the estimated fluid volume recovered during drilling, well development, and aquifer testing

On January 3, 2005, mobilization of drilling equipment and supplies to the I-6 site was completed and drilling began. The borehole was initially drilled with a 12¼-inch (in.)-diameter tricone bit using air-only drilling methods. The borehole was advanced to a depth of 15 ft bgs. Concurrently, 13⅜-in. surface casing was advanced to a depth of 15 ft bgs.

On January 4, 13⅜-in. surface casing was advanced to a TD of 60.5 ft bgs. Drilling continued at 57 ft bgs using air-rotary with fluid assist (air, water and QUIK-FOAM®) methods and a 12¼-in. diameter tricone bit to a depth of 285 ft bgs.

On January 5, the borehole was advanced using a 12¼-in. diameter tricone bit to a depth of 495 ft bgs, the approximate depth where basalt was encountered. The drill string (bit and drill rod) was then removed (tripped out) from the borehole to measure DTW and change the drill bit. The DTW measurement indicated the borehole was dry. The drill bit was replaced with a 12¼-in. DTHH bit, and the borehole was advanced from 495 to 515 ft bgs.

On January 6, the borehole was advanced from 515 ft bgs to the TD of 720 ft bgs. After removing the drill string from the borehole, the DTW was 695 ft bgs.

On January 7, the DTW was 661.65 ft bgs. A sample (CAMO-05-56789) of the borehole fluids was collected using a bailer. Following sample collection, borehole video and natural gamma logging was conducted. Sampling activities are presented in Section 3.0.

On January 8, the DTW was measured in the borehole at 661.65 ft bgs. An induction log and a second borehole video were conducted. A trace amount of flowing water was observed in the lower portion of the borehole. At the end of the shift, the DTW was 661.15 ft bgs. The final borehole video log is located on the DVD in Appendix A.

On January 9, the DTW in the borehole was 661.45 ft bgs. The bottom of the borehole was measured at 717 ft bgs. A bentonite seal was emplaced from 717 ft bgs to 715 ft bgs. Approximately 32 gallons (gal.) of water were bailed from the borehole and groundwater recharge was monitored. The final DTW measurement for the shift was 662.08 ft bgs.

On January 10, the DTW was 661.85 ft bgs. The depth of the borehole was 714 ft bgs, likely due to swelling of the hydrated bentonite. The approved well design was received and installation of the casing and well screen began. Details of the well construction are presented in Section 6.0.

On January 11, installation of the well casing and screen was completed. The well screen was set from 686.0 to 709.0 ft bgs. Annular backfill materials were emplaced to a depth of 291 ft bgs.

On January 12, placement of annular backfill materials was completed to a depth of 90 ft bgs and demobilization activities were initiated.

On January 13, the 13⅝-in. surface casing was pulled. A cement grout seal was applied from 90 ft to approximately 1 ft bgs. The drill rig and equipment were demobilized from the drill site.

3.0 SAMPLING ACTIVITIES

Core, cuttings, groundwater screening samples, and waste characterization samples were collected at I-6. Sampling activities were conducted in accordance with the drilling plan (Kleinfelder 2004b). Deviations are noted in Section 9.0.

3.1 Sampling of Core and Drill Cuttings

Core was collected from 0 to 498.2 ft bgs and was sampled to analyze for anions, moisture content, tritium, and stable isotopes (Table 3.1-1). Samples were placed in appropriate sample jars and protective plastic bags for delivery to LANL's Sample Management Office (SMO). The remaining core was placed in lay-flat plastic or Lexan™ tubing, labeled, and stored in standard LANL Environmental Restoration core boxes, which were transported to the Field Support Facility (FSF) for archiving and storage.

During rotary drilling, drill cuttings were collected at approximately 5-ft intervals from ground surface to TD from the borehole discharge line. Portions of the cuttings were sieved (using #10 and #35 mesh) and placed in chip trays along with unsieved cuttings. An additional aliquot of the >#10 fraction of cuttings was prepared for all intervals where sufficient returns were available. The sieved fractions were placed in labeled plastic bags and submitted to LANL for potential mineralogic, petrographic, and geochemical analyses. Remaining cuttings were sealed in Ziploc® bags, labeled, and archived in core boxes at the FSF. With the exception of waste characterization, drill cuttings were not submitted for chemical analyses.

LANL RCTs screened the core and cuttings prior to removal from site.

3.2 Groundwater Sampling

On October 22, 2004, alluvial groundwater was encountered during coring. DTW was measured at approximately 57.5 ft bgs. Insufficient water was obtained by bailing the open corehole; therefore, the crew used water retained in core sample tubes from 50.5 to 58.2 ft bgs to collect the groundwater sample (CAMO-05-56788). The sample was submitted to LANL's SMO. Due to the small volume of groundwater obtained, the analysis was limited to total Kjeldahl nitrogen (TKN). No additional groundwater occurrences were noted during drilling of the corehole.

On January 7, 2005, a groundwater-screening sample was collected from the I-6 open borehole. Prior to collecting the sample, the DTW was 661.65 ft bgs and the borehole TD was 720 ft bgs. Within this interval, the zone for groundwater contribution is not known. The groundwater-screening sample (CAMO-05-56789) was collected using a clean stainless-steel bailer and submitted to the SMO for metals, tritium, stable isotopes, TKN, and radionuclide analyses.

Table 3.1-1. Core Samples Collected and Analyzed

Location ID MO-24227 - I-6									
Core Samples			ANALYSES						
Sample ID	Sample interval (ft)	Date/Time	Moisture	Tritium (H3)	anions/ cations	N14N15	D2H O18O16	ARS (DOT screening)	Notes
CAMO-05-56746	9-13.5	10/21/04; 16:00	x	x	x	x		x	
CAMO-05-56747	18.9-20.5	10/22/04; 08:30	x	x	x	x		x	
CAMO-05-56748	30-31.2	10/22/04; 10:00	x	x	x	x		x	
CAMO-05-56749	40-41.2	10/22/04; 10:25	x	x	x	x		x	
CAMO-05-56750	47.5-49.2	10/22/04; 11:00	x	x	x	x		x	
CAMO-05-56751	58.2-59.4	10/22/04; 12:40	x	x	x	x		x	
CAMO-05-56752	68.2-69.6	10/22/04; 13:15	x	x	x	x		x	
CAMO-05-56753	77.6-78.8	10/22/04; 13:50	x	x	x	x		x	
CAMO-05-56754	91.6-92.4	10/23/04; 11:00	x		x	x		x	poor recovery, no N isotopes

Table 3.1-1. Core Samples Collected and Analyzed (cont'd)

Core Samples			ANALYSES						
Sample ID	**Sample interval (ft)**	**Date/Time**	**Moisture**	**Tritium (H3)**	**anions/ cations**	**N14N15**	**D2H O18O16**	**ARS (DOT screening)**	**Notes**
CAMO-05-56755	99.6-102.2	10/23/04; 11:30	x	x	x	x		x	
CAMO-05-56756	118-119.3	10/23/04; 14:47	x	x	x	x		x	
CAMO-05-56757	140-141.7	10/23/04; 15:30	x	x	x	x		x	
CAMO-05-56758	152.5-153	10/23/04; 15:40					x	x	
CAMO-05-56759	160.8-162.3	10/23/04; 16:15	x	x	x	x		x	
CAMO-05-56760	180.7-182.2	10/23/04; 17:00	x	x	x	x		x	
CAMO-05-56761	199-200.8	10/23/04; 17:47	x	x	x	x	x	x	
CAMO-05-56762	219.2-221.2	10/23/04; 18:33	x	x	x	x		x	
CAMO-05-56763	240.4-241.9	10/24/04; 09:29	x	x	x	x		x	
CAMO-05-56764	250.5-251.5	10/24/04; 10:00					x	x	
CAMO-05-56765	260.4-261.9	10/24/04; 10:36	x	x	x	x		x	
CAMO-05-56766	280.6-282.1	10/24/04; 11:40	x	x	x	x		x	

Table 3.1-1. Core Samples Collected and Analyzed (cont'd)

Core Samples			ANALYSES						
Sample ID	**Sample interval (ft)**	**Date/Time**	**Moisture**	**Tritium (H3)**	**anions/ cations**	**N14N15**	**D2H O18O16**	**ARS (DOT screening)**	**Notes**
CAMO-05-56767	299.8-301.8	10/26/04; 09:26	x	x	x	x	x	x	
CAMO-05-56768	320.7-322.2	10/26/04; 11:30	x	x	x	x		x	
CAMO-05-56769	340.3-341.8	10/26/04; 13:47	x	x	x	x		x	
CAMO-05-56770	351.6-352.6	10/26/04; 15:04					x	x	
CAMO-05-56771	360.4-361.9	10/26/04; 16:22	x	x	x	x		x	
CAMO-05-56772	380.9-382.4	10/26/04; 19:00	x	x	x	x		x	
CAMO-05-56773	401.4-402.4	10/27/04; 10:35					x	x	
CAMO-05-56774	429.7-431.2	10/27/04; 17:00	x	x	x	x		x	
CAMO-05-56775	451.5-452.3	10/27/04; 18:52					x	x	
CAMO-05-56776	473-478.3	10/28/04; 12:30	x		x	x		x	
CAMO-05-56777	496-497.5	10/28/04; 18:09	x	x	x	x	x	x	

On February 27, 2005, a sample (CAMO-05-56791) was collected from the I-6 well near the completion of the aquifer test. The sample was submitted to the SMO for tritium, stable isotopes, TKN and radionuclides analyses.

3.3 Waste Characterization Sampling

Drill cuttings, decon water, and recovered drilling fluids and groundwater were sampled for waste characterization on February 9, 2005. These samples were submitted to Hall Environmental Analysis Laboratory in Albuquerque, New Mexico, for anions, polychlorinated biphenyls, semi-volatile organic compounds, volatile organic compounds, metals, mercury, radionuclides, tritium, and perchlorate, and explosives analyses. Analytical results were received on March 4, 2005 and submitted to DOE and LANL for review.

4.0 BOREHOLE LOGGING

Kleinfelder conducted video and geophysical logging on the I-6 borehole prior to well installation to acquire visual observations and characterize borehole conditions and hydrostratigraphy. Project personnel used this information to facilitate well design. Table 4.0-1 summarizes the video and geophysical logs that were run in the I-6 borehole.

Table 4.0-1
Borehole Logging Conducted

Operator	Date	Cased Footage (ft bgs)	Open-Hole Interval (ft bgs)	Logged Interval (ft bgs)	Remarks	Tools
Kleinfelder	1/07/05	0-60.5	60.5-720	0-approx. 600[1]	DTW measured prior to logging was 661.65 ft bgs; video terminated due to counter malfunction	Video camera
Kleinfelder	1/07/05	0-60.5	60.5-720	0-720	None	Natural gamma
Kleinfelder	1/08/05	0-60.5	60.5-720	60.5-720	None	Array induction
Kleinfelder	1/08/05	0-60.5	60.5-720	0-660[1]	trace flowing water in lower portion of borehole; DTW prior to video logging was 661.65 ft bgs	Video camera

[1] **video counter discrepancy, reported depth based on DTW measurement**

4.1 Video Logging

Kleinfelder personnel ran borehole video logs on January 7 and 8, 2005 to evaluate the borehole for evidence of water zones (Table 4.0-1). On January 8, 2005, a discrepancy between the video counter display and the actual depths was noted. The manufactured accuracy of the Kleinfelder-owned GeoVISION™ Junior video camera counter is +/- 2%. The reported depth has been adjusted to estimated actual depth based on DTW measurements taken before and after logging. These DTW measurements are approximately 661 ft bgs. The video counter for the log indicates the DTW at approximately 670 ft bgs, thus reading approximately 10 ft deeper than actual depths for the lower portion of the borehole log. A small volume of groundwater was observed entering the lower potion of the borehole. The final video log conducted on January 8, 2005 is attached as a DVD in Appendix A.

4.2 Geophysical Logging

On January 7 and 8, 2005, Kleinfelder used a Mount Sopris MGXII geophysical console to run LANL-owned natural gamma and array induction geophysical tools from 0 to approximately 720 ft bgs and from 60.5 to 720 ft bgs, respectively (Table 4.0-1). The purpose of geophysical logging was to identify geologic and hydrogeologic units, with an emphasis on gathering moisture distribution data on water-bearing zones and obtaining lithologic/stratigraphic data. The natural gamma and array induction logs are shown in Figure 4.2-1.

5.0 HYDROGEOLOGY

LANL's Earth and Environmental Sciences 6 staff provided preliminary interpretation of geologic contacts based on cores and cuttings. Groundwater occurrence is interpreted from drilling observations, open-hole video logging, geophysical logging, and water-level measurements.

5.1 Geology

Visual examination of cores, borehole drill cuttings, open-hole video logs, and geophysical logs were used to construct a stratigraphic column (Figure 5.1-1). In descending order, the stratigraphic units encountered during drilling of the I-6 borehole are alluvium, Cerro Toledo interval, Otowi Member of the Bandelier Tuff, Guaje Pumice Bed, Puye Formation, and Cerros del Rio basalt. Appendix B contains the lithologic log for I-6 based on visual examination of the drill cuttings and core samples.

5.2 Groundwater Occurrence and Characteristics

Alluvial groundwater was encountered during coring at approximately 57.5 ft bgs. No additional groundwater-bearing zones were noted in the corehole (TD of 498.2 ft bgs).

Drilling observations and borehole video logs indicate a single zone of saturation near the bottom of the I-6 borehole within the Cerros del Rio basalt. On January 7, 2005, one day after reaching the TD of 720 ft bgs, DTW in the borehole was 661.65 ft bgs. A lower bentonite seal was emplaced, 32 gals of groundwater were bailed from the open hole, and following approximately one day of recharge, groundwater had returned to near-original levels.

On January 21, 2005, prior to initiating well development, the DTW was measured at approximately 662 ft bgs. This reading was also consistent with the initial groundwater level

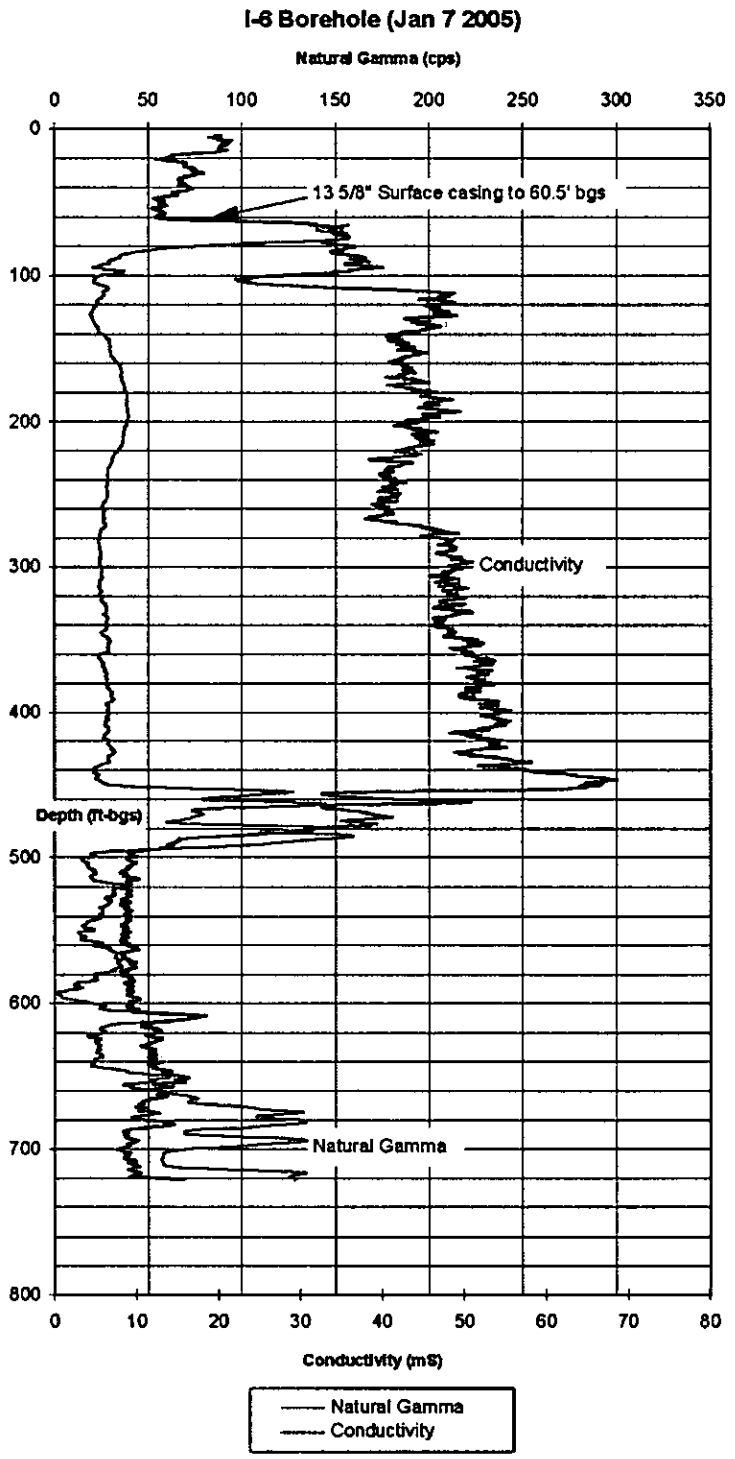


Figure 4.2-1. Natural Gamma and Induction Array Geophysical Logs

prior to starting the constant-rate aquifer test (February 24 through 28). During the recovery period of the aquifer test, groundwater levels failed to reach this original DTW reading; however, one month following the test, the DTW had returned to 662.07 ft bgs.

On May 27, 2005, immediately before installing the permanent pump, the DTW was 663.76 ft bgs. Prior to testing the sampling system on June 14, 2005, the DTW was 663.86 ft bgs.

Results from the aquifer test provide further information on the nature of the saturated interval (Section 7.2 and Appendix C).

6.0 WELL DESIGN AND CONSTRUCTION

Kleinfelder received DOE, LANL and the New Mexico Environment Department (NMED) approved well construction specifications on January 10, 2005. The well was installed between January 10 and 13, 2005.

6.1 Well Design

The "Mortandad Canyon Groundwater Work Plan, Revision 1" (LANL 2004) called for a single-screened interval in the base of the Cerros del Rio basalt to characterize potential contaminants and groundwater chemistry in the intermediate perched water zone above the regional aquifer.

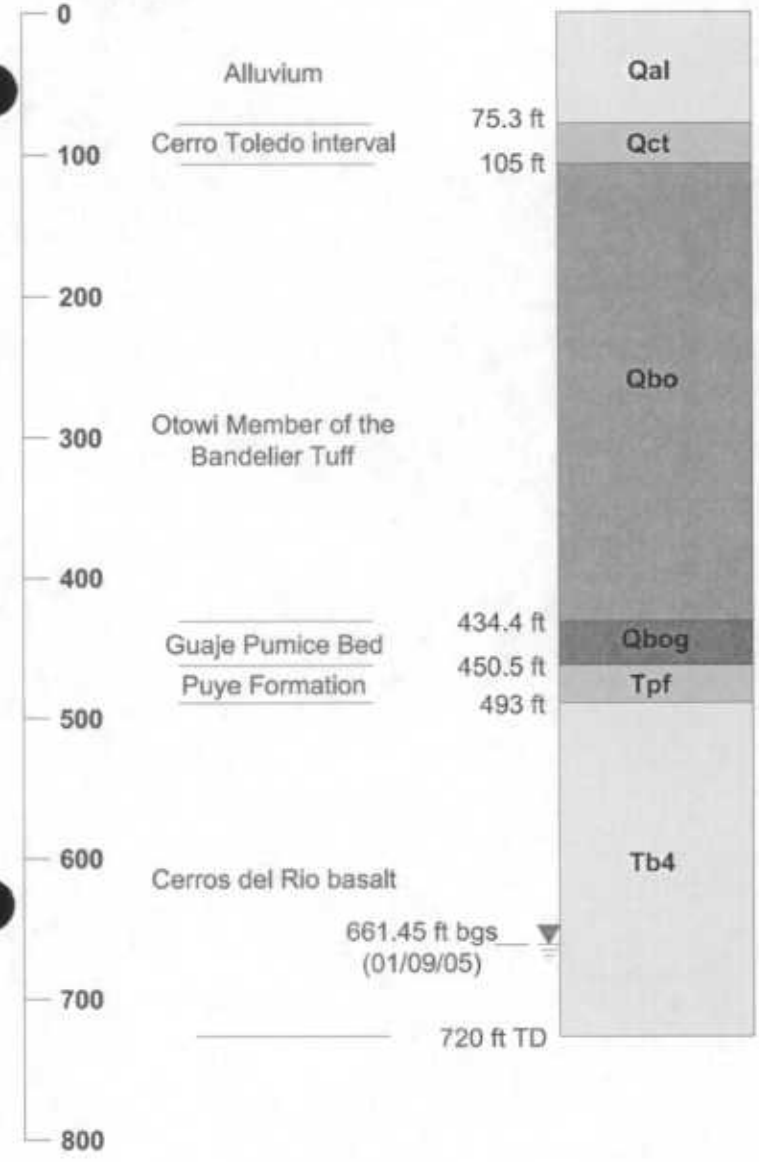
Final placement of the screened interval from 686.0 to 709.0 ft bgs was determined from geophysical data, field observations, borehole cuttings, and water level measurements including the evaluation of groundwater recharge from the open hole following the placement of a lower bentonite seal.

6.2 Well Construction

The casing and screen used in the construction of the I-6 well were factory-cleaned before shipment and delivery to the well site. Additionally, the stainless-steel components were decontaminated on site prior to well construction using a high-pressure hot water cleaner.

The well was constructed in accordance with LANL "Environmental Restoration Standard Operating Procedures for Well Construction, Revision 3" ER-SOP-05.01 (LANL 2001) using type A304, stainless-steel casing fabricated to standards in American Society for Testing and Materials (ASTM) A312-05, "Standard Specification for Seamless, Welded, and Heavily Cold Worked Austenitic Stainless Steel Pipes." External couplers, also of type A304 stainless steel, were used to connect individual casing and screen joints. Two 12-ft lengths of 5.27-in. OD, 0.020-in. slot, wire-wrapped, rod-based well screen were coupled to construct the screened interval. The screened interval was set from 686.0 to 709.0 ft bgs. The combined length of the lower screen weld ring and well end-piece provide a 3.6-ft stainless steel sump. (Figure 6.2-1).

Prior to installing well casing into the borehole, approximately 1.3 cubic feet (ft^3) of coated bentonite pellets were placed in the bottom of the borehole to form a seal from approximately 717 to 715 ft bgs. The following day, the bottom of the borehole was measured at 714 ft bgs, likely due to swelling of the hydrated bentonite. The well casing and screen was installed and the screened interval set at 686.0 to 709.0 ft bgs. A 2-in. OD steel tremie pipe was then used to place filter pack. A primary filter pack of 10/20 silica sand was placed from 714 to 669 ft bgs. After placement of the primary filter pack, the screened interval was swabbed to promote settling and



DRILLING INFORMATION

DRILLING COMPANY/PERSONNEL

WDC Exploration
M. Daniels, C. Matthews, R. Price
Drill Rig: Gefco 50k
Spectrum Exploration
S. Jager
Drill Rig: DB-540

DRILLING METHOD

Corehole
0 - 498.2 ft bgs
Borehole
Air Rotary Tri-cone bit with casing hammer (0 - 60.5 ft bgs)
Air Rotary Tri-cone bit (60.5 - 495 ft bgs)
Air Rotary Downhole hammer (495 - 720 ft bgs)

Corehole
Drilling Start Date: 10/21/04 Time: 15:40
Drilling End Date: 10/28/04 Time: 18:09
Borehole
Drilling Start Date: 01/03/05 Time: 18:05
Drilling End Date: 01/06/05 Time: 17:28

DRILLING FLUID TYPE

Corehole: Air (0 - 498.2 ft bgs)
Borehole: Air, water, QUIK-FOAM®
Air (0-60.5 ft bgs)
Air+water+QUIK-FOAM® (60.5 - 720 ft bgs)

Notes:
1. Geologic contacts are preliminary and subject to change.
2. Wet/saturated zone in Alluvium at approximately 57.5 ft bgs in corehole.
3. Groundwater level in open borehole after reaching TD was 661.45 ft bgs.

KLEINFELDER

Drawn By: C. Landon	Date: April 2006
Project No.: 49436	Filename: 49436_01_0.dwg
Scale: not – to – scale	Revision: –

BOREHOLE SUMMARY DATA SHEET
I-6
Mortandad Canyon
Los Alamos National Laboratory
Los Alamos, New Mexico

FIGURE
5.1-1

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compaction of the filter pack. A fine sand collar consisting of 20/40 silica sand was then placed above the primary filter pack from 669 to 667 ft bgs. An initial seal of coated bentonite pellets was placed from 667 to 652 ft bgs. Pellets were used to delay hydration through the standing water column. The remaining seal consisted of bentonite chips placed from 652 to 90 ft bgs, hydrated with potable water as it was emplaced. The 13⅜-in. surface casing was removed and cement grout was placed from 90 to approximately 1 ft bgs. The cement grout consisted of a 3000 pounds per square inch (psi) cement/sand slurry blended with powdered bentonite (1% bentonite, calculated as dry weight bentonite to dry weight cement plus bentonite). The volume of annular fill materials is summarized in Table 6.2-1

Table 6.2-1

Annular Fill Materials Used in Well Construction

Material	Volume
Grout seal: cement slurry	108 ft^3
Upper bentonite seal: pellets & chips	481.1 ft^3
Fine sand collar: 20/40 silica sand	2.0 ft^3
Primary filter: 10/20 silica sand	33 ft^3
Lower bentonite seal: pellets	1.3 ft^3
Potable water	850 gallons

7.0 WELL DEVELOPMENT, AQUIFER TESTING, AND PUMP INSTALLATION

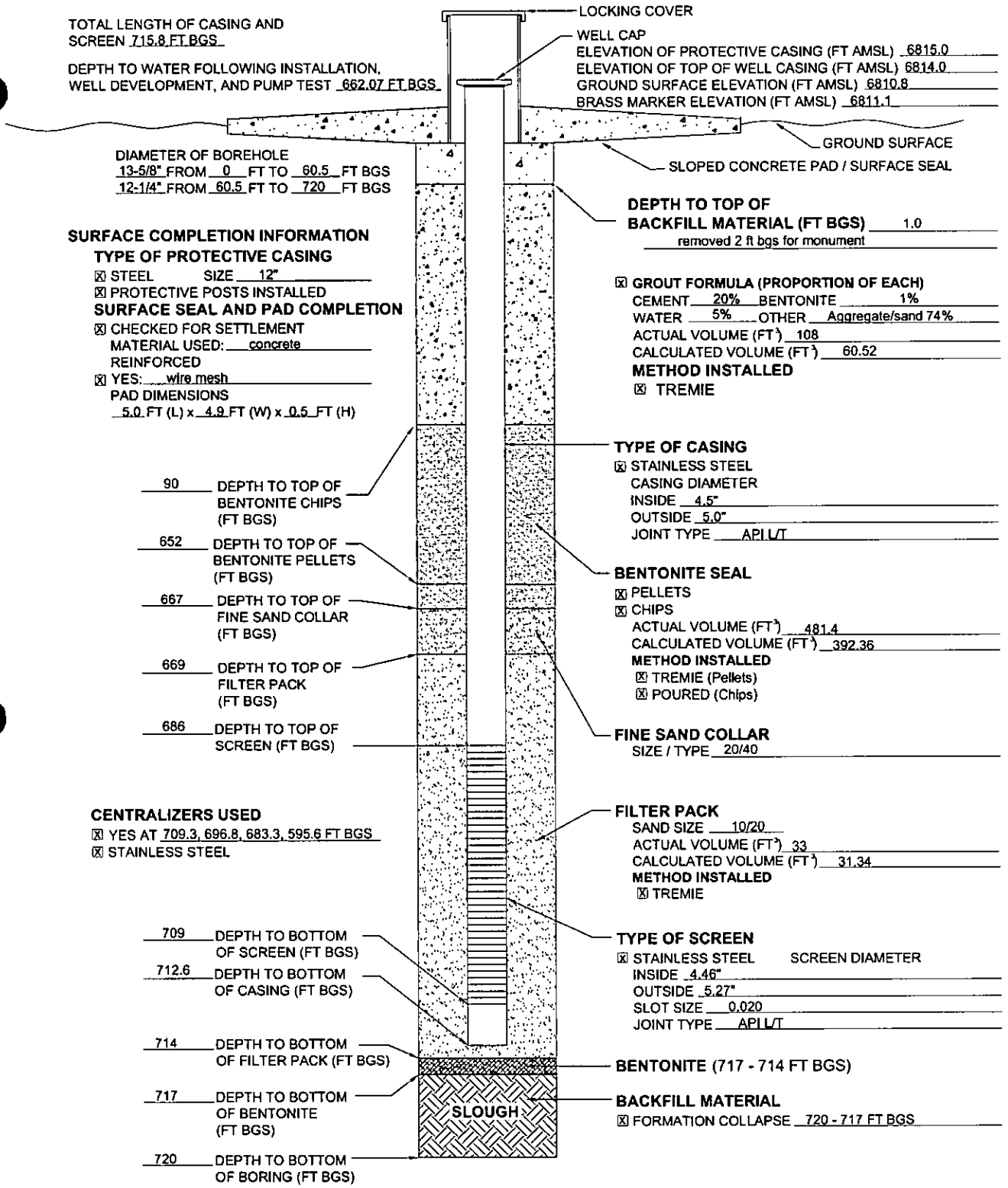
Development activities at I-6 were conducted on January 21, 2005 and were limited to bailing and swabbing of the well screen. An aquifer test was conducted from February 24 through 28, 2005.

7.1 Well Development

Development of I-6 began by bailing and swabbing the screened interval to enhance filter-pack settling and to remove drilling fluids and sediment that were introduced into the well during drilling and installation. On January 21, 2005, bailing was conducted with a stainless-steel bailer and swabbing was conducted by repeatedly drawing a swab across the screened interval. Approximately 60 gal. of water were removed during swabbing and bailing. During the initial stages of development groundwater parameters were not obtained, and it was apparent that the intermediate perched interval had very low recharge.

7.2 Aquifer Testing

Aquifer testing consisted of two trial tests per day on February 24 and 25, 2005 and a constant-rate pumping and recovery test conducted from February 26 to 28, 2005. The complete aquifer testing report can be found in Appendix C. A Grundfos™ submersible pump was used for aquifer testing. Additional well development occurred as the well was pumped during the aquifer testing. Approximately 3,612 gal. were removed during testing. A groundwater sample (CAMO-05-56791) was collected on February 27, 2005, near the completion of pump test activities.



KLEINFELDER

Drawn By: C. Bhongir	Date: April 2006
Project No.: 49436	Filename: 49436_02_0.dwg
Scale: Not-to-scale	Revision: –

WELL SCHEMATIC
I-6
Mortandad Canyon
Los Alamos National Laboratory
Los Alamos, New Mexico

FIGURE
6.2-1

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Multiple tests were conducted due to a malfunction in the check valves on the pump discharge pipe on February 24. It was necessary to remove the pumping string, replace the check valves, reinstall the pump, and restart the testing process.

The 27-hour constant-rate pumping test began at 8:30 am on February 26. The well was pumped at approximately 1.94 gallons per minute (gpm) for 1,620 minutes (27 hrs). Recovery measurements were recorded for 1,266 minutes (21.1 hrs).

The following information summarizes the results of the pumping and recovery tests on I-6:

- Four short-duration trial tests and one 27-hour constant-rate pumping test were conducted.
- The lack of clear response of formation pressure (apparent hydrograph) to changes in barometric pressure implied a barometric efficiency of nearly 100%, consistent with what has been observed in most of the wells on the plateau.
- Casing storage effects were eliminated from the drawdown data sets. However, it appeared that a slow drainage event must have occurred during pumping because the water level rebound following pump shutoff was a result of storage effects. The effect was slight in the short tests, but significant in the 27-hour test.
- The transmissivity values calculated for the 8-ft-thick perched zone from 686 to 708 ft bgs were consistent, falling within a narrow range and averaging 64 gallons per day (gpd)/ft. The resulting average hydraulic conductivity was 8.0 gpd/ft^2, or 1.1 ft per day.
- Lower-bound transmissivity values obtained from specific capacity data and slug test responses averaged 57 gpd/ft, consistent with the transmissivity values obtained by conventional analysis.
- The data showed the effects of delayed yield associated with unconfined conditions.
- Water levels consistently failed to recover to the starting static water level after each pumping event, indicating a lateral limit to the perched zone or permeability reduction away from the well (or both). The latter scenario is likely, because perched conditions are known to extend to R-15 and I-5, and the perched zone in I-5 has low transmissivity.
- The 27-hour pumping test showed unusual drainage-related responses that were probably related to saturated zone heterogeneities. It was possible that the drainage and refilling of discrete fractures or pockets of sediment caused the observed drawdown and recovery anomalies.

7.3 Dedicated Sampling System Installation

A dedicated sampling pump and riser pipe was installed at I-6 on May 27, 2005. The dedicated pump is a Grundfos™ 1.8 gpm, 3.9-in. OD, submersible pump (model number 5S20-39DS). The pump intake is positioned within the screened interval at 685.2 ft bgs. Discharge from the pump intake to ground surface is provided by a 1-in. ID, stainless steel riser pipe with check valves located at 481.2 ft bgs, 279.1 ft bgs, and 77.7 ft bgs. A bleed valve is located at 17.1 ft bgs to drain water in the riser pipe to below the frost line upon completion of a pumping event.

8.0 WELLHEAD COMPLETION, SURVEY, AND SITE RESTORATION ACTIVITIES

8.1 Wellhead Completion

Wellhead completion consisted of the installation of the protective well monument, surface seal, and pad. A 12-in. OD, steel well monument with locking lid was installed from approximately 1 ft bgs to 4 ft above ground surface (ags) to protect the well riser. Concurrent with the placement of the monument and surface seal using concrete backfill, the reinforced concrete pad, 5.0-ft long by 4.9-ft wide by 6.5-in. thick, was installed around the well casing to provide long-term structural integrity for the well. A brass survey cap was embedded in the northwest corner of the pad. The pad is slightly elevated and sloped away from the well casing to promote runoff. Four bollards are placed around the perimeter of the pad to protect against vehicular damage.

8.2 Geodetic Survey

The abandoned corehole, ground surface, well casing, and brass cap of the I-6 borehole were surveyed by ASTS, Inc. on May 6, 2005. The survey data are presented in Table 8.2-1.

Table 8.2-1
Geodetic Data

Description	Northing	Easting	Elevation*
Abandoned corehole	1768423.27	1635335.75	6810.5
Ground surface	1768429.56	1635345.2	6810.8
Brass cap in I-6 pad	1768428.06	1635345.65	6811.1
Top of stainless-steel well casing	1768426.02	1635347.01	6814.0
Top of protective well monument casing[1]	NM[2]	NM	6815.0

*Measured in ft above mean sea level (amsl) relative to the National Geodetic Vertical Datum of 1929, accurate to +/- 0.1 foot.

[1]Measured from geodetic surveyed brass marker using staff and level.

[2]NM – not measured

8.3 Site Restoration Activities

Cuttings and fluids produced during drilling and development/aquifer testing were containerized and sampled on February 9, 2005, in accordance with the October 13, 2004, Waste Characterization Strategy Form prepared for the drilling and installation of boreholes and wells in Mortandad Canyon (Appendix C in Kleinfelder 2004b). Analytical results were received on March 4, 2005, and submitted to DOE and LANL for review. Fluid sample results were compared to the State of New Mexico Water Quality Control Commission Regulation 3103 groundwater standards. Water generated during drilling, development and aquifer testing was land-applied in accordance with the Workplan Notice of Intent Decision Tree, revised July 15, 2002, and in coordination with NMED. Cuttings sample results were compared to local geochemical background values and soil screening levels (SSLs) from the NMED Soil Screening

Levels, Revision 2.0, February 2004, and submitted to DOE for approval to use as site restoration fill.

Site restoration activities included removing the water from the containment area and applying it back to the land, removing the polyethylene liner and cuttings from the containment area, removing the containment berms, backfilling and grading the containment area, and disposing of the containment liner. Remaining cuttings not utilized to backfill the containment area were thinly spread over the site. The site has been reseeded and temporary materials emplaced for BMPs have been removed.

9.0 DEVIATIONS FROM THE WORKPLAN

In general, drilling, sampling, and well construction at I-6 were performed as specified in the "Final Drilling Plan for Intermediate Wells, Mortandad Canyon, Los Alamos National Laboratory" (Kleinfelder 2004b). Deviations from planned activities are as follows:

- TD of the corehole was 498.2 ft bgs rather than 500 ft bgs as noted in the drill plan.
- The drill plan calls out for specific sampling intervals and analyses for collected core. During intervals of poor recovery, sampling intervals and analyses were adjusted as needed.
- Sampled core was not analyzed for cations or radionuclide suite as specified in the drill plan.
- Due to the lack of accumulated groundwater, the water sample collected from the corehole at approximately 57.5 ft bgs was collected from the core-containing Lexan™ tubes rather than from the open corehole using a bailer. Analysis was limited to TKN.
- During plugging and abandonment of the corehole, cement grout was emplaced from 90 ft bgs rather than 75 ft bgs as specified in the drill plan.
- TD of the borehole was 720 ft bgs rather than 760 ft bgs as noted in the drill plan.
- Groundwater sample CAMO-05-56789, collected from the open borehole, was not analyzed for anions or perchlorate.
- Due to the very low aquifer yield, well development was limited.
- Groundwater parameters were not collected.
- A groundwater sample was not collected following well development. A sample was collected upon completion of aquifer testing, but was not submitted for analysis.

10.0 ACKNOWLEDGMENTS

ASTS, Inc. conducted the final geodetic survey of finished well components.

David Schafer and Associates conducted aquifer testing and analysis.

Duratek Federal Services, Inc. performed a review of the analytical results of the drill cuttings for waste determinations.

EnviroWorks, Inc. provided site preparation and restoration services.

Hall Environmental Analysis Laboratory conducted laboratory analysis for waste characterization samples

Spectrum Exploration Inc. provided coring services.

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

WDC Exploration & Wells provided rotary drilling and well development services.

11.0 REFERENCES

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Appendix A

Borehole Video Log

Appendix B

Lithologic Log

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Qal, Alluvium	No recovery. Sample not available for examination. **Note: Descriptions presented in this lithologic log are primarily based on observations made during visual examination of drill core and cuttings. From 0-498.2 ft bgs, lithologic description was generatad from drill core. Drill cuttings, collected on 5 foot intervals, were used from 498.2 ft to 720 ft bgs. Stratigraphic contacts are based on available information from review of drill core and limited geophysical logs. Unrecovered and/or sampled core in sections of less than 5 ft are not noted unless relevant to lithologic description.**	0-4	6810.8-6806.8
	Unconsolidated sediments, silty to very fine sand, moderate yellowish brown (10YR 5/4). Well-sorted (60% silt, 40% very fine sand); trace coarse sand size pumice fragments (subrounded); sand composed of tuff fragments, intermediate composition volcanic clasts (often rounded) with felsic (quartz and sanidine unless otherwise noted) crystals, faceted and bipyramidal; dry.	4-13.5	6806.8-6797.3
	Unconsolidated sediments, silty sand, moderate yellowish brown (10YR 5/4). Moderately sorted (20% silt, 20% fine sand, 40% medium sand, 10% coarse sand, 10% very coarse sand); felsic crystal rich (bipyramidal and faceted crystals); coarse sand to very coarse sand, intermediate composition volcanic clasts and pumice; dry.	13.5-20.5	6797.3-6790.3
	Unconsolidated sediments, as above; moist, slight increase in pumice percentage.	20.5-21.3	6790.3-6789.5
	Unconsolidated sediments, sandy silt, moderate yellowish brown (10YR 5/4). Well sorted (40% sand, 60% silt); subrounded to round sand; felsic crystal rich - frequent bipyramidal quartz, faceted crystal fragments; subround fine to medium sized welded tuff; trace fine gravel size intermediate composition volcanic clasts; dry.	21.3-27.5	6789.5-6783.3
	Unconsolidated sediments, sandy silt, pale yellowish brown (10YR 6/2). Well-sorted (10% coarse sand, 30% fine sand, 60% silt); trace felsic crystals, fine to coarse sand size; lithics and trace welded tuff, coarse sand-sized; dry.	27.5-28	6783.3-6782.8
	Unconsolidated sediments, sandy silt, pale brown (5YR 5/2). Moderately sorted (30% sand, 70% silt); highly weathered tuff, coarse sand to fine gravel sized, subrounded; felsic crystals, coarse sand to very coarse sand-sized fragments, subrounded to rounded, trace faceted surfaces; trace rootlets at 31.2 ft bgs; dry.	28-32.6	6782.8-6778.2
	Unconsolidated sediments, silts to very fine sand, light brown (5YR 6/4). Moderately sorted (70% silt, 30% sand); trace coarse to very coarse sand sized subrounded welded tuff fragments; dry. Grades to silty sand at 34.5 ft bgs predominantly coarse-grained, subrounded felsic crystals; moist.	32.6-34.5	6778.2-6776.3

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Qal, Alluvium	Unconsolidated sediments, silty to very fine sand, light brown (5YR 6/4). Moderately sorted (20% silt, 78% fine sand, 2% coarse to very coarse sand); trace coarse to very coarse sand-size felsic crystals, rounded; trace coarse sand to fine gravel sized welded tuff; trace rootlets; moist.	34.5-37.5	6776.3-6773.3
	Unconsolidated sediments, sandy gravel, moderate brown (5Y 5/6). Poorly sorted (60% gravel, 10% coarse sand, 20% fine sand, 10% very fine sand); felsic crystal sand matrix, subrounded; subrounded gravels, up to 3 cm; moist.	37.5-38.5	6773.3-6772.3
	Unconsolidated sediments, silty sand, light brown (5YR 5/6) to moderate brown (5YR 4/4). Moderately sorted, predominantly coarse to very coarse sand; predominately felsic crystals (frequent bipyramidal quartz) and lesser amounts of intermediate composition volcanic clasts; trace welded tuff fragments to 5 cm; damp.	38.5-41.2	6772.3-6769.6
	Unconsolidated sediments, gravelly silt, moderate brown (5YR 4/4); wet.	41.2-42.5	6769.6-6786.3
	Unconsolidated sediments, silty sand, grayish brown (5YR 3/2). Poorly sorted (65-75% fine to coarse grained sand, 25-35% silt); felsic crystal rich, subrounded; 0-5% gravels to 10 mm, subrounded to subangular.	42.5-45.0	6786.3-6765.8
	Unconsolidated sediments, as above, grading to moderate brown (5YR 4/4), predominantly medium to coarse grained sand, moderately sorted, 90% felsic crystals with trace pumice and dark volcanic composition clasts; wet.	45.0-46.2	6765.8-6764.6
	Unconsolidated sediments, as above, grading to fine to medium grained silty sand, poorly sorted (0-5% gravel, 75-85% sand, 15-25% silt); rare dacite lithics; wet.	46.2-50.5	6764.5-6760.3
	Colluvium (weathered tuff) with unconsolidated sediments, grayish brown (5YR 3/2), poorly welded/unconsolidated. Tuff weathered to poorly graded sand with silt, fine to medium grained; felsic crystal rich; wet (saturated).	50.5-51.9	6760.3-6758.9
	Colluvium, as above, grading to silty sand, fine to coarse grained, poorly sorted (5-10% gravel, 60-70% sand, 20-35% fines); welded fragments > 40 mm with devitrified pumice to 5 mm, large felsic crystals; wet.	51.9-55.7	6758.9-6755.1
	Unconsolidated sediments, silty sand, pale brown (5YR 5/2). Welll sorted (5-10% gravel, 60-70% sand, 25-35% fines); fine grained sand, felsic crystals and minor intermediate composition volcanic clasts; tuff fragments up to 60 mm, felsic crystal rich, subrounded; wet (saturated).	55.7-59.4	6755.1-6751.4
	Unconsolidated sediments, silty sand, moderate brown (5YR 3/4). Poorly sorted (20-30% gravel, 50-60% sand, 20-30% fines); sand fine to coarse grained; tuff fragments > 50 mm, slightly to moderately weathered along tuff surface, pinkish gray, felsic crystal rich, frequent devitrified grayish pumice; wet.	59.4-63.2	6751.4-6747.6

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Qal, Alluvium	Colluvium (tuff), pale red (5R 6/2). Ash matrix; 25-35% felsic crystals; 5-15% devitrified pumice, up to 25 mm, aspect ratio 4:1; lithic poor; tuff surfaces and pumice slightly oxidized.	63.2-64.8	6747.6-6746.0
	Unconsolidated sediments, silty sand, grayish brown (5YR 3/2). Moderately sorted (0-5% gravel, 70-80% sand, 20-30% fines); predominantly fine grained sand, felsic crystals frequently rounded, bipyramidal quartz frequent; gravels to 10 mm, dacitic-andecitic clasts, subrounded; wet (saturated).	64.8-68.0	6746.0-6472.8
	Unconsolidated sediments, as above, grading to fine grained, well sorted silty sand with clay, 25-35% silt content.	68.0-69.6	6472.8-6741.2
	Unconsolidated sediments, clayey sand with gravel, moderate brown (5YR 4/4). Moderately sorted, (30% clay and silt, 60% fine to very coarse sand, 10-15% gravels); predominantly fine grained matrix, felsic crystal rich, low to medium plasticity; dark subrounded gravels to 30 mm; wet (saturated).	69.6-73.2	6741.2-6737.6
	Unconsolidated sediments, silty clayey sand, moderate brown (5YR 4/4). Possible slough from 73.2 to 73.6 ft bgs. Poorly sorted, (30-40% fines, 40-50% sand, 5-10% gravel); low plasticity matrix; sand composed of very fine to medium grain size felsic crystals, subangular to rounded, 20% pumice fragments and lithics; gravel clasts up to 1 cm, composed of pumice and intermediate composition volcanic clasts; wet.	73.2-73.6	6737.6-6737.2
	Unconsolidated sediments, well sorted sand. Felsic crystal rich zone composed of: 15% felsic crystals (broken and faceted) increasing to 50% at 73.9 ft bgs; 25% intermediate volcanic composition clasts decreasing across interval; 10-15% tuff fragments, brown devitrified pumice; possible organic material at 74.3 ft bgs.	73.6-74.3	6737.2-6736.5
	Unconsolidated sediments, clayey sandy silt, moderate brown (5YR 4/4). Poorly sorted; sand predominately very fine to fine, trace felsic crystals, occasional faceted surfaces.	74.3-74.8	6736.5-6736.0
	Unconsolidated sediments, poorly sorted sand with minor fines. Felsic crystal rich zone; fine to very coarse felsic crystals, bipyramidal quartz.	74.8-75.3	6736.0-6735.5
Qct, Cerro Toledo interval	Volcaniclastic sediments, sandy silt, light brown (5YR 5/6), unconsolidated. Poorly sorted sand composed of: 3-5% white vitric pumice, moisture altered, 3-5 mm, subrounded, rare hornblende phenocryst; 1-2% felsic crystals, small, rounded; rare obsidian fragment. **Note: The base of the alluvium/colluvium and the contact with the underlying Cerro Toledo interval is interpreted to be at 75.3 ft bgs.**	75.3-75.7	6735.5-6735.1
	Volcaniclastic sediments, silty sand, moderate brown (5YR 4/4), unconsolidated. Moderately sorted; sands composed of 60% pumice fragments, 20-30% lithic clasts, 20% felsic crystals.	75.7-76.5	6735.1-6734.3

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Qct, Cerro Toledo interval	Volcaniclastic sediments, silty sand, moderate brown (5YR 4/4), unconsolidated. Moderately sorted; sands composed of 60% pumice fragments, 20-30% lithic clasts, 20% felsic crystals.	76.5-76.9	6734.3-6733.9
	Volcaniclastic sediments, pumiceous sand with silt, grayish orange (10YR 7/4) to dark yellowish orange (10YR 6/6), unconsolidated. Moderately sorted (1% gravel, 84% sand, 15% fines); trace intermediate composition volcanic gravel clasts up to 1.0 cm; sand composed of predominately pumice, with 10-15% felsic crystals and 20-25% intermediate composition volcanic clasts, subrounded to subangular; wet.	76.9-78.8	6733.9-6732.0
	Volcaniclastic sediments, as above, poorly sorted, pale brown (5YR 5/2) to very pale orange (10YR 8/2); pumice slightly altered from moisture, noteable decrease in moisture content.	78.8-80.7	6732.0-6730.1
	Volcaniclastic sediments, gravelly sand, light brown (5YR 6/4) to grayish orange (10YR 7/4), unconsolidated. Moderately sorted, 30% poorly sorted gravels, predominately intermediate composition volcanic clasts, up to 3 cm and small pumice fragments; 50% poorly sorted sand, equal amounts of felsic crystals, pumice and lithic fragments; moist.	80.7-83.2	6730.1-6727.6
	Volcaniclastic sediments, pumiceous sand with gravel, pale yellowish brown (10YR 6/2), unconsolidated. Poorly sorted composed of 30-40% fine to coarse grained felsic crystals, 30-40% pumice fragments, 5-10% fine to coarse lithic clasts; 10-15% gravel, up to 3 cm; damp.	83.2-86.0	6727.6-6724.8
	No recovery and/or core sampled. No core available for examination.	86.0-105	6724.8-6705.8
Qbo, Otowi Member of the Bandelier Tuff	Tuff, grayish orange (10YR 7/4), poorly welded. Ash matrix; 10-15% felsic crystals; 10-15% vitric pumice, up to 4 cm, felsic phenocrysts; 5-10% lithics, up to 10 mm, subrounded. **Note: The base of the Cerro Toledo interval (Qct) and the contact with the underlying Otowi Member of the Bandelier Tuff (Qbo) is interpreted to be at 105 ft bgs.**	105-108	6795.8-6702.8
	Tuff, moderate reddish orange (10R 5/4), poorly welded. Ash matrix; 5-15% felsic crystals, fine to coarse grained; 10-15% pumice, up to 5 mm, white (N9), slightly weathered; 0-5% lithics, medium to coarse grained, subrounded.	108-113	6702.8-6697.8
	Tuff, moderate reddish orange (10R 5/4), poorly welded. Ash matrix; 10-15% felsic crystals decreasing percentage with depth, fine to medium grained; 0-5% pumice, up to 5 mm, vitric, white (N9), moderate weathering, 1:1 aspect ratio; 0-5% lithics, up to 40 mm, subangular to subrounded.	113-118	6697.8-6692.8
	Tuff, moderate orange pink (10R 7/4) to moderate reddish orange (10R 6/6), poorly sorted. Ash matrix; 15-20% felsic crystals, medium to very coarse; 10-15% pumice, up to 25 mm, vitric, 2:1 to 1:1 aspect ratio, trace oxidation; 10-15% lithics, up to 20 mm, subrounded.	118-123	6692.8-6687.8

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Qbo, Otowi Member of the Bandelier Tuff	Tuff, moderate orange pink (10R 7/4) to moderate reddish orange (10R 6/6), poorly welded. Ash matrix; 10-15% felsic crystals, fine to coarse grained; 5-10% pumice, up to 10 mm, 1:1 aspect ratio, vitric, felsic phenocrysts; 10-15% lithics, medium to coarse grained, subrounded.	123-128	6687.8-6682.8
	Tuff, moderate orange pink (10R 7/4) to moderate reddish orange (10R 6/6), poorly welded. Ash matrix; 20-25% felsic crystals, fine to coarse grained; 10-15% pumice, moderate reddish orange (10R 6/6), up to 2 cm, vitric, felsic phenocrysts; 10-15% lithics (dacite included) up to 1.5 cm, subrounded.	128-133	6682.8-6677.8
	Tuff, moderate orange pink (10R 7/4) to moderate reddish orange (10R 6/6), poorly welded. Ash matrix; 15-20% felsic crystals; 10-15% pumice, up to 20 mm, vitric, felsic phenocrysts; 15-20% lithics, subrounded.	133-136	6677.8-6674.8
	Tuff, moderate orange pink (10R 7/4) to light brown (5YR 5/6), poorly welded. Ash matrix; 20-25% felsic crystals; 10-15% vitric pumice, 1:1 aspect ratio few 2:1, slight weathering along pumice surface; 15-20% lithics, up to 15 mm (including dacite), subrounded.	136-137.7	6674.8-6673.1
	Tuff, pale yellow orange (10YR 8/2), poorly welded. Ash matrix; 30-35% felsic crystals; pumice with felsic phenocrysts, rare mafic phenocrysts; 10-15% intermediate compostion volcanic lithics.	137.7-143	6673.1-6667.8
	Tuff, very pale orange (10YR 8/2) to grayish orange (10YR 7/4), poorly welded. Ash matrix; 15-20% felsic crystals; 15-20% lithics, up to 3 cm, subangular; 5-10% vitric pumice, up to 1 cm, occasional pumice up to 4 cm, 1:1 to 2:1 aspect ratio; moist.	143-153	6667.8-6657.8
	Tuff, very pale orange (10YR 8/2), poorly welded. Ash matrix; 20-30% fine to coarse felsic crystals; 5-15% dark yellow orange pumice, up to 3 cm, vitric with altered surfaces; 5- 10% dark lithics, up to 2 cm, at 156.1 ft bgs dacite lithics to greater than 50 mm, subangular.	153-163	6657.8-6647.8
	Tuff, very pale orange (10YR 8/2) to grayish orange (10YR 7/4), poorly welded. Ash matrix; 20-30% felsic crystals; 20-30% vitric pumice, up to 3 cm, trace weathered and altered; 5-15% lithics, up to 1 cm.	163-180.7	6647.8-6630.1
	Tuff, pale yellowish brown (10YR 6/2). poorly welded. Ash matrix; 5-15% felsic crystals; 0-15% pumice, up to 5 cm, vitric, silghtly weathered, felsic phenocrysts; 0-5% lithic up to 1 cm, subrounded.	180.7-203	6630.1-6607.8
	Tuff, pale yellowish brown (10YR 6/2), poorly welded. Ash matrix; 5-10% felsic crystals, very fine to medium grained; 0-5% pumice, vitric, up to 2 cm, aspect ratio 1:1; 0-5% lithics, up to 3 cm, subrounded.	203-208	6607.8-6602.8

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Qbo, Otowi Member of the Bandelier Tuff	Tuff, pale yellowish brown (10YR 6/2), poorly welded. Ash matrix; 5-15% felsic crystals, predominantly quartz, very fine to medium grained; 0-5% pumice, vitric, up to 3 cm, felsic phenocrysts; 5-10% lithics, up to 4 cm, subangular to subrounded; possible altered mica flecks, rare, very small.	208-213	6602.8-6597.8
	Tuff, pale yellowish brown (10YR 6/2), poorly welded. Ash matrix; 5-10% felsic crystals; 0-5% pumice, up to 1 cm, aspect ratio 1:1, vitric, felsic phenocrysts; 5-10% lithics, up to 2 cm, subangular to subrounded, pumice pale yellowish orange (10YR 8/6) to dark yellowish orange (10YR 6/6).	213-223	6597.8-6587.8
	Tuff, pale yellowish brown (10YR 6/2), poorly welded. Ash matrix; 5-10% felsic crystals; 0-5% pumice, dark yellowish orange (10YR 6/6), up to 2 cm, aspect ratio 1:1 to 2:1, vitric, felsic phenocrysts; 0-5% lithics, subrounded.	223-228	6587.8-6582.8
	Tuff, pale yellow brown (10YR 6/2), poorly welded. Ash matrix; 10-15% felsic crystals; 5-10% vitric pumice, up to 2 cm, dark yellowish orange (10YR 6/6), aspect ratio 1:1 to 2:1, felsic phenocrysts, alteration and weathering along pumice surfaces; 0-5% lithics, up to 5 cm intermediate composition volcanic clasts, subrounded to subangular; high angle fractures at 230.5 ft and 233 ft bgs, clay coated surfaces.	228-243	6582.8-6567.8
	Tuff, pale yellowish brown (10YR 6/2), poorly welded. Ash matrix; 15-25% felsic crystals; 10-15% vitric pumice, up to 2 cm, apsect ratio of 2:1 to 1:1, dark yellowish orange, felsic phenocrysts, altered pumice surfaces; 5-10% lithics, up to 1 cm, subrounded.	243-260	6567.8-6550.0
	Tuff, pale yellowish brown (10YR 6/2) to moderate yellowish brown (10YR 5/4), poorly welded. Ash matrix; 10-20% felsic crystals; 10-20% vitric pumice, up to 2 cm, occasionally up to 6 cm, dark yellowish orange to moderate orange, felsic phenocrysts, absence of weathering on pumice surfaces, aspect ratios predominantly 2:1; 5-15% lithics, up to 0.5 cm, subrounded to subangular.	260-280	6550.8-6530.8
	Tuff, very pale orange (10YR 8/2) to pale yellowish brown (10YR 6/2), poorly welded. Ash matrix; 0-10% felsic crystals; 0-5% pumice, up to 2.5 cm, vitric, minor oxidation and alteration of the pumice fibers, larger pumice have felsic phenocrysts; 0-5% lithics, subrounded; 0-2% mafic fragments.	280-293	6530.8-6517.8
	Tuff, very pale orange (10YR 8/2) to pale yellowish brown (10YR 6/2), poorly welded. Ash matrix; 0-10% felsic crystals; 0-5% pumice, vitric, trace alteration, up to 2.0 cm, aspect ratio 1:1, felsic phenocrysts; 0-5% lithics, up to 1.5 cm, subangular to subrounded.	293-312	6517.8-6498.8

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Qbo, Otowi Member of the Bandelier Tuff	Tuff, pale yellowish brown (10 YR 6/2), poorly welded. Ash matrix; 3% pumice, white (N9), 2 mm to 1 cm, vitric, fibrous, felsic phenocrysts, rare mafic phenocrysts and surficial Mn/Fe oxide specks; 3% lithics, up to 1cm, subrounded to rounded; 7% felsic crystals; moist.	312-326	6498.8-6484.8
	Tuff, as above, decrease in average pumice size (1-5 mm); decrease in felsic crystals to 5%; dry.	326-327.1	6484.8-6483.7
	Tuff, pale yellowish brown (10YR 6/2), poorly welded. Ash matrix; 3% pumice, white (N9) to yellowish brown, 2 mm to 1.5 cm, vitric, subhedral felsic phenocrysts; 3-7% felsic crystals (in matrix) are medium to coarse sized, subhedral; 3% lithics, subrounded to rounded, coarse sand to granule to rarely gravel-sized; intermediate composition volcanic lithics; moist.	327.1-341	6483.7-6469.8
	Tuff, pale yellowish brown (10YR 6/2), poorly welded. Ash matrix; 2-5% pumice, white (N9), 1 mm to 2 cm, vitric, subhedral felsic phenocrysts, surficial Mn/Fe specks; 3-7% felsic crystals (in matrix), subhedral; 2-5% lithics, subrounded to rounded, coarse sand to granule to rarely gravel-sized, intermediate composition volcanics; moist.	341-361.9	6469.8-6448.9
	Tuff, pale yellowish brown (10YR 6/2), poorly welded. Ash matrix; 2-5% pumice, white (N9), 1 mm to 2 cm, vitric, fibrous, subhedral mafic felsic phenocrysts, trace Mn/Fe oxide staining; 3-7% felsic crystals, coarse sand sized, subhedral; 2-5% lithics, subrounded to rounded, coarse sand to granule to rarely gravel-sized; moist.	361.9-402	6448.9-6408.8
	Tuff, pale yellowish brown (10YR 6/2), poorly welded. Ash matrix; 2-5% pumice, white (N9), 1 mm to 2 cm, vitric, rare mafic and felsic phenocrysts, occasional surficial Mn/Fe specks; 3-7% felsic crystals are coarse sand sized, subhedral; 2-5% lithics, subrounded to rounded, coarse sand to granule to rarely gravel-sized; moist.	402-423	6408.8-6387.8
	Tuff, pale yellowish brown (10YR 6/2), poorly welded. Ash matrix; 2-5% pumice, white (N9), 1 mm to 2 cm, vitric, fibrous, coarse sand sized subhedral felsic phenocrysts; 3-7% felsic crystals, coarse sand sized, subhedral; 2-5% lithics, subrounded to rounded, coarse sand to granule to rarely gravel-sized; moist, minor alteration due to moisture.	423-433	6387.8-6377.8
	Tuff, as above, marked increase in pumice to 60%.	433-434.4	6377.8-6376.4

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Qbog, Guaje Pumice Bed of the Otowi Member of the Bandelier Tuff	Pumice Bed, very light gray (N8), poorly welded. 60-80% pumice, white (N9), 2 mm to 2.5 cm, vitric, coarse subhedral felsic phenocrysts, very rare subhedral mafic phenocrysts(<1mm); 10-20% felsic crystals; 2-5% lithics, coarse sand to rarely granule or gravel-sized, subrounded to rounded; moist. **Note: The base of the Otowi Member of the Bandelier Tuff (Qbo) and the contact with the underlying Guaje Pumice Bed (Qbog) is interpreted to be at 434.4 ft bgs.**	434.4-447	6376.4-6363.8
	Pumice Bed, as above, pumice increase up to 95%, average size increase with depth.	447-450.5	6363.8-6360.3
Tpf, Puye Formation (fanglomerate)	Volcaniclastic sediments, clayey silt with sand, moderate yellowish brown (10YR 5/4), moderately consolidated. Very well sorted (0% gravel, 1% sand, 99% fines); very thin (0.5 cm) layer of clay altered ash at top of formation, moist. **Note: The base of the Guaje Pumice Bed (Qbog) and the contact with the underlying Puye Formation (Tpf) is interpreted to be at 450.5 ft bgs.**	450.5-453	6360.3-6357.8
Tpf, Puye Formation (fanglomerate)	Volcaniclastic sediments, as above, decrease in clay and silt percentage (50-70%), increase in fine sand (30-50%) and appearance of rare coarse sand gravel (0-2%), intermediate composition volcanic clasts and pumice (0-1%) with depth.	453-463	6357.8-6347.8
	Volcaniclastic sediments, sandy silty gravel, moderate yellowish brown (10YR 5/4), unconsolidated. Poorly sorted (50-70% gravel, 25-45% sand, 5% fines); felsic crystal rich; intermediate composition volcanic clasts, very coarse gravel up to 4 cm; rare pumice; subrounded; moist.	463-468.8	6347.8-6342.0
	As above; with large dacite clasts, dark gray, approximately 10 mm, frequent feldspar phenocrysts.	468.8-469.9	6342.0-6340.9
	No recovery and/or core sampled. No core available for examination.	469.9-493	6340.9-6317.8
Tb4, Cerros del Rio Basalt	Basalt, medium light gray (N6), highly vesicular. Aphanitic groundmass, 2% olivine phenocrysts; moist in sample tube. At 496 ft bgs, large, single white crystal growth; at 497.5 ft bgs, near-horizontal fracture with clay-lined aperature. **Note: The base of the Puye Formation (Tpf) and the contact with the underlying Cerros del Rio Basalt (Tb4) is interpreted to be at 493 ft bgs.**	493-498.2	6317.8-6312.6

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Tb4, Cerros del Rio Basalt	Basalt; medium light gray (N5), intermixing of cuttings with overlying formation. WR (whole rock, unsieved): basalt chips coated with very pale orange (10YR, 8/2) fines. 10+F (i.e. plus No. 10 sieve-size fraction): 50% basalt, vesicular, frequently oxidized/altered pit linings, up to 1.5 cm, subangular to subrounded; 50% intermediate composition volcanic clasts, hornblende dacite frequent, up to 1.5 cm, subangular to subrounded, probable contaminant from Tpf. 35+F(i.e. plus No. 35 sieve-size fraction): very poor returns. **Note: from 498.2 ft bgs to 720 ft bgs, lithologic description generated from drill cuttings.**	498.2-500	6312.6-6310.8
	Basalt, medium gray (N5) to medium dark gray (N4), vesicular. WR: 90% fragments of basalt with minor siltstone and fines. 10+F: 95% basalt chips, vesicular, medium gray, 1-2% olivine phenocyst, minor clay lining of pits, slightly granular texture; 1-2% siltstone fragments; 1-2% white, vitric pumices; 1-2% lithics, up to 2 cm, angular to subrounded. 35+F: finer fraction as described for 10+F, plus 5-10% felsic crystals, occasional faceted surface.	500-510	6310.8-6300.8
	Basalt; brownish gray (5YR 4/1) to grayish red (10R 4/2), massive to vesicular. 10+F: basalt chips, grayish red to brownish gray, alteration of vesicules decreasing across interval, moderate reddish brown (10R 4/6) staining and vesicular basalt predominant from 515-520 ft bgs. 35+F: finer fraction as described for 10+F with 2-5% felsic crystals.	510-530	6300.8-6280.8
	Basalt; brownish gray (5YR 4/1), massive with minor vesicles; WR: basalt chips with trace fines coating. 10+F basalt chips, up to 1 cm, broken fragments, massive, trace vesicles, minor alteration, slightly granular texture, 1-2% olivine phenocrysts. 35+F finer fraction as described for 10+F, plus 2-5% felsic crystals.	530-550	6280.8-6260.8
	Basalt, as above, slight color change to medium light gray (N6).	550-560	6260.8-6250.8
	Basalt; medium dark gray (N4) to grayish black (N2), minor alteration to grayish olivine green (5GY 3/2), massive. 10+F: basalt, massive, minor alteration, fragments up to 2 cm, angular. 35+F: as for 10+F, finer fraction.	560-570	6250.8-6240.8
	Poor, intermixed returns.	570-575	6240.8-6235.8
	Basalt, medium gray (N5), massive. 10+F: basalt chips up to 1.5 cm, angular, 1-2% olivine (green to reddish brown) phenocrysts, microcrystalline (granular texture) to aphanitic; trace alteration; trace clay fragments beginning at 590 ft bgs. 35+F: finer fraction as described for 10+F, plus minor pumice and very fine felsic fragments.	575-600	6235.8-6210.8

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Tb4, Cerros del Rio Basalt	Basalt, medium gray (N5), massive. 10+F: basalt fragments up to 2 cm, angular, granular to aphanitic texture, 1-2% olivine (green to reddish brown) phenocrysts; trace (2-3%) sandstone/clay fragments, lamination present, minor alteration of fragments. 35+F: finer fraction as described for 10+F.	600-610	6210.8-6200.8
	Basalt with mixed returns, including pumice, felsic crystals; predominantly medium dark gray (N4), massive to vesicular basalt. 10+F: basalt, massive, slightly granular, gray fragments approximately 65% decreasing to 40% across interval, 1-2% olivine phenocrysts; vesicular, reddish brown fragments approximately 35% increasing to 50% across interval, frequently altered, clay lined pits; 0-5% pumice, white, vitric; 1-5% sandstone/clay fragments; trace lithics (subrounded). 35+F: 35-40% felsic crystals decreasing to trace at 620 ft bgs, fine grain-size; finer fraction as described for 10+F.	610-625	6200.8-6185.8
	Basalt; grayish black (N2) to very dusky red (10R 2/2), massive and vesicular. 10+F: basalt, massive and vesicular fragments, 1-2% olivine phenocrysts, trace clay fragments. 35+F: finer fraction as described for 10+F.	625-630	6185.8-6180.8
	Poor returns - similar returns to 610-625 feet interval.	630-635	6180.8-6175.8
	Basalt, brownish gray (5YR 4/1), massive. 10+F: basalt, massive, slightly vesicular, 1-2% dark reddish brown olivine phenocrysts, slightly granular texture. 35+F: finer fraction as described for 10+F; plus 2-5% felsic, occasional faceted surface; trace clay fragments/pumice.	635-650	6175.8-6160.8
	Basalt with minor returns of felsic crystals, silt/clay and pumice fragments; basalt, dark gray (N3), massive, minor vesicles. 10+F: 98% basalt fragments, massive with minor vesicles, 1-2% dark reddish brown to green olivine phenocrysts, occasional clay infill of pits and lining of surfaces; 2% clay fragments and vitric pumices; up to 1 cm, angular. 35+F: 10-25% felsic crystals, occasional faceted surfaces; 75% basalt as described for 10+F.	650-665	6160.8-6145.8
	Basalt with minor returns of felsic crystals, silt/clay and pumice fragments; basalt, black (N1) to dark gray (N3); massive to weakly vesicular; fresh, clean appearance. 10+F: basalt, massive to weakly vesicular, minor clay lining on fragments, dark gray to black, very fine grained groundmass, 2-3% phenocrysts, including olivine, dark gray to dark reddish brown; 5-10% clay fragments. 35+F: finer fraction as described for 10+F with minor free felsic crystals.	665-680	6145.8-6130.8

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Tb4, Cerros del Rio Basalt	Basalt with minor fines, medium dark gray (N3). WR: massive basalt with trace yellowish gray fines. 10+F: basalt fragments, up to 2 cm, massive with 0-2% altered vesicles, aphanitic, 1-2% phenocrysts, olivine noted; 2-5% clay fragments; trace free felsic crystals. 35+F: finer fractions as described for 10+F, 60-70% basalt, 15-20% clay fragments, 10-15% free felsic crystals, occasional faceted surface.	680-695	6130.8-6115.8
	Basalt with minor fines, medium dark gray (N3). WR: massive basalt with trace yellowish gray (5Y 8/1) fines. 10+F: basalt fragments, up to 2 cm, massive, aphanitic, 1% olivine phenocrysts; 2-5% clay fragments; free felsic crystal fragments at 695-700 ft bgs. 35+F: variable percentages of free felsic crystals (occasional faceted surface), basalt chips, and clay fragments.	695-710	6115.8-6100.8
	Basalt, medium dark gray (N3). WR: massive and vesicular fragments with rare fines. 10+F: 98% basalt, massive fragments up to 1.5 cm, microcrystalline to aphanitic, 1-2% olivine phenocrysts; 2% vesicular basalt, aphanitic, clay lining; trace lithic clast - likely displaced. 35+F: 65-80% basalt chips; 10-15% clay fragments; 30-35% felsic crystals, occasional faceted surface.	710-720	6100.8-6090.8
	TOTAL BOREHOLE DEPTH (TD) IS AT 720 FT BGS.		

NOTES:

Descriptions presented in this lithologic log are primarily based on observations made during visual examination of drill core and cuttings. From 0- 498.2 ft bgs, lithologic description was generated from drill core. Drill cuttings, collected on 5 foot intervals, were used from 498.2 ft to 720 ft bgs. Unrecovered and/or sampled core in sections of less than 5 ft are not noted unless relevant to lithologic description.

Stratigraphic contacts are based on available information from review of drill core and limited geophysical logs. There is general agreement between this borehole log and the geophysics report.

Descriptions of drill chips and drill core from sedimentary units such as the Quaternary Alluvium, Cerro Toledo Interval and the Puye Formation utilized principles outlined in *Petrology of Sedimentary Rocks* by Robert L. Folk. Color Descriptions were determined using The Geological Society of America, Rock-Color Chart.

Cuttings were collected at nominal 5 or 10-ft intervals and divided into three sample splits: (1) unsieved, or whole rock (WR), sample; (2) 10+F sieved fraction (No. 10 sieve equivalent to 2.0 mm); and (3) 35+F sieved fraction (No. 35 sieve equivalent to 0.5 mm). When cuttings were overall finer grained, then cuttings were divided into a 35+F sieved fraction and a 60+F sieved fraction.

Fractures were visually inspected for an approximate orientation. The angle of the fracture surface is approximated from vertical.

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

REFERENCES:

Folk, Robert L., 1980, *Petrology of Sedimentary Rocks*, Hemphill Publishing Company.

The Geological Society of America, 1991, Rock-Color Chart.

Appendix C

Aquifer Test Report

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I-6 PUMPING TEST ANALYSIS

INTRODUCTION

This section describes the analysis of constant-rate pumping tests conducted in February 2005 on intermediate well I-6, located in Mortandad Canyon, not far from R-15 and I-5. The primary objective of the analysis was to determine the hydraulic properties of the saturated sediments screened in I-6. Consistent with the protocol used in most of the R-well pumping tests, the I-6 testing incorporated an inflatable packer above the pump to minimize barometric effects and eliminate the effects of casing storage on the measured data. Packer implementation was partially successful in minimizing storage effects.

I-6 is completed with a single screen, 22 feet (ft) long, in a perched zone within the Cerros del Rio basalt a few hundred ft above the regional aquifer, between the depths of 686 and 708 ft. The perched water level lies 24 ft above the top of the well screen, at approximately 662 ft below ground surface (bgs).

The saturated zone consists of alternate layers of basalt and porous interflow breccias. According to geophysical logs, there are massive, presumably tight, basalt flows from 686 to 692 ft (top 6 ft of well screen) and 700 to 715 ft (overlapping the bottom 8 ft of well screen). The deeper basalt flow may form the perching unit at this location. The screened aquifer was considered to be the 8-ft-thick interflow zone from 692 to 700 ft between the massive basalt flows. It was expected that there were additional permeable interflow zones above the screened interval as well, but the degree of their hydraulic connection to the pumped zone was uncertain, because of the intervening basalt flow.

Testing consisted of two trial tests on February 24, two more trials on February 25 and a constant-rate pumping and recovery test conducted from February 26 to 28. The reason for the multiple trial tests was that the check valves in the drop pipe string failed following the February 24 testing. Therefore, it was necessary to remove the pumping string, replace the check valves, reinstall the pump and restart the testing process.

The first trial tests were conducted after the pump was installed on February 24. In trial 1, the well was pumped at 1.83 gpm for 69 minutes (min.) from 3:14 pm to 4:23 pm, followed by 120 min. of recovery until 6:23 pm. In trial 2, the well was pumped at multiple flow rates, averaging 1.7 gpm, for 117 min. from 6:23 pm to 8:20 pm, followed by 908 min. of recovery until packer deflation at 11:28 am on February 25.

Following confirmation that the check valves had failed, the pump was removed and reinstalled, and two additional trial tests were performed. In trial 3, the well was pumped at 1.8 gpm for 20 min. from 3:41 pm to 4:01 pm, followed by 70 min. of recovery until 5:11 pm. In trial 4, the well was pumped at 1.84 gpm for 71 min. from 5:11 pm to 6:22 pm, followed by 848 min. of recovery until initiation of the constant-rate test at 8:30 am on February 26.

The 27-hour (hr) constant-rate pumping test was begun at 8:30 am on February 26. The well was pumped at 1.94 gpm for 1620 min. until 11:30 am on February 27. Following pump shutoff, water level recovery data were recorded for 1266 min. until 8:36 am on February 28. The

extended recovery data that followed the constant-rate test and each day of trial testing also served as background data.

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 saturated zone 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 vicinity that can affect local groundwater levels, earth tides and long-term trends related to weather patterns. The background data hydrographs from the I-6 tests were compared to barometric pressure data from the area to determine if a correlation existed.

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

Subsequent pumping tests, including I-6, have utilized a *non-vented* 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 using a vented transducer, an *increase* in barometric pressure of 1 unit causes a *decrease* in recorded down-hole pressure of 0.9 units, because the water level is forced downward 0.9 units by the barometric pressure change. However, using a non-vented transducer, the total measured pressure *increases* by 0.1 units (the combination of the barometric pressure increase and the water level decrease). Thus, the resulting apparent hydrograph changes by a factor of 100 minus the barometric efficiency, and in the same direction as the barometric pressure change, rather than in the opposite direction.

Barometric pressure data were obtained from the Los Alamos National Laboratory TA-54 tower site from RRES-Meteorology and Air Quality. The TA-54 measurement location is at an elevation of 6548 ft above mean sea level (amsl), whereas the wellhead elevation was approximately 6850 ft amsl. Furthermore, the static water level in I-6 was about 662 ft bgs, making the water table elevation approximately 6188 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 I-6.

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

$$P_{WT} = P_{TA54} \exp\left[-\frac{g}{3.281R}\left(\frac{E_{16} - E_{TA54}}{T_{TA54}} + \frac{E_{WT} - E_{16}}{T_{WELL}} \right) \right],$$

where

P_{WT} = barometric pressure at the water table inside I-6
P_{TA54} = barometric pressure measured at TA-54
g = acceleration of gravity, in m/sec^2 (9.80665 m/sec^2)
R = gas constant, in J/Kg/degree Kelvin (287.04 J/Kg/degree Kelvin)
E_{I6} = land surface elevation at I-6, in feet (approximately 6850 ft)
E_{TA54} = elevation of barometric pressure measuring point at TA-54, in feet (6548 ft)
E_{WT} = elevation of the water level in I-6, in feet (6188 ft)
T_{TA54} = air temperature near TA-54, in degrees Kelvin (assigned a value of 33.4 degrees Fahrenheit, or 273.9 degrees Kelvin)
T_{WELL} = air temperature inside I-6, in degrees Kelvin (assigned a value of 56.7 degrees Fahrenheit, or 286.9 degrees Kelvin)

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

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

Early Data Response

In many low-yield pumping tests, such as those conducted in the monitoring wells on the plateau, casing storage effects dominate the early-time data, hindering the data 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 observed in pumped well at time t_c, in feet

In some instances, it is possible to eliminate casing storage effects by setting an inflatable packer above the tested screen interval prior to conducting the test. Therefore, this option has been implemented for the R-well testing program, including the I-6 pumping test.

Time-Drawdown Methods

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

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

where

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

and

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

and where

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

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

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

$$S = \frac{Tut}{2693r^2},$$

where

T = transmissivity, in gpd/ft
S = storage coefficient
Q = discharge rate, in gpm

$W(u)$ = match point value
s = match point value, in feet
u = match point value
t = match point value, in minutes

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

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

where

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

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

For small radius values (e.g., corresponding to borehole radii), u is less than 0.05 at very early pumping times and, therefore, is less than 0.05 for nearly all measured drawdown values. Thus, for pumped wells, the Cooper-Jacob equation usually can be considered a valid approximation of the Theis equation. (Note: an exception to this can occur when the transmissivity is exceedingly low. If the transmissivity is sufficiently small, some of the very early time measurements may not meet the u-value criterion, even in the pumped well.)

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

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

where

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

The Neuman (1974) method for a partially penetrating well in an unconfined aquifer also was applied to the drawdown data to account for partial penetration effects. This analysis was

performed to see if the results were consistent with other analyses. The Neuman equation expresses drawdown in a partially penetrating well in an unconfined aquifer as follows:

$$s = \frac{Q}{4\pi T}\int_0^\infty 4yJ_0\left(y\sqrt{\beta}\right)\left[u_0(y)+\sum_{n=1}^{\infty}u_n(y)\right]dy,$$

where

$$\beta = \frac{r^2K_z}{b^2K_r}$$

$$\sigma = \frac{S}{S_y}$$

$$u_0(y) = \frac{\left\{1-\exp\left[-t_s\beta\left(y^2-\gamma_0^2\right)\right]\right\}\left\{\sinh\left(\gamma_0 z_{2D}\right)-\sinh\left(\gamma_0 z_{1D}\right)\right\}}{\left\{y^2+(1+\sigma)\gamma_0^2-\left(y^2-\gamma_0^2\right)^2/\sigma\right\}\cosh\left(\gamma_0\right)}\cdot$$

$$\frac{\sinh\left[\gamma_0(1-d_D)\right]-\sinh\left[\gamma_0(1-l_D)\right]}{(z_{2D}-z_{1D})\gamma_0(l_D-d_D)\sin(\gamma_0)}$$

$$u_n(y) = \frac{\left\{1-\exp\left[-t_s\beta\left(y^2+\gamma_n^2\right)\right]\right\}\left\{\sinh\left(\gamma_n z_{2D}\right)-\sinh\left(\gamma_n z_{1D}\right)\right\}}{\left\{y^2-(1+\sigma)\gamma_n^2-\left(y^2+\gamma_n^2\right)^2/\sigma\right\}\cosh\left(\gamma_n\right)}\cdot$$

$$\frac{\sinh\left[\gamma_n(1-d_D)\right]-\sinh\left[\gamma_n(1-l_D)\right]}{(z_{2D}-z_{1D})\gamma_n(l_D-d_D)\sin(\gamma_n)}$$

The gamma terms are the roots of the following equations:

$$\sigma\gamma_0\sinh\left(\gamma_0\right)-\left(y^2-\gamma_0^2\right)\cosh\left(\gamma_0\right)=0,\gamma_0^2<y^2$$

and

$$\sigma\gamma_n\sin\left(\gamma_n\right)+\left(y^2-\gamma_n^2\right)\cos\left(\gamma_n\right)=0,(2n-1)/(\pi/2)<\gamma_n<n\pi,n>=1.$$

In these equations, the parameters are defined as follows:

b = aquifer thickness
d_D = vertical distance between top of pumping well screen and initial water table divided by the aquifer thickness
J_0 = Bessel function of first kind, zero order
K_r = horizontal hydraulic conductivity

K_z = vertical hydraulic conductivity
l_D = vertical distance between bottom of pumping well screen and initial water table divided by the aquifer thickness
r = radial distance
S = elastic storage coefficient
S_y = specific yield
t_s = dimensionless time with respect to specific storage, equal to Tt/Sr^2
t = recovery time
T = transmissivity
z_{1D} = vertical distance from bottom of aquifer to bottom of observation well screen divided by aquifer thickness
z_{2D} = vertical distance from bottom of aquifer to top of observation well screen divided by aquifer thickness

A potential advantage of the Neuman method is that it accounts for both partial penetration and vertical movement of the water table in an unconfined aquifer, as the sediments drain and re-saturate during pumping and recovery. A disadvantage of this method is that the complex equations are difficult to solve, are non-intuitive, and often lead to bizarre or impossible solutions of parameter combinations. As a consequence, it is particularly important to closely scrutinize output from the Neuman solution method.

RECOVERY METHODS

Recovery data were analyzed by the Theis Recovery Method. This is 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.

Theis curve matching also was applied to the recovery data. This was done by plotting recovery time versus feet of recovery (difference between the maximum drawdown observed at the end of the pumping test and the residual drawdown) and performing curve matching analogous to the time-drawdown method. This method of analysis is valid for early recovery time.

SLUG TEST METHODS

During the testing of I-6, water leaked out of the 1-inch (in.) drop pipe into the annulus between the drop pipe and the 4.5-in. ID well casing. It is likely that the leaks occurred through the coupling joints. However, in previous tests where this occurred, the drop pipe was found to have

a defective weld seam, allowing water to leak directly through the pipe itself, so this could have been the cause also. After test pumping, when the packer was deflated, the accumulated water above the packer was delivered to the well rapidly, similar to a slug test stress. Therefore, slug test methods were used to analyze this event in I-6.

When water levels equilibrate back toward the static level following a slug event, the observed water levels can be used to estimate a lower-bound value for transmissivity based on the rate of water level recovery. The following formula, in mixed units, can be applied to perform the calculation:

$$T = \frac{1.25}{t} \ln\frac{y_1}{y_2} \ln\frac{R}{r_w}\left(D^2 - d^2\right),$$

where

T = transmissivity, in ft^2/day
y_1, y_2 = measurements of the water level change from static conditions, in feet
t = elapsed time between measurements, in minutes
R = effective radius of influence, in feet
r_w = borehole radius, in feet (0.51 feet)
D = inside diameter of well casing, in inches (4.5 in.)
d = outside diameter of drop pipe, in inches (1.315 in.)

Both the Hvorslev (1951) method and the Bouwer & Rice (1976) method were used to estimate the lower-bound transmissivity value. In the Hvorslev method, the value of R, the effective radius of influence, is chosen based on the well and aquifer geometry. For example, in a well screened at the bottom of a thick aquifer, R is set equal to twice the well screen length. In the Bouwer & Rice method, R is determined graphically using an empirical method developed by Bouwer & Rice.

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 percent efficient. The resulting hydraulic conductivity is the value required to sustain the observed specific capacity. If the actual well is less than 100 percent efficient, it follows that the actual hydraulic conductivity would have to be greater than calculated to compensate for well inefficiency. Thus, because the efficiency is unknown, the computed hydraulic conductivity value represents a lower bound. The actual conductivity is known to be greater than or equal to the computed value.

The Cooper-Jacob equation can be rearranged and iterated to solve for the lower-bound hydraulic transmissivity as follows:

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

where all terms are as defined above and r_w represents the radius of the borehole.

To apply this formula, a storage coefficient value must be assigned. The assigned value was based on unconfined conditions, based on the observation of delayed yield phenomena, signaling drainage of the sediments above the screened interval in the I-6 test. Storage coefficient values for unconfined aquifers typically range from a few percent to 20 percent or more, with the majority of the values falling between approximately 5 and 15 percent. Thus, in the absence of site-specific storage coefficient data, a value of 0.1 is deemed to be a reasonable choice for performing the calculations for unconfined conditions. 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. A storage coefficient value of 0.1 was applied to the calculations using late time data from the I-6 27-hr constant-rate pumping test. Some specific capacity based, lower-bound transmissivity estimates were made also from early data from the slug test response mentioned above following packer deflation. For these early time analyses, an elastic storage coefficient of 0.001 was used in the calculations. This magnitude of elastic storage is typical of early time response in unconfined systems.

Note that transmissivity appears on both sides of the equation as presented above. This means that an iterative solution must be used to obtain a solution.

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

I-6 DATA ANALYSIS

This section presents the data obtained from the I-6 test pumping and the results of the analytical interpretations. Analyses were applied to the four trial pumping events and the 27-hr constant-rate pumping test.

Background Data

Figure 1 shows the apparent water level hydrograph for I-6 and the barometric pressure data recorded throughout the testing period. The graph shows that the barometric pressure fluctuations were minor, spanning just 0.2 ft. The vertical scale for the hydrograph is compressed, masking subtle groundwater pressure fluctuations, but the graph provides a sense of the water level responses during testing. Figure 2 shows a typical segment of the Figure 1 data, from late February 25 to early February 26 just before the start of the constant-rate test, with the vertical axes scaled the same for aquifer and barometric pressure. The groundwater pressure changes associated with ongoing water level recovery appeared to be unaffected by changes in barometric pressure. This implied a barometric efficiency of nearly 100 percent, consistent with the barometric efficiencies observed in most of the wells on the plateau.

The most significant observation was that, unlike the regional aquifer test results that showed rapid water level recovery back to static conditions, the perched zone water levels recovered sluggishly, falling short of the starting static water level after each pumping event. Note, however, that the apparent drop in head between the first pump installation on February 24/25 and the second pump installation on February 25/26 was exaggerated by an offset in the installation depth – the second installation was about one foot shallower. Nevertheless, the

decline in water level peaks was apparent, especially after the 27-hr constant-rate pumping test. This response suggested boundary conditions indicating a laterally limited saturated zone, rather than a really extensive one.

Trial 1 Pumping Test

Trail 1 was conducted on February 24. The well was pumped at 1.83 gpm for 69 min. from 3:14 pm to 4:23 pm. Following shutdown, recovery measurements were recorded for 120 min. until 6:23 pm.

Time-Drawdown Analysis

Figure 3 shows time-drawdown data from trial 1. Because the pump started against an empty drop pipe, the low initial head resulted in a high initial discharge rate. As the drop pipe filled, the pumping rate declined.

The initial submergence of the transducer was 26.66 ft. Nevertheless, the recorded drawdown reached nearly 32 ft. This meant that a partial vacuum (about 5 ft) was created beneath the packer. It appeared, however, that the well remained reasonably well sealed and largely free from casing and filter pack storage effects. For example, the rapid initial drawdown (30 ft in less than two min.) would not have been possible if significant casing or filter pack drainage had occurred.

However, as described below, there may have been a slow leak of vadose zone air into the filter pack when the well was drawn down. Such an occurrence would result in negligible storage response during pumping because of the low leakage rate, but once a small portion of the filter pack had drained during pumping, its presence would be obvious during recovery because the accumulated air at the top of the pack would compress like a spring when water levels rose following pump shut off.

The variable and unknown pumping rate precluded analysis of the drawdown data.

Recovery Analysis

Figure 4 shows a semilog plot of the recovery data following the trial 1 pumping. The transmissivity calculated form the graph was 48 gpd/ft. Note that the early recovery data did not fall on the straight line of best fit, implying that the u value was greater than 0.05 and that Theis curve matching should be used to solve for transmissivity.

Figure 5 shows Theis curve matching analysis of the data, revealing a transmissivity estimate of 60 gpd/ft. This is likely more accurate than the value obtained from the semilog plot.

Note on Figure 4 that at the end of the recovery, 0.4 ft of drawdown remained. This is strong evidence of a negative boundary. The negative boundary could be either a limit in the size of the saturated perched zone or, alternatively, a reduction in hydraulic conductivity some distance from the pumped well. The latter scenario is possible here, as perched zones are known to exist in both R-15 and I-5 at similar elevation, and the hydraulic conductivity of the I-5 sediments is very low.

About 30 min. into recovery, water levels dropped 0.25 ft over a 10-min. period and then rebounded (the "wiggle" in the data curve at late recovery time on Figure 4). There was no explanation for this exceedingly unusual response. No other recovery data sets showed the effect.

An interesting feature of the plot on Figure 5 is the deviation from the type curve during the first minute of recovery. This has the appearance of a very small storage effect – perhaps just a fraction of a gallon (gal.) total volume, based on the limited duration. A possible explanation could be minor antecedent drainage of a very small portion of the filter pack, allowing refilling during recovery. Because the hypothesized drained portion of the filter pack was 20 ft above the top of the screened interval, there would be a very short delay in observing its effect, consistent with the observations on Figure 5. The observed straight-line segment on the log-log plot during the first minute of recovery (from 0.3 to 0.9 min.) also was consistent with a storage phenomenon. It is only conjecture that filter pack storage caused the anomaly seen on Figure 5, but it is a reasonable hypothesis.

It is significant that the late data showed a flat slope. This suggests drainage from above – likely delayed yield associated with unconfined conditions at the top of the saturated zone.

Trial 2 Pumping Test

Trial 2 was conducted on February 24 following the trial 1 recovery. The well was pumped at multiple flow rates, ending at and averaging 1.7 gpm for 117 min. from 6:23 pm to 8:20 pm. Following shutdown, recovery measurements were recorded for 908 min. until packer deflation at 11:28 am on February 25.

Time-Drawdown Analysis

Figure 6 shows time-drawdown data from trial 2. The multiple discharge rates precluded analysis of the data. Note also that the very early data showed evidence of a check valve leak. Antecedent drainage of a small portion of the drop pipe, through a leaky check valve or leaky coupling joints, would have allowed the pump to start against reduced head briefly, resulting in a momentary higher pumping rate and greater drawdown.

Recovery Analysis

Figure 7 shows the recovery data following the trial 2 pumping. The transmissivity calculated form the graph was 52 gpd/ft. Note that the early recovery data did not fall on the straight line of best fit, implying that the u value was greater than 0.05.

Figure 8 shows Theis curve matching analysis of the data, revealing a transmissivity estimate of 68 gpd/ft. This is likely more accurate than the value obtained from the semi log plot.

Note that the last measured water level was 0.5 ft below the static level even after recovering overnight. This provided additional evidence of the presence of a negative boundary.

The same very brief storage response observed in trial 1 was seen on Figure 8. Finally, the flat slope of the late data again suggested delayed yield associated with unconfined conditions.

Slug Event Caused By Packer Deflation

Following trial 2 recovery, it was discovered that the check valves had failed allowing drainage of the drop pipe. Therefore, the decision was made to remove the pump, replace the check valves and redo the trial tests. When the packer was deflated, the head above the transducer increased by more than 35 ft, indicating that a substantial volume of water had leaked from the drop pipe into the annulus above the packer, likely through defective threads in the drop pipe. Deflating the packer allowed the trapped water to flow down the well and into the perched zone.

Figure 9 shows the hydraulic response measured following packer deflation. Data from this event were used to estimate a lower-bound transmissivity using the specific capacity method. This was done by observing the rate of drainage of the well casing for a given head buildup. From this it was possible to calculate a specific capacity to use in estimating transmissivity.

For example, between 1 and 1.1 min. following packer deflation, 0.414 gal. of water drained into the aquifer with an average head buildup of 31.52 ft. This made the flow rate into the aquifer 4.14 gpm and the specific capacity 4.14/31.52 = 0.131 gpm/ft at an average injection time of 1.05 min.. Assuming a storage coefficient value of 0.001 and applying the Cooper-Jacob equation yielded a lower-bound transmissivity estimate of 59 gpd/ft. Similarly, at 2.05 min. of injection, the inflow rate was 3.23 gpm with 26.65 ft of head buildup, for a specific capacity of 0.121 gpm/ft. The corresponding lower bound transmissivity estimate was 65 gpd/ft. These values were consistent with the pumping test transmissivity estimates.

Trial 3 Pumping Test

Trial 3 was conducted on February 25. The well was pumped at 1.8 gpm for 20 min. from 3:41 pm to 4:01 pm. Following shutdown, recovery measurements were recorded for 70 min. until 5:11 pm.

Drawdown Analysis

Figure 10 shows time-drawdown data from trial 3. Because the pump started against an empty drop pipe, the low initial head resulted in a high initial discharge rate. As the drop pipe filled, the pumping rate declined.

The initial submergence of the transducer was 25.75 ft. Nevertheless, the recorded drawdown reached nearly 34 ft. This meant that a partial vacuum (about 8 ft) was created beneath the packer. Again, it appeared that the well remained reasonably well sealed and largely free from casing and filter pack storage effects. For example, the rapid initial drawdown (33 ft in less that two min.) would not have been possible if significant casing or filter pack drainage had occurred.

Because of the variable pumping rate, the data were not analyzed.

Recovery Analysis

Figure 11 shows the recovery data following the trial 3 pumping. The transmissivity calculated from the graph was 49 gpd/ft. Again, the early recovery data did not fall on the straight line of best fit, implying that the u value was greater than 0.05.

Figure 12 shows Theis curve matching analysis of the data, revealing a transmissivity estimate of 64 gpd/ft. This is likely more accurate than the value obtained from the semilog plot.

As in previous recovery plots, the data showed the momentary storage effect (Figure 12) and sustained drawdown (0.75 ft) at the end of recovery (Figure 11), confirming the negative boundary.

Trial 4 Pumping Test

Trial 4 was conducted on February 25 following the trial 3 recovery. The well was pumped at 1.84 gpm for 71 min. from 5:11 pm to 6:22 pm. Following shutdown, recovery measurements were recorded for 848 min. until 8:30 am on February 26.

Time-Drawdown Analysis

Figure 13 shows time-drawdown data from trial 4. The Cooper-Jacob analysis yielded a transmissivity of 62 gpd/ft. Figure 14 shows the results of the Theis analysis yielding a transmissivity value of 60 gpd/ft. There was negligible apparent storage response in the data as would be expected if a slow leak had been the cause of the eventual storage responses observed in the recovery data. Finally, the effects of delayed yield were apparent in the flattening of the data curve at late time.

Recovery Analysis

Figure 15 shows the recovery data following the trial 4 pumping. The transmissivity calculated form the graph was 51 gpd/ft. As in the other trial tests, the early recovery data did not fall on the straight line of best fit, implying that the u value was greater than 0.05.

Figure 16 shows Theis curve matching analysis of the data, revealing a transmissivity estimate of 68 gpd/ft. This is likely more accurate than the value obtained from the semilog plot.

Both the momentary storage effect and the late flat slope associated with delayed yield from above were apparent in the data plots on Figures 15 and 16. The final water level remained 0.75 ft below the starting level, even after nearly a day of recovery, consistent with negative boundary conditions.

27-Hour Constant-Rate Pumping Test

The 27-hr constant-rate pumping test was begun at 8:30 am on February 26. The well was pumped at 1.94 gpm for 1620 min. until 11:30 am the next day. Following shutdown, recovery measurements were recorded for 1266 min. until 8:36 am on February 28.

Time-Drawdown Data

Figures 17 and 18 show semilog and log-log plots of time-drawdown data from the 27-hr constant-rate pumping test. Note that the recorded time values were adjusted by an offset of 0.8 seconds before plotting to account for the elapsed time between the last background water level

measurement and pump startup. (The offset value was determined by adjusting it until the Theis type curve provided a good match to the data.)

The calculated transmissivity values from the early data were 74 gpd/ft and 65 gpd/ft from the two graphs. Note that there was no evidence of a storage response in the early drawdown data, consistent with what was observed in the trial 4 drawdown data.

The data showed the flattening associated with delayed yield, similar to the trial tests. In addition, the test was long enough to show the resumption of a steep slope at late time, once drainage associated with delayed yield was complete. Figure 19 shows an expanded-scale graph of the late data from which a transmissivity of 68 gpd/ft was calculated. Although this value agreed with other results, this was probably fortuitous and not an independent measurement of transmissivity. The late data would be expected to reflect the entire transmissivity of the saturated zone – both the screened portion and the interval above the well screen. Thus, the late-time slope should have been flatter, yielding a greater transmissivity. It is likely that the slope was affected by the suspected boundary conditions and that the compensating factors of increased transmissivity (of the entire saturated thickness) and the negative boundary resulted in a slope that was coincidentally similar to the early-time slope.

The Neuman method for unconfined aquifers was applied to the data, as shown on Figure 20. The resulting hydraulic conductivity value of 8 gpd/ft^2 was consistent with previous results. Multiplying this value by the effective screened interflow thickness of 8 ft yielded a transmissivity of 64 gpd/ft, consistent with other results. Note that at late time, the Neuman type curve predicted a flatter slope than that of the actual data trace. This confirmed the idea that the late time slope was affected simultaneously by both the transmissivity of the entire saturated thickness and boundary conditions.

Unusual transient drawdown fluctuations were seen in the late drawdown data. They showed up most clearly on Figure 17 as water level "spikes". The expanded-scale plot on Figure 21 shows these anomalies more prominently.

Pumping rate measurements showed that during the first peak there had been no change in discharge rate from the well to account for the temporary drawdown reduction. A possible explanation for this response was that the pumping water level in the aquifer was pulled low enough to relieve a portion of the partial vacuum in the borehole above the well screen, allowing drainage of an aquifer feature such as a fracture. For example, a submerged fracture filled with water would be under a vacuum and remain filled but, once exposed to vadose zone air, could possibly drain. The magnitude and duration of the water level peak were consistent with an influx of just a few gallons of water, so a minor aquifer feature could have accounted for the unusual response. While the actual cause of this anomaly was not completely clear, it was *not* attributable to a discharge rate fluctuation.

During the second peak, on the other hand, the discharge rate declined by two to three percent for a little less than 30 min., based on flow rate measurements made during the test. The drawdown response observed on the graph was consistent with this and, thus, resulted directly from the change in discharge rate. The mystery, however, is what caused the rate reduction. There was no apparent explanation for the observed change in production rate.

Recovery Analysis

Figure 22 shows a graph of the recovery data following the 27-hr constant-rate pumping test. The data are unusual in two respects. First, the storage response was more pronounced than those observed in the short trial tests. It is reasonable to assume that the extended pumping time allowed more filter pack or aquifer drainage to occur, thus creating a larger storage effect in the recovery data set. Second, there appeared to be a secondary storage effect in the data set. This phenomenon may be related to the refilling of previously drained aquifer features, such as fractures. Overall, the recovery data trace was much more "lumpy" than typical recovery graphs. This was ironic because, in most tests, the recovery curve is smoother and easier to analyze than the drawdown curve. In this test, however, the drawdown curve was more usable.

To illustrate the more pronounced storage response in the recovery data, Figure 23 provides a comparison of the recovery from the 27-hr test to recovery from trials 3 and 4. (All data were corrected mathematically to the same pumping rate for comparison purposes.) The trial test recovery curves were similar, deviating only slightly from the Theis type curve, as was shown on earlier plots. The 27-hr test recovery curve, on the other hand, showed a significant departure. Theoretically, all three curves should coincide.

Figure 24 shows another revealing comparison. The recovery data were converted to "calculated recovery" by extrapolating the original drawdown curve and computing the difference between the extrapolated drawdown and the residual drawdown. The calculated recovery data were plotted on the same graph as the original drawdown data. Theoretically, the two curves should coincide. Clearly, however, the drawdown trace showed no storage effect, while the calculated recovery curve showed significant storage effects. Note that after about 40 min. the two curves did nearly coincide.

A final observation (Figure 22) was that after recovery overnight, the water level remained 1.74 ft below the static water level, or about one foot lower than the recovered level following trial 4. This reinforced the idea of significant boundary conditions.

Slug Event Caused By Packer Deflation

When the packer was deflated at the conclusion of testing, the head in the well rose more than 66 ft, similar to the response observed following the first packer deflation event. As stated above, the leakage was likely attributable to defective threads in the drop pipe used to run the pump.

Figure 25 shows the measured hydraulic response. The early water level decay data were used to estimate lower-bound transmissivity values as was done previously.

The data showed a flow rate (casing drainage rate) into the aquifer of 6.63 gpm with 60.83 ft of head buildup after 1.05 min. of flow. This information yielded a lower-bound transmissivity value of 46 gpd/ft. One minute later, the data showed an injection rate of 5.32 gpm with 52.93 ft of head buildup after 2.05 min., yielding a lower-bound transmissivity of 51 gpd/ft.

The overall data response was evaluated using both the Hvorslev method and the Bouwer & Rice method as shown in Figure 26. These analyses yielded lower-bound transmissivity values of 73 gpd/ft and 42 gpd/ft, respectively. It should be pointed out that the Hvorslev procedure is based

on steady state pumping (i.e., long-term) and, as a result, overestimates the effective radius of influence, which, in turn, leads to an overestimate of transmissivity. This idea helps explain the high value of 73 gpd/ft obtained from this method.

Overall Average Hydraulic Properties

The drawdown and recovery analyses using Theis curve matching yielded transmissivity values ranging from 60 to 68 gpd/ft and averaging 64 gpd/ft. Assuming an 8-ft-thick interflow interval made the hydraulic conductivity 8.0 gpd/ft^2, or about 1.1 ft per day. The Neuman unconfined analysis yielded nearly identical values.

Specific Capacity Data

The observed specific capacity from I-6 was used to estimate lower-bound transmissivity values for the production zone for comparison to values obtained using conventional analysis techniques. After 27 hrs of pumping the well at 1.94 gpm, the observed drawdown was 24.54 ft. Other input values used in the calculation included a storage coefficient of 0.1 and a borehole radius of 0.51 ft. The resulting lower-bound transmissivity value obtained using the Cooper-Jacob equation was 60 gpd/ft.

As discussed above, short-term specific capacity data from the slug events following packer deflation led to computed lower-bound transmissivity values ranging from 46 to 65 gpd/ft. Finally, the slug test analyses gave lower-bound values of 42 and 73 gpd/ft (with the latter value known to be the least realistic estimate).

In general, these results were consistent with the conventional test analyses.

SUMMARY

The following information summarizes the results of the pumping and recovery tests on I-6:

1. Four short-duration trial tests and one 27-hr constant-rate pumping test were conducted on I-6.
2. The lack of clear response of formation pressure (apparent hydrograph) to changes in barometric pressure implied a barometric efficiency of nearly 100 percent, consistent with what has been observed in most of the wells on the plateau.
3. Casing storage effects were eliminated from the drawdown data sets. However, it appeared that a slow drainage event must have occurred during pumping, because the water level rebound following pump shutoff was storage-affected. The effect was slight in the short tests, but significant in the 27-hr test.
4. The transmissivity values calculated for the 8-ft-thick interflow zone were consistent, falling within a narrow range and averaging 64 gpd/ft. The resulting average hydraulic conductivity was 8.0 gpd/ft^2, or 1.1 ft per day.
5. Lower-bound transmissivity values obtained from specific capacity data and slug test responses averaged 57 gpd/ft, consistent with the transmissivity values obtained by conventional analysis.

6. The data showed the effects of delayed yield associated with unconfined conditions.
7. Water levels consistently failed to recover to the starting static water level after each pumping event, indicating negative boundary conditions, that is, a lateral limit to the perched zone or a permeability reduction away from the well (or both). The latter scenario is likely, because perched conditions are known to extend to R-15 and I-5 and the sediments in the I-5 perched zone are very tight.
8. The 27-hr pumping test showed unusual drainage-related responses that were probably related to saturated zone heterogeneities. It was possible that the drainage and refilling of discrete fractures or pockets of sediment caused the observed drawdown and recovery anomalies.

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Figure 1. Comparison of I-6 Apparent Hydrograph and TA-54 Adjusted Barometric Pressure

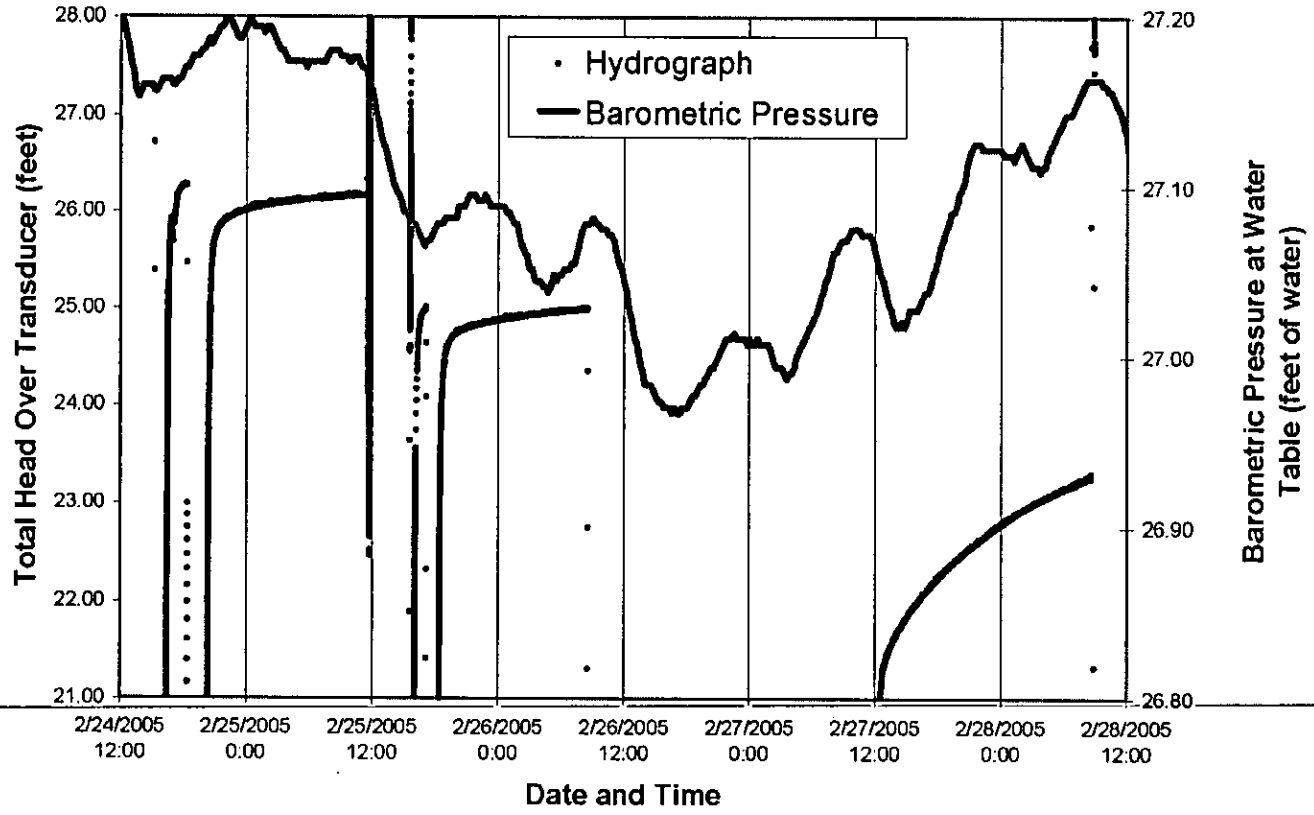


Figure 2. Pretest Comparison of I-6 Apparent Hydrograph and TA-54 Adjusted Barometric Pressure

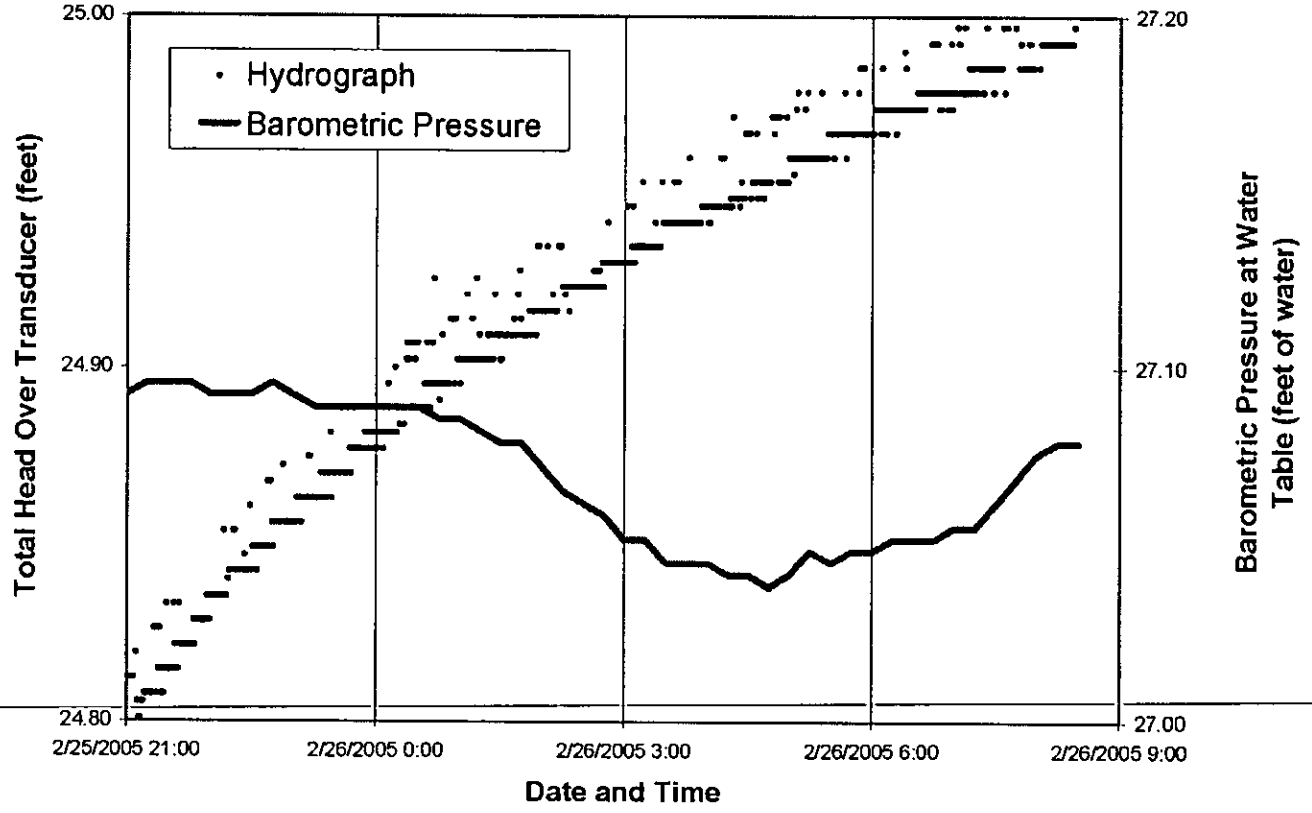


Figure 3. Well I-6 Trial 1 Drawdown

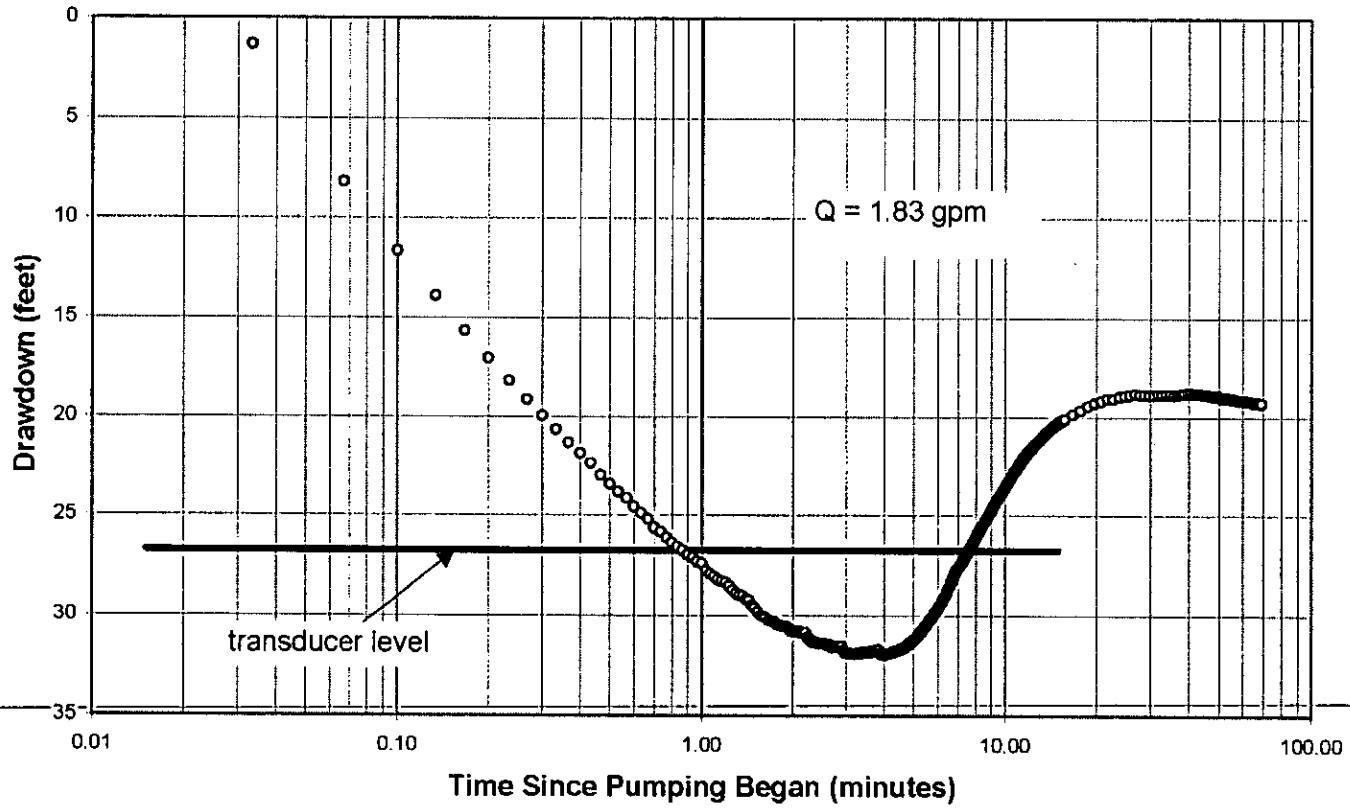


Figure 4. Well I-6 Trial 1 Recovery

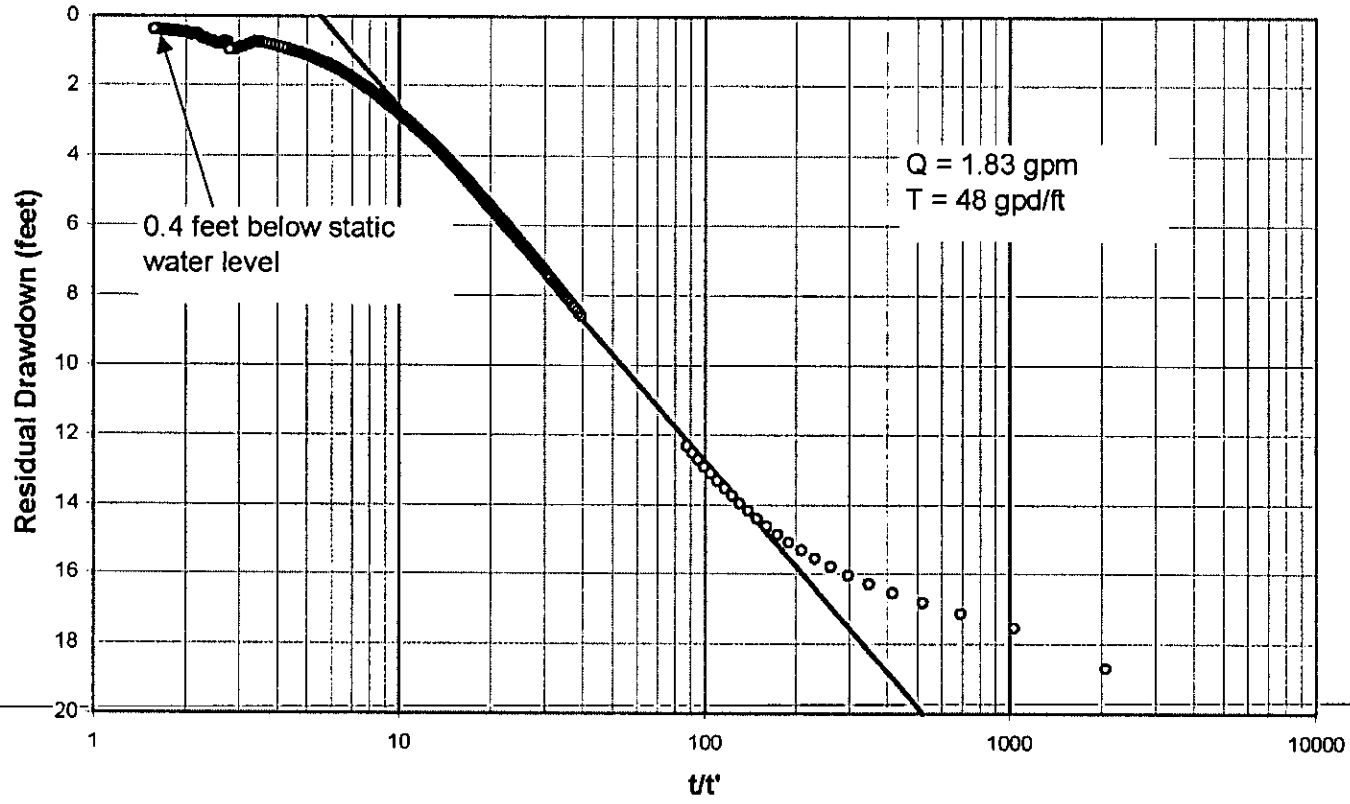


Figure 5. Well I-6 Trial 1 Recovery - Theis Analysis

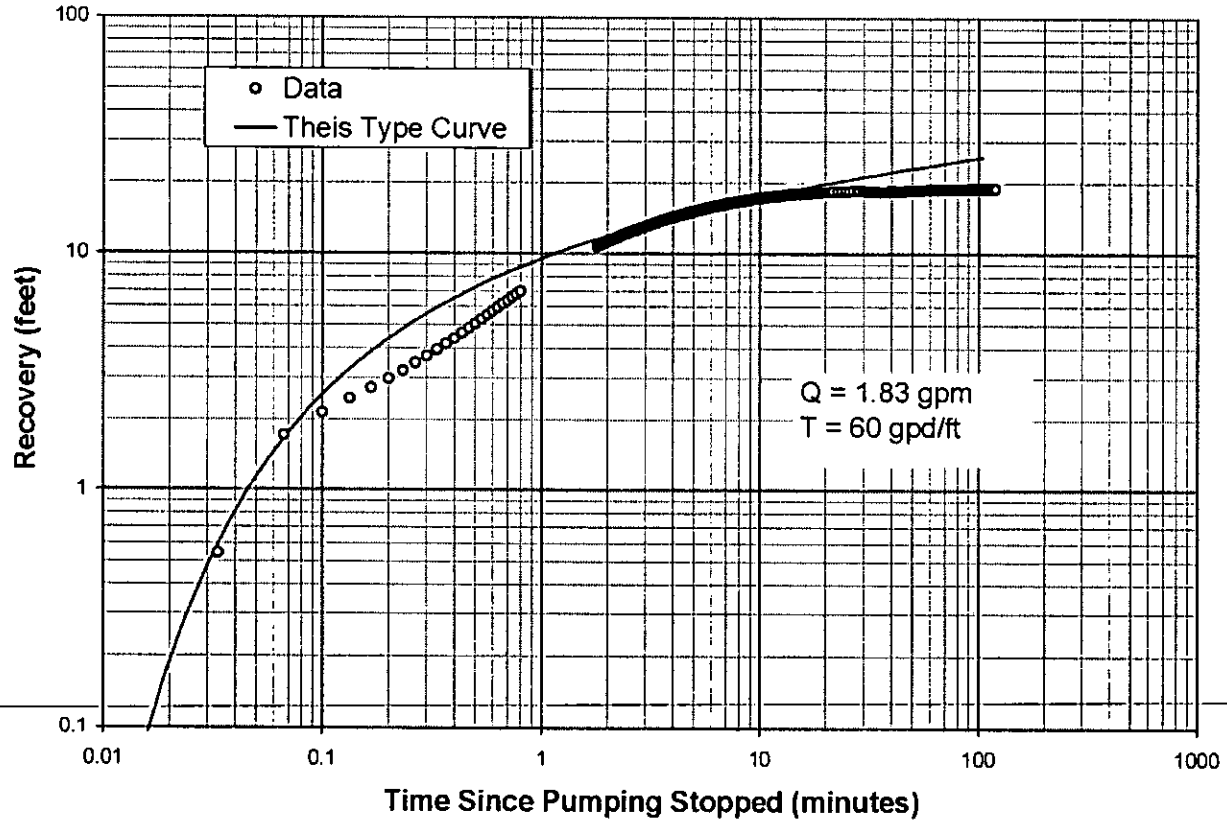


Figure 6. Well I-6 Trial 2 Drawdown

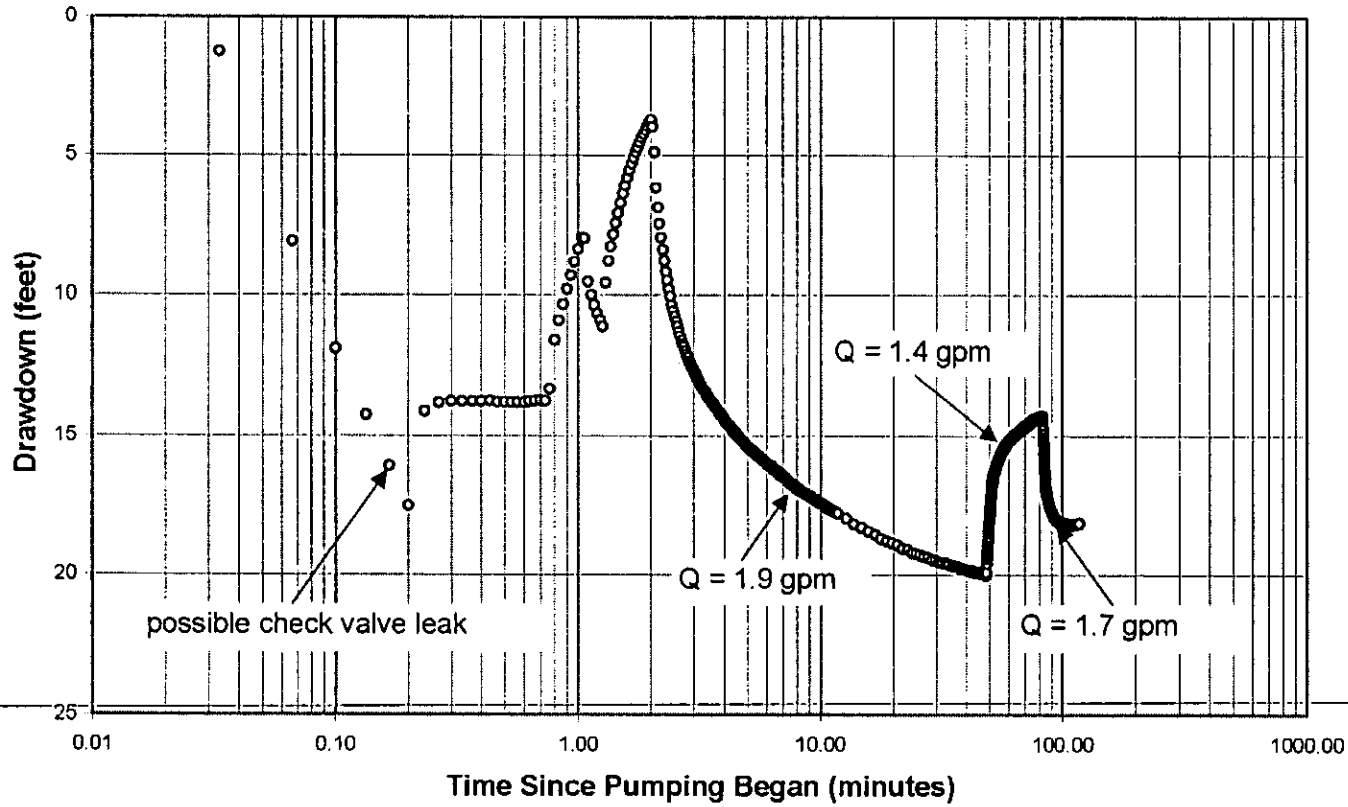


Figure 7. Well I-6 Trial 2 Recovery

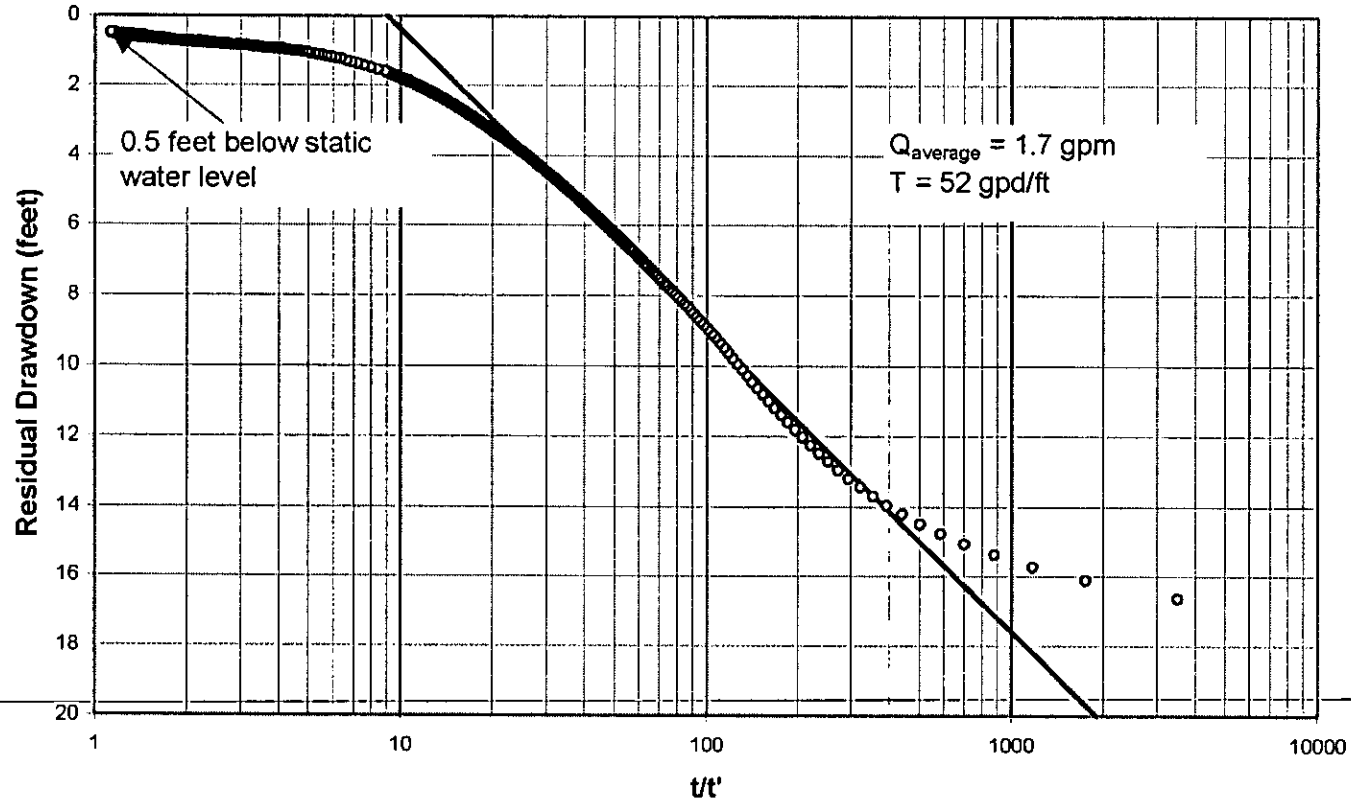


Figure 8. Well I-6 Trial 2 Recovery - Theis Analysis

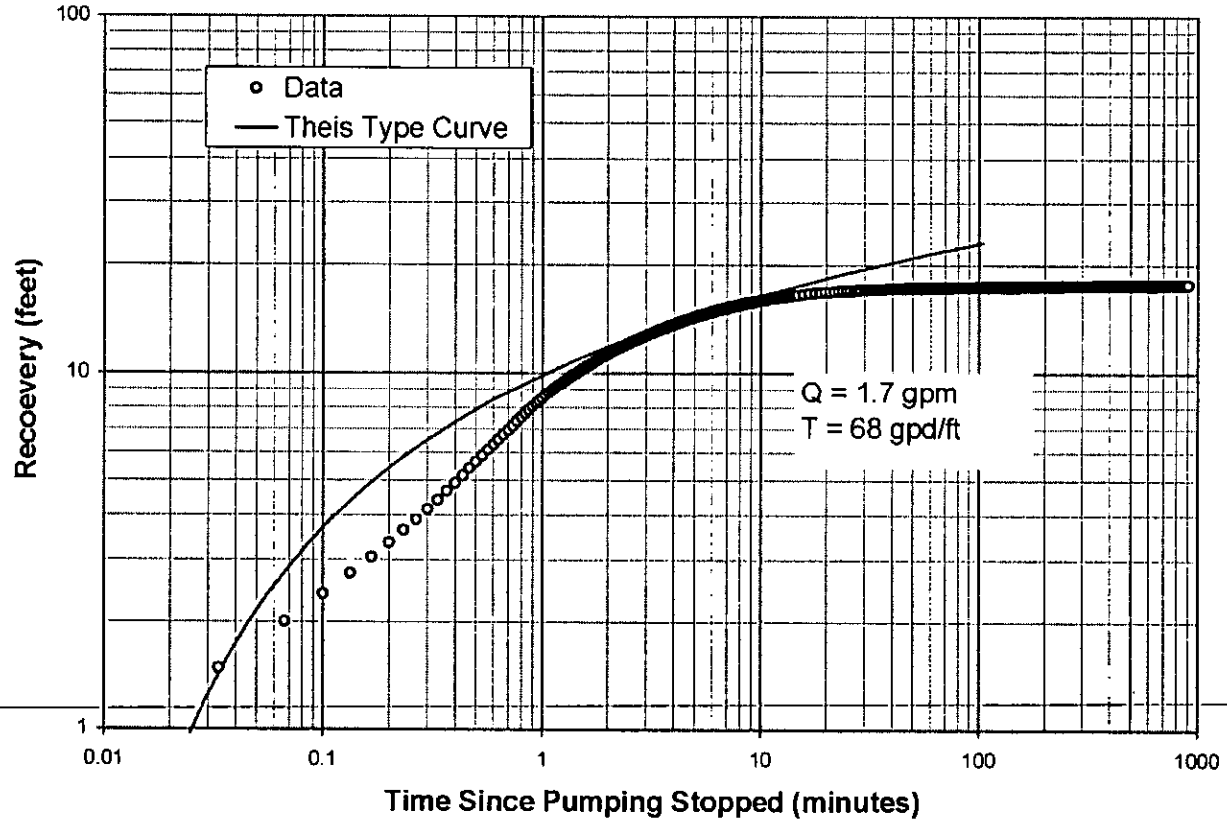


Figure 9. Packer Deflation Following Trial 2 Recovery

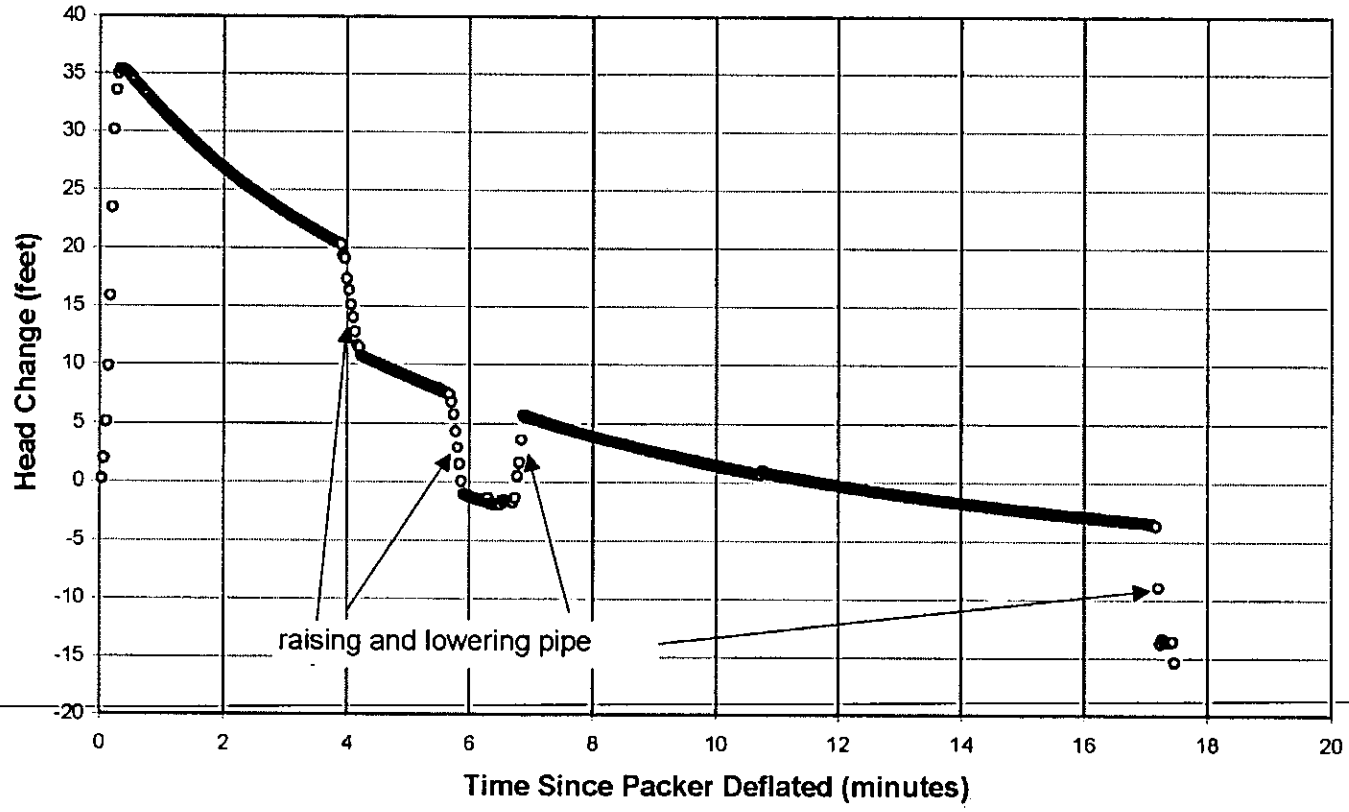


Figure 10. Well I-6 Trial 3 Drawdown

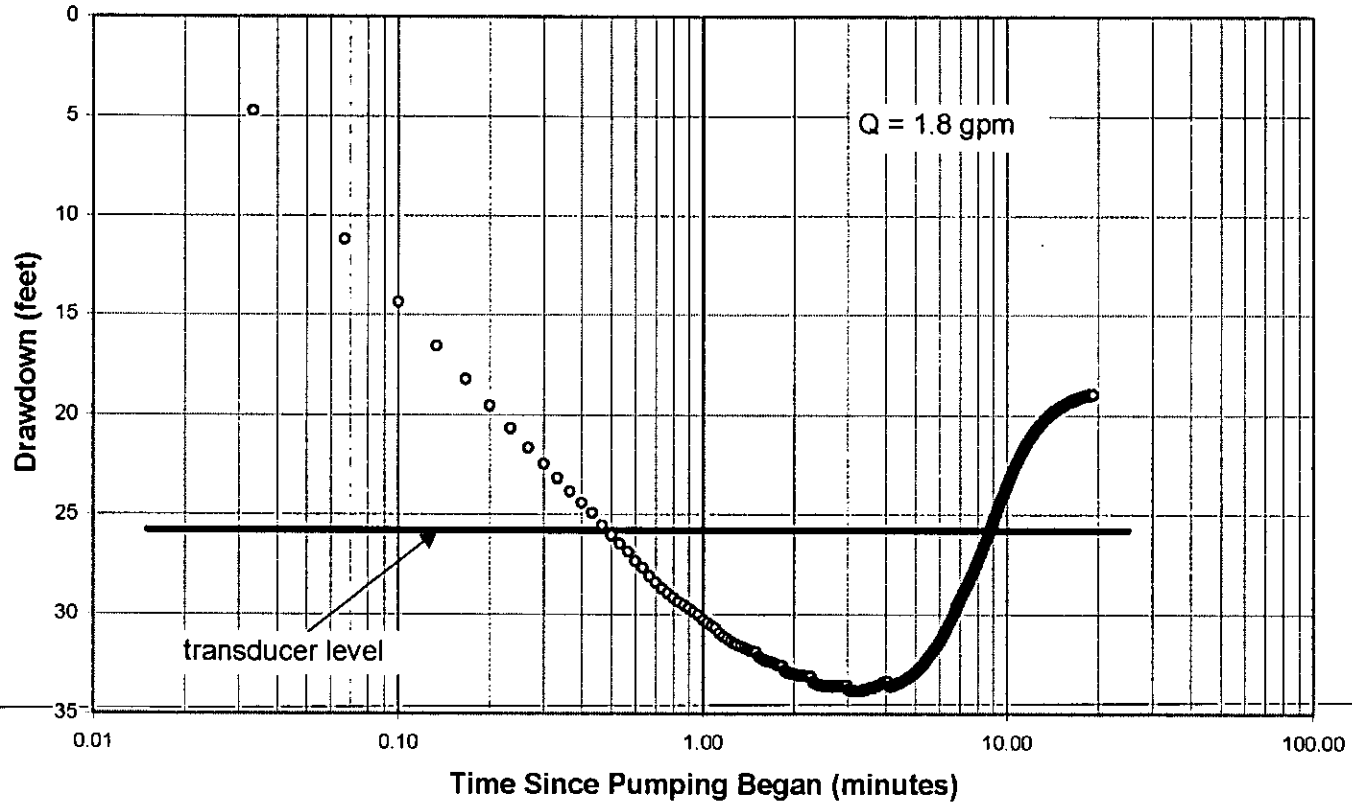


Figure 11. Well I-6 Trial 3 Recovery

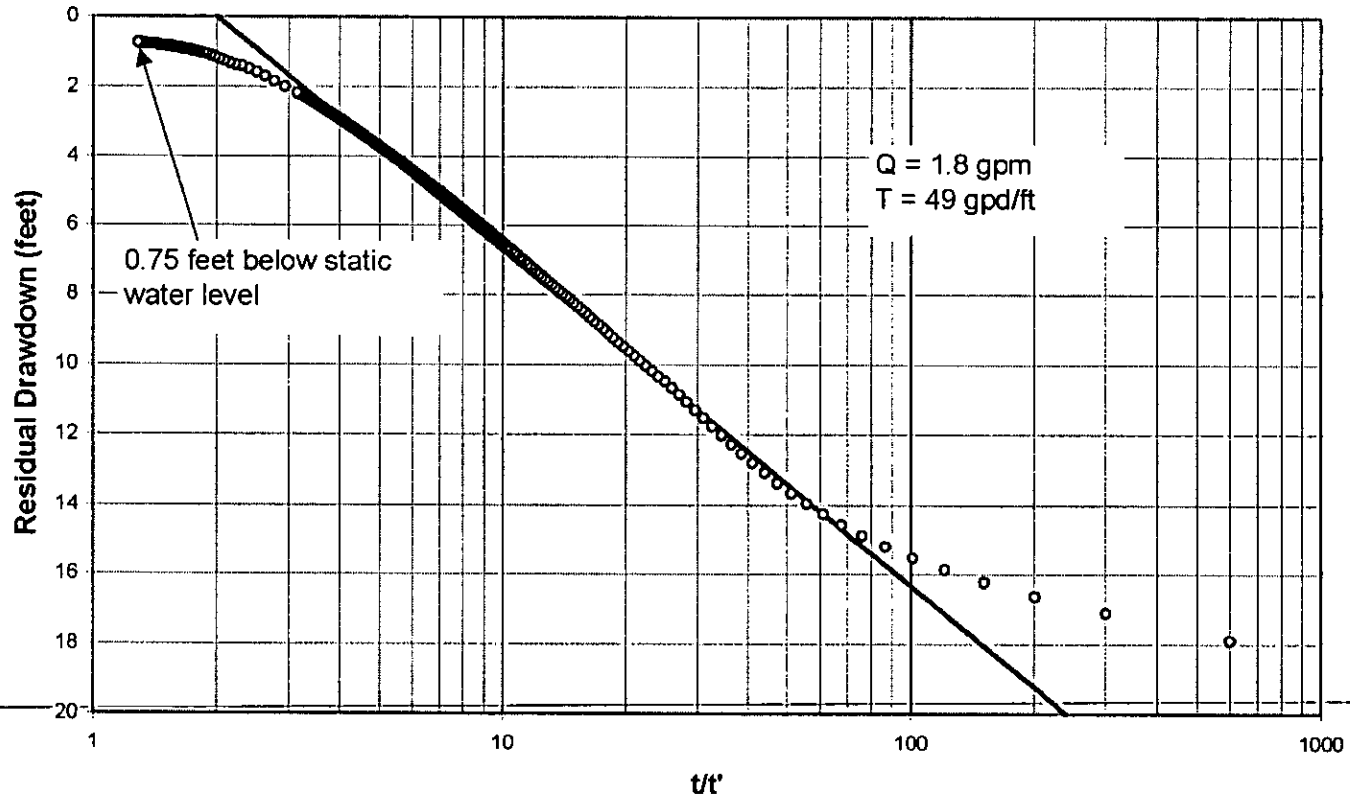


Figure 12. Well I-6 Trial 3 Recovery - Theis Analysis

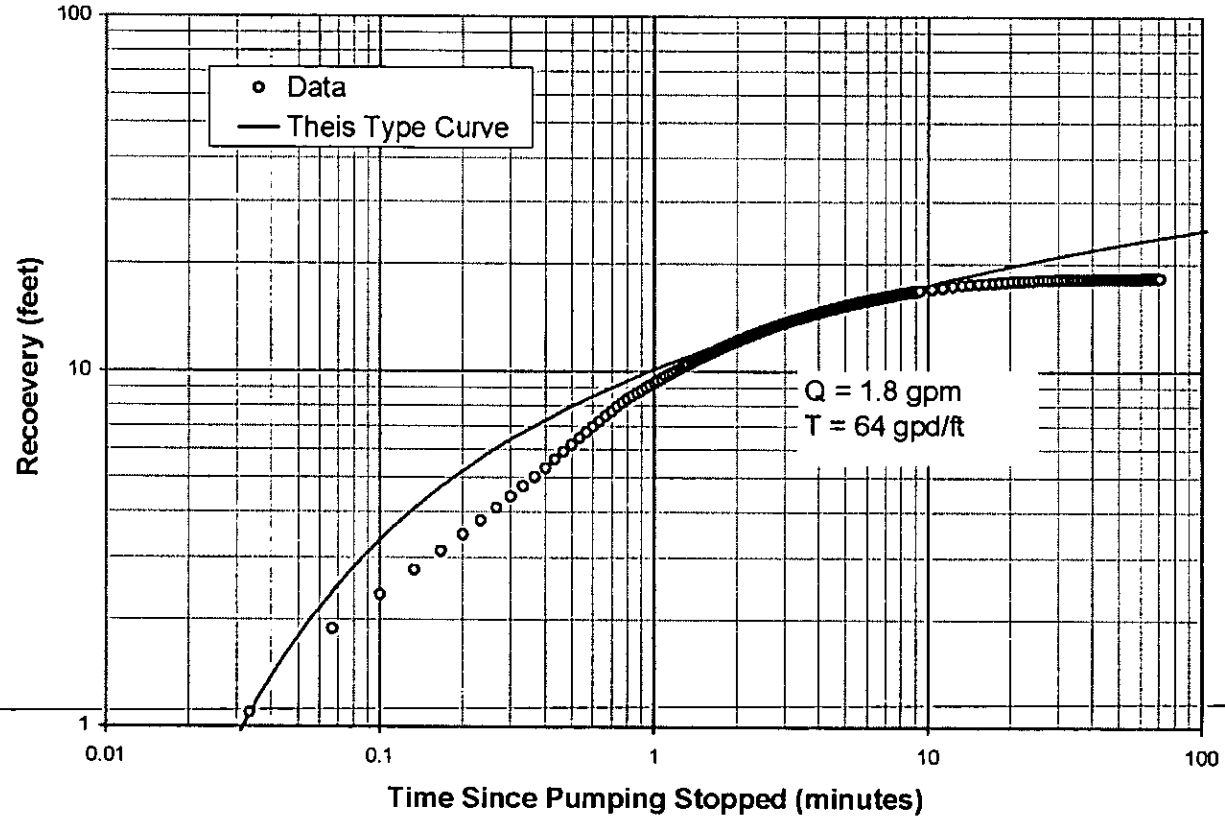


Figure 13. Well I-6 Trial 4 Drawdown

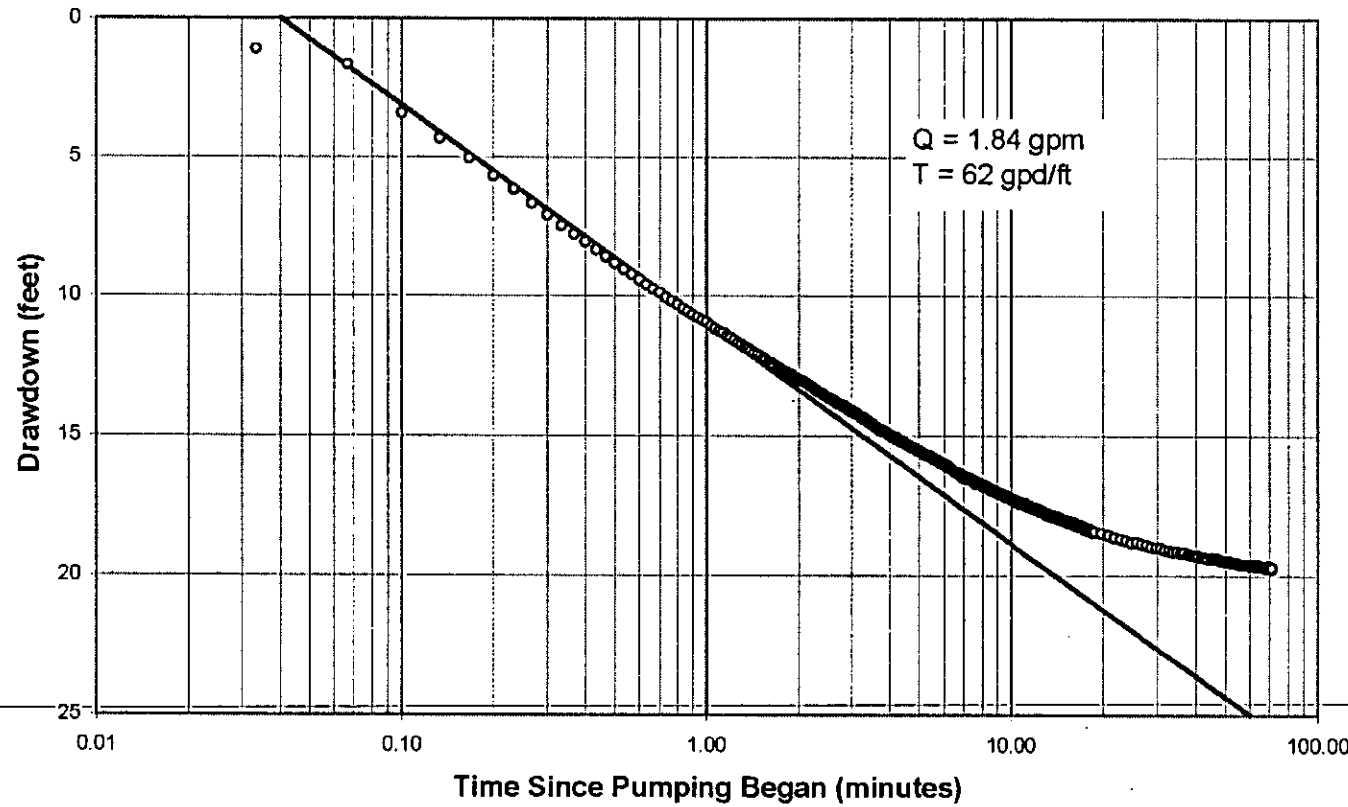


Figure 15. Well I-6 Trial 4 Recovery

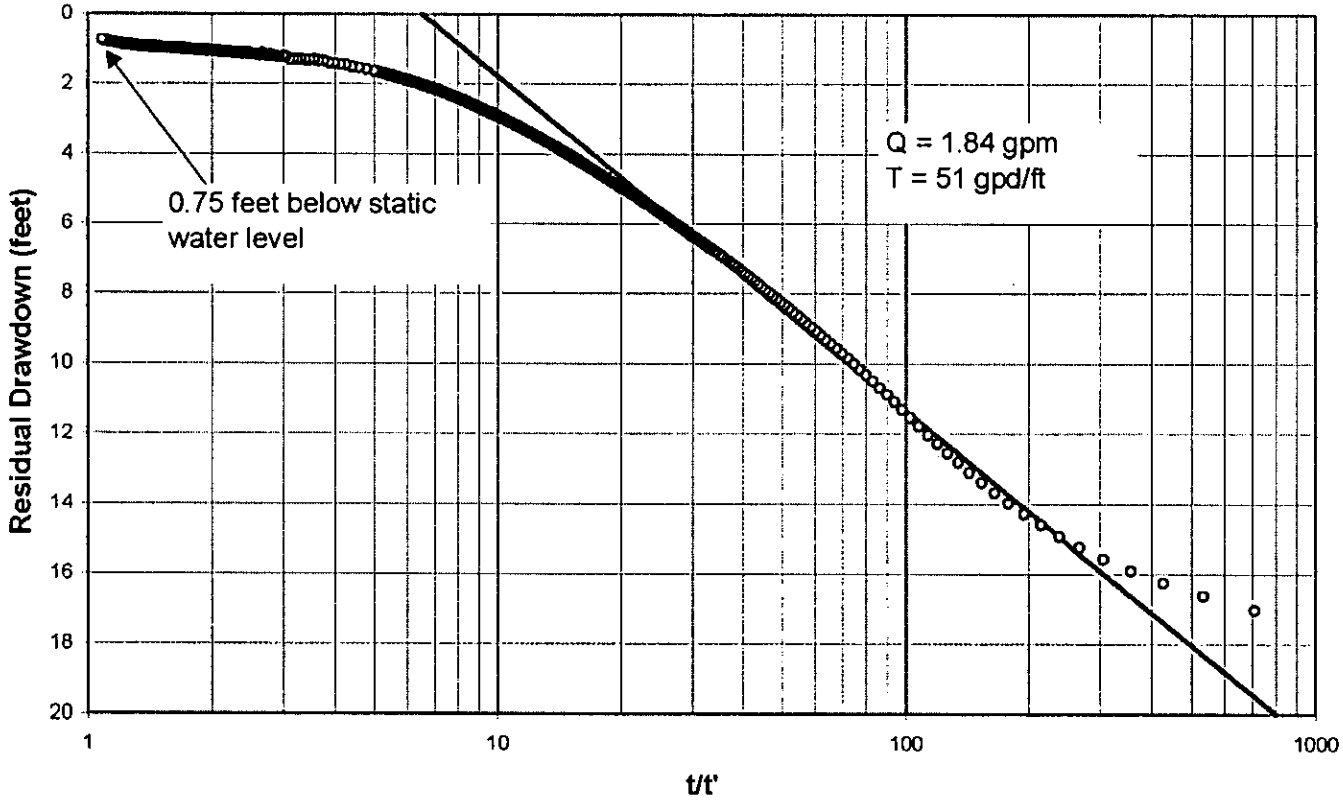


Figure 16. Well I-6 Trial 4 Recovery - Theis Analysis

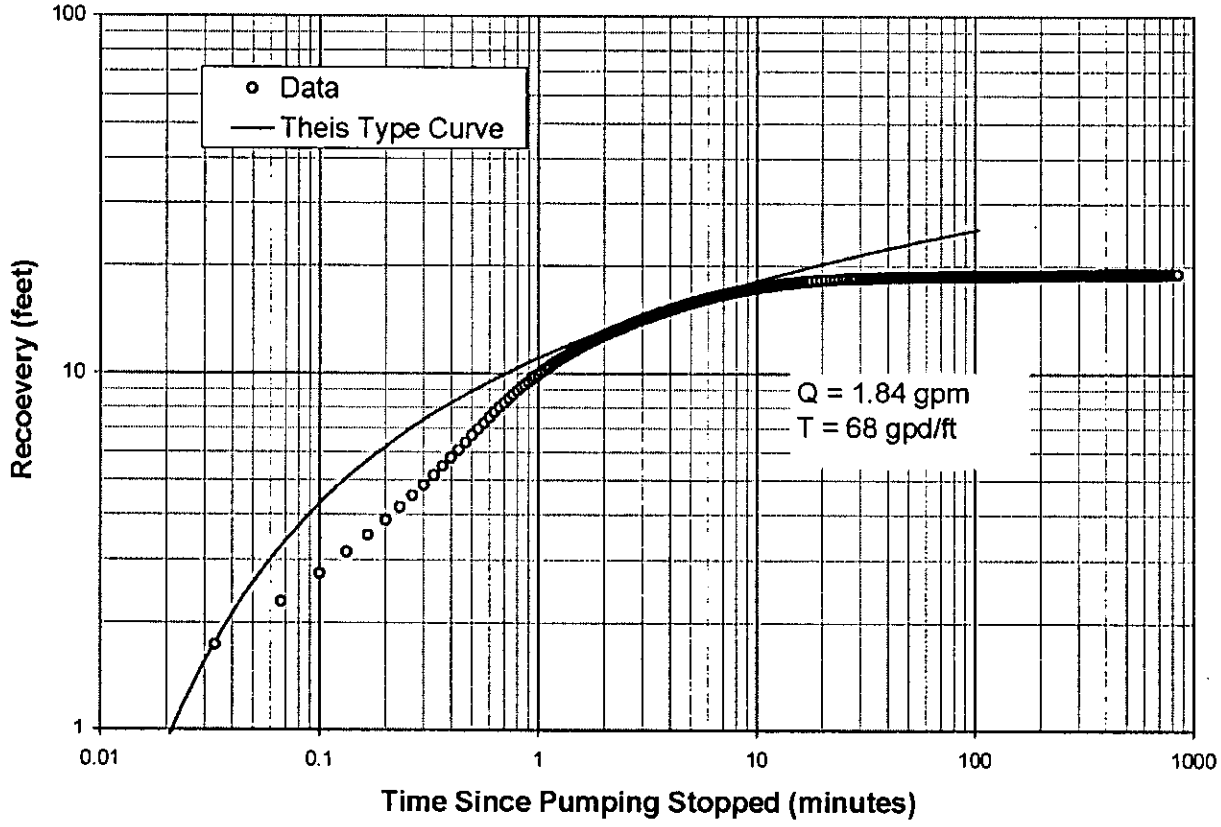


Figure 17. Well I-6 Drawdown

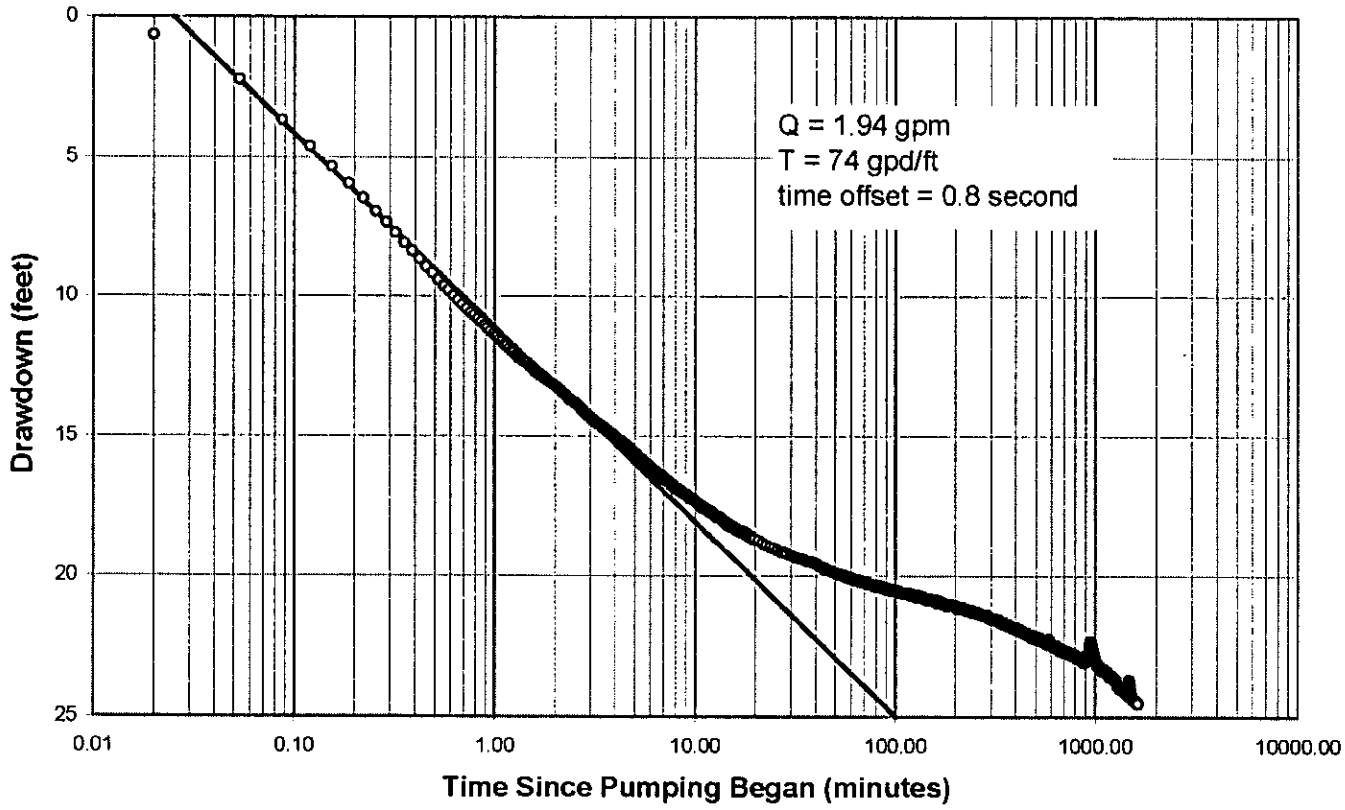


Figure 18. Well I-6 Drawdown - Theis Analysis

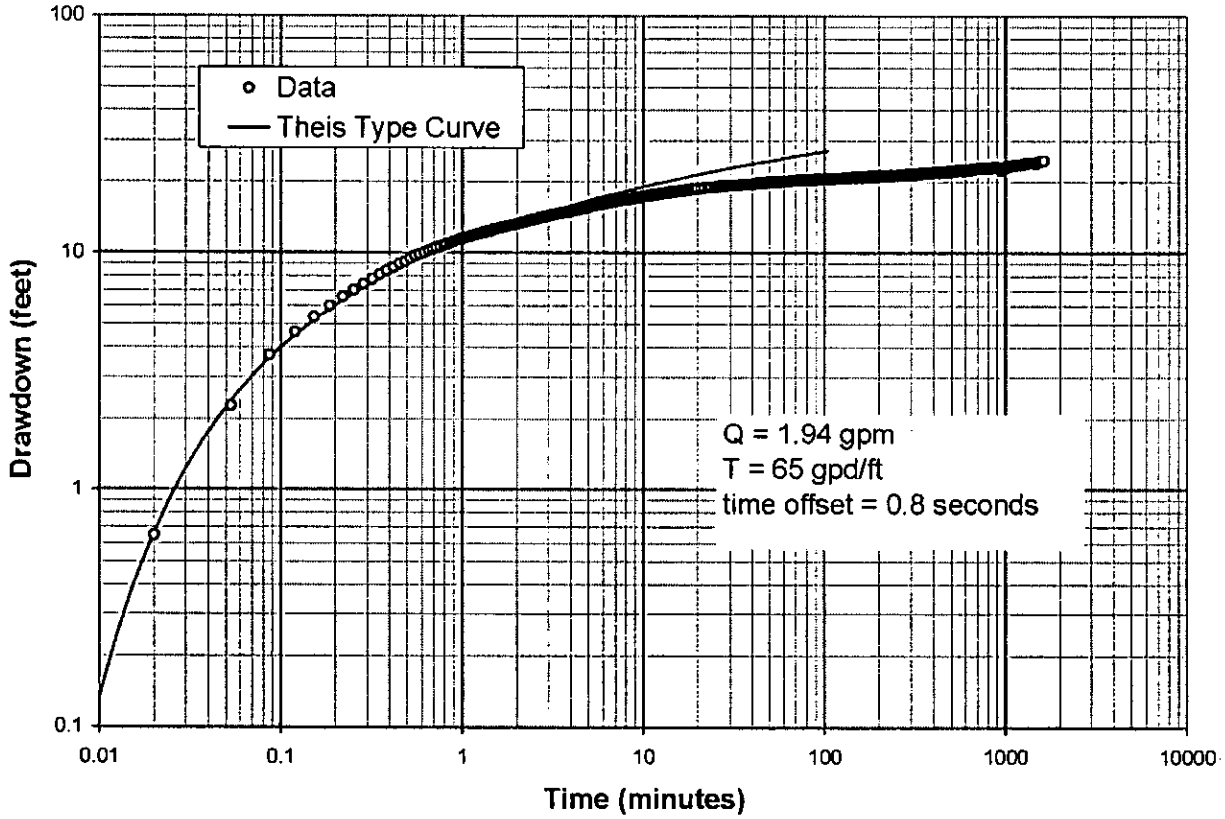


Figure 19. Well I-6 Drawdown - Late Data

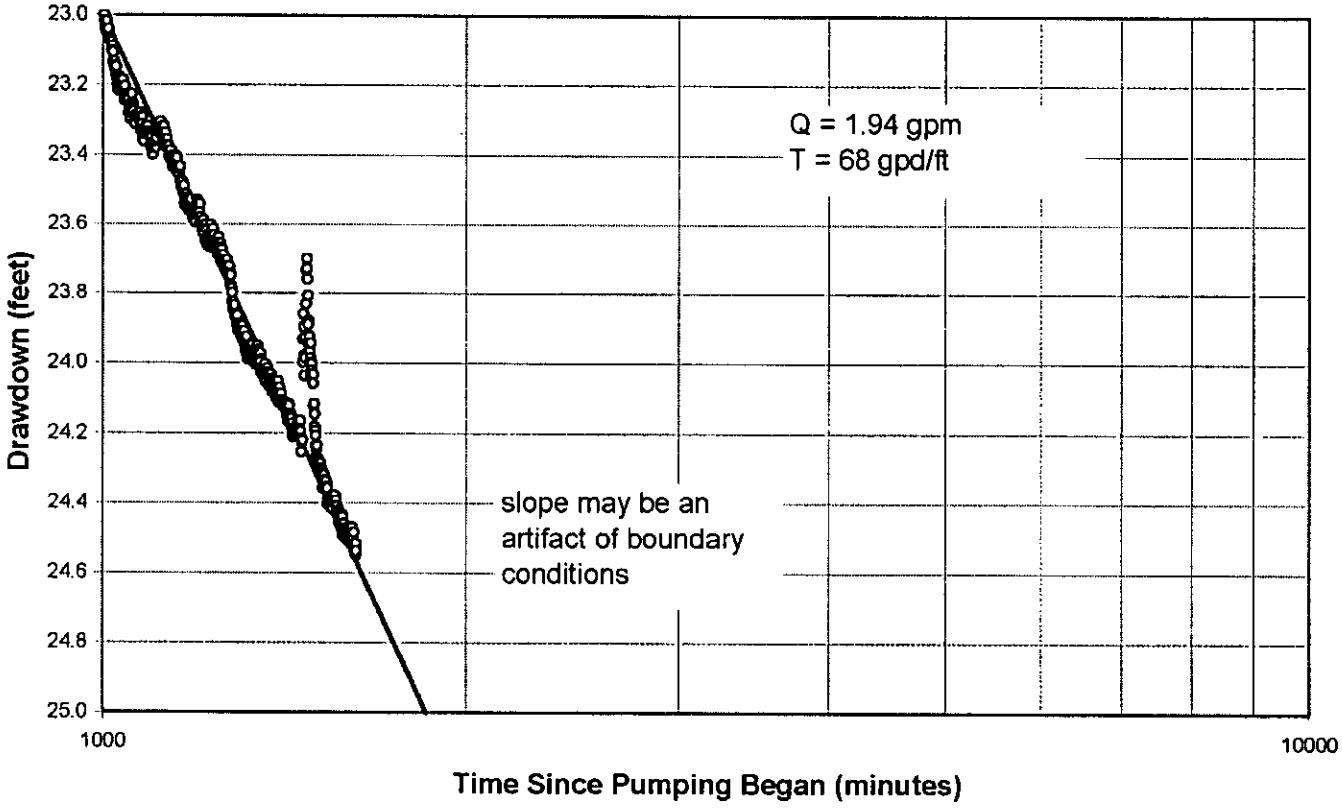


Figure 20. Well I-6 Drawdown
Neuman Solution For Unconfined Aquifers

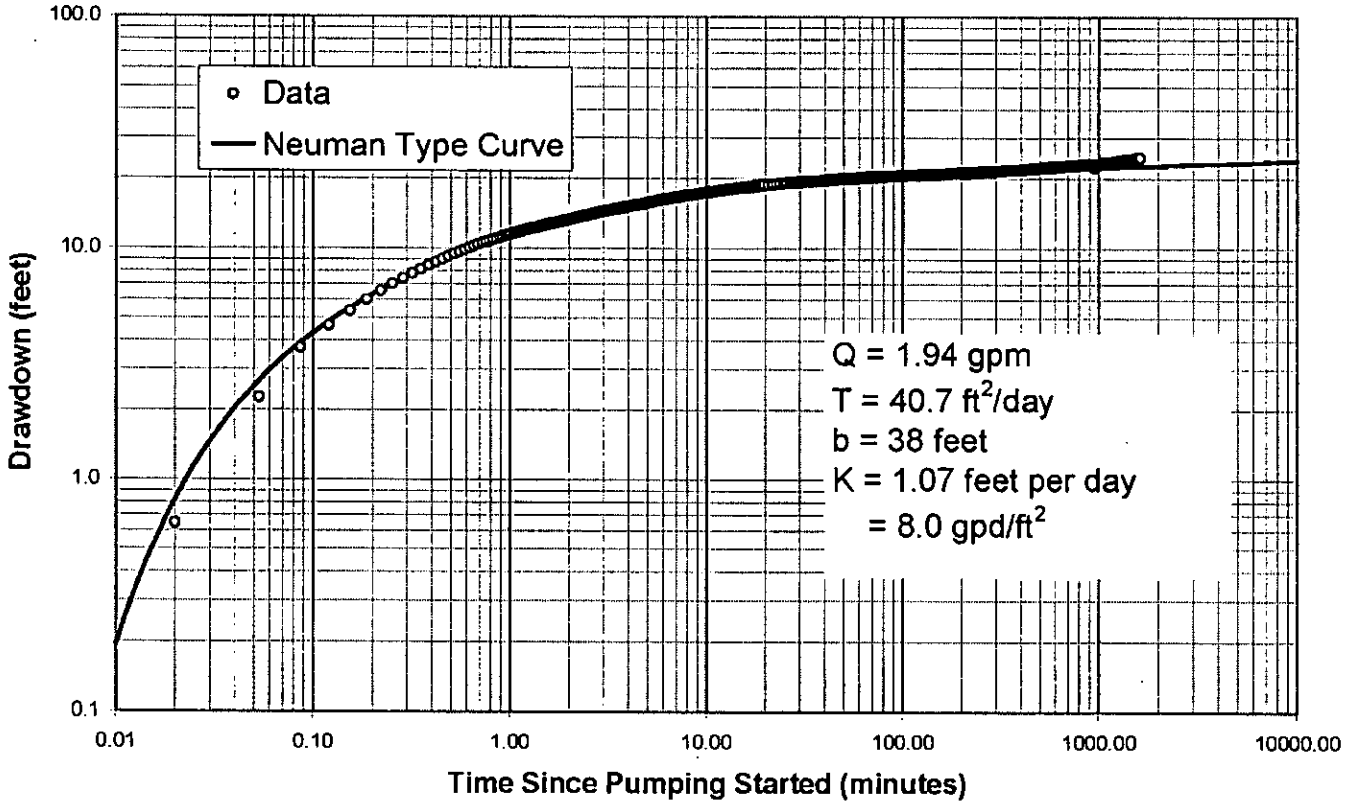


Figure 21. Well I-6 Drawdown - Linear Plot

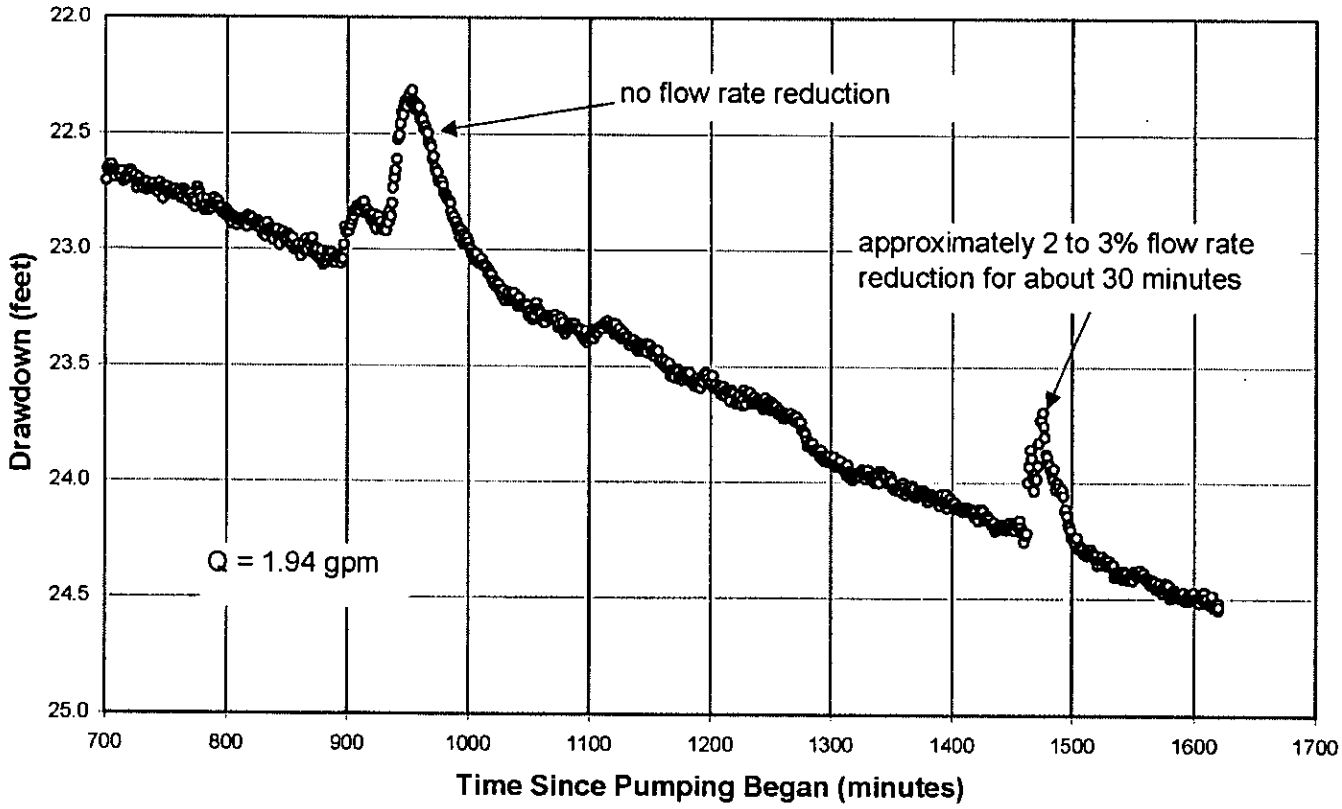


Figure 22. Well I-6 Recovery

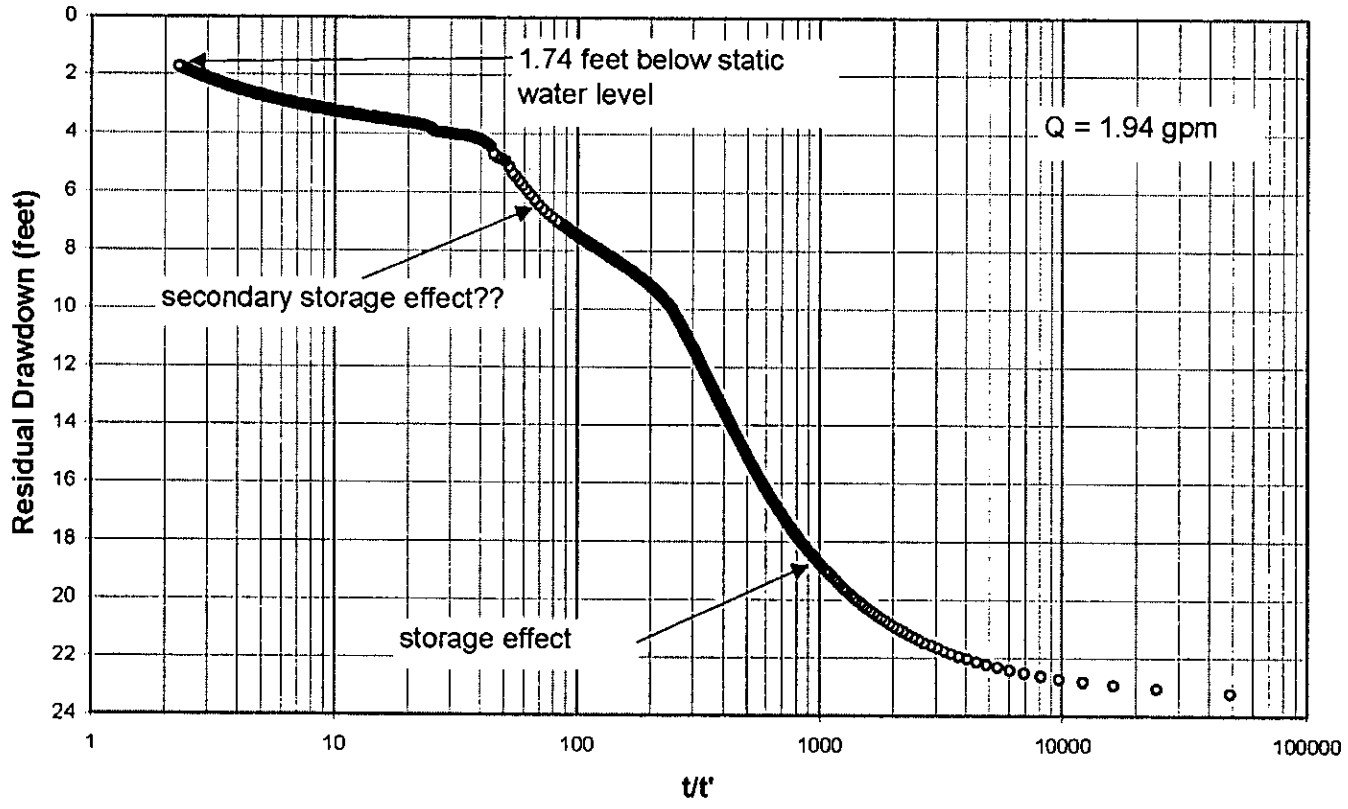


Figure 23. Comparison of Well I-6 Trial 3, Trial 4 and 27-Hour Test Recovery

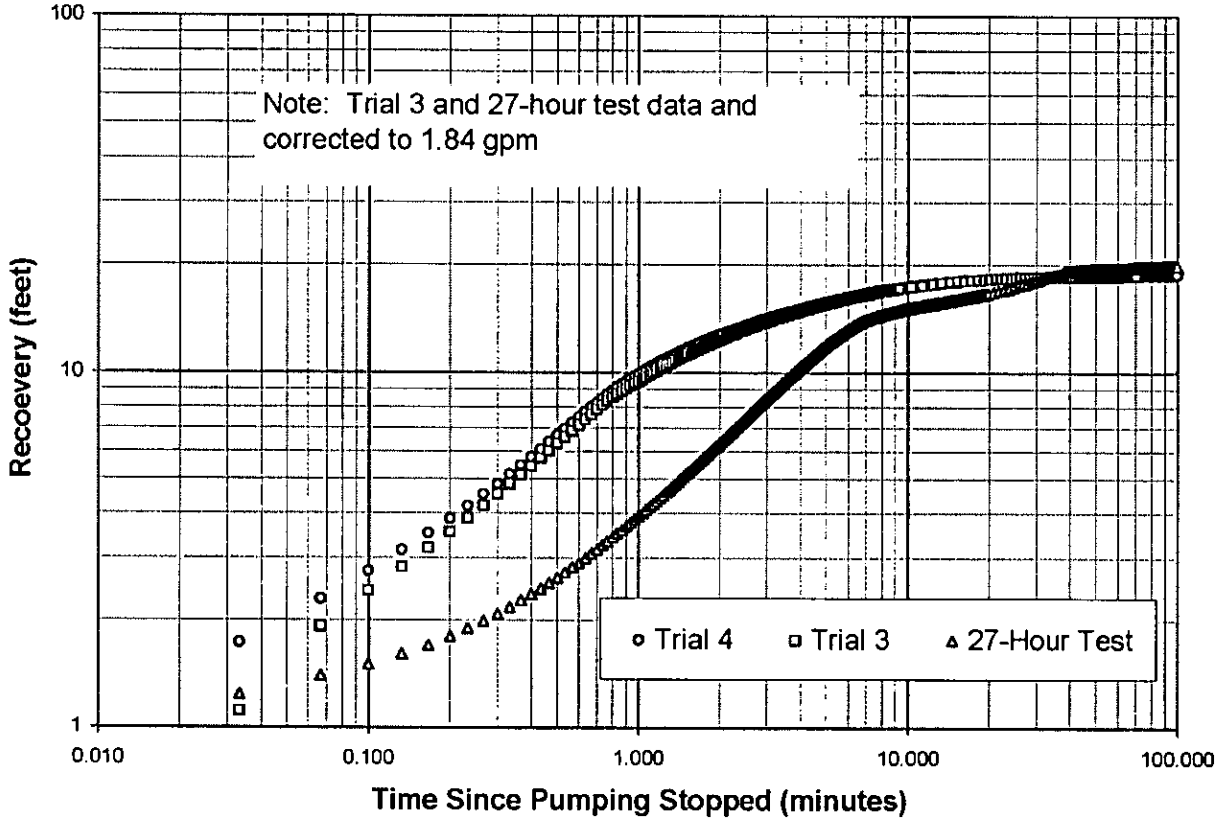


Figure 24. Well I-6 Comparison of Drawdown and Calculated Recovery

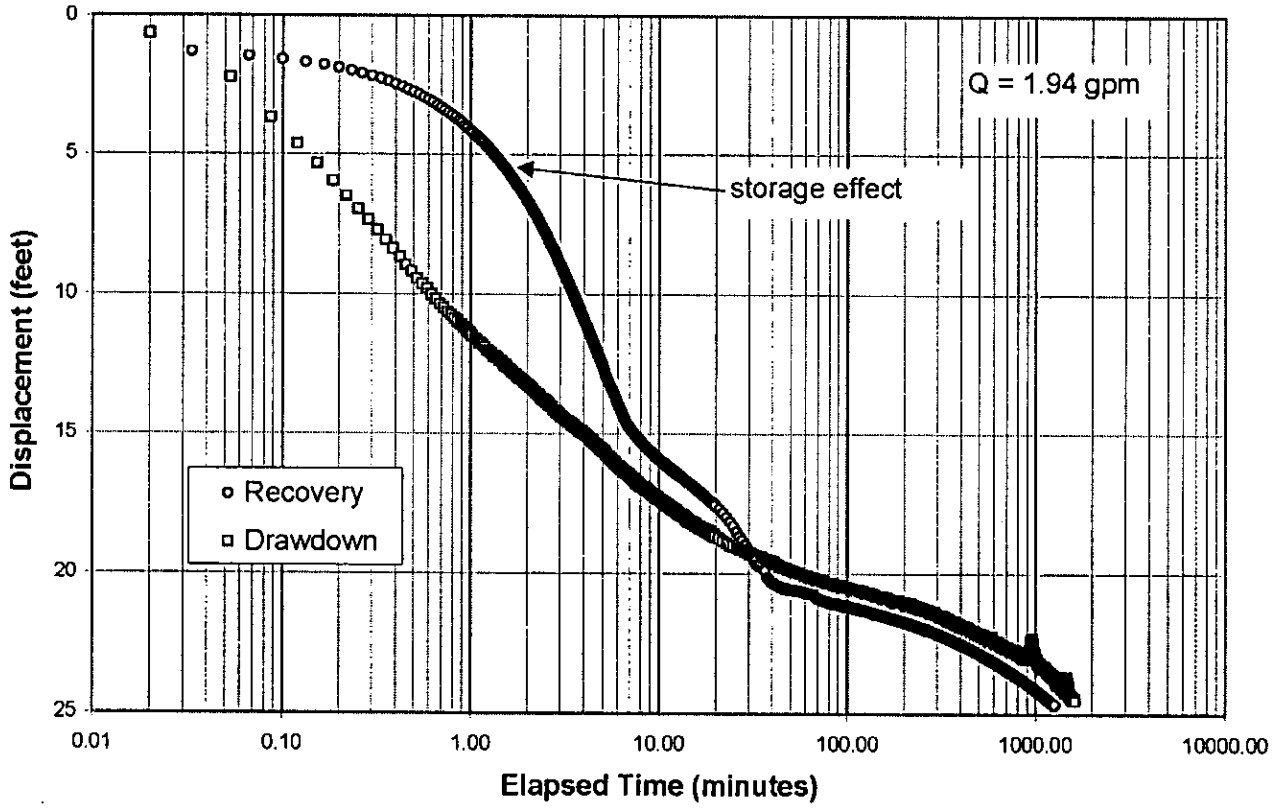


Figure 25. Packer Deflation Following Final Recovery

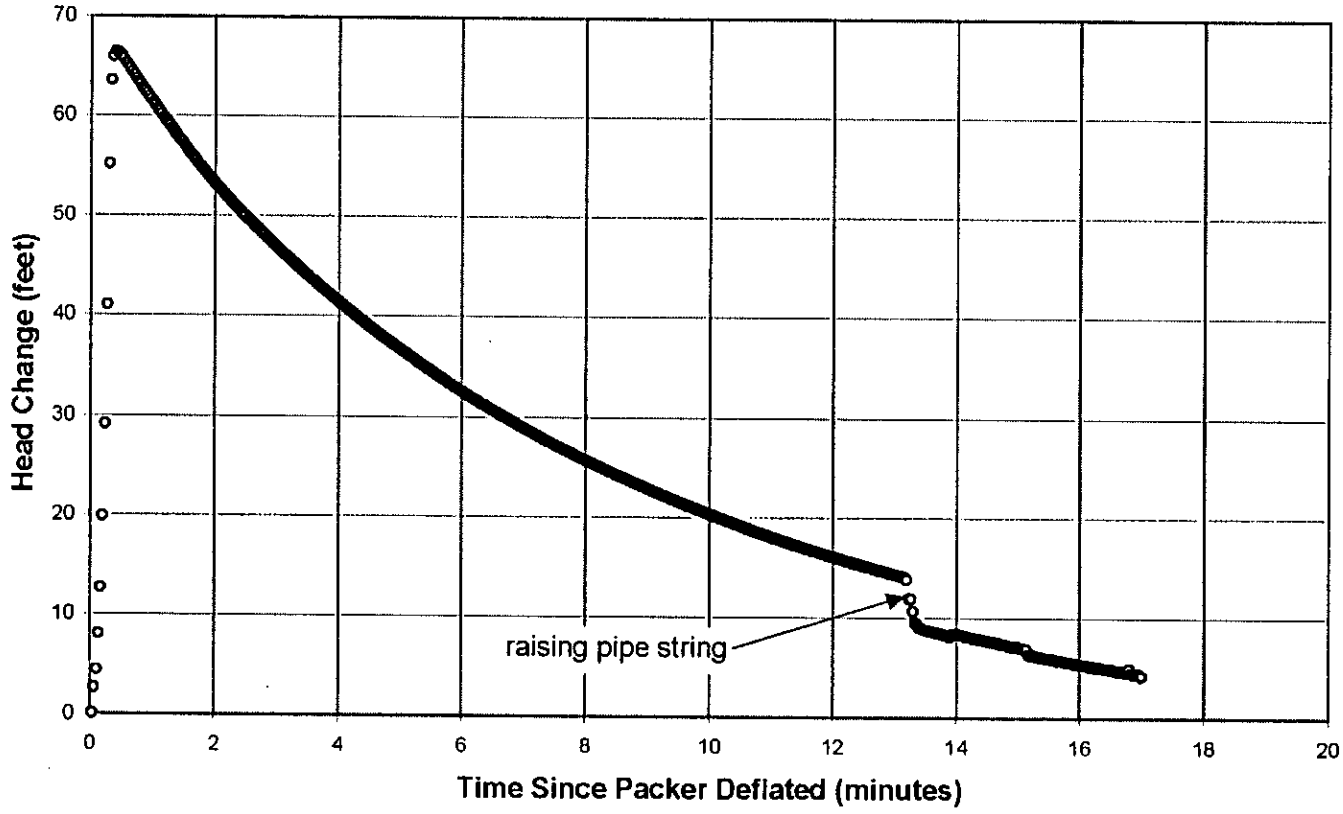
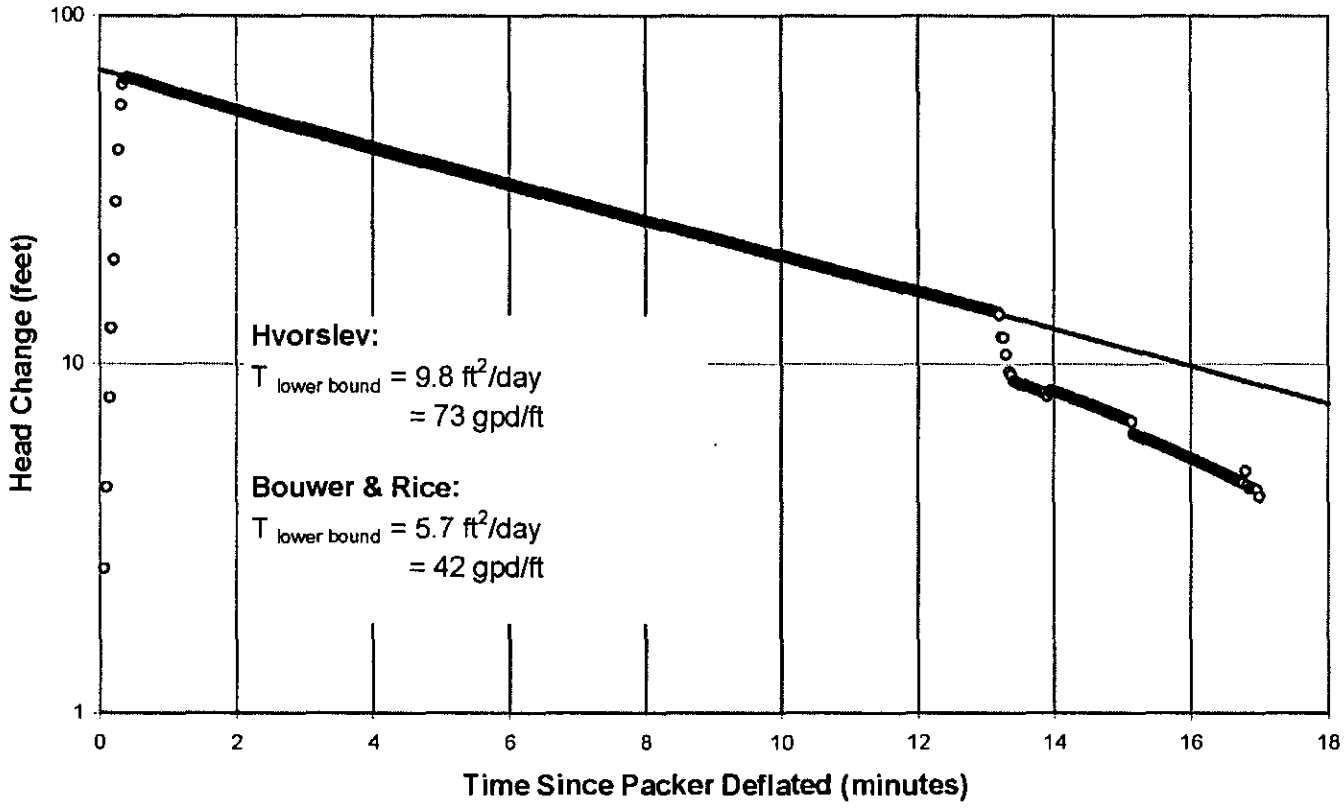


Figure 26. Packer Deflation Slug Test Analysis



FINAL
COMPLETION REPORT
INTERMEDIATE WELL I-8
LOS ALAMOS NATIONAL LABORATORY
LOS ALAMOS, NEW MEXICO
PROJECT NO. 49436

Prepared for:

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Prepared by:

KLEINFELDER

8300 Jefferson NE, Suite B
Albuquerque, New Mexico 87113

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LIST OF ACRONYMS AND ABBREVIATIONS

ags	above ground surface
amsl	above mean sea level
ASTM	American Society for Testing and Materials
bgs	below ground surface
BMPs	best management practices
DTHH	down-the-hole hammer
DOE	Department of Energy
DTW	depth to water
FSF	Field Support Facility
ft	foot/feet
ft^3	cubic feet
gal.	gallon/gallons
gpm	gallons per minute
hr/hrs	hour/hours
in.	inch/inches
Kleinfelder	Kleinfelder, Inc.
LANL	Los Alamos National Laboratory
NM	not measured
NMED	New Mexico Environment Department
OD	outer diameter
psi	pounds per square inch
RCT	radiation control technician
SMO	Sample Management Office
SSL	soil screen levels
Technical Area	TA
TD	total depth
TKN	total Kjeldahl nitrogen
US	United States

ABSTRACT

Intermediate well I-8 was installed as part of the Risk Reduction and Environmental Stewardship-Remediation Services project at Los Alamos National Laboratory (LANL) in accordance with the "Mortandad Canyon Groundwater Work Plan, Revision 1" (LANL 2004) and the "Final Drilling Plan for Intermediate Wells, Mortandad Canyon, Los Alamos National Laboratory" (Kleinfelder 2004b). The United States (US) Department of Energy (DOE), with technical assistance from LANL, contracted and directed the installation of this well.

Data from I-8 will be used in conjunction with data from other wells in Mortandad Canyon to improve the conceptual model of the geology, hydrogeology, and hydrochemistry of the area to provide data for numerical models that address contaminant migration in the vadose (unsaturated) zone. This information will be used to facilitate decision-making with regard to regulatory compliance, risk assessment, and remediation.

The majority of the fieldwork at I-8 was completed between November 16, 2004, and January 3, 2005, during which a separate corehole and borehole were drilled. The corehole was drilled to a depth of 522.8 feet (ft) below ground surface (bgs). Video and geophysical logs were conducted before the corehole was backfilled with bentonite and abandoned. The borehole was advanced to a total depth of 745 ft bgs using fluid-assisted air-rotary drilling methods. Geophysical logging was performed in the open borehole to help delineate the hydrostratigraphy and to facilitate proper well design. Samples of drill cuttings were collected at regular intervals for potential stratigraphic, petrographic, and geochemical analysis. The stratigraphic units that were encountered during drilling include, in descending order, alluvium, Tshirege Member of the Bandelier Tuff, Tsankawi Pumice Bed, Cerro Toledo interval, Otowi Member of the Bandelier Tuff, Guaje Pumice Bed, upper Puye Formation, Cerros del Rio basalt, and lower Puye Formation.

The I-8 borehole was completed as a characterization well with a single screen installed from 665.0 to 675.0 ft bgs within the Cerros del Rio basalt. Total depth of the well is 678.6 ft bgs. The depth to water (DTW) following well installation, development, aquifer test and recovery was 676.06 ft bgs.

1.0 INTRODUCTION

This completion report summarizes the site preparation, drilling, well installation, and related activities for intermediate well I-8. Kleinfelder, Inc. (Kleinfelder), under contract to the United States (US) Army Corps of Engineers, was responsible for drilling, installing, testing, and sampling activities. The US Department of Energy (DOE) with technical assistance from Los Alamos National Laboratory (LANL) contracted and directed this work.

Intermediate well I-8 is located in Technical Area (TA) 5 within Mortandad Canyon at LANL (Figure 1.0-1). I-8 was installed to provide contaminant information for the upper vadose zone and to determine the occurrences of possible intermediate (sub-alluvial) perched groundwater zones in Mortandad Canyon. The data quality objectives are provided in the "Mortandad Canyon Groundwater Work Plan, Revision 1" (LANL 2004) and the "Final Drilling Plan for Intermediate Wells, Los Alamos National Laboratory" (Kleinfelder 2004b). Water quality, geochemical data, aquifer characteristics, and geologic information obtained from I-8 will augment the conceptual model and knowledge of contaminant distribution in the intermediate perched zone in the Mortandad Canyon system.

The objectives of coring and drilling activities were to collect core and cuttings of encountered geologic formations, to collect groundwater samples from perched intermediate aquifers (if present), and to install a single-screen characterization well within the Cerros del Rio basalt. The corehole was drilled to assess contaminant profiles in the upper 530 feet (ft) of the vadose zone. The actual total depth (TD) of the corehole was 522.8 ft below ground surface (bgs). The projected TD of the I-8 borehole was 750 ft bgs. The actual TD was 745 ft bgs. The I-8 borehole was completed as a characterization well with a single screen installed from 665.0 to 675.0 ft bgs.

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, New Mexico office and LANL's Records Processing Facility. Further analyses and interpretation of geologic, geochemical, and aquifer data will be included in separate technical documents to be prepared by LANL.

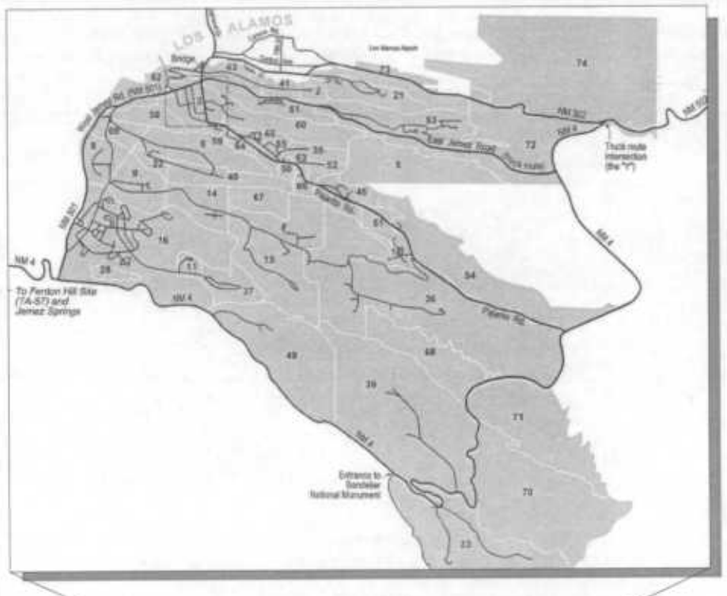
2.0 SITE PREPARATION AND DRILLING ACTIVITIES

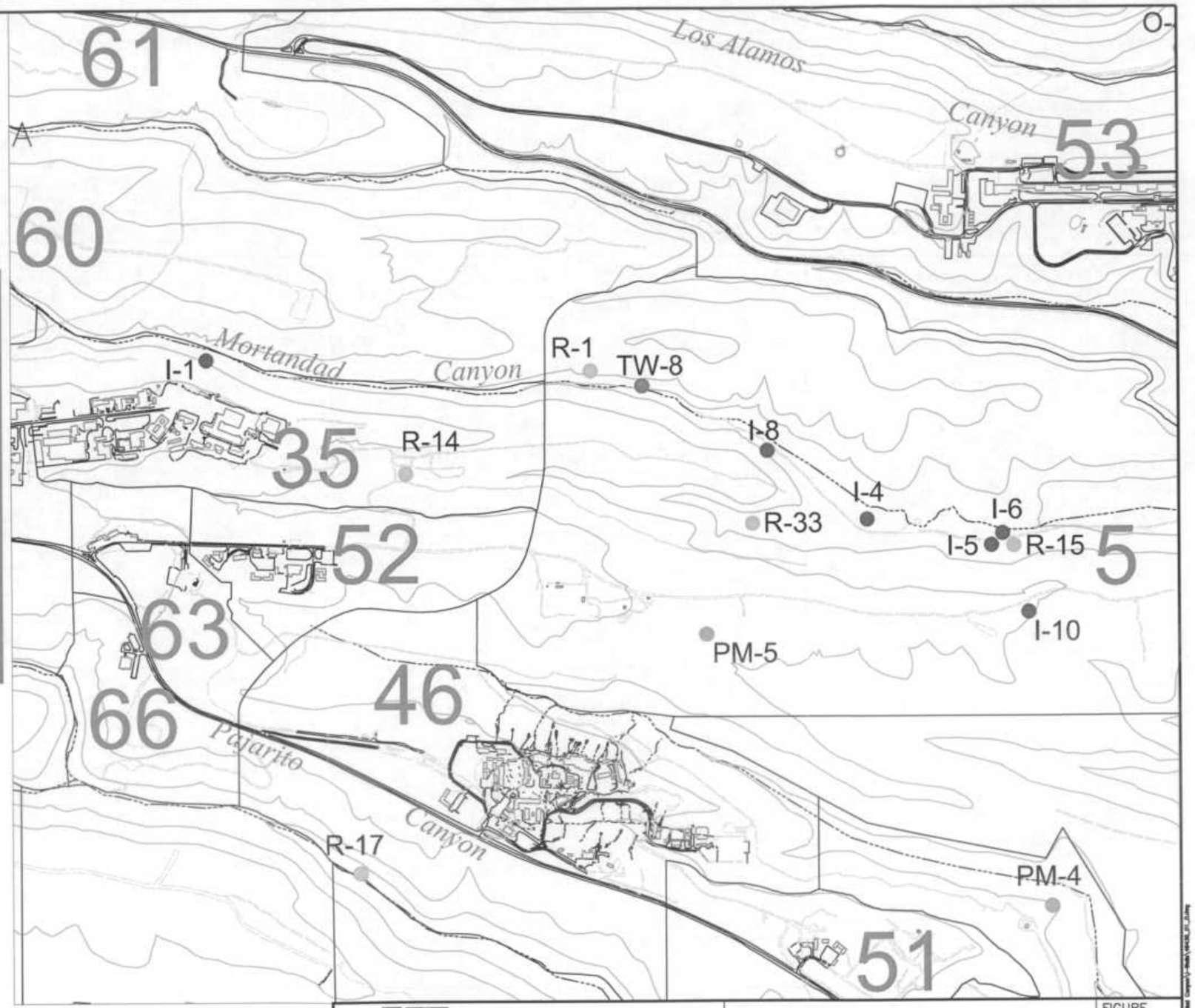
Site preparation consisted of constructing and lining the cuttings pit, erecting silt fencing to prevent erosion and runoff from the drill site, and setting up the exclusion zone. Best management practices, also known as BMPs, were installed as specified in the "Storm Water Pollution Prevention Plan, Mortandad Canyon Ground Water Work Plan, Los Alamos National Laboratory" (Kleinfelder 2004a). EnviroWorks, Inc. completed these tasks from November 2 through November 9, 2004. A radiation control technician (RCT) from LANL's Health, Safety, and Radiation Protection Group-1 screened the site before site preparation activities. A geology trailer, generator, compressor, and safety lighting equipment were moved to the site during the subsequent mobilization of drilling equipment.

The I-8 location was initially cored to characterize vertical contaminant profiles in the vadose zone. From November 16 through November 20, 2004, I-8 was cored from 0 ft to 522.8 ft bgs.

Legend

- = Intermediate perched zone wells (proposed)
- = Regional aquifer wells installed since 1998
- = Older test wells
- = Water supply wells
- 58 = Technical area identification
- = 100-ft contours





1000 0 500 1000

SCALE: 1 inch = 1000 ft

KLEINFELDER

Drawn By: C. Landon	Date: April 2006
Project No.: 49436	Filename: 49436_01_0.dwg
Scale: 1" = 1000'	Revision: –

SITE LOCATION MAP
Intermediate Wells I-1, I-4, I-5, I-6, I-8, I-10
Mortandad Canyon
Los Alamos National Laboratory
Los Alamos, New Mexico

FIGURE
1.0-1

Following geophysical and borehole video logging, the corehole was plugged with bentonite chips and abandoned. A separate borehole was drilled to a TD of 745 ft bgs using fluid-assisted air-rotary drilling methods and completed as a characterization well to 678.6 ft bgs. The majority of the fieldwork was conducted from December 18, 2004 through January 3, 2005, with well installation activities continuing through January 13, 2005.

Drilling activities were generally performed in one 12-hour (hr) shift per day, 7 days per week, by the drill crew and two site geologists.

2.1 Coring Activities

Coring operations were performed by Spectrum Exploration, Inc. using a Delta Base DB540 drill rig equipped with split spoon, HQ3 Coring Geobarrel®, and 115-millimeter Tubex drilling systems.

On November 16, 2004, mobilization of coring equipment and supplies to the I-8 site was completed and coring began. Split-spoon sampling was conducted from 0 to 10 ft bgs. Continuous-core, air-assisted drilling was conducted from 10 to 522.8 ft bgs. Temporary 6⅝-inch (in.) outer diameter (OD) surface casing was installed to a depth of 10 ft bgs using a 7⅜-in. Tubex under-reamer system. The corehole was then advanced from 10 to 100 ft bgs using a 4¾-in. Geobarrel® core bit. The under-reamer system was again used to advance the casing to 100 ft bgs, after which air-assisted coring proceeded to 522.8 ft bgs. On November 22, following video and geophysical logging, the corehole was backfilled with bentonite to 2 ft bgs. Samples collected during coring are described in Section 3.0

The corehole was monitored for groundwater during the drilling effort. Perched groundwater was not encountered; however, indications of a moist zone were noted from 80-95 ft bgs. Additional information on groundwater occurrences is presented in Section 5.2.

2.2 Well Drilling Activities

WDC Exploration & Wells drilled a separate borehole at the I-8 site using a GEFCO Speedstar 90K drill rig equipped with conventional drilling rods and drill collars, tricone bits, down-the-hole hammer (DTHH) bits, air compressors, and support equipment. I-8 was drilled using fluid-assisted air-rotary drilling techniques. Drilling fluids, consisting of a mixture of municipal water with QUIK-FOAM® surfactant, were used as needed to improve borehole stability and facilitate cuttings removal from the borehole. An approximate tally of the total drilling fluids introduced into the borehole, as well as the total fluids recovered, is presented in Table 2.0-1.

Table 2.0-1
Introduced and Recovered Fluids

Material		Volume (gal.)
Introduced	QUIK-FOAM®	55
	Potable water	2,450
	Total introduced fluids[1]	2,505
Recovered	Total recovered fluids[2]	1838

[1] Represents fluids that were introduced during drilling
[2] Represents the estimated fluid volume recovered during drilling, well development, and hydrologic testing

On December 18, 2004, the drilling rig and support equipment were mobilized onsite. Fluid-assisted (air, water, QUIK-FOAM®) air rotary drilling methods were used to advance a $12^{1}/_{4}$-in. tricone bit to 30 ft bgs while simultaneously driving 13⅜-in. OD temporary surface casing.

On December 19, the surface casing was advanced to 78.7 ft bgs while advancing the hole to 80 ft bgs.

On December 20 and 21, the 12¼ -in. tricone bit was used to advance the borehole to 525 ft bgs. The drill string was then removed (tripped out), and DTW was measured (dry). A 12¼ -in. DTHH bit was used to advance the borehole from 525 to 628 ft bgs.

On January 3, 2005, the drill crew returned from days off and advanced the borehole to a TD of 745 ft bgs.

On January 4, the DTW was measured at 741.3 ft bgs. Natural gamma, array induction, and borehole video camera logging tools were run. The video log showed standing water at 741 ft bgs. The final borehole video log is located on the DVD in Appendix A.

On January 5, the DTW in the open borehole was 729.32 ft bgs. A groundwater sample was collected from the open hole (sample set CAMO-05-56803 and CAMO -05-56798), after which coated bentonite pellets were emplaced from the bottom of the hole to approximately 708 ft bgs. Details of the groundwater sampling are presented in Section 3.2.

On January 6, the bentonite seal was completed and tagged at 681 ft bgs. DTW was monitored for one hour. The final DTW reading for the shift was 671.10 ft bgs.

On January 7, DTW was monitored for seven hours. The final DTW measurement was 656.70 ft bgs. The approved well design was received and well installation began. Details of the well installation are presented in Section 6.0.

On January 8, installation of the well casing and screen was completed. The screen was set from 665.0 ft to 675.0 ft bgs. The lower bentonite seal was tagged at 678.5 ft bgs, a higher level than following application due to hydration and swelling of the bentonite. Application of the remaining backfill materials resumed.

On January 9, backfill materials were applied to 85 ft bgs and the 13⅜-in surface casing was pulled. Formation material fell into the hole to approximately 66 ft bgs.

On January 12, the drill rig was demobilized.

On January 13, the cement grout sealed was applied from 66 ft bgs to ground surface.

3.0 SAMPLING ACTIVITIES

Core, cuttings, groundwater screening samples, and waste characterization samples were collected at I-8. Sampling activities were conducted in accordance with the drilling plan (Kleinfelder 2004b). Deviations are noted in Section 9.0.

3.1 Core and Cuttings Sampling

Core was collected from 0 to 522.8 ft bgs and sampled to analyze for anions, moisture content, tritium, and stable isotopes, as summarized in Table 3.1-1. Samples were placed in appropriate

sample jars and protective plastic bags and submitted to LANL's Sample Management Office (SMO) for analysis. The remaining core was placed in lay-flat plastic or Lexan™ tubing, labeled, stored in standard LANL Environmental Restoration core boxes, and transported to the Field Support Facility (FSF) for archiving and storage.

During rotary drilling, drill cuttings were collected at approximately 5-ft intervals from ground surface to TD from the borehole discharge line. Portions of the cuttings samples were sieved (using #10 and #35 mesh) and placed in chip trays along with unsieved cuttings. Aliquots of the >#10 fraction of cuttings were prepared for all intervals where sufficient returns were available. The sieved fractions were placed in labeled plastic bags and submitted to LANL for potential mineralogic, petrographic, and geochemical analyses. The remaining cuttings were sealed in Ziploc® bags, labeled, and archived in core boxes at the FSF. Drill cuttings were submitted for only chemical analyses for waste characterization.

LANL RCTs screened the core and cuttings prior to removal from site.

3.2 Groundwater Sampling

Groundwater was not encountered during drilling of the corehole.

On January 5, 2005, a groundwater sample was collected from the open borehole. Prior to collecting the sample, the DTW was 729.32 ft bgs and the borehole TD was 745 ft bgs. Within this interval, the zone for groundwater contribution is not known. The groundwater screening sample (sample set CAMO-05-56803 and CAMO-05-56798) was collected using a clean stainless-steel bailer and submitted to LANL's SMO for analysis of anions, metals, stable isotopes, perchlorate, total Kjeldahl nitrogen (TKN), tritium and radionuclides analyses.

Due to the low yield of groundwater in I-8, post-well development and post-aquifer testing samples were not collected.

3.3 Waste Characterization Sampling

On January 26, 2005, samples of drill cuttings, decon water, recovered drilling fluids and groundwater generated during well development/aquifer testing were collected for waste characterization. These samples were submitted to Hall Environmental Analysis Laboratory in Albuquerque, New Mexico, for analysis of anions, polychlorinated biphenyls, volatile organic compounds, semi-volatile organic compounds, metals, mercury, radionuclides, tritium, explosives, and perchlorate. Analytical results were received on February 16, 2005, and submitted to DOE and LANL for review.

Table 3.1-1. Core Samples Collected and Analyzed

Location ID MO-24229 I-8

Core Samples			ANALYSES						
Sample ID	Sample interval (ft)	Date/Time	Moisture	Tritium (ID)	anions/cations	N14N15	D2H O18O16	ARS (DOT screening)	Notes
CAMO-05-56851	8.0-11.0	11/16/04; 13:20	x	x	x	x		x	
CAMO-05-56852	17.8-19.2	11/16/04; 14:20	x	x	x	x		x	
CAMO-05-56853	28.4-29.4	11/16/04; 15:10	x	x	x	x		x	
CAMO-05-56854	38.8-40	11/16/04; 15:42	x	x	x	x		x	
CAMO-05-56855	49.5-51.6	11/16/04; 16:10	x	x	x	x	x	x	
CAMO-05-56856	60.3-61.9	11/16/04; 16:24	x	x	x	x		x	
CAMO-05-56857	70.3-71.9	11/16/04; 16:41	x	x	x	x		x	
CAMO-05-56858	79.9-80.5	11/16/04; 16:51	x	x	x	x		x	
CAMO-05-56859	88.2-89.8	11/16/04; 17:12	x	x	x	x		x	
CAMO-05-56860	108.8-110.9	11/17/04; 11:40	x	x	x	x	x	x	
CAMO-05-56861	117.5-118.4	11/17/04; 12:27	x		x	x		x	insufficient core volume
CAMO-05-56862	138.1-139.7	11/17/04; 14:00	x	x	x	x		x	
CAMO-05-56863	152-152.6	11/17/04; 13:17					x	x	
CAMO-05-56864	159.3-160.9	11/17/04; 14:30	x	x	x	x		x	
CAMO-05-56865	179.6-181.2	11/17/04; 15:09	x	x	x	x		x	
CAMO-05-56866	200.2-201.3	11/17/04; 16:03					x	x	
CAMO-05-56867	218.1-219.7	11/17/04; 16:41	x	x	x	x		x	
CAMO-05-56868	238.5-240.1	11/17/04; 17:17	x	x	x	x		x	
CAMO-05-56869	248.3-249.4	11/17/04; 17:50					x	x	
CAMO-05-56870	259-260.6	11/17/04; 18:13	x	x	x	x		x	
CAMO-05-56871	279.8-281.3	11/18/04; 8:56	x	x	x	x		x	
CAMO-05-56872	299.3-300.5	11/18/04; 9:45					x	x	
CAMO-05-56873	319.6-321.2	11/18/04; 10:37	x	x	x	x		x	
CAMO-05-56874	338.9-340.5	11/18/04; 11:25	x	x	x	x		x	
CAMO-05-56875	349-350	11/18/04; 11:57					x	x	
CAMO-05-56876	359.6-361.2	11/18/04; 12:39	x	x	x	x		x	
CAMO-05-56877	379.4-381.1	11/18/04; 14:17	x	x	x	x		x	
CAMO-05-56878	399.9-400.4	11/18/04; 15:57					x	x	
CAMO-05-56879	429.5-431.1	11/19/04; 13:27	x	x	x	x		x	
CAMO-05-56880	450.7-451.8	11/19/04; 16:00					x	x	
CAMO-05-56881	477-478.1	11/20/04; 8:19	x	x	x	x		x	
CAMO-05-56882	507.5-508.6	11/20/04; 15:20					x	x	
CAMO-05-56883	198.9-200.2	11/22/04; 12:05	x	x	x	x			Sample tracks to CAMO-05-56866
CAMO-05-56884	298.1-299.3	11/22/04; 12:10	x	x	x	x			Sample tracks to CAMO-05-56872

4.0 COREHOLE AND BOREHOLE LOGGING

Kleinfelder conducted video and geophysical logging on the I-8 corehole prior to backfilling and abandonment. The corehole was logged in two events. The first event was conducted while the casing remained in the hole, followed by a second event after the casing was removed. The second logging effort was conducted only across the former cased interval and did not include a video log.

The I-8 borehole was logged upon reaching the borehole TD of 745 ft bgs to acquire visual observations and geophysical data to help characterize borehole conditions and hydrostratigraphy. Project personnel used this information to facilitate proper well design. Table 4.0-1 summarizes the video and geophysical logs that were run in the I-8 corehole and borehole.

Table 4.0-1
Corehole and Borehole Logging

Operator	Corehole or Borehole	Date	Cased Footage (ft bgs)	Open-Hole Interval (ft bgs)	Logged Interval (ft bgs)	Remarks	Tools
Kleinfelder	Corehole	11/21/04	0-100	100-522.8 (sloughed to 515)	100-514	Gamma log run from 0 to 514 ft; dry to TD	Array induction, natural gamma, video camera
Kleinfelder	Corehole	11/21/04	none	100-522.8 (sloughed to 515)	0-125	Pulled casing to log upper 100 ft of corehole	Natural gamma and array induction
Kleinfelder	Borehole	1/04/05	0-78.7	78.7-745	0-741	At 669 ft bgs, water trickling down borehole wall. Standing fluid at 741 ft bgs.	Video camera
Kleinfelder	Borehole	1/04/05	0-78.7	78.7-745	0-751	Over ran base of borehole	Natural gamma
Kleinfelder	Borehole	1/04/05	0-78.7	78.7-745	79-743	Lost power at beginning of run	Array induction

4.1 Video Logging

Kleinfelder personnel conducted corehole video logging on November 21, 2004 and a borehole video log on January 4, 2005 to assess for evidence of water-bearing zones (Table 4.0-1). Groundwater was not noted in the I-8 corehole video. The I-8 borehole video did show indications of groundwater at approximately 669 ft bgs where water was observed entering the borehole, possibly along a fracture. Standing water was noted at approximately 741 ft bgs. DTW measurements taken prior to video logging were approximately 741 ft bgs, indicating a strong correlation between the Kleinfelder-owned GeoVISION™ Junior video camera counter and actual depths. The I-8 borehole video log is attached as a DVD in Appendix A.

4.2 Geophysical Logging

Kleinfelder used a Mount Sopris MGX2 geophysical console with LANL-owned array induction and natural gamma geophysical tools to conduct geophysical logging on the I-8 corehole and borehole. The purpose of geophysical logging was to identify geologic and hydrogeologic units, with an emphasis on gathering moisture distribution data on water-bearing zones and obtaining lithologic/stratigraphic data. The natural gamma and array induction logs for the I-8 borehole are shown in Figure 4.2-1.

5.0 HYDROGEOLOGY

LANL's Earth and Environmental Sciences Group 6 staff provided preliminary interpretation of geologic contacts based on cores and cuttings. Groundwater occurrence is interpreted from drilling observations, open-hole video logging, geophysical logging, and water-level measurements.

5.1 Geology

Visual examination of core, borehole drill cuttings, open-hole video logs, and geophysical logs were used to determine the stratigraphy of I-8 (Figure 5.1-1). In descending order, the stratigraphic units encountered during drilling of the I-8 borehole are alluvium, Tshirege Member of the Bandelier Tuff, Tsankawi Pumice Bed, Cerro Toledo interval, Otowi Member of the Bandelier Tuff, Guaje Pumice Bed, upper Puye Formation, Cerros del Rio basalt, and lower Puye Formation. Appendix B presents the lithologic log for I-8 based on examination of drill cuttings and core.

5.2 Groundwater Occurrence and Characteristics

While advancing the corehole, a moist interval was encountered from approximately 80 to 95 ft bgs. The interval was encountered at the end of shift, and upon resuming fieldwork the following morning, the DTW measurement indicated the corehole was dry. Difficulty with sample recovery impeded further assessment of the interval. Based on geophysical logs, the moist interval lies within the Cerro Toledo interval.

The borehole video log identified a single zone of saturation in the I-8 borehole. The video log indicates flowing water at approximately 669 ft bgs within the Cerros del Rio basalt, possibly along a fracture.

The DTW measurement in the open borehole preceding well construction was 656.70 ft bgs. Following well completion, static water levels within the completed well have generally corresponded to the top of the sump (approximately 675 ft bgs) suggesting groundwater is able to enter and drain across the screened interval and filter pack. Results from the aquifer test provide further information on the nature of the saturated interval (Section 7.2 and Appendix C).

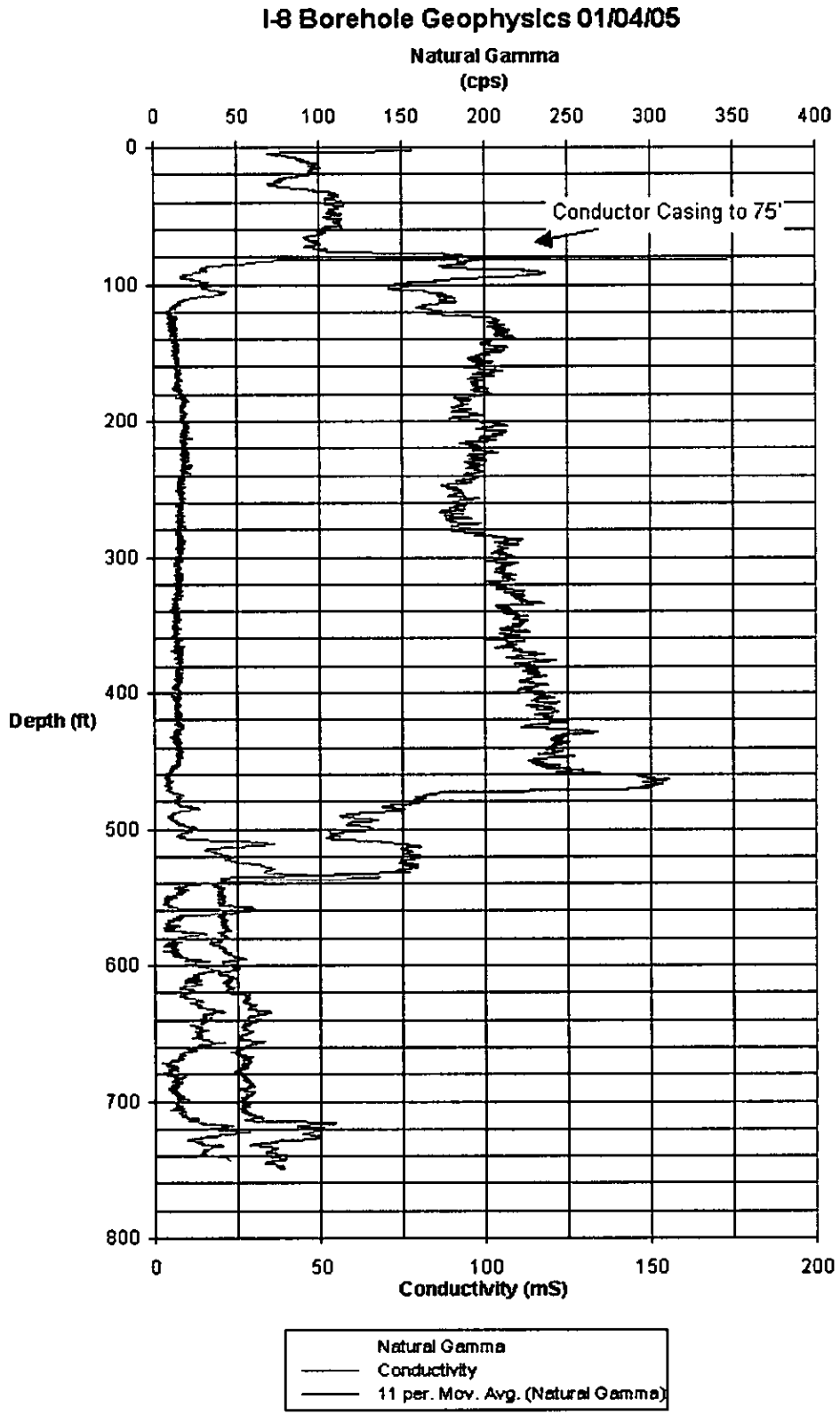
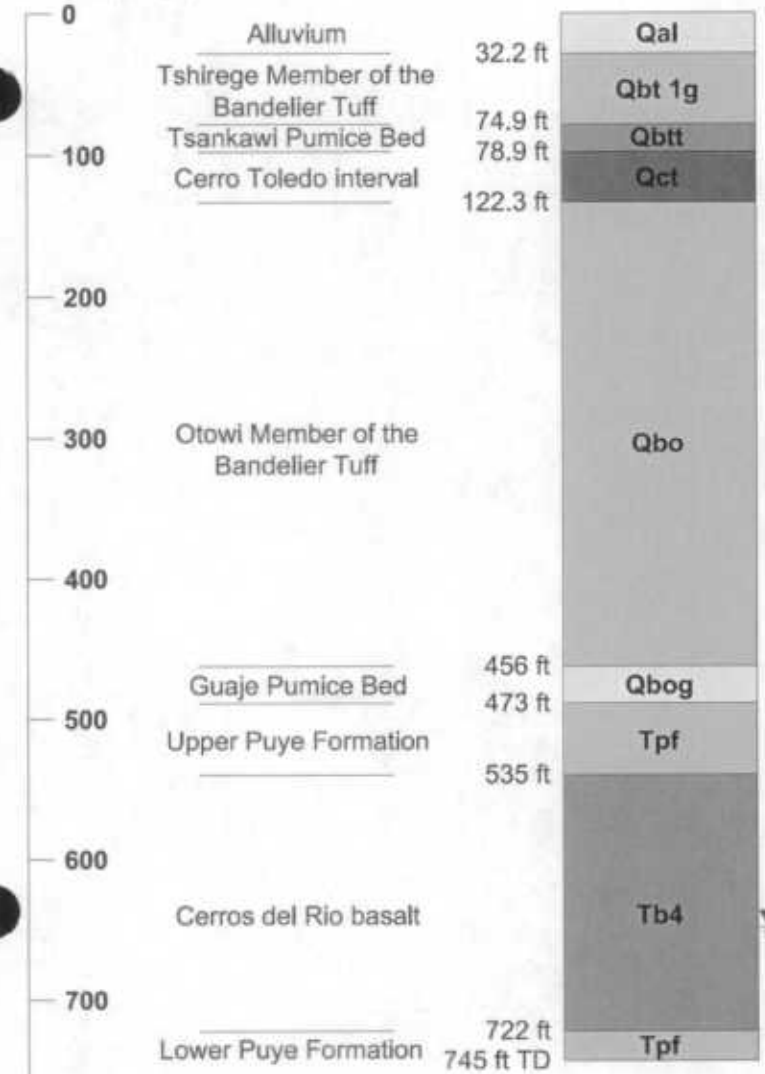


Figure 4.2-1. Natural Gamma and Induction Array Geophysical Logs



▼ 656.7 ft bgs (01/07/05)

DRILLING INFORMATION

COREHOLE
DRILLING COMPANY/PERSONNEL
Spectrum Exploration
S. Jager, B. Anderson
Drill Rig: DB-540

DRILLING METHOD
Continuous core air-assisted
(0 - 522.8 ft bgs)

Drilling Start Date: 11/06/04 Time: 13:06
Drilling End Date: 11/20/04 Time: 07:45

BOREHOLE
DRILLING COMPANY/PERSONNEL
WDC Exploration
C. Bufkin, R. Price, C. Mathews
Drill Rig: Speedstar 90k

DRILLING METHOD
Air Rotary fluid assisted:
Tri-cone bit with casing hammer (0 - 78.7 ft bgs)
Tri-cone bit (78.7 - 525 ft bgs)
Down the hole hammer (525 - 745 ft bgs)

Drilling Start Date: 12/18/04 Time: 12:43
Drilling End Date: 01/03/05 Time: 16:50

DRILLING FLUID TYPE
Air+water+QUIK-FOAM® (0 - 745 ft bgs)

Notes:
1. Geologic contacts are preliminary and subject to change.
2. Geologist noted no wet/saturated zones during coring; a moist core zone noted from 80 – 95 ft bgs.
3. Groundwater level in open borehole after reaching TD was 729.32 ft bgs and 656.7 ft bgs following placement of bentonite seal to 679.5 ft bgs.

KLEINFELDER

Drawn By: C. Landon	Date: April 2006
Project No.: 49436	Filename: 49436_01_0.dwg
Scale: not – to – scale	Revision: –

BOREHOLE SUMMARY DATA SHEET
I-8
Mortandad Canyon
Los Alamos National Laboratory
Los Alamos, New Mexico

FIGURE
5.1-1

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6.0 WELL DESIGN AND CONSTRUCTION

Kleinfelder received the well construction specification on January 7, 2005, after approval by DOE, LANL, and the New Mexico Environment Department (NMED). The well was installed from January 7 through January 8, 2005.

6.1 Well Design

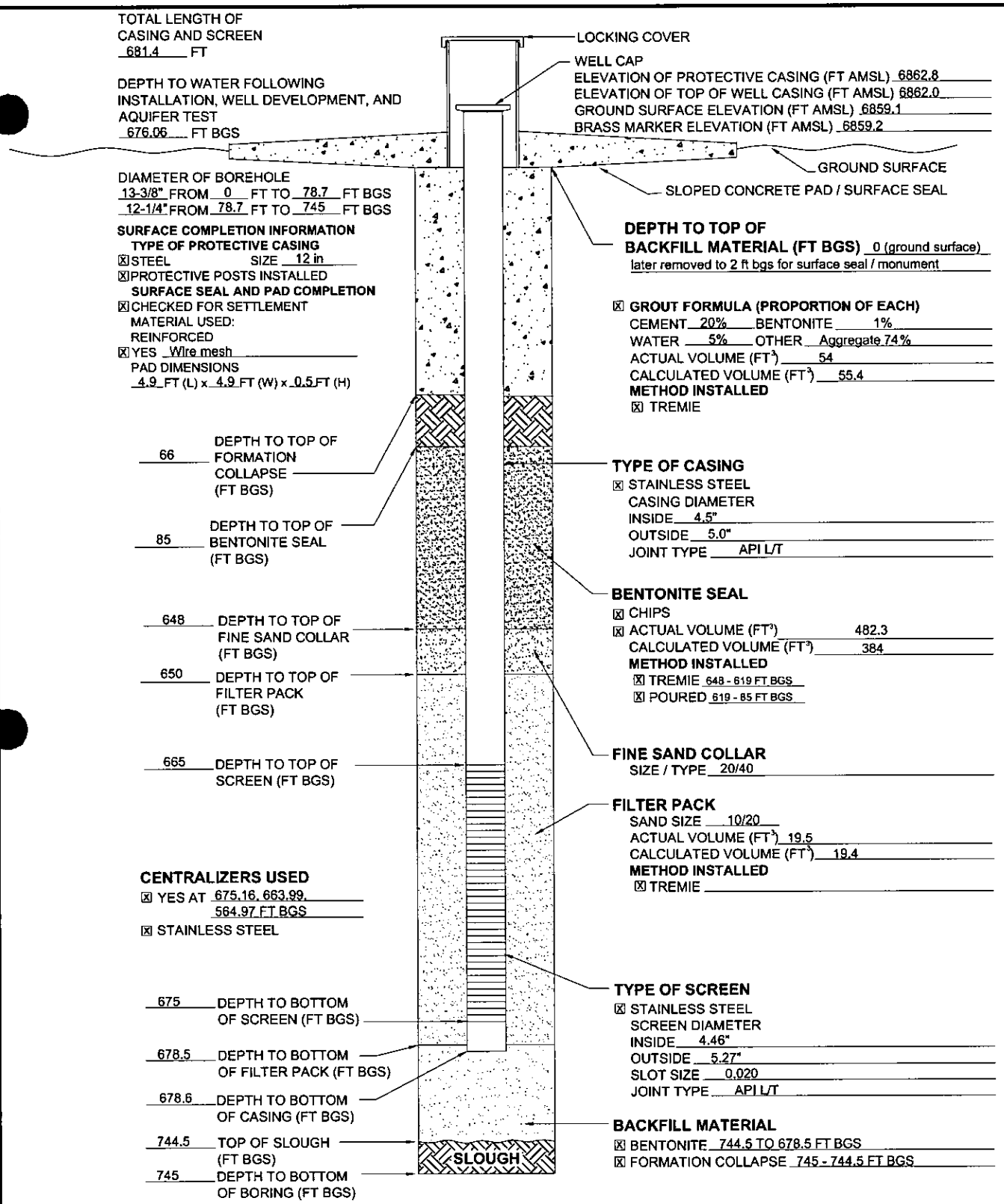
The "Mortandad Canyon Groundwater Work Plan, Revision 1" (LANL 2004) called for a single-screened interval in the Cerros del Rio basalt to characterize groundwater chemistry in the perched intermediate zone. Data from geophysical logs, borehole cuttings, water-level measurements, and field observations were evaluated to determine the placement of the screened interval.

6.2 Well Construction

The casing and screen were factory-cleaned before shipment and delivery to the site; additional decontamination of the stainless-steel components was performed on site prior to well construction using a high-pressure steam cleaner.

I-8 was constructed in accordance with LANL "Environmental Restoration Standard Operating Procedures for Well Construction, Revision 3" ER-SOP- 05.01 (LANL 2001) using 4.5-in. inside diameter (ID)/5.0-in. OD, type A304, stainless-steel casing fabricated to standards in American Society for Testing and Materials (ASTM) A312-05, "Standard Specification for Seamless, Welded, and Heavily Cold Worked Austenitic Stainless Steel Pipes." External couplers, also of type A304 stainless steel, were used to connect individual casing and screen joints. A single 10-ft section of 5.27-in. OD, stainless steel, 0.020-in. slot size, wire-wrapped, rod-based well screen was installed from 665.0 to 675.0 ft bgs. The combined length of the lower screen weld ring and well end-piece provide a 3.6-ft stainless steel sump (Figure 6.2-1).

Prior to installing the well, the bottom of the borehole was tagged at 744.5 ft bgs, indicating that 0.5 ft of formation material (slough) had accumulated. Bentonite pellets were emplaced from 744.5 ft to 678.5 ft bgs using a 2-in. OD steel tremie pipe. Following installation of the well casing and screen, the primary filter pack of 10/20 silica sand was emplaced from 678.5 to 650 ft bgs. After placement of the primary filter pack, the screened interval was swabbed to promote settling and compaction of the filter pack. A fine sand collar consisting of 20/40 silica sand was then placed above the primary filter pack from 650 to 648 ft bgs. A bentonite seal was placed from 648 to 85 ft bgs. The 13⅜-in surface casing was pulled, during which formation material sloughed into the annulus from 85 to 66 ft bgs. Cement grout was placed from 66 ft bgs to ground surface. The cement grout consisted of a 3000 pounds per square inch (psi) cement/sand slurry blended with powdered bentonite (1% bentonite calculated as dry weight bentonite to dry weight cement plus bentonite). Approximately 2 ft of the grout seal was later removed for placement of the protective well monument, pad, and surface seal (See Section 8.1). Table 6.2-1 summarizes the volumes of annular fill materials used to complete I-8.



KLEINFELDER

Drawn By: C. Bhongir	Date: April 2006
Project No.: 49436	Filename: 49436_02_0.dwg
Scale: Not-to-scale	Revision: –

WELL SCHEMATIC
I-8
Mortandad Canyon
Los Alamos National Laboratory
Los Alamos, New Mexico

FIGURE
6.2-1

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Table 6.2-1

Annular Fill Materials Used in Well Construction

Material	Volume
Grout seal: cement slurry	54 ft^3
Bentonite seal (upper): bentonite chips	482.3 ft^3
Fine sand collar: 20/40 silica sand	1.5 ft^3
Primary filter: 10/20 silica sand	19.5 ft^3
Bentonite seal (lower): bentonite pellets	43.6 ft^3
Potable water	2703 gal.

7.0 WELL DEVELOPMENT, AQUIFER TESTING, AND PUMP INSTALLATION

7.1 Well Development

On January 20, 2005, the I-8 well was bailed and swabbed to enhance filter-pack settling and to remove drilling fluids and sediment that were introduced into the well during drilling and installation. Bailing was conducted using a stainless-steel bailer. Swabbing was conducted by repeatedly drawing the tool across the screened interval. During bailing and swabbing, I-8 exhibited very low yield. Initial bailing and swabbing yielded the greatest volume of 25 gallons (gal.) before the well was dry. Following 1.5 hrs for recharge, an additional 10 gal. were removed before the well was again dry. An aquifer test was conducted on I-8 following the bailing attempt, indicating very low yields and poor well recharge (Section 7.2 and Appendix C). Because the bailing and swabbing volume is not consistent with later attempts to remove water, the initial higher yield may be due to removing fluids used during drilling or draining zones of very limited production.

7.2 Aquifer Testing

Due to the very low yield of the perched zone, a constant-rate pump test was not feasible. Therefore, the perched zone was tested by removing water from the well and monitoring recharge. The aquifer test was conducted at I-8 on February 26, 2005. The DTW before the start of the test was 674.83 ft bgs. Approximately 2.5 gal. of water were bailed from the well after which the well was "dry". DTW measurements were then taken for approximately 31 hrs, after which time the DTW was 676.06 ft bgs (approximately 1.23 ft below the initial DTW level). The results of the aquifer test are presented in detail in Appendix C, and the key points are summarized here.

- The specific capacity was estimated by observing the casing refill rate near the end of the monitoring period. The average computed refill rate was 0.000146 gallons per minute (gpm).
- The conclusions derived from the I-8 test were constrained by the nature of the limited saturated formation being tested and the slow recovery rate. Based on the

limits of the available test, the hydraulic conductivity is between 10^{-4} and 10^{-2} ft per day.

7.3 Pump Installation

Pending further assessment of static water levels in I-8, a dedicated sampling system will be purchased for I-8 to be used as needed by LANL staff. The sampling device will be suitable for low-yield aquifers.

8.0 WELLHEAD COMPLETION, SURVEY, AND SITE RESTORATION

8.1 Wellhead Completion

Wellhead completion consisted of the installation of the protective well monument, surface seal, and pad. A 12-in. OD steel well monument with locking lid was installed from approximately 1.3 ft bgs to 3.7 ft above ground surface (ags) to protect the well riser. Concurrent with the placement of the monument and surface seal using concrete backfill, a reinforced concrete pad, 4.9-ft wide by 4.9-ft long by 6.5-in. thick, was installed around the well casing to provide long-term structural integrity for the well. A brass survey cap was embedded in the northwest corner of the pad. The pad is slightly elevated and sloped away from the well casing to promote runoff. Four bollards are placed around the perimeter of the pad to protect against vehicular damage.

8.2 Geodetic Survey

The ground surface, well casing, and brass cap at the I-8 wellhead were surveyed by ASTS, Inc., on March 10, 2005. The survey data are presented in Table 8.2-1.

Table 8.2-1
Geodetic Data

Description	Northing	Easting	Elevation*
Abandoned corehole	1769191.53	1633332.50	6859.9
Well ground surface	1769215.74	1633329.38	6859.1
Brass cap in I-8 well pad	1769214.4	1633329.74	6859.2
Top of stainless-steel well casing	1769211.87	1633330.12	6862.0
Top of protective well monument casing[1]	NM[2]	NM	6862.8

*Measured in ft above mean sea level (amsl) relative to National Geodetic Vertical Datum 1929, accurate to +/-0.1 foot

[1] Measured from the geodetic surveyed brass cap using level and staff

[2] NM – not measured

8.3 Site Restoration Activities

Cuttings and fluids produced during drilling and development were containerized and sampled on January 26, 2005 in accordance with the October 13, 2004, Waste Characterization Strategy

Form prepared for the drilling and installation of boreholes and wells in Mortandad Canyon (Appendix C in Kleinfelder 2004b). Analytical results were received on February 16, 2005, and submitted to DOE and LANL for review. Fluid sample results were compared to the State of New Mexico Water Quality Control Commission Regulation 3103 groundwater standards. Water generated during drilling, development and aquifer testing was land-applied in accordance with the Workplan Notice of Intent Decision Tree, revised July 15, 2002, and in coordination with NMED. Cuttings sample results were compared to local geochemical background values and soil screening levels (SSLs) from the NMED Soil Screening Levels, Revision 2.0, February 2004, and submitted to DOE for approval to use as site restoration fill.

Site restoration was delayed due to the restrictions for the spotted owl mating season. Once approval to return to the site was obtained, activities included removing the water from the containment area and applying it back to the land, removing the polyethylene liner and cuttings from the containment area, removing the containment berms, backfilling and grading the containment area, and disposing of the containment liner. Remaining cuttings not utilized to backfill the containment area were thinly spread over the site. The site has been reseeded and temporary materials emplaced for BMPs have been removed.

9.0 DEVIATIONS FROM THE FINAL DRILLING PLAN

In general, drilling, sampling, and well construction at I-8 was performed as specified in the "Final Drilling Plan for Intermediate Wells, Mortandad Canyon, Los Alamos National Laboratory" (Kleinfelder 2004b). Deviations from planned activities were:

- Total depth of the corehole was 522.8 ft bgs rather than 530 ft bgs as noted in the drill plan.
- The drill plan calls out specific sampling intervals and analyses of collected core. During intervals of poor recovery, sampling intervals and analyses were adjusted as needed.
- The final analytical sample was collected at 508.6 ft bgs rather than the TD of 522.8 ft bgs.
- Sampled core was not analyzed for cations or radionuclide suite as specified in the drill plan.
- Total depth of the borehole was 745 ft bgs rather than 750 ft bgs as noted in the drill plan.
- Due to the very low aquifer yield, well development was limited, and groundwater parameters were not collected.
- Due to the low aquifer yield, post-well development and post-aquifer test groundwater samples were not collected.

10.0 ACKNOWLEDGEMENTS

ASTS, Inc. conducted the final geodetic survey of finished well components.

David Schafer and Associates conducted aquifer testing and analysis.

Duratek Federal Services, Inc. performed a review of the analytical results of the drill cuttings for waste determinations.

EnviroWorks, Inc. provided site preparation services.

Hall Environmental Analysis Laboratory conducted laboratory analysis for waste characterization samples

Spectrum Exploration, Inc. provided coring services.

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

WDC Exploration & Wells provided rotary drilling and well development services.

11.0 REFERENCES

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Kleinfelder, Inc., 2004a. "Storm Water Pollution Prevention Plan, Mortandad Canyon Ground Water Work Plan, Los Alamos National Laboratory," Los Alamos, New Mexico, Project Number 49436, August 2004.

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Appendix A

Borehole Video Log

Appendix B

Lithologic Log

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Qal, Alluvium	Volcaniclastic sediments, silty sand and gravel, light brown (5YR 5/6). Poorly sorted (10% silt, 10% fine sand, 25% medium sand, 40% coarse sand, 15% gravel); subrounded clasts; felsic (quartz and/or sanidine unless otherwise noted) crystal poor; intermediate volcanic composition clasts up to 2 cm; dry. **Note: Descriptions presented in this lithlog are primarily based on those made during visual examination of the drill core and cuttings. From 0 to 522.8 ft bgs drill core was primarily used to generate the lithlog, while drill cuttings were used from 520 to 745 ft bgs. Stratigraphic contacts are based on available information from review of drill core and limited geophysical logs. Unrecovered and/or sampled core in sections of less than 5 ft are not noted unless relevant to lithologic description.**	0-1	6859.1-6858.1
	Volcaniclastic sediments, silty coarse sand, dark yellowish brown (10YR 4/2). Moderately sorted (20% silt, 10% fine sand, 20% medium sand, 50% coarse sand); subangular; felsic crystal rich; coarse sand includes intermediate composition volcanic clasts and trace very pale orange (10YR 8/2) pumice; organic matter (roots); moist.	1-4	6858.1-6855.1
	Volcaniclastic sediments, as above; decrease in organic matter and moisture content (dry); gravel to pebble-sized tuff with devitrified pumice; rare white vitric pumice.	4-14	6855.1-6845.1
	Colluvium block, tuff, grayish orange pink (5YR 7/2). Ash matrix; 10% devitrified pumice, light brownish gray (5YR 6/1) and moderate yellowish brown (10YR 5/4); 10% felsic crystals, medium to coarse subangular quartz and sanidine; 5% lithics, coarse subrounded intermediate composition volcanic clasts; alteration of tuff block at 24.5 ft bgs.	14-25.5	6845.1-6833.6
	Volcaniclastic sediments, sandy silt, light brown (5YR 6/4). Moderately sorted (10% medium sand, 10% coarse sand, 80% silt); sand grains subangular; felsic crystal rich; rare light brown (5YR 5/6) devitrified pumice; dry.	25.5-28	6833.6-6831.1
	Volcaniclastic sediments, silty sand, moderate brown (5YR 3/4). Well-sorted sand, 10% silt, 5% fine sand, 10% medium sand, 75% coarse sand; subangular; intermediate composition volcanic clasts; felsic crystal rich; rare very pale orange (10YR 8/2) vitric pumice; moist.	28-29.5	6831.1-6829.6
	Volcaniclastic sediments, sandy silt with clay, light brown (5YR 5/6). Moderately sorted (5% medium sand, 10% coarse sand, 70% silt, 15% clay); subangular, felsic crystal rich; coarse sand grains of intermediate composition volcanic clasts; moist.	29.5-32.2	6829.6-6826.9
Qbt 1g, Tshirege Member of the Bandelier Tuff	Tuff, moderate orange pink (5YR 8/4), poorly welded. Ash matrix; 20% pumice, pinkish gray (5YR 8/1), vitric, fibrous, felsic phenocrysts; 7% subhedral felsic and mafic crystals; 2% lithics intermediate composition volcanic clasts, coarse sand size to rarely gravel sized, subrounded; moist. **Note: The base of the alluvium/colluvium and the contact with the underlying Unit 1g of the Tshirege Member of the Bandelier Tuff (Qbt 1g) is interpreted to be at 32.2 ft bgs.**	32.2-42	6826.9-6817.1
	Tuff, moderate orange pink (5YR 8/4), poorly welded. Ash matrix; 20% pumice, pinkish gray (5YR 8/1) to white (N9), vitric, fibrous, felsic phenocrysts; 7% subhedral felsic and mafic crystals, medium to coarse; 2% lithics coarse size to rarely gravel sized subrounded intermediate composition volcanic clasts; moist.	42-57.5	6817.1-6801.6
	Tuff, as above; minor manganese/iron (Mn/Fe) oxide staining.	57.5-61.0	6801.6-6798.1

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Qbt 1g, Tshirege Member of the Bandelier Tuff	Tuff, very pale orange (10YR 8/2), poorly welded. Ash matrix; 20% pumice, pinkish gray (5YR 8/1) to white (N9), vitric, fibrous, felsic phenocrysts; 7% subhedral felsic (medium to coarse) and mafic (fine to medium) crystals; 2% lithics, coarse sand size to rarely gravel sized subrounded intermediate composition volcanic clasts; dry.	61.0-74.6	6798.1-6784.5
	Tuff, light gray (N8) to yellowish gray (5YR 8/1) with grayish orange (10YR 7/4) bedding. Ash with 3-5% felsic crystals and 1% small (1 mm) lithics; pumice-poor; moist.	74.6-74.75	6784.5-6784.35
	Tuff, as above, grayish orange (10YR 7/4); 10% white, vitric pumices up to 3 mm; moist.	74.75-74.9	6784.35-6784.2
Qbtt, Tsankawi Pumice Bed of the Tshirege Member of the Bandelier Tuff	Pumice Bed, light brown (5YR 5/6). 90% felsic crystals, subangular to subrounded, fine to coarse; 10% fines. **Note: The base of the Qbt 1g and the contact with the underlying Tsankawi Pumice Bed of the Tshirege Member of the Bandelier Tuff (Qbtt) is interpreted to be at 74.9 ft bgs.**	74.9-75	6784.2-6784.1
	Pumice bed, as above; 10% vitric pumice, white to light brown.	75-76.1	6784.1-6783.0
	Pumice bed, altered, light brown (5YR 5/6), poorly welded. 30-40% felsic crystals, subangular; 30-40% white vitric pumice with rare mafic phenocrysts; 10-15% altered ash to clay/silt; clays around fringes of crystal constituents; trace lithics; moist.	76.1-76.7	6783.0-6782.4
	No recovery. No core unavailable for examination.	76.7-77	6782.4-6782.1
	Pumice bed, as above; slough likely from 77 to 77.3 ft bgs; decrease in felsic crystals to 10-15%, generally very fine to coarse; occasional very coarse felsic phenocryst in fibrous white pumice; slight increase in altered ash/pumice (fines) and lithics.	77-78.9	6782.1-6780.2
Qct, Cerro Toledo interval	No cuttings returned; no sample available for examination. **Note: The base of the Tsankawi Pumice Bed (Qbtt) and the contact with the underlying Cerro Toledo interval (Qct) is interpreted to be at 78.9 ft bgs based on geophysical logs.**	78.9-82.5	6780.2-6776.6
	Volcaniclastic sediments, silty sand with gravel, grayish orange (10YR 7/4), unconsolidated. Poorly sorted (10% silt, 10% fine sand, 25% medium sand, 40% coarse sand, 15% gravel); subrounded; felsic and mafic crystal poor; abundant white (N9) very coarse sand-sized pumice; subrounded to rounded intermediate composition volcanic clasts; moist.	82.5-87	6776.6-6772.1
	Volcaniclastic sediments, silty sandy gravel, moderate yellowish brown (10YR 5/4), unconsolidated. Poorly sorted (5% silt, 15% fine to very coarse sand, 80% gravel); subrounded; felsic and mafic crystal poor; gravel of intermediate composition volcanics clasts, up to 3.5 cm; moist.	87-87.7	6772.1-6771.4
	Volcaniclastic sediment, pumiceous silty sand, grayish orange (10YR 7/4), unconsolidated. Poorly sorted (90% of sediment is pumice, 3% silt, 7% fine to coarse sand); subrounded sand; felsic crystal poor; pumice white (N9), up to 2 cm, vitric, trace mafic phenocrysts; moist.	87.7-100	6771.4-6759.1
Qct, Cerro Toledo interval	Volcaniclastic sediments, silty sand, grayish orange (10YR 7/4), unconsolidated. Well sorted medium to coarse sand (5% silt, 30% medium sand, 65% coarse sand); felsic crystal poor; trace intermediate composition volcanic clasts and coarse sand sized very pale orange (10YR 8/2) pumice; large dacite clast at 101.6 ft bgs; wet.; limited saturated sediments, moisture may represent water that accumulated overnight.	100-101.8	6759.1-6757.3
	No recovery. No core available for examination.	101.8-107	6757.3-6752.1

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Qct, Cerro Toledo interval	Volcaniclastic sediments, as above.	107-107.4	6752.1-6751.7
	Volcaniclastic sediments, pumiceous sand, light brown (5YR 5/6), unconsolidated. Moderately sorted sand (90% pumice and ash, 10% fine to medium sand); pumice are white (N9), up to 1 cm, vitric, rare small mafic phenocrysts, subrounded; minor stratification visible; moist.	107.4-108	6751.7-6751.1
	Volcaniclastic sediments, as above, color change to grayish orange pink (10R 8/2); minor <1 cm thick intervals of light brown throughout.	108-122	6751.1-6737.1
	Volcaniclastic sediments, tuffaceous silty sandy gravel, grayish orange (10YR 7/4), unconsolidated. Poorly sorted (40% silt, 20% coarse sand; 40% gravel); silt-sized ash; subrounded sand; felsic crystal poor; subrounded gravels of intermediate composition volcanics, up to 4.5 cm; obsidian granules; moist.	122-122.3	6737.1-6736.8
Qbo, Otowi Member of the Bandelier Tuff	Tuff, light brown (5YR 5/6), poorly welded. Ash matrix; 5-10% felsic crystals; 2-3% lithics, occasional clast up to 1 cm, subrounded; 5% brown vitric pumices, fibrous, up to 2 cm, occasional felsic phenocrysts, trace surficial Mn/Fe oxide specks; damp to dry. **Note: The base of the Cerro Toledo interval (Qct) and the contact with the underlying Otowi Member (Qbo) is interpreted to be at 122.3 ft bgs.**	122.3-133.4	6736.8-6725.7
	Tuff, light brown (5YR 5/6), poorly welded. Ash matrix; 5-10% felsic crystals; 2-3% lithics, generally <0.5 cm, occasionally up to 5 cm, angular to subrounded surfaces; 1-2% pumice, up to 2 cm, rounded, light brown, vitric, felsic phenocrysts; damp to dry.	133.4-147	6725.7-6712.1
	Tuff, light brown (5YR 6/4), poorly welded. Ash matrix; 3-5% medium to coarse felsic crystals; 2-3% lithics, up to 2 cm, subangular; 2-3% pumices, yellow orange, vitric, felsic phenocrysts; dry to damp.	147-155	6712.1-6704.1
	Tuff, as above, increase in felsic crystals to 3-7%; increase in lithics to 3-5%, predominantly <0.5 cm; damp to dry.	155-157	6704.1-6702.1
	Tuff, grayish orange pink (5YR 7/2), poorly welded. Ash matrix; 2-3% felsic crystals; 3-7% lithics generally <0.5 cm, subangular; 1-2% pumices, yellow orange, <1 cm, vitric, felsic phenocrysts; damp to dry.	157-170	6702.1-6689.1
	Tuff, grayish orange pink (5YR 7/2), poorly welded. Ash matrix; 3-5% felsic crystals; 2-3% lithics, occasional lithic up to 1.5 cm, angular; 1-3% pumice, up to 3 cm, yellow orange and white, vitric, felsic phenocrysts; damp to dry.	170-188	6689.1-6671.1
	Tuff, as above; grayish orange pink (5YR 7/2) to light brown (5YR 6/4); lithic clasts up to 5 cm, subrounded; damp.	188-193.5	6671.1-6665.6
	Tuff, as above; grayish orange pink (5YR 7/2); dry to damp.	193.5-202	6665.6-6657.1
	Tuff, grayish orange pink (5YR 7/2), poorly welded. Ash matrix; 2-3% felsic crystals; 3-5% lithics, up to 1.5 cm, subangular; 2-3% pumice, yellow orange and white, vitric, felsic phenocrysts; dry to damp.	202-214.5	6657.1-6644.6
	Tuff, as above; pumice predominantly white.	214.5-238	6644.6-6621.1
	Tuff, as above; slight color change to pale yellowish brown (10YR 6/2) to grayish orange pink (5YR 7/2); pumice increase in yellow orange.	238-242	6621.1-6617.1
Qbo, Otowi Member of the Bandelier Tuff	Tuff, yellowish brown (10YR 6/2), poorly welded. Ash matrix; 2-3% felsic crystals; 3-5% lithics up to 1.5 cm, angular to subangular, brownish black; 1-2% vitric pumices, yellow orange; dry to damp.	242-247	6617.1-6612.1
	Tuff, as above, increase in pumice to 3-5%, up to 3 cm.	247-255	6612.1-6604.1
	Tuff, as above; grayish orange pink (5YR 7/2).	255-267	6604.1-6592.1

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Qbo, Otowi Member of the Bandelier Tuff	Tuff, grayish orange pink (5YR 7/2) to pale yellowish brown (10YR 6/2), poorly welded. Ash matrix; 7-10% felsic crystals, decreasing to 3-5%; 2-3% lithics, aphyric, black to brownish black, angular to subangular; 2-3% pumices, yellowish orange, vitric, fibrous, occasional felsic phenocrysts; dry to damp.	267-278	6592.1-6581.1
	Tuff, grayish orange pink (5YR 7/2), poorly welded. Ash matrix; 2-5% felsic crystals; 2-3% lithics, aphyric, black to brownish black, angular to subangular, generally <0.5 cm; 1-2% pumice, vitric, yellowish orange and occasional white; dry to damp.	278-303.5	6581.1-6555.6
	Tuff, as above, slight increase in felsic crystals to 5-7%; increase in lithics to 5-7%.	303.5-309	6555.6-6550.1
	Tuff, as above, pumice predominantly white; from 310-312 ft, trace altered mafics.	309-328	6550.1-6531.1
	Tuff, as above, slight increase in pumice to 2-5%; slight decrease in lithics to 2-3% and felsic crystals to 5%.	328-337	6531.1-6522.1
	Tuff, pale yellowish brown (10YR 6/2), poorly welded. Ash matrix; 5-10% lithics, angular to subangular, trace andesitic composition, up to 0.5 cm; 5% white to silvery gray pumice, up to 1 cm, vitric; 5% felsic crystals.	337-352	6522.1-6507.1
	Tuff, as above; few larger lithics to 1 cm size.	352-362	6507.1-6497.1
	Tuff, pale yellowish brown (10YR 6/2), poorly welded. 70-80% ash matrix; 10-15% felsic crystals; 5-10% dacitic-andesitic lithics, up to 1 cm, angular to subangular; 1-4% pumice, white to silvery gray, vitric, up to 1 cm.	362-369	6497.1-6490.1
	Tuff, as above; less pumice evident - 1-2%, some altered from moisture; moist.	369-380	6490.1-6479.1
	Tuff, as above, decrease in felsic crystals; 3-10% small lithics.	380-390	6479.1-6469.1
	Tuff, pale yellowish brown (10YR 6/2), poorly welded. 70-80% Ash matrix; 5-15% felsic crystals; 5-15% dacitic to andesitic lithics, angular to subangular, up to 1 cm; 1-2% white pumice, up to 1 cm, vitric, some altered from moisture; dry to moist.	390-412	6649.1-6447.1
	Tuff, as above; very poorly to non-welded; moist to wet.	412-413.4	6447.1-6445.7
	Tuff, pale yellowish brown (10YR 6/2), poorly welded. 80% ash matrix; 1-2% white pumice, partly altered (from moisture), up to 0.5 cm; 5-10% subangular to angular lithics, dacitic to andesitic, up to 0.5 cm; 5-10% felsic crystals; dry to moist.	413.4-445	6445.7-6414.1
	Tuff, pale yellowish brown (10YR 6/2), poorly welded. Ash matrix, soft; crumbly; 5-10% lithics, angular to subangular, dacitic to andesitic, up to 1 cm; 5-10% felsic crystals; 1-2% pumice, vitric, partly altered, white to yellow; minor alteration of pumice/matrix from moisture, no staining; moist.	445-456	6414.1-6403.1
Qbog, Guaje Pumice Bed of the Otowi Member of the Bandelier Tuff	Pumice Bed, very light gray (N8). 98% vitric pumice, fragments up to 2 cm, felsic phenocrysts; 2% lithics, subangular, dacitic to andesitic; moist. **Note: The base of the Otowi Member (Qbo) and the contact with the underlying Guaje Pumice Bed (Qbog) is interpreted to be at 456 ft bgs.**	456-460	6403.1-6399.1
	Pumice Bed, very light gray (N8); 90% light gray vitric pumice, fragments up to 1.5 cm, occasional felsic phenocrysts and rare hornblende phenocrysts; 5-10% lithics; 5% free felsic crystals; slight alteration of lithics from 460-462 ft; damp to moist.	460-473	6399.1-6386.1

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Tpf, Puye Formation (fanglomerate)	Volcaniclastic sediments, sandy silt, moderate brown (5YR 4/4). 60-70% fines, 30-40% fine to coarse sand, sand composed of subrounded to lithics (subrounded to rounded), occasional felsic crystal fragments and white pumice fragments; damp. **Note: The base of the Guaje Pumice Bed (Qbog) (base of the Otowi Member and the Bandelier Formation) and the contact with underlying Puye Formation (Tpf) is interpreted to be at 473 ft bgs.**	473-473.7	6386.1-6385.4
	No recovery. No core available for examination.	473.7-482	6385.4-6377.1
	Volcaniclastic sediments, poor recovery, silty gravel, varicolored clasts generally medium dark gray (N4) with occasional mottled reddish pink, unconsolidated. Moderately sorted gravels, up to 6 cm, smaller clasts subangular; large clast of dacite with aphanitic groundmass, frequent rectangular feldspar phenocrysts up to 0.5 cm, white; mafic phenocryst poor; minor fines.	482-482.3	6377.1-6376.8
	No recovery. No core available for examination.	482.3-497	6376.8-6362.1
	Volcaniclastic sediments, as above.	497-497.2	6362.1-6361.9
	No recovery. No core available for examination.	497.2-507	6361.9-6352.1
	Volcaniclastic sediments, sand with silt, grayish brown (5YR 3/2). Poorly sorted; subangular to subrounded clasts of intermediate volcanics, with felsic fragments and occasional pumice; trace gravel, subangular to subrounded; damp.	507-509.5	6352.1-6349.6
	Volcaniclastic sediments, pumiceous tephra, very light gray (N8). 95% pumice and pumice fragments, vitric, common biotite phenocrysts, frequent black faceted crystals <1mm; trace lithics, felsic crystals and ash; very slight Mn/Fe staining.	509.5-512	6349.6-6347.1
	Volcaniclastic sediments, pumiceous tephra, very pale orange (10YR 8/2). 98% altered pumice, up to 1 cm, biotite phenocrysts; 2% 1 mm size subangular lithics; trace felsic crystals.	512-517.1	6347.1-6342.0
	Volcaniclastic sediments, sandy gravel, moderate brown (5YR 3/4). Poorly-sorted intermediate composition volcanic clasts, up to 5 cm, subrounded, aphanitic groundmass; 15-20% sands; minor fines.	517.1-517.8	6342.0-6341.3
	No recovery; no core available for examination (coring attempt extended to 522.8 ft bgs). **Note: Remainder of lithologic log is based on visual inspection of cuttings.**	517.8-520	6341.3-6339.1
	Volcaniclastic sediments, moderately sorted gravel with sand, varicolored-light gray (N7) to moderate reddish orange (10R 6/6). WR (whole rock, unsieved): varied gravel clasts with minor sands, trace fines; 55-60% fine to medium gravel; 40-45% fine to medium sand, 5% fines. 10+F (i.e. plus No. 10 sieve-size fraction): broken to subrounded clasts of intermediate composition volcanic clasts including hornblende and biotite dacite, clay coating. 35+F (i.e. plus No. 35 sieve-size fraction): finer fraction as described for 10+F, with 5% pumices and trace felsic crystals.	520-525	6339.1-6334.1
	No cuttings returned; no sample available for examination.	525-530	6334.1-6329.1
	Volcaniclastic sediments, poorly sorted sand, varicolored, light gray (N7) to moderate orange pink (10R 7/4). WR: poorly sorted sand with minor fines and gravel. 10+F varied clasts of intermediate composition volcanic clasts, <0.5 cm, rounded to angular, biotite and hornblende dacite noted. 35+F finer fractions as described for 10+F.	530-535	6329.1-6324.1
Tb4, Cerros del Rio Basalt	Intermixing of cuttings, as above with trace vesicular basalt chips. **Note: The base of the Puye Formation (Tpf) and the contact with the underlying Cerros del Rio Basalt (Tb4) is interpreted to be at 535 ft bgs based on geophysical logs and first Tb4 appearance.**	535-540	6324.1-6319.1

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Tb4, Cerros del Rio Basalt	Basalt - Basalt fragments with equal percent of volcaniclastic sediments from above. Basalt, grayish black (N2), vesicular. 10+F: mixed returns of intermediate composition volcaniclasts (subrounded and rounded surfaces) from overlying formation and basalt; basalt grayish black, vesicular, frequent staining of vesicles. 35+F: finer fraction as described for 10+F, trace clay.	540-545	6319.1-6314.1
	Basalt; grayish black (N2). WR: basalt, massive, with minor vesicles, slightly granular groundmass. 10+F: basalt fragments, minor vesicles, 2-5% olivine phenocrysts - predominately reddish brown, trace olive green crystals, occasional reddish brown surrounding olivine green crystal (iddingsite), chips up to 2 cm, angular. 35+F: finer fraction as described for 10+F with trace intermediate composition volcanics.	545-560	6314.1-6299.1
	Basalt, grayish black (N2). WR: basalt, massive with minor vesicles. 10+F: basalt, massive with minor vesicles, 1-2% olivine (reddish brown) phenocrysts; 15% vesicular basalt with oxide staining and clay infilling of pits; trace clay fragments. 35+F: finer fraction as described for 10+F.	560-580	6299.1-6279.1
	Basalt; grayish black (N2). WR: basalt, massive with minor vesicles. 10+F: basalt chips, up to 2 cm, broken, massive with minor vesicles, 1-2% olivine (reddish brown and green) phenocrysts; 10-20% vesicular basalt with oxide staining and clay infilling of pits. 35+F: finer fraction as described for 10+F.	580-595	6279.1-6264.1
	Basalt; grayish black (N2) to very dusky red (10R 2/2), reddish basalt predominantly from 600-605 ft bgs. WR: basalt, massive with minor vesicles. 10+F: basalt chips, up to 2 cm, angular, massive with minor vesicles, 1-2% olivine (reddish brown and green) phenocrysts, trace clay infilling of pits. 35+F: finer fraction as described for 10+F.	595-615	6264.1-6244.1
	Basalt, grayish black (N2), minor very dusky red (10 R 2/2). WR: basalt, massive with minor vesicles. 10+F: basalt chips, broken, up to 3 cm, massive with minor vesicles, 1-2% olivine (reddish brown to green). 35+F: finer fraction as described for 10+F, trace clay fragments.	615-625	62441.1-6234.1
Tb4, Cerros del Rio Basalt	Basalt, intermixing of cuttings with overlying formation, pale yellowish brown (10YR 6/2). WR: 2-5% gravel, composed of fragments of lithics and pumices; 5-10% sand composed of fragments of felsic crystals, lithics and pumices; 85-90% ash-like fines. 10+F: 50% white, vitric pumices, felsic phenocrysts; 50% intermediate composition volcanic clasts; trace basalt. 35+F: finer fraction as described for 10+F with 20% felsic crystals, faceted faces noted.	625-630	6234.1-6229.1
	Basalt, intermixing of cuttings with overlying formation, varicolored, clasts generally medium gray (N5) to very dusky red (10R 2/2), with grayish orange (10YR 7/4) fines. WR: variable returns; 5-20% gravel; 65-80% fine to coarse grained sand; 5-15%fines. 10+F: basalt fragments, 50% increasing to 80% across interval, fragments up to 0.5 cm, vesicular, grayish black to very dusky red, angular to rounded edges, pits frequently clay lined are oxidized, 1-2% olive phenocrysts; 50% decreasing to 20% across interval intermediate composition volcaniclasts; trace pumices; trace sandstone. 35+F: finer fraction as described in 10+F with 15-40% felsic crystals.	630-650	6229.1-6209.1

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Tb4, Cerros del Rio Basalt	Basalt, medium gray (N5) to very dusky red (10R 2/2). WR: basalt, vesicular, angular to subrounded fragments, grayish orange (10YR 7/4) clay fines. 10+F: vesicular basalt fragments up to 1.5 cm, subangular to subrounded, 1-2% olivine phenocrysts; 2-5% intermediate composition volcaniclasts including dacite (intermixed cuttings); significant clay returns from 655-660 ft bgs, laminated. 35+F: 50-80% basalt fragments; 5-10% lithics clasts; 2% broken felsic crystals; 10-30% clay.	650-660	6209.1-6199.1
	Basalt, dark gray (N5). WR: basalt, massive. 10+F basalt chips, massive, 1-2% olivine phenocrysts (reddish brown to green). 35+F: finer fraction as described for 10+F, plus trace clay fragments and felsic crystals.	660-675	6199.1-6184.1
	Basalt, medium gray (N5). WR: basalt, massive. 10+F: basalt chips, up to 1.5 cm, slightly granular texture, 2-5% olivine phenocrysts (reddish brown to green), minor alteration/clay. 35+F: finer fraction as described for 10+F.	675-695	6184.1-6164.1
	Basalt, medium dark gray (N5). WR: basalt chips, massive, minor fines. 10+F: basalt chips, broken fragments, up to 2 cm, slightly granular texture, massive, 2-3% olivine phenocrysts (green and reddish brown); from 700-705 ft bgs: 5-10% greenish black (5G 2/1) basalt fragments with increased olivine phenocrysts. 35+F: finer fraction as described for 10+F, with trace clay fragments, trace free olivine crystals.	695-710	6164.1-6149.1
	Basalt, medium dark gray (N5). WR: basalt chips, massive, minor fines. 10+F: basalt chips, broken fragments, up to 2 cm, slightly granular texture, massive, 2-3% olivine phenocrysts (green and reddish brown); 5-10% weathered vesicular basalt, weathering appears as oxidation, vesicles frequently clay-lined, strongly aphanitic groundmass; large clast of siltstone at 720-725 ft. 35+F: finer fraction as described for 10+F, with 5-10% clay fragments increasing down hole; 720-725 ft moderate reddish brown (10R 4/6) fragments of sandstone/siltstone	710-725	6149.1-6134.1
Tpf, Puye Formation (fanglomerate)	Volcaniclastic sediments, silty sand with gravel, fines light brown (5YR 6/4) with varicolored clasts, predominately gray. WR: poorly sorted sand 40-50%, fines 30-35%, fine to medium gravels 10-15%. 10+F: varied clasts of intermediate composition volcanics, porphyritic with aphanitic groundmass, dacitic, andesite composition, trace rhyolitic composition, clasts varicolored including predominately gray clasts with lesser moderate red to white clasts, angular to subangular, trace rounded, generally <1.5 cm; trace clay, sandstone fragments; 5% basalt fragments. 35+F: finer fraction as described for 10+F, clay/ fragments approximately 15% of returns. **Note: The base of the Cerros del Rio Basalt (Tb4) and the contact with the underlying Puye Formation (Tpf) is interpreted to be at 722 ft bgs.**	725-730	6134.1-6129.1
	Volcaniclastic sediments, moderately sorted gravel with sand, fines light brown (5YR 6/4) with varicolored clasts. WR: 60-70% moderately sorted fine to medium gravel, 20-25% sand - poorly sorted, 5-10% fines. 10+F: as for 725 to 730 ft bgs interval with increase of siltstone/sandstone fragments to 2-5%. 35+F: finer fraction as described for 725 - 730 ft bgs interval.	730-735	6129.1-6124.1
	Volcaniclastic sediments, sandy silt, light brown (5YR 6/4). WR: 20-25% poorly sorted sands, 10-15% fine gravel, 70% fines. 10+F: as for 730-735 ft bgs interval. 35+F: as for 730-735 ft bgs interval.	735-740	6124.1-6119.1
	Volcaniclastic sediments, gravelly silt, light brown (5YR 6/4). WR: 20% well sorted fine gravel, 10-15% sand, 60-70% fines. 10+F: as described for 730-735 ft bgs interval, with trace clasts with black, cleavage poor phenocrysts in light colored aphanitic groundmass. 35+F finer fraction as described for 10+F, trace clay/sandstone fragments.	740-745	6119.1-6114.1

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
	TOTAL BOREHOLE DEPTH (TD) IS AT 745 FT BGS.		

NOTES:

Descriptions presented in this lithlog are primarily based on those made during visual examination of the drill core and cuttings. From 0 to 520 ft bgs drill core was primarily used to generate the lithlog, while drill cuttings were used from 520 to 745 ft bgs.

Stratigraphic contacts are based on available information from review of drill core and limited geophysical logs. There is general agreement between this borehole log and the geophysics report. Unrecovered and/or sampled core in sections of less than 5 ft are not noted unless relevant to lithologic description.

Descriptions of drill chips and drill core from sedimentary units such as the Quaternary Alluvium, Cerro Toledo Interval and the Puye Formation utilized principles outlined in *Petrology of Sedimentary Rocks* by Robert L. Folk. Color Descriptions were determined using The Geological Society of America, Rock-Color Chart.

Cuttings were collected at nominal 5 or 10-ft intervals and divided into three sample splits: (1) unsieved, or whole rock (WR), sample; (2) 10+F sieved fraction (No. 10 sieve equivalent to 2.0 mm); and (3) 35+F sieved fraction (No. 35 sieve equivalent to 0.5 mm). When cuttings were overall finer grained, then cuttings were divided into a 35+F sieved fraction and a 60+F sieved fraction.

Fractures were visually inspected for an approximate orientation. The angle of the fracture surface is approximated from vertical.

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

REFERENCES

Folk, Robert L., 1980, *Petrology of Sedimentary Rocks*, Hemphill Publishing Company.

The Geological Society of America, 1991, Rock-Color Chart.

Appendix C

Aquifer Testing Report

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I-8 BAIL TEST ANALYSIS

INTRODUCTION

This section describes the analysis of a hydraulic test conducted in February 2005 on intermediate well I-8, located in Mortandad Canyon. I-8 is completed in a low yielding perched zone in the Cerros del Rio basalt. The well was tested by bailing it dry and monitoring the slow refill for about 31 hours. Unfortunately, as described below, the data obtained did not support a definitive determination of formation conductivity. However, interpretations of the data are offered that provides some insight into formation properties.

I-8 is completed with a single screen, 10 feet long between the depths of 665 and 675 feet (the latter dimension actually documented as 674.96 feet) within the Cerros del Rio basalt. The original borehole was drilled to 745 feet, about 23 feet below the base of the Cerros del Rio into the Puye Formation. Video inspection of the open hole showed water entering a fracture in the basalt at a depth of 669 feet, and a stabilized water level overnight of 729.3 feet below land surface. Thus, because the water level did not rise to the visible entry point, it appeared that water entering the borehole was bypassing the perching layer and flowing into the Puye formation. It was not possible to know whether the perching zone was the lower portion of the basalt or the upper portion of the Puye Formation.

The borehole was grouted back to 681 feet and the static water level measured overnight was 658.5 feet. This could have represented the actual piezometric surface of the sediments above 669 feet, although multiple water level measurements were not made over time to see if the level changed.

After the well was completed, the measured static water level was 675 feet. This level was confirmed with a measurement of 674.83 feet below land surface on February 25, a day prior to testing. These static water level measurements, if accurate, coincided with the top of the sump beneath the well screen. (The sump is the blank casing zone below the well screen.) This suggested that the completed well served as a conduit for the perched water at 669 feet to flow past the perching unit.

BACKGROUND DATA

On February 26, approximately 2.5 gallons of water was bailed from the well from 8:10 am to 8:29 am, although the exact bailed volume is a little uncertain. Then periodic water level measurements were made until 3:27 pm on February 27. The wet inner wall of the well casing and screen caused several false water level indications initially. The first reliable reading was obtained at 9:30 am, 80 minutes after bailing began, yielding a water level of 677.68 feet below land surface. This was 2.85 feet below the static water level. Note that 2.85 feet of 4.5-inch ID casing holds 2.35 gallons of water, so this result was not inconsistent with the estimate of the volume of water bailed from the well.

Figure 1 shows the head change from the static water level measured in the 31 hours following bailing. Note on the graph that at 10:51 am, 81 minutes after the initial drawdown measurement, the water level had risen 0.61 feet (677.68-677.07). It is probable that an even greater inflow (recovery) would have occurred in the previous 80 minutes, between 8:10 am (when bailing

started) and 9:30 am. Applying this hypothetical extrapolation would put the initial bailed water level at a depth greater than 677.68 + 0.61 = 678.29 feet, or more than 3.46 feet below the static water level of 674.83 feet. Note that 3.46 feet of casing holds 2.86 gallons of water, meaning that the total volume of bailed water would have been greater than 2.86 gallons, again not inconsistent with the rough estimate of 2.5 gallons bailed from the well. Although the exact casing volume emptied is not known, it likely is not out of line with the bailed volume estimate.

I-8 DATA ANALYSIS

The initial static water level of 674.83 feet essentially coincided (remarkably, well within measurement error) with the recorded depth to the top of the well sump at 674.96 feet. On its face, this would suggest that down-flowing perched water that entered the well screen had filled the sump and then overflowed and continued migrating downward, bypassing the perching horizon. This would imply that the well and filter pack spanned the perching horizon providing a conduit for downward flow to the underlying vadose zone. However, there are problems with this scenario.

If a significant trickle of water was flowing into the well at 669 feet and providing water volume to refill the well sump after bailing, the refill rate into the sump should have been constant. This would be true if the inflow rate were constant and the downward rate bypassing the perching horizon were constant – both plausible assumptions. The refill rate then would be the difference between the inflow rate and the bypass rate. This, in turn, would have given a linear water level rise, and a straight line on Figure 1. Clearly, this was not the case, as the rate of rise was observed to decrease steadily over time. It even appeared that the water level may have been trending toward an asymptote significantly below the starting level. Figure 2 shows the calculated refill rate in gpm, computed as the volume of casing refilled between water level measurements divided by the time between measurements. Instead of a constant refill rate, the actual rate declined steadily by two orders of magnitude during the monitoring period. These observations seemed to rule out the idea of steady, significant influx of water into the borehole from 669 feet.

This leaves a couple of questions: 1) Where did the water come from that refilled a portion of the sump, and 2) why was the refill rate high at first, falling off dramatically over time?

One possibility is that the initial static water level was actually a foot or so above the top of the sump, within the filter pack, rather than right at the top of the sump. Although the well construction records and static water level measurement placed the water level and top of sump within about a tenth of a foot of each other, it would be surprising if all of the relevant measurements (casing lengths, water level and land surface references used during well construction and testing) were accurate to such a tight tolerance. It seems possible that there could have been discrepancies among the various measurements of up to a foot or so. Thus, even though the measured water level appeared to be right at the top of the sump, the actual water level could have been a little higher.

If the water level was above the top of the sump, a short distance up into the well screen, this could explain the observed water level response. Bailing water out of the well would allow drainage of the saturated filter pack above the sump. Such drainage would occur at a relatively

greater rate initially, gradually declining, consistent with observations, as the moisture content of the filter pack dropped.

At late time, once the filter pack was fully drained, additional water would have to come from the surrounding formation. This water could have come from saturated sediments adjacent to the previously saturated filter pack. Under this scenario, it is probable that the perched zone originally supporting the trickle of water at 669 feet may have been of limited extent and may have dried up (drained away).

Also, under this scenario, the volume of water removed by bailing would have included the approximately 3.46 feet of well casing and screen described above (2.86 gallons) plus an additional small volume from a short interval of filter pack. Even so, this new volume would not be seriously at odds with the very approximate estimate of 2.5 gallons bailed from the well. It is possible that operation of the bailer would have splashed a small volume of water up into filter pack pore spaces above the original static water level, where a certain fraction would have remained by capillary action. Also, if water leaked from the bailer during the trips out of the well, some of the leaked water would have wet the inner wall of the casing above the water table and would have remained there. Thus, the measured volume bailed from the well plus these losses could have corresponded closely with the water removed from the well casing and filter pack.

If this latter scenario is the correct one, the transmissivity of the short saturated screen zone can be estimated by treating the recovery event as a constant-drawdown pumping test (Jacob and Lohman, 1952). If L is the height of the original static water level above the top of the well sump (i.e., saturated screen length), during refilling of the sump the effective drawdown on the saturated zone would have been equal to L. In this analysis, the saturated formation thickness was taken to be the distance from the static water level to the base of the filter pack. Because of the extremely low flow rates, it was judged that friction losses in the filter pack and vertical convergence losses through the filter pack to the well screen would have been negligible. Thus, hydraulically, the system was assumed to perform as though the screen extended through the entire filter pack length. The filter pack extended to 678.5 feet, or 3.5 feet below the bottom of the well screen. Defining b as the saturated formation thickness, it follows that: $b = L + 3.5$.

To compute the transmissivity of the short saturated zone, the reciprocal of the flow rate (refill rate) is plotted versus time on a semilog graph. A straight line of best fit is constructed through the data points and its slope is calculated as the change in $1/Q$ over one log cycle of the graph. The transmissivity is computed as follows:

$$T = \frac{35.3}{L\Delta(1/Q)},$$

where

T = transmissivity, in ft^2/day
L = drawdown, in feet [equal to the saturated screen length]
$\Delta(1/Q)$ = change in $1/Q$ over one log cycle, in minutes per gallon

Hydraulic conductivity then is computed as follows:

$$K = \frac{T}{b} = \frac{35.3}{(L+3.5)L\Delta(1/Q)},$$

where K is expressed in feet per day.

Figure 3 shows a semilog plot of $1/Q$ versus time. The early data showing the flat slope presumably corresponded to times when drainage from the filter pack contributed to flow. Conversely, the steep slope presumably corresponded to times when filter pack drainage was negligible and the saturated formation contributed all of the flow. The straight line of best fit yielded the following:

$$K = \frac{0.0042}{(L+3.5)L}.$$

For saturated screen lengths of 0.5, 1 and 2 feet, the computed K values were 0.0021, 0.00093 and 0.00038 feet per day, respectively. These values are depicted graphically on Figure 4.

Unfortunately, the actual saturated height above the bottom of the well screen can't be known precisely, although based on the limited volume of water bailed from the well and the refill volume coming primarily from the filter pack, an estimate of about a foot (plus or minus) is probably "in the ballpark."

The gist of this analysis is that the hydraulic conductivity of the limited saturated zone sediments at the base of the well screen is very low, consistent with intuitive conclusions based on the extremely slow refill rate after bailing, exhibited on Figures 1 and 2 at late time.

As a second attempt to quantify formation properties, the specific capacity of the well was 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 percent efficient. The resulting hydraulic conductivity is the value required to sustain the observed specific capacity. If the actual well is less than 100 percent efficient, it follows that the actual hydraulic conductivity would have to be greater than calculated to compensate for well inefficiency. Thus, because the efficiency is unknown, the computed hydraulic conductivity value represents a lower bound. The actual conductivity is known to be greater than or equal to the computed value.

For this analysis, the Cooper-Jacob equation was solved for transmissivity and iterated to yield a solution:

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

where

T = transmissivity, in gpd/ft
Q = flow rate, in gpm
s = drawdown, in feet [equal to L, the saturated screen height]
t = time, in days
r_w = borehole radius, in feet

From this, hydraulic conductivity was computed as follows:

$$K = \frac{T}{7.48b},$$

where

K = hydraulic conductivity, in feet per day
b = saturated thickness (from static water level to bottom of filter pack), in feet
$= L + 3.5$

To apply the Cooper-Jacob formula, a storage coefficient value must be assigned. There was no technical basis for assigning a storage coefficient value, confined or unconfined. Several storage coefficient values were tried and it was found that solution convergence could not be achieved for storage coefficient values in the unconfined range. Therefore, an arbitrary value of 0.003 was assigned for the analysis. This falls between confined and unconfined storage coefficient values. It also is typical of the elastic storage coefficient exhibited by unconfined systems that have not yet gravity drained. The calculation result is not especially sensitive to the choice of storage coefficient value, so a rough estimate of the storage coefficient was adequate to support the estimates.

The specific capacity was estimated by observing the casing refill rate near the end of the monitoring period. Over the last three water level measurements, from 1537 minutes to 1877 minutes (average elapsed time of 1707 minutes), the observed average refill rate was computed to be 0.000146 gpm. Other input parameter values used were a borehole radius of 0.51 feet and saturated screen lengths of 0.5, 1 and 2 feet (corresponding to b = 4, 4.5 and 5.5 feet, respectively).

For assumed saturated screen lengths of 0.5, 1, and 2 feet, the resulting lower-bound hydraulic conductivity estimates were 0.0046, 0.0016 and 0.00042 feet per day, as diagrammed on Figure 4. These values were very low and, while somewhat different than previously obtained values (actually a little greater), were of the same order of magnitude.

The preceding analyses were based on several assumptions that were difficult to verify. Unfortunately, the minimal (and unknown) saturated formation height above the sump, coupled with the very slow recovery, produced a data set that did not lend itself to any other analyses. In other words, the conclusions derived from the I-8 test were constrained by the nature of the

limited saturated formation being tested and the slow recovery rate. Based on the limits of the available test, the hydraulic conductivity may be between about 10^{-4} and 10^{-2} feet per day.

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Cooper, H. H., Jr. and C.E. Jacob, 1946. "A Generalized Graphic Method for Evaluating Formation Constants and Summarizing Well Field History," Transactions Am. Geophys. Union, vol. 27, no. 4, pp. 526-534.

Jacob, C.E. and S.W. Lohman, 1952. "Nonsteady Flow to a Well of Constant Drawdown in an Extensive Aquifer," Am. Geophys. Union Trans., vol. 33, p. 559-569.

Figure 1. Bail Test Data - Linear Scale

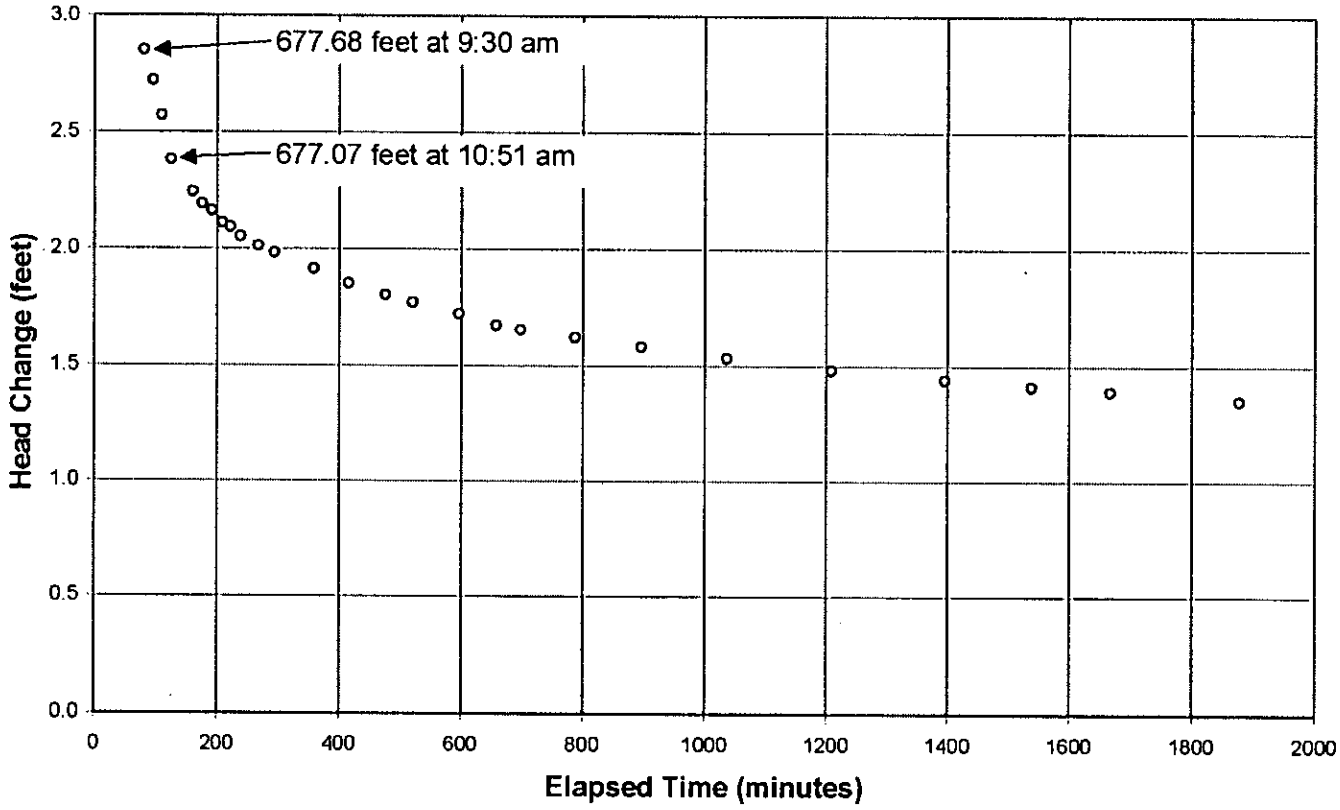


Figure 2. Refill Rate Versus Time

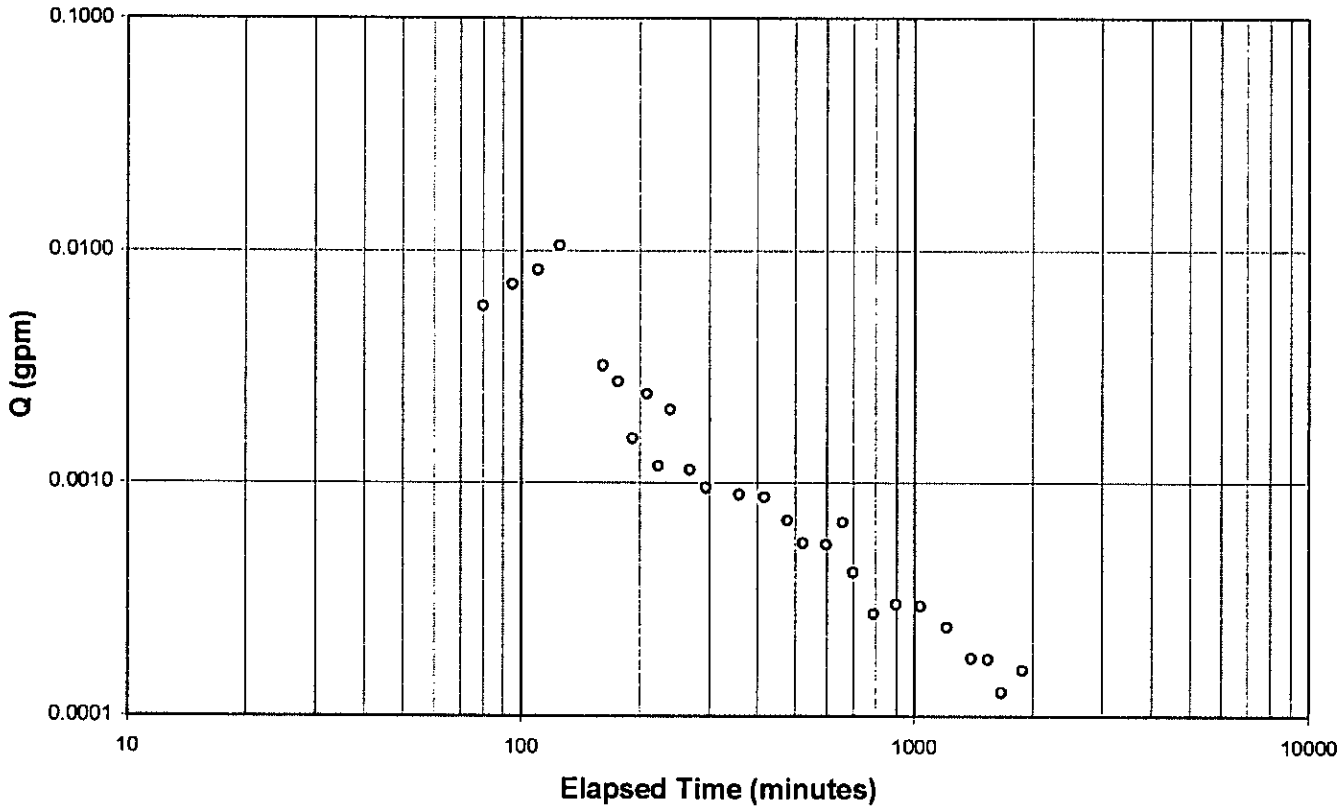


Figure 3. Reciprocal of Refill Rate Versus Time

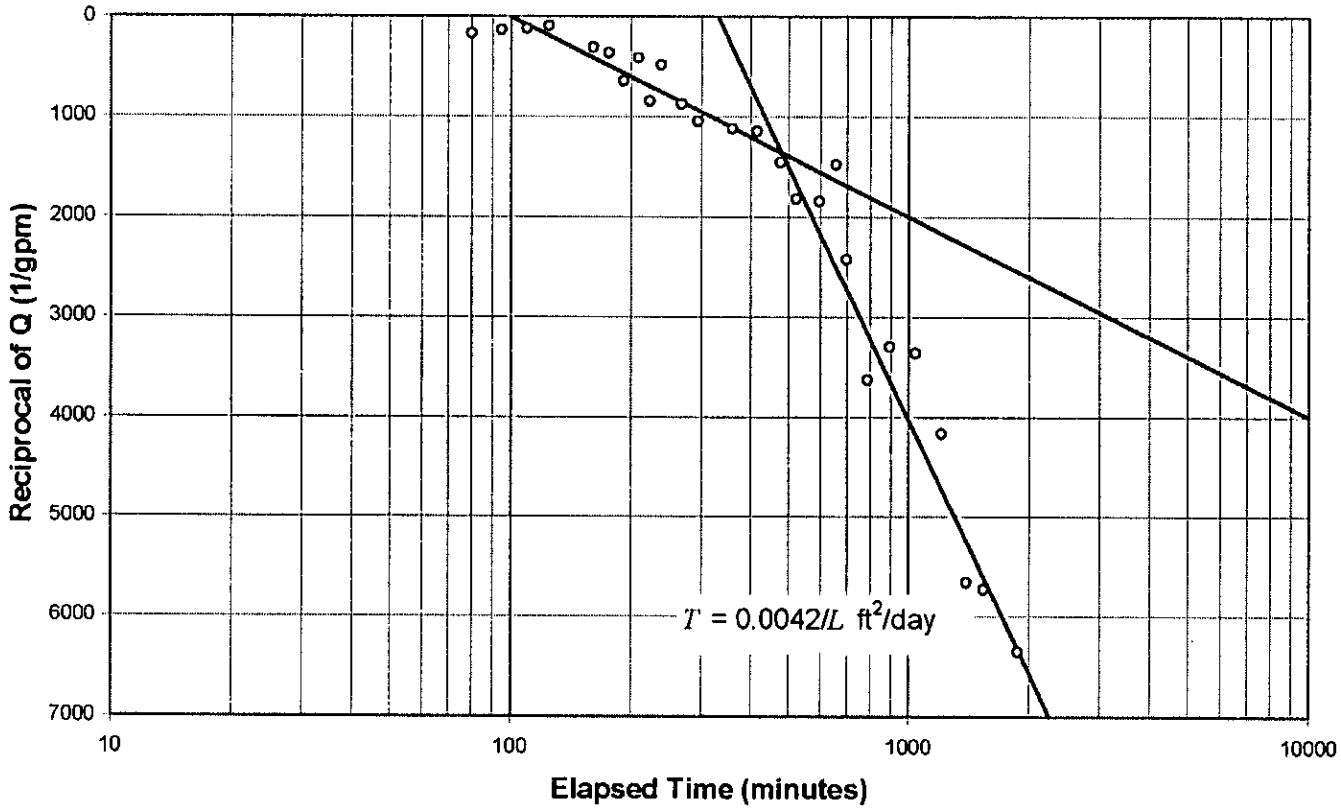
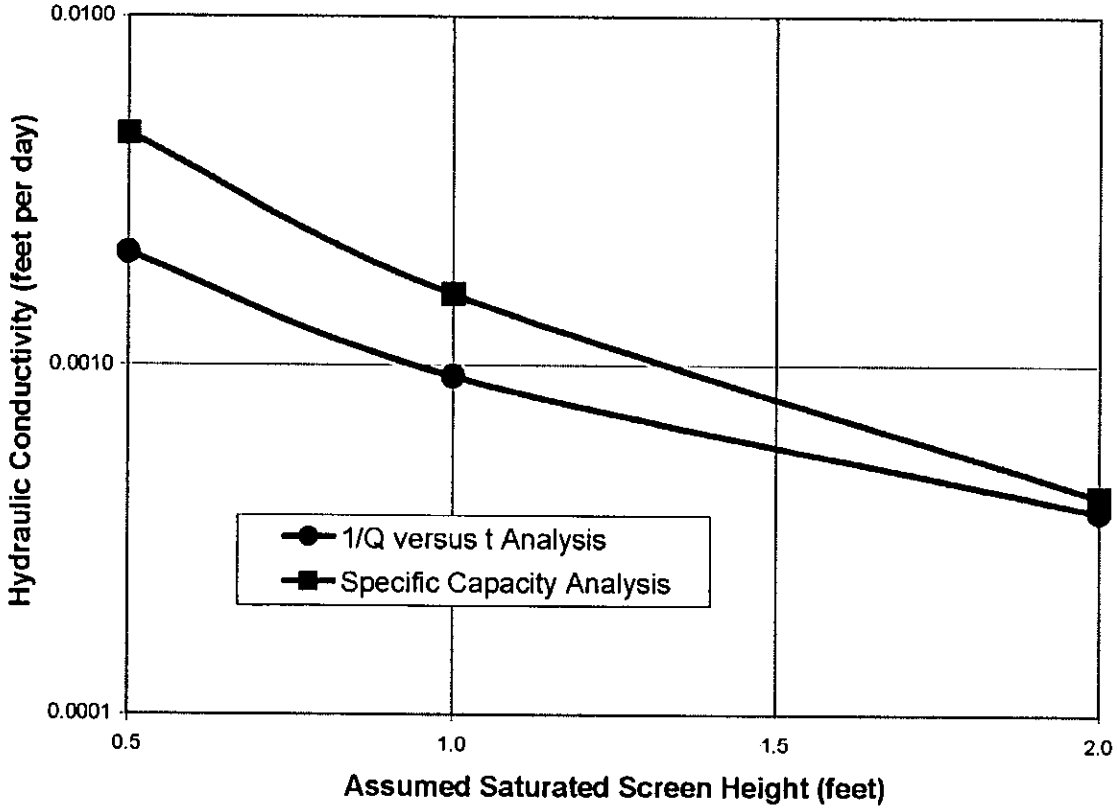


Figure 4. Hydraulic Conductivity Estiamtes



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COMPLETION REPORT
INTERMEDIATE WELL I-10
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

amsl	above mean sea level
bgs	below ground surface
BMPs	best management practices
DOE	United States Department of Energy
DTHH	down-the-hole hammer
DTW	depth to water
FSF	Field Support Facility
ft	foot/feet
ft^3	cubic feet
gal.	gallon/gallons
hr	hour
in.	inch/inches
Kleinfelder	Kleinfelder, Inc.
LANL	Los Alamos National Laboratory
lb	pound/pounds
NMED	New Mexico Environment Department
OD	outer diameter
psi	pounds per square inch
RCT	radiation control technician
SSLs	Soil Screening Levels
SMO	Sample Management Office
TA	Technical Area
TD	total depth
TKN	total Kjeldahl nitrogen
US	United States

ABSTRACT

Intermediate well I-10 was installed as part of the Risk Reduction and Environmental Stewardship-Remediation Services project at Los Alamos National Laboratory (LANL). I-10 was installed in accordance with the "Mortandad Canyon Groundwater Work Plan, Revision 1" (LANL 2004) and the "Final Drilling Plan for Intermediate Wells, Mortandad Canyon, Los Alamos National Laboratory" (Kleinfelder 2004b). The United States (US) Department of Energy (DOE), with technical assistance from LANL, contracted and directed the work.

Data from I-10 will be used in conjunction with data from other wells in Mortandad Canyon to improve the conceptual model of the geology, hydrogeology, and hydrochemistry of the area to provide data for numerical models that address contaminant migration in the vadose (unsaturated) zone. This information will be used to facilitate decision-making with regard to regulatory compliance, risk assessment, and remediation.

The majority of the fieldwork at I-10 was completed from November 3, 2004, through February 10, 2005, during which a separate corehole and borehole were drilled. The corehole was drilled to assess contaminant profiles from 300 to 800 feet (ft) below ground surface (bgs). The actual interval of core collection was from 300 to 727.3 ft bgs. Because I-10 is located on a mesa top, core did not need to collected above 300 ft bgs (approximate level of the Mortandad Canyon floor). Video and geophysical logs were run before the corehole was backfilled with bentonite and abandoned. A separate I-10 borehole was drilled to a total depth of 1,050 ft bgs using air-rotary and fluid-assisted air-rotary drilling methods. Video and geophysical logging was performed in the open borehole to help delineate the hydrostratigraphy. The stratigraphy encountered during borehole drilling included, in descending order, Tshirege Member of the Bandelier Tuff (Unit 3, Unit 2, Unit 1v, Unit 1g, and the Tsankawi Pumice Bed), Otowi Member of the Bandelier Tuff, Guaje Pumice Bed, upper Puye Formation, Cerros del Rio basalt, and lower Puye Formation.

Groundwater was not observed entering the borehole, thus it was plugged and abandoned.

1.0 INTRODUCTION

This completion report summarizes the site preparation, drilling, plug and abandonment, and related activities for I-10. Kleinfelder, Inc. (Kleinfelder), under contract to the United States (US) Army Corps of Engineers, was responsible for executing the drilling, installation, testing, and sampling activities. The US Department of Energy (DOE), with technical assistance from Los Alamos National Laboratory (LANL), contracted and directed the this work

I-10 is located in Technical Area (TA) 5 on the mesa south of Mortandad Canyon in LANL (Figure 1.0-1), and was installed to evaluate whether contaminated perched groundwater is migrating southward along geologically controlled features such as bedding surfaces or paleochannels within the Cerro Toledo interval and Cerros del Rio basalt. The data quality objectives are provided in the "Mortandad Canyon Groundwater Work Plan, Revision 1" (LANL 2004) and the "Final Drilling Plan for Intermediate Wells, Los Alamos National Laboratory" (Kleinfelder 2004b). Geochemical and hydrostratigraphic data and geologic information obtained from I-10 will augment the conceptual model and knowledge of contaminant distribution in the intermediate perched zone in the Mortandad Canyon system.

The objectives of the coring and drilling activities were to collect core and cuttings of encountered geologic formations, collect groundwater samples from perched intermediate aquifers (if present), and install a single-screen characterization well near the base of the Cerros del Rio basalt if saturation was encountered. A separate corehole and borehole were drilled. The corehole was drilled to assess contaminant profiles from 300 to 800 feet (ft) below ground surface (bgs). The projected total depth (TD) of the borehole was 1,000 ft bgs. The actual TD of the I-10 borehole was 1,050 ft bgs. Groundwater was not encountered in the corehole or borehole; therefore, they were plugged and abandoned.

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, New Mexico office and LANL's Records Processing Facility. Further analysis and interpretation of geologic and geochemical data will be included in separate technical documents to be prepared by LANL.

2.0 SITE PREPARATION AND DRILLING ACTIVITIES

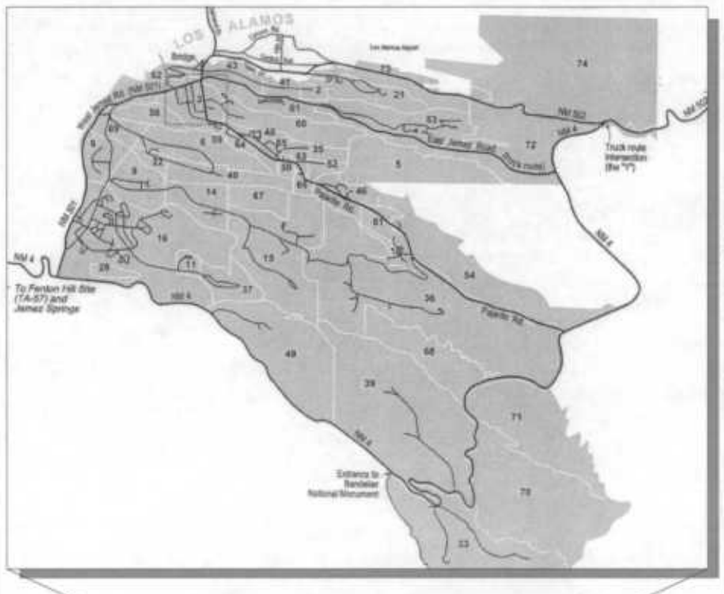
Site preparation consisted of constructing and lining the cuttings pit, erecting silt fencing to prevent erosion and runoff from the drill site, and setting up the exclusion zone. Best management practices, also known as BMPs, were installed as specified in the "Storm Water Pollution Prevention Plan, Mortandad Canyon Ground Water Work Plan, Los Alamos National Laboratory" (Kleinfelder 2004a). EnviroWorks, Inc. completed these tasks from October 27 through November 1, 2004. A radiation control technician (RCT) from LANL's Health, Safety, and Radiation Protection Group-1 screened the site before site preparation activities. A geology trailer, generator, compressor, and safety lighting equipment were moved to the site during the subsequent mobilization of drilling equipment.

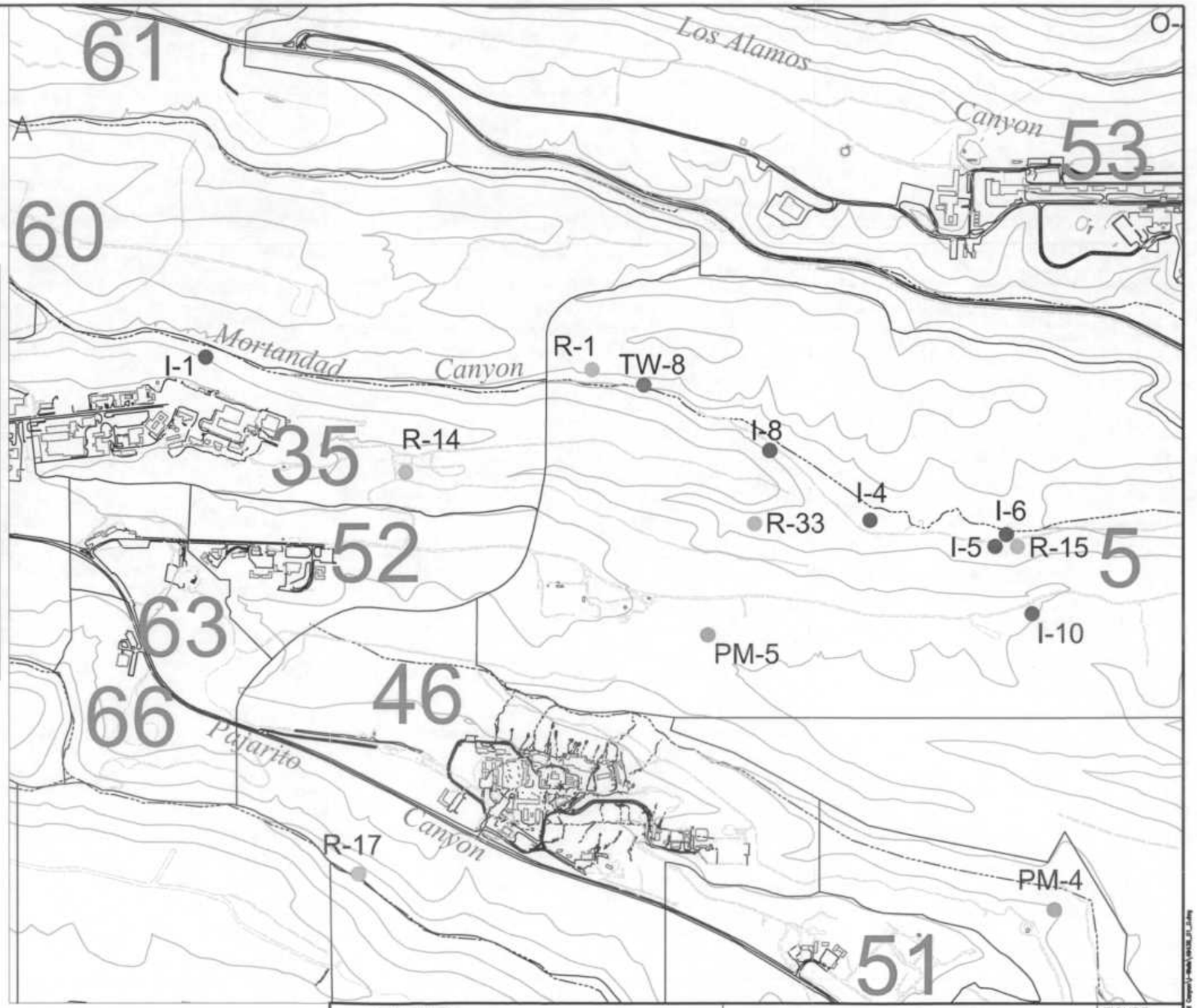
The I-10 corehole was advanced from ground surface to 727.3 ft bgs from November 3 to November 10, 2004. The corehole was backfilled with bentonite and abandoned.

From January 19 through January 27, 2005, a separate borehole was advanced to a TD of 1,050 ft bgs using air-rotary and fluid-assisted, air-rotary drilling methods. Groundwater-bearing zones

Legend

- = Intermediate perched zone wells (proposed)
- = Regional aquifer wells installed since 1998
- = Older test wells
- = Water supply wells
- 58 = Technical area identification
- = 100-ft contours





1000 0 500 1000

SCALE: 1 inch = 1000 ft

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Scale: 1" = 1000'	Revision: –

SITE LOCATION MAP
Intermediate Wells I-1, I-4, I-5, I-6, I-8, I-10
Mortandad Canyon
Los Alamos National Laboratory
Los Alamos, New Mexico

FIGURE
1.0-1

were not encountered. Thus, the borehole was abandoned by backfilling with bentonite and bentonite-cement grout. Drilling activities were performed generally in one 12-hour (hr) shift per day, 7 days per week, by the drill crew and two site geologists.

2.1 Coring Activities

Coring operations were performed by Spectrum Exploration, Inc. using a Delta Base DB540 drill rig equipped with split spoon, HQ3 Coring, Geobarrel®, and 115-millimeter Tubex drilling systems.

On November 3, 2004, mobilization of coring equipment and supplies to the I-10 site was completed and drilling began. Core was collected from 300 to 727.3 ft bgs. The continuous-core drilling began on November 4, using air-only coring methods. Drilling fluids were not used to advance the I-10 corehole. Core sampling and analysis is presented in Section 3.0.

Temporary casing was utilized to improve corehole stability. Initially, 6⅝-inch (in.) outside diameter (OD) surface casing was installed to a depth of 25 ft bgs using a 7⅜-in. Tubex under-reamer system. Due to corehole instability, the 6⅝-in. casing was later advanced to 200 ft bgs. An additional casing string (5½-in. OD) was telescoped through the 6⅝-in. casing to a depth of 345 ft bgs. This temporary casing string later slipped downhole approximately 30 ft such that the lower end of the casing was at 375 ft bgs.

After reaching 727.3 ft bgs (TD) on November 10, 2004, a Kleinfelder representative conducted geophysical and video logging of the corehole. During coring, the corehole was monitored for the presence of groundwater using a depth to water (DTW) meter. Groundwater was not detected during drilling or in the video log. On November 11 and 15, 2004, the corehole was backfilled with bentonite chips to 2 ft bgs concurrent with the removal of the temporary casing. A cement grout seal was applied to ground surface, and the corehole was abandoned.

2.2 Well Drilling Activities

WDC Exploration & Wells drilled a separate borehole at I-10 using air-rotary and fluid-assisted, air-rotary drilling techniques. The borehole was drilling using a GEFCO Speedstar 50K drill rig equipped with conventional drilling rods and drill collars, tricone bits, down-the-hole hammer (DTHH) bits, air compressors, and support equipment. Drilling fluids, consisting of a mixture of municipal water with QUIK-FOAM® and EZ-MUD®, were used as needed to improve borehole stability and facilitate cuttings removal from the borehole. An approximate tally of the total drilling fluids introduced into the borehole, as well as the total fluids recovered, is presented in Table 2.2-1.

Table 2.2-1
Introduced and Recovered Fluids

Material		Amount (gallons)
Introduced	QUIK-FOAM®	295
	EZ-MUD®	2
	Potable Water	9,915
	Total introduced fluids[1]	10,212
Recovered	Total recovered fluids[2]	7,500

[1]Represents the fluids introduced during drilling
[2]Represents the estimated fluid volume recovered during drilling

On January 19, 2005, mobilization of drilling equipment and supplies to the I-10 site was completed. Drilling began using a 12¼-in. diameter tricone bit, advanced to 23 ft bgs. A 23-in. OD hole-opener was advanced to 9.3 ft bgs followed by the installation of 16-in. OD permanent surface casing, also to 9.3 ft bgs. The casing was cemented in place.

On January 20, the borehole was advanced using air rotary with fluid assist (water with QUIK-FOAM®) and a 12¼-in. diameter tricone bit to 710 ft bgs. Basalt was encountered at approximately 710 ft bgs. Removal of the drill string (tricone bit and drill rod) began to measure the DTW and change the drill bit.

On January 21, the remaining drill string was removed (tripped out) and DTW was measured in the borehole at 690.70 ft bgs. Attempts to collect a sample of the fluids using a stainless-steel bailer were unsuccessful. Borehole video logging was conducted using Kleinfelder equipment. The video was run to approximately 700 ft bgs where dry, collapsed formation material was encountered. Water was not observed in the borehole. The tricone drill bit was replaced with a 12¼-in. DTHH bit, and the borehole was advanced to 770 ft bgs.

On January 22, the borehole was advanced to 1,010 ft bgs.

On January 23, drilling continued with the 12¼-in. DTHH from 1,010 ft bgs to the TD of 1050 ft bgs. The drill string was tripped out to allow for DTW measurements and borehole video logging.

On January 24, a borehole video log was conducted using LANL equipment. A bridge of formation material was observed in the borehole at 881 ft. The DTHH was replaced with a 12¼-in.-diameter tricone bit, and advanced to 963 ft bgs to remove the bridged material.

On January 25, borehole cleaning continued across the bridged interval. The drill bit became plugged, and the drill string was removed to clean the bit. Borehole cleaning resumed to the original TD of 1,050 ft bgs. A small volume of EZ-MUD® was added to facilitate borehole stability.

On January 26, the bottom of the borehole was measured at 1,047 ft bgs, indicating 3 ft of formation material had accumulated overnight. The drill string was removed to allow for borehole video logging using LANL equipment. During video logging, standing fluids were observed at 1,041 ft bgs. Gamma and induction geophysical logging was conducted.

On January 27, an additional borehole video log was conducted using LANL equipment. Fluids were observed at 1,041 ft bgs. Water was not observed entering the borehole. The final borehole video log is located on the DVD in Appendix A.

On January 28, DTW was 1041.20 ft bgs. A sample of borehole fluids (sample set CAMO-05-56808 and CAMO-05-56813) was collected using disposable and stainless-steel bailers. DOE elected to plug and abandon the borehole because a perched zone was not evident. Mobilizing of plugging materials to the site and demobilizing of equipment began. The bottom of the borehole was tagged at 1041 ft bgs. Backfilling began using a mixture of bentonite and 10/20 sand from 1,041 to 1,011 ft bgs.

On January 29 through 31, backfilling using bentonite and sand continued from 1,011 to 383 ft bgs.

On February 1, the borehole was backfilled with a mixture of bentonite and 10/20 sand from 383 to 323 ft bgs. From 323 to 248 ft bgs, a cement-bentonite grout was used.

On February 2, the GEFCO 50K drill rig was demobilized from the site, and the location secured for days off.

On February 8, the crew returned from days off and continued demobilization activities. Application of the grout seal was delayed due to heavy snow.

On February 9 and 10, the borehole was backfilled with cement-bentonite grout from 248 ft bgs to ground surface. The 16-in. surface casing was left in place.

3.0 SAMPLING ACTIVITIES

Core, cuttings, groundwater screening samples, and waste characterization samples were collected at I-10. Sampling activities were conducted in accordance with the drilling plan (Kleinfelder 2004b). Deviations are noted in Section 9.0.

3.1 Sampling of Core and Drill Cuttings

Core was collected from 300 to 727.3 ft bgs. Samples of the core were analyzed for anions, moisture content, tritium, and stable isotopes as summarized in Table 3.1-1. Samples were placed in appropriate sample jars and protective plastic bags and submitted to LANL's Sample Management Office (SMO) for analysis. The remaining core was placed in lay-flat plastic tubing, labeled, stored in standard LANL Environmental Restoration core boxes, and transported to the Field Support Facility (FSF) for archiving and storage.

During rotary drilling, drill cuttings were collected from 0 ft bgs to TD at approximately 5-ft intervals from the borehole discharge line. Portions of the cuttings samples were sieved (using #10 and #35 mesh) and placed in chip trays along with unsieved cuttings. Aliquots of the >#10 fraction of cuttings were prepared for all intervals where sufficient returns were available. The sieved fractions were placed in labeled plastic bags and submitted to LANL for potential mineralogic, petrographic, and geochemical analyses. The remaining cuttings were sealed in Ziploc® bags, labeled, and stored in core boxes, and transported to the FSF for archival and storage. With the exception of waste characterization, drill cuttings were not submitted for chemical analyses.

Table 3.1-1. Core Samples Collected and Analyzed

Location ID MO-24232 I-10

Core Samples			ANALYSES						
Sample ID	Sample interval (ft)	Date/Time	Moisture	Tritium (H3)	anions/cations	N14N15	D2H O18O16	ARS (DOT screening)	Notes
CAMO-05-56885	300-301.7	11/4/2004 14:06	x	x	x	x	x	x	
CAMO-05-56886	311.3-312.5	11/4/2004 14:39	x	x	x	x		x	
CAMO-05-56887	323-324.5	11/4/2004 17:25	x	x	x	x		x	
CAMO-05-56888	333-334.5	11/4/2004 17:52	x	x	x	x		x	
CAMO-05-56889	308.5-350	11/7/2004 7:30	x	x	x	x	x	x	
CAMO-05-56890	363.5-365	11/7/2004 8:10	x		x	x	x	x	
CAMO-05-56891	368.5-370	11/7/2004 8:20	x	x	x	x		x	
CAMO-05-56892	379.5-381	11/7/2004 8:50	x	x	x	x		x	
CAMO-05-56893	390.5-392	11/7/2004 9:20	x		x	x		x	poor recovery, no N isotopes
CAMO-05-56894	401-402	11/7/2004 10:00					x	x	
CAMO-05-56896	438.3-440	11/7/2004 12:15	x	x	x	x		x	
CAMO-05-56897	450.5-451.5	11/7/2004 12:55					x	x	
CAMO-05-56898	489.5-491	11/7/2004 15:10	x	x	x	x		x	
CAMO-05-56899	501-502	11/7/2004 15:40					x	x	
CAMO-05-56900	539.3-540.8	11/7/2004 0:00	x	x	x	x		x	
CAMO-05-56901	550.2-551.2	11/7/2004 0:00					x	x	
CAMO-05-56902	590.7-592.2	11/8/2004 11:40	x	x	x	x		x	
CAMO-05-56903	601.1-602.1	11/8/2004 12:18					x	x	
CAMO-05-56904	640.7-641.2	11/8/2004 14:50	x	x	x	x		x	
CAMO-05-56905	650.8-651.8	11/8/2004 15:30					x	x	
CAMO-05-56906	693.5-695	11/9/2004 9:40	x	x	x	x		x	
CAMO-05-56907	698.5-699.5	11/9/2004 10:25					x	x	
CAMO-05-56911	721.1-723.4	11/10/2004 8:15	x	x	x	x	x	x	

LANL RCTs screened the cuttings and core prior to their removal from the site.

3.2 Groundwater Sampling

Groundwater was not detected in the corehole; therefore, a sample was not collected.

On January 28, 2005, three days after drilling the borehole to TD, borehole fluids were collected from the open borehole. Prior to sample collection, the DTW was 1041.20 ft bgs and borehole TD was approximately 1,047 ft bgs; however, a borehole TD measurement conducted later in the shift was approximately 1041 ft bgs presenting some uncertainty of the actual depth during sample collection. A limited volume of fluids was available for sampling. The sample (sample set CAMO-05-56808 and CAMO-05-56813) was submitted to SMO for analyses of anions, metals, and tritium.

3.3 Waste Characterization Sampling

On February 9, 2005, samples of drill cuttings and recovered drilling fluids were collected for waste characterization. These samples were submitted to Hall Environmental Analysis Laboratory in Albuquerque, New Mexico for anions, polychlorinated biphenyls, volatile organic compounds, semi-volatile organic compounds, metals, mercury, radionuclides, perchlorate, explosives, and tritium analyses. Analytical results were received on March 4, 2005, and submitted to DOE and LANL for review.

4.0 BOREHOLE LOGGING

Kleinfelder logged the I-10 corehole and borehole to acquire visual observations and geophysical data to help characterize borehole conditions and hydrostratigraphy. Table 4.0-1 summarizes the video and geophysical logs that were run in the I-10 corehole and borehole.

Table 4.0-1
Borehole Logging Conducted

Operator	Date	Corehole/ Borehole	Cased Footage (ft bgs)	Open-Hole Interval (ft bgs)	Logged Interval (ft bgs)	Remarks	Tools
Kleinfelder	11/11/04	Corehole	0-375	375-727.3	17-722	Coring completed; video does not extend to base of hole, no water observed on walls	Video camera
Kleinfelder	11/11/04	Corehole	0-375	375-727.3	375-727.3	None	Array induction
Kleinfelder	11/11/04	Corehole	0-375	375-727.3	0-727.3	None	Natural gamma
Kleinfelder	1/21/05	Borehole	0-9.3	9.3-710 (slough to 700)	0-700	Dry	Video camera
LANL	1/24/05	Borehole	0-9.3	9.3-1,050	0-880	Bridge in borehole at 881 ft bgs	Video camera
LANL	1/26/05	Borehole	0-9.3	9.3-1,050 (slough to 1047)	0-1041	Standing water at 1,041 ft bgs	Video camera
Kleinfelder	1/26/05	Borehole	0-9.3	9.3-1,050 (slough to 1047)	0-1047	None	Array induction, Natural gamma
LANL	1/27/05	Borehole	0-9.3	9.3-1,050 (slough to 1047)	0-1041	Standing water at 1,041 ft bgs	Video camera

4.1 Video Logging

Video logging was conducted during coring and drilling to evaluate for the presence of perched water-bearing zones. The video logging conducted at I-10 is shown in Table 4.0-1. Kleinfelder personnel ran a video log upon reaching the corehole TD of 727.3 ft bgs. The video was run to approximately 722 ft bgs and did not extend to the base of the corehole. Corehole walls were dry from 0 to 722 ft bgs and did not indicate the presence of groundwater. The Kleinfelder-owned Geo VISION™ Junior video camera counter has a manufactured accuracy of +/-2%; therefore, the video presents approximate depths.

Borehole videos were conducted on several occasions. On January 21, 2005, a video was conducted by Kleinfelder to assess for groundwater at the top of the Cerros del Rio basalt. The borehole was dry. LANL personnel conducted subsequent videos after reaching the borehole TD of 1050 ft bgs. These videos were conducted using LANL equipment. No evidence of groundwater was observed. A small volume of standing fluids was noted in the borehole. Appendix A contains the DVDs of the corehole and final borehole videos.

4.2 Geophysical Logging

Kleinfelder used a Mount Sopris MGX2 geophysical console to run LANL-owned array induction and natural gamma geophysical tools. Logging of corehole was conducted to approximately 727 ft bgs. Natural gamma and array induction geophysical logging were run on the I-10 borehole to identify geologic and hydrogeologic units, with an emphasis on gathering moisture distribution data, identifying water-bearing zones, and obtaining lithologic/stratigraphic data. The natural gamma and array induction logs for the I-10 borehole are presented in Figure 4.2-1.

5.0 HYDROGEOLOGY

LANL's Earth and Environmental Sciences Group 6 staff provided preliminary interpretation of geologic contacts. Conclusive evidence of groundwater occurrence was not observed during drilling operations, open-hole video logging, geophysical logging, or water-level measurements.

5.1 Geology

Visual examination of core, borehole drill cuttings, open-hole video logs, and geophysical logs were used to determine the stratigraphy at I-10 (Figure 5.1-1). In descending order, the stratigraphic units encountered while drilling of the I-10 borehole are Tshirege Member (Unit 3, Unit 2, Unit 1v, Unit 1g, and the Tsankawi Pumice Bed) of the Bandelier Tuff, the Otowi Member of the Bandelier Tuff, Guaje Pumice Bed, upper Puye Formation, Cerros del Rio basalt, and lower Puye Formation. Appendix B presents the lithologic log based on the examination of drill cuttings and core.

5.2 Groundwater Occurrence and Characteristics

The "Mortandad Canyon Groundwater Work Plan, Revision 1" (LANL 2004) references a perched, intermediate zone in the lower part of the Cerros del Rio basalt discovered while drilling well R-15. I-10 was drilled to determine if this intermediate zone extends beneath the I-10 location. The Cerros del Rio basalt was encountered at 710 to 974 ft bgs. The corehole

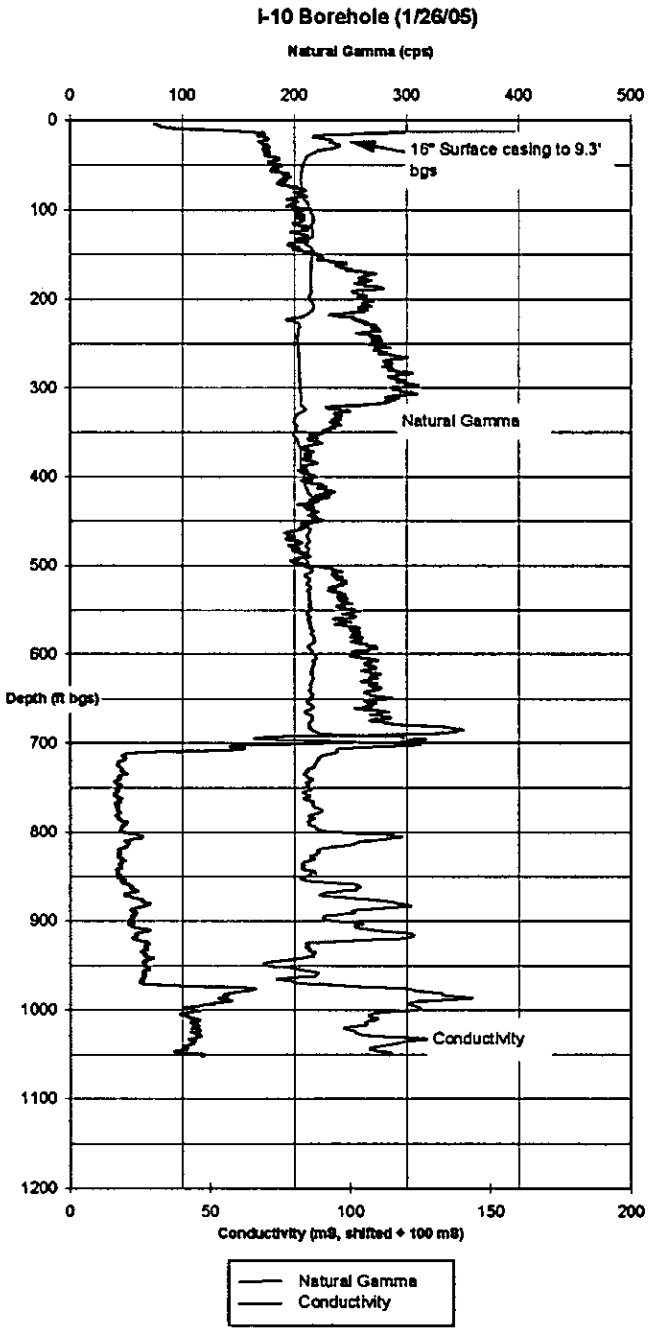
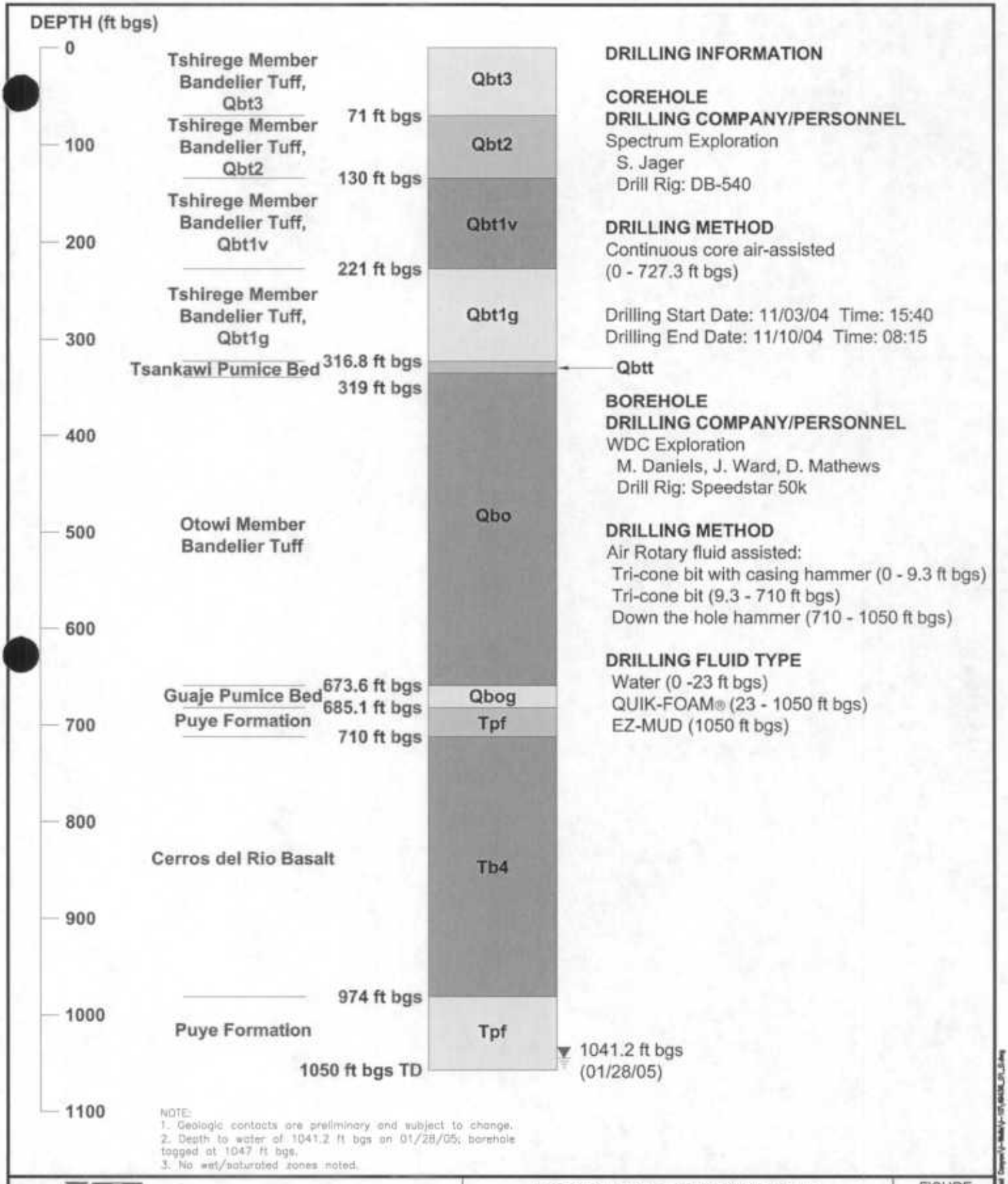


Figure 4.2-1. Natural Gamma and Induction Array Geophysical Logs



NOTE:
1. Geologic contacts are preliminary and subject to change.
2. Depth to water of 1041.2 ft bgs on 01/28/05; borehole tagged at 1047 ft bgs.
3. No wet/saturated zones noted.

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Scale: As referenced	Revision: –

BOREHOLE SUMMARY DATA SHEET
I-10
Mortandad Canyon
Los Alamos National Laboratory
Los Alamos, New Mexico

FIGURE
5.1-1

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penetrated into the Cerros del Rio basalt. DTW measurements collected during and after coring, as well as observations from the video logging indicate the corehole was dry.

The borehole was drilled through the Cerros del Rio basalt interval. Borehole video logs were run on three occasions after reaching TD of 1050 ft bgs. Groundwater was not observed entering the borehole. A small volume of fluids was detected at the base of the borehole and sampled (Section 3.2).

6.0 PLUG AND ABANDONMENT

As presented in Section 2.1, the corehole was abandoned by backfilling with bentonite chips to 2 ft bgs followed by a bentonite-cement grout to ground surface.

A well was not installed at the I-10 borehole because a perched groundwater-bearing zone was not encountered. Following approval by DOE, Kleinfelder plugged and abandoned the borehole. Plug and abandonment activities were conducted from January 28 through February 10, 2005.

Prior to backfilling, the base of the borehole was measured at 1041 ft bgs, indicating an accumulation of 9 ft of formation material. Bentonite and sand, or bentonite chips alone were placed from 1,041 to 323 ft bgs. Bentonite chips were emplaced using tremie pipe or by pouring from the ground surface. Sand was added to minimize plugging of the tremie pipe. A cement-bentonite grout was pumped into place from 323 ft to ground surface. The 16-in. surface casing was grouted in place (Figure 6.1-1). Table 6.1-1 summarizes the materials used for plugging the borehole.

Table 6.1-1

Materials Used to Plug Borehole

Material	Volume
Surface seal: cement slurry	576.4 ft^3
Bentonite seal: bentonite chips	1,179 ft^3
Bentonite seal: sand (to flush tremie pipe)	86 ft^3
Potable water	650 gallons (gal)

7.0 SURFACE COMPLETION, SURVEY, AND SITE RESTORATION

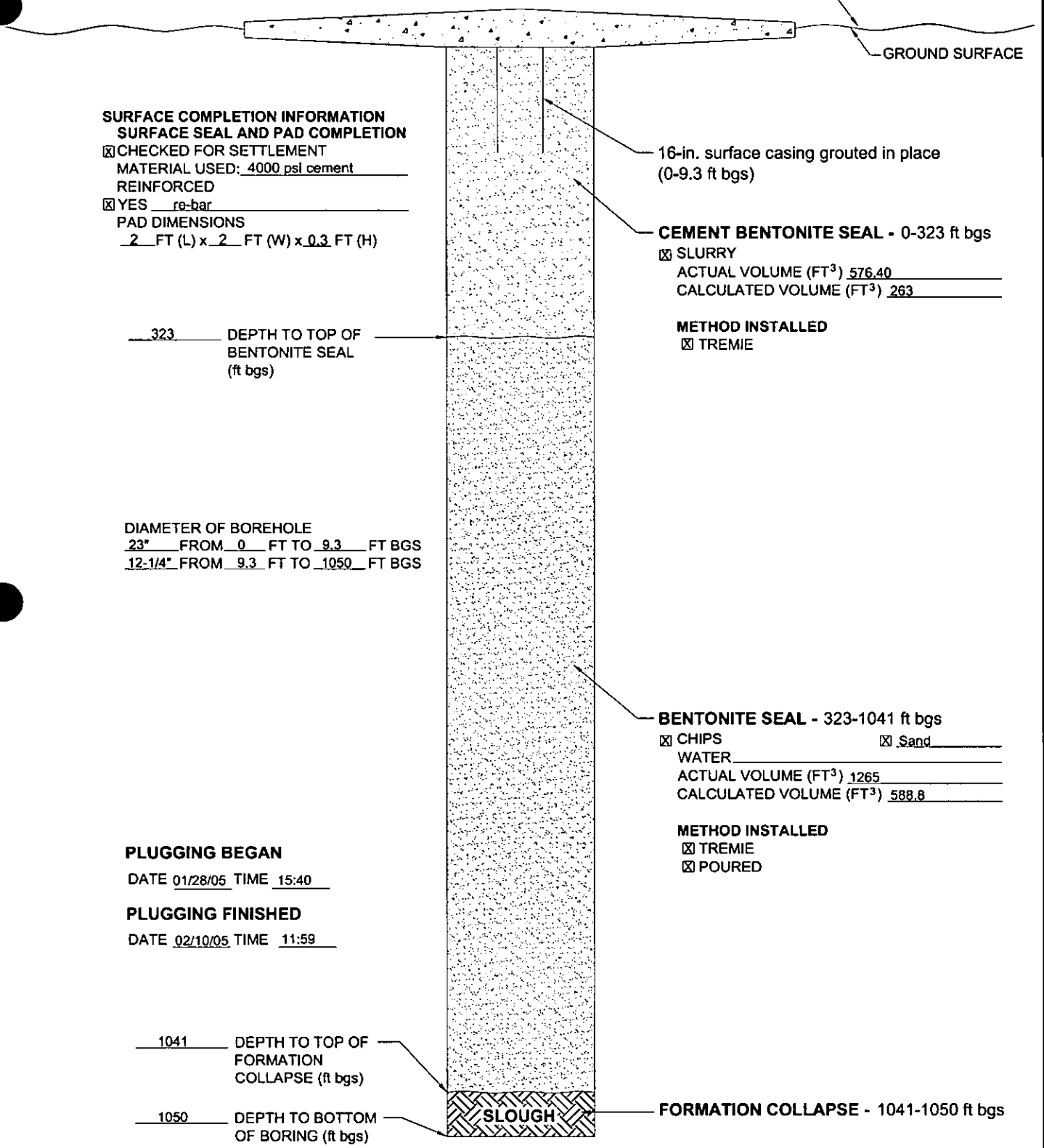
7.1 Surface completion

The borehole and corehole were dry; therefore, wellhead completion was not conducted for the abandoned holes. A reinforced (4000 pounds per square inch (psi)) concrete pad, 2-ft wide by 2-ft long by 4-in. thick, was installed over the abandoned borehole. A brass survey marker was embedded in the concrete pad.

7.2 Geodetic Survey

The abandoned corehole and borehole were surveyed by ASTS, Inc. on March 10, 2005, and March 7, 2006, respectively. The survey data are shown in Table 7.2-1.

GROUND SURFACE ELEVATION (FT AMSL) 7034.46
BRASS CAP ELEVATION (FT AMSL) 7034.57



SURFACE COMPLETION INFORMATION
SURFACE SEAL AND PAD COMPLETION
☒ CHECKED FOR SETTLEMENT
MATERIAL USED: 4000 psi cement
REINFORCED
☒ YES re-bar
PAD DIMENSIONS
2 FT (L) x 2 FT (W) x 0.3 FT (H)

16-in. surface casing grouted in place (0-9.3 ft bgs)

CEMENT BENTONITE SEAL - 0-323 ft bgs
☒ SLURRY
ACTUAL VOLUME (FT^3) 576.40
CALCULATED VOLUME (FT^3) 263

METHOD INSTALLED
☒ TREMIE

323 DEPTH TO TOP OF BENTONITE SEAL (ft bgs)

DIAMETER OF BOREHOLE
23" FROM 0 FT TO 9.3 FT BGS
12-1/4" FROM 9.3 FT TO 1050 FT BGS

BENTONITE SEAL - 323-1041 ft bgs
☒ CHIPS ☒ Sand
WATER
ACTUAL VOLUME (FT^3) 1265
CALCULATED VOLUME (FT^3) 588.8

METHOD INSTALLED
☒ TREMIE
☒ POURED

PLUGGING BEGAN
DATE 01/28/05 TIME 15:40

PLUGGING FINISHED
DATE 02/10/05 TIME 11:59

1041 DEPTH TO TOP OF FORMATION COLLAPSE (ft bgs)

1050 DEPTH TO BOTTOM OF BORING (ft bgs)

FORMATION COLLAPSE - 1041-1050 ft bgs

KLEINFELDER

Drawn By: C. Landon	Date: April 2006
Project No.: 49436	Filename: 49436_02_0.dwg
Scale: Not-to-scale	Revision: –

BOREHOLE PLUGGING SCHEMATIC
I-10
Mortandad Canyon
Los Alamos National Laboratory
Los Alamos, New Mexico

FIGURE
6.1-1

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Table 7.2-1
Geodetic Data

Description	Northing	Easting	Elevation*
Corehole Ground Surface	1767606.21	1635365.02	7033.2
Borehole Ground Surface	1767640.93	1635356.61	7034.5
Borehole Brass Marker	1767639.14	1635357.93	7034.6

*Measured in feet above mean sea level (amsl) relative to the National Geodetic Vertical Datum of 1929, accurate to +/- 0.1 foot

7.3 Site Restoration Activities

Cuttings and fluids produced during drilling were containerized and sampled on February 9, 2005, in accordance with the October 13, 2004, Waste Characterization Strategy Form prepared for the drilling and installation of boreholes and wells in Mortandad Canyon (Appendix C in Kleinfelder 2004b). Analytical results were received on March 4, 2005, and submitted to DOE and LANL for review. Fluid sample results were compared to the State of New Mexico Water Quality Control Commission Regulation 3103 groundwater standards. Water generated during drilling, development and aquifer testing was land-applied in accordance with the Workplan Notice of Intent Decision Tree, revised July 15, 2002, and in coordination with New Mexico Environmental Department (NMED). Cuttings sample results were compared to local geochemical background values and soil screening levels (SSLs) from the NMED Soil Screening Levels, Revision 2.0, February 2004, and submitted to DOE for approval to use as site restoration fill.

Site restoration activities included removing the water from the containment area and applying it to the land, removing the polyethylene liner and cuttings from the containment area, removing the containment berms, backfilling and grading the containment area, and disposing of the containment liner. Remaining cuttings not utilized to backfill the containment area were thinly spread over the site. The site has been reseeded using LANL Seed Mix, applied at a rate of 20 pounds (lb)/acre. Biosol® organic fertilizer was utilized (800 lb/acre) to support re-vegetation.

Temporary materials emplaced for BMPs have been removed.

8.0 DEVIATIONS FROM THE WORKPLAN

In general, field activities were performed as specified in the "Final Drilling Plan for Intermediate Wells, Mortandad Canyon" (Kleinfelder 2004b). Deviations from planned activities are as follows:

- The total depth of the corehole was 727.3 ft bgs; the planned depth was 800 ft bgs. Core was therefore collected to 727.3 ft bgs.
- Core samples were not analyzed for cations or radionuclide suite.
- The total depth of the borehole was 1,050 ft bgs rather than 1,000 ft bgs as noted in the drill plan.
- Due to the limited volume of fluids in the borehole, the water sample was not submitted for stable isotopes, radionuclides, total Kjeldahl nitrogen (TKN), or perchlorate analyses.

9.0 ACKNOWLEDGEMENTS

ASTS, Inc. conducted the final geodetic survey of finished well components.

Duratek Federal Services, Inc. performed a review of the analytical results of the drill cuttings for waste determinations.

EnviroWorks, Inc, provided site preparation services.

Hall Environmental Analysis Laboratory conducted laboratory analysis for waste characterization samples.

Spectrum Exploration, Inc. provided coring services.

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

WDC Exploration & Wells provided rotary drilling services.

10.0 REFERENCES

Kleinfelder, Inc., 2004a. "Storm Water Pollution Prevention Plan, Mortandad Canyon Ground Water Work Plan, Los Alamos National Laboratory," Los Alamos, New Mexico, Project Number 49436, August 2004.

Kleinfelder, Inc., 2004b. "Final Drilling Plan for Intermediate Wells, Mortandad Canyon, Los Alamos National Laboratory," Los Alamos, New Mexico, Project No. 49436, October 2004.

Los Alamos National Laboratory, 2001. "Environmental Restoration Project Standard Operating Procedure for Well Construction, Revision 3," ER-SOP-5.01, April 2001.

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Appendix A

Borehole Video Log

Appendix B

Lithologic Log

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Qbt3,Tshirege Member of the Bandelier Tuff	Tuff, very light gray (N8), poorly welded. WR (whole rock, unsieved): devitrified tuff with dark gray pumice (up to 5mm) in ash matrix, felsic crystal rich. 10+F (i.e. plus No. 10 sieve-size fraction): 80% broken fragments of poorly welded, devitrified tuff with dark gray pumice (up to 5 mm), felsic crystal rich; 15% free felsic crystals; 5% free intermediate composition volcanic lithics. 35+F (i.e. plus No. 35 sieve-size fraction): 90% felsic crystals; 5-10% broken tuff fragments; 5% lithic fragments. **Note: Descriptions presented in this lithologic log are primarily based on those made during visual examination of drill cuttings and core material as follows: 0 to 300 ft bgs - drill cuttings; 300 to 727.3 ft bgs - drill core; and, 727.3 to 1050 ft bgs - drill cuttings. Stratigraphic contacts are based on available information from review of drill core and limited geophysical logs.**	0-20	7034.5-7014.5
	Tuff, pinkish gray (5YR 8/1), poorly welded. WR: devitrified tuff with dark gray pumice (up to 3mm) in felsic crystal rich, ash matrix; rare intermediate composition volcanic lithics; weathered zone of iron (Fe) oxide staining at 20-25'. 10+F: 75% broken fragments of poorly welded devitrified tuff; 20-25% free felsic crystals. 35+F: 95% felsic crystals; 5% broken tuff fragments; rare lithic fragments.	20-40	7014.5-6994.5
	Tuff, very light gray (N8), poorly welded. WR: devitrified tuff with dark gray pumice in felsic crystal rich ash matrix; rare lithic fragments. 10+F: 90% free felsic crystals; 5-10% broken tuff fragments; rare intermediate composition volcanic lithics . 35+F: 90% felsic crystals; 5-10% broken tuff fragments; 1-5% lithic fragments as described for 10+F. **Note: The base of Unit 3 of the Tshirege Member of the Bandelier Tuff (Qbt3) and the contact with the underlying Unit 2 of the Tshirege Member of the Bandelier Tuff (Qbt2) is interpreted to be at 71 ft bgs.**	40-80	6994.5-6954.5
Qbt2, Tshirege Member of the Bandelier Tuff	Tuff, very light gray (N8), poorly welded, poor recovery over interval with no recovery from 90-95' and 110-115'. WR: devitrified tuff with dark gray devitrified (sugary texture) pumice in felsic crystal rich ash matrix; rare lithic fragments. 10+F: 75% broken tuff fragments with dark gray devitrified pumice; 20% free felsic crystals; 5% intermediate composition volcanic lithics, including dacite. 35+F: 70% felsic crystals; 20% pumice and broken tuff fragments; 10% lithic fragments.	80-130	6954.5-6904.5

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Qbt1v, Tshirege Member of the Bandelier Tuff	No cuttings returned; no sample available for examination. **Note: The base of Qbt2 and the contact with the underlying Unit 1v of the Tshirege Member of the Bandelier Tuff (Qbt1v) is interpreted to be 130 ft bgs.**	130-135	6904.5-6899.5
	Tuff, very light gray (N8), poorly welded. WR: devitrified tuff with dark gray devitrified (sugary texture) pumice in felsic crystal rich ash matrix; rare lithic fragments. 10+F: 60-80% broken tuff fragments; 15-25% free felsic crystals; 5-10% intermediate composition volcanic lithics. 35+F: 70-80% felsic crystals; 10-15% lithic fragments; 5-10% pumice and broken tuff fragments.	135-160	6899.5-6874.5
	Tuff, very light gray (N8), poorly welded. WR: felsic crystal rich tuff with devitrified (sugary texture) pumice; intermediate composition volcanic lithics. 10+F: 30-60% free felsic crystals; 20-50% broken tuff fragments; 5-10% intermediate composition volcanic lithics, including dacite, trace andesite. 35+F: 85-95% felsic crystals; 5-15% lithic fragments, devitrified pumice fragments, and broken tuff fragments.	160-210	6874.5-6824.5
	Tuff, very light gray (N8) to grayish orange pink (5YR 7/2), poorly welded. WR: felsic crystal and lithic rich tuff with dark gray pumice in ash matrix, lithic fragments up to 8mm. 10+F: 40-50% felsic crystals; 25-30% broken tuff fragments with devitrified pumice; 20-25% lithic fragments. 35+F: finer fraction as described for 10+F.	210-220	6824.5-6814.5
Qbt1g, Tshirege Member of the Bandelier Tuff	Tuff, moderate orange pink (5YR 8/2), poorly welded. WR: tuff with vitric pumice in felsic crystal rich ash matrix. 10+F: 50-60% felsic crystals; 30-40% broken tuff fragments; 10-20% lithic fragments and moderate orange pink vitric pumice. 35+F: finer fraction as described for 10+F. **Note: The base of Qbt1v and the contact with the underlying Unit 1g of the Tshirege Member of the Bandelier Tuff (Qbt1g) is interpreted to be 221 ft bgs.**	220-225	6814.5-6809.5

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Qbt1g, Tshirege Member of the Bandelier Tuff	Tuff, dark yellowish orange (10YR 6/6) to moderate orange pink (5YR 8/4), poorly welded. WR: tuff with vitric pumice, felsic crystal rich. 10+F: 25-60% tuff fragments, lithic poor, felsic crystal rich, pumice rich, pumice are fibrous and vitric with iron/manganese (Fe/Mn) oxide surface staining, frequent dark colored pumices; 20-35% free felsic crystals; 0-10% intermediate volcanic composition lithics, likely dacite. 35+F: 40-60% felsic crystals, subrounded to euhedral; 30-40% white to orange vitric pumice; 10-20% lithic fragments as described for 10+F.	225-245	6809.5-6789.5
Qbt1g, Tshirege Member of the Bandelier Tuff	Tuff, grayish orange pink (5YR 7/2), poorly welded. WR: felsic crystal and vitric pumice rich tuff in ash matrix. 10+F: 90% white to very pale orange (10YR 8/2) vitric pumice with felsic phenocrysts, fibrous texture; 10% lithic fragments. 35+F: 60% felsic crystals; 35% pumice (as described for 10+F); 5% lithic fragments.	245-250	6789.5-6784.5
	Tuff, grayish orange pink (5YR 7/2), poorly welded. WR: tuff with felsic crystal rich ash matrix and vitric pumice. 10+F: 50-80% vitric pumice, occasional felsic phenocrysts and rare mafic phenocrysts, possibly hornblende; 5-30% free felsic crystals, angular to euhedral; 10-25% lithic fragments; rare obsidian fragment likely remnant of dark pumice. 35+F: 50-60% subangular to angular felsic crystals; 20-30% vitric pumice; 20% intermediate composition volcanic lithics.	250-270	6784.5-6764.5
	Tuff, grayish orange pink (5YR 7/2) to moderate orange pink (5YR 8/4), poorly welded. WR: tuff, felsic crystal rich, pumice rich in ash matrix. Increasing lithics and decreasing pumice across interval. 10+F: 70-95% white to very pale orange vitric pumice; 5-25% intermediate composition volcanic lithics; 0-15% subrounded to euhedral felsic crystals, predominately quartz. 35+F: 45-65% subrounded to angular felsic crystals; 30-45% white to yellow vitric pumice; 5-10% lithic fragments as for 10+F; rare obsidian fragment likely remnant of dark pumice.	270-290	6764.5-6744.5
	Tuff, very pale orange (10YR 8/2), poorly welded. WR: vitric pumice rich tuff with ash matrix. 10+F: 80-90% white to very pale orange vitric pumice, up to 2cm; 0-15% felsic crystals; 0-5% intermediate composition volcanic lithics, aphanitic. 35+F: 55-60% felsic crystals; 30-35% white to yellow vitric pumice; 10% lithic fragments.	290-300	6744.5-6734.5

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Qbt1g, Tshirege Member of the Bandelier Tuff	Tuff, very pale orange (10YR 8/2), poorly welded. 75 to 80% fine ash; 10-20% white, vitric pumice with fibrous texture, up to 2cm, aspect ratio approx. 1.5:1, unaltered, trace mafic phenocrysts; 5-7% felsic crystals; trace lithic fragments; dry. Color change to yellowish gray (5Y 8/1) at 315.9 ft bgs. **Note: From 300 ft to 727.3 ft bgs, the lithologic log was generated by visual examination of drill core; therefore, sieved fractions are not applicable. Unrecovered and/or sampled core in sections of less than 5 ft are not noted unless the interval contains a stratigraphic contact/lithologic changes.**	300-316.8	6734.5-6717.7
Qbtt, Tsankawi Pumice Bed of the Tshirege Member of the Bandelier Tuff	Pumice bed, very light gray (N8), poorly welded. Felsic crystal rich matrix with abundant white vitric pumice fragments, rare lithic fragments (up to 0.5cm), minor ash; pumice increase to 50% at 316.6', up to 3cm, rare mafic phenocrysts in pumice. **Note: The base of Qbt1g and the contact with the underlying Tsankawi Pumice Bed (Qbtt) is interpreted to be 316.8 ft bgs.**	316.8-319	6717.7-6715.5
Qct, Cerro Toledo interval Qbo, Otowi Member of the Bandelier Tuff ?	No recovery or available core sampled. Core unavailable for examination. **Note: The contact of the Tsankawi Pumice Bed with the underlying unit occurs in this unrecovered section and is estimated to occur at 319 ft based on geophysical logs. The immediately underlying formation is either the Cerro Toledo interval (Qct) or the Otowi Member of the Bandelier Tuff (Qbo). The Cerro Toledo interval (Qct), if present, is a thin formation occurring within the unrecovered interval.**	319-328	6715.5-6706.5
Qbo, Otowi Member of the Bandelier Tuff	Tuff, moderate orange pink (5YR 8/4), poorly welded. 70% ash matrix; 10-15% pumice, pale orange, vitric, fibrous texture, up to 3cm, trace felsic phenocrysts, Fe/Mn oxide staining; 5-10% lithics, subrounded to angular lithic fragments up to 4cm, predominantly intermediate composition volcanics; 2-3% subrounded to subangular felsic crystals; dry. **Note: The contact of the Otowi Member with the overlying formation is poorly defined due to lack of recovery, presently assigned at 319 ft depth.**	328-328.8	6706.5-6705.7
	No recovery or available core sampled. Core unavailable for examination.	328.8-345	6705.7-6689.5

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Qbo, Otowi Member of the Bandelier Tuff	Tuff, moderate orange pink (5YR 8/4), poorly welded. Ash matrix; 3-5% felsic crystals; 2-3% moderate orange pink vitric pumice, up to 5cm; 3-5% lithics generally <1cm, up to 2cm; dry.	345-346.7	6689.5-6687.8
	No recovery or available core sampled. Core unavailable for examination.	346.7-353.5	6687.8-6681.0
	Tuff, as above.	353.5-355.5	6681.0-6679.0
	Tuff, grayish orange pink (5YR 7/2), poorly welded. Ash matrix; 5-7% felsic crystals; 2-3% lithic fragments; 1-2% yellow orange, vitric pumice, up to 4cm, felsic phenocrysts; dry	355.5-355.9	6679.0-6678.6
	No recovery or available core sampled. Core unavailable for examination.	355.9-358.5	6678.6-6676.0
	Tuff, moderate orange pink (5YR 8/4) to very pale orange (10YR 8/2), poorly welded. Ash matrix; 3-5% felsic crystals; 1-2% yellow orange vitric pumice; 2-3% subrounded to subangular lithic fragments, up to 3 cm; dry.	358.5 - 361	6676.0-6673.5
	No recovery or available core sampled. Core unavailable for examination.	361 - 365	6673.5-6669.5
	Tuff, grayish orange pink (5YR 7/2), poorly welded. Ash matrix; 5-7% felsic crystals; 1-2% yellow orange vitric pumices, occasionally up to 5 cm with felsic phenocrysts; 2-3% lithics, generally up to 1 cm (from 370 to 375', lithics are up to 5 cm), subrounded; dry	365-408.5	6669.5-6626.0
	Tuff, grayish orange pink (5YR 7/2), poorly welded. Ash matrix; 2-5% felsic crystals; sparse yellow orange vitric pumices, occasional felsic phenocrysts; 1-3% lithics; rare obsidian; dry to damp.	408.5-434.5	6626.0-6600.0
	No recovery or available core sampled. Core unavailable for examination.	434.5-443.5	6600.0-6591.0

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Qbo, Otowi Member of the Bandelier Tuff	Tuff, grayish orange pink (5YR 7/2) to pale yellowish brown (10YR 6/2), poorly welded. Ash matrix; 3-5% felsic crystals; 2-3% lithic fragments, up to 4.5 cm, angular to subangular; sparse yellow orange vitric pumice, generally small, occasionally up to 5cm, felsic phenocrysts; dry to damp. Note: from 483.5 to 486.5', slight color change from grayish orange pink (5YR 7/2) to light brown (5YR 6/4).	443.5-499	6591.0-6535.5
	Tuff, as above, color change to pale yellowish brown (10YR 6/2).	499-499.5	6535.5-6535.0
	Tuff, grayish orange pink (5YR 7/2), poorly welded. Ash matrix; 3-5% felsic crystals; 2-3% lithic fragments; 3-5% yellowish orange to white vitric pumice, fibrous, up to 2 cm, occasional felsic phenocrysts; dry to damp. Note: from 525.5 to 526', interval of increased pumice concentration; from 558.5 -558.7' large clasts of strongly welded tuff, up to 5cm, oval.	499.5-563.5	6535.0-6471.0
	Tuff, grayish orange pink (5YR 7/2), poorly welded. Ash matrix; 5-7% felsic crystals; 3-5% lithics, predominately <1 cm ; 2-3% yellow orange to white vitric pumice, up to 2cm, fibrous texture, felsic phenocrysts; dry to damp. Note: at 571.5', small pumice rich zone.	563.5-661	6471.0-6373.5
	Tuff, very pale orange (10YR 8/2), poorly welded. Ash matrix; 5-7% felsic crystals; 7-10% white rounded vitric pumice with fibrous texture, up to 2cm, trace felsic phenocrysts; 1-2% lithic fragments up to 1-2mm; dry to damp.	661-673.6	6373.5-6360.9
Qbog, Guaje Pumice Bed of theOtowi Member of the Bandelier Tuff	Pumice bed, very light gray (N8), poorly welded. Matrix predominately fine pumice fragments and felsic crystals; large pumice 10-15%, increasing to 50% across interval, up to 4cm, vitric, white, felsic phenocrysts; 2-5% lithic fragments, up to 4mm, trace rounded lithic fragments. **Note: The base of the Otowi Member (Qbo) ash flow and the contact with the underlying Guaje Pumice Bed (Qbog) is interpreted to be at 673.6 ft bgs.**	673.6-685.1	6360.9-6349.4
Tpf, Puye Formation (fanglomerate)	No recovery. Core unavailable for examination. **Note: The base of the Guaje Pumice Bed (Qbog) and the contact with the underlying Puye Formation (Tpf) occurs within the unrecovered interval. Based on limited geophysical logs, the contact is interpreted to be at 685.1 ft bgs.**	685.1-688.5	6349.4-6346.0

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Tpf, Puye Formation (fanglomerate	Volcaniclastic sediment, sandy silt with gravels to silty sand with gravel, moderate brown (5YR 4/4), moderately indurated. Poorly-sorted sand (very fine to coarse) with fines (silt and clay); 10-15% gravel of subrounded intermediate composition volcanic clasts, up to 1.5cm, predominantly aphanitic; trace vitric pumice; dry to damp.	688.5-695	6346.0-6339.5
	Volcaniclastic sediment, silty sand with minor gravels, light brown (5YR 5/6), moderately indurated. Poorly-sorted sand (very fine to coarse); 2-3% well-sorted gravels of intermediate composition volcanic clasts, up to 1cm, rounded to angular; 1% white vitric pumice.	695-695.8	6339.5-6338.7
	Volcaniclastic sediment, gravelly silt with sand, dark yellowish orange (10YR 6/6), strongly indurated- possible breccia clast of poorly- sorted gravels of intermediate composition volcanic clasts 25-30%, angular to subrounded, up to 2.5 cm in an indurated groundmass of fines with minor sands; dry to damp.	695.8-696	6338.7-6338.5
	No recovery or available core sampled. Core unavailable for examination.	696-703.5	6338.5-6331.0
	Volcaniclastic sediment, silt with minor sand (ML), light brown (5YR 5/6), moderately indurated. Well- sorted sand (very fine to fine); trace possible relic root structure; large intermediate composition volcanic clast at 703.5 ft bgs; fractures of 45 and 70 degrees at 709 ft and 709.4 ft bgs respectively, no aperture; dry to damp.	703.5-710	6331.0-6324.5
Tb4, Cerros del Rio Basalt	Flow-top rubble with basalt blocks, silt interlayered with basalt, light brown (5YR 5/6) and black (N1). Basalt, vesicular, 1% olivine phenocrysts. Trace subrounded basalt at 711.2 ft bgs; basalt rubble at 713 ft bgs. **Note: The base of the Puye Formation (Tpf) and the contact with the underlying Cerros del Rio Basalt (Tb4) is interpreted to be at 710 ft bgs.**	710-713.8	6324.5-6320.7
	Basalt, black (N1), vesicular, aphanitic, 1% olivine phenocrysts, trace vesicles contain white clay. Fractures at: 714.3 ft bgs (45 degree, stained fracture surface); 716 ft bgs (30 degree, slight aperture, light brown stained; 716.9 ft bgs (10 degree, slight aperture, light brown stained); 719.5 ft bgs (horizontal, slight aperture, light brown aperture surface); and 720 ft bgs (45 degree, slight aperture, light brown surface).	713.8-727.3	6320.7-6307.2

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Tb4, Cerros del Rio Basalt	Basalt, medium light gray (N6). WR (whole rock, unsieved): weakly porphyritic basalt, aphanitic, weakly vesicular. 10+F (i.e., plus No.10 sieve-size fraction): aphanitic, weakly vesicular basalt, 0-1% plagioclase and olivine phenocrysts, trace Fe oxide staining in vesicles; 15-20% rounded to subrounded dacite and pumice fragments. 35+F (i.e., plus No.35 sieve-size fraction): 80-95% basalt; 5-10% felsic crystals, angular fragments; 5% pumice and lithic fragments. **Note: From 727.3 to 1050 ft bgs, the lithologic log was generated by visual examination of drill cuttings. Drill cuttings examined from the Cerros del Rio Basalt reflect intermixing of returns with overlying formations as interpreted from the similar lithologies of constituents with overlying formations and borehole instability encountered during drilling.**	727.3-740	6307.2-6294.5
	Basalt, medium gray (N5). WR: weakly vesicular basalt, weakly porphyritic; trace free felsic crystals and pumice. 10+F: subrounded to subangular basalt fragments, 1-2% olivine phenocrysts, 1% plagioclase phenocrysts; trace subrounded intermediate composition volcanic clasts. 35+F: 90-95% basalt; 5-10% felsic crystals.	740-750	6294.5-6284.5
	Basalt, medium light gray (N6). WR: basalt, massive with trace vesicles, aphanitic, weakly porphyritic. 10+F: 60-80% basalt, trace olivine phenocrysts; 10-30% pumice and intermediate composition volcanic clasts. 35+F: 70-90% basalt; 5-20% white vitric pumice; 5-10% felsic crystals (broken and faceted surfaces present).	750-775	6284.5-6259.5
	No cuttings returned; no sample available for examination.	775-780	6259.5-6254.5
	Basalt, medium light gray (N6). WR: basalt, massive with trace vesicles, weakly porphyritic, aphanitic. 10+F: 60-80% basalt, trace olivine phenocrysts; 10-30% pumice and intermediated composition volcanic clasts. 35+F: 70-90% basalt; 5-20% white vitric pumice; 5-10% felsic crystals (broken and faceted surfaces present).	780-785	6254.5-6249.5
	Basalt, medium light gray (N5). WR: massive basalt, weakly porphyritic with aphanitic groundmass. 10+F: 75-90% basalt with trace olivine phenocrysts; orange vitric pumice; intermediate composition volcanic clasts including dacite, minor oxidized surfaces. 35+F: 60-80% basalt; 5-20% orange vitric pumice; 10-15% felsic crystals (broken and faceted surfaces present); 5% intermediate composition volcanic clasts.	785-805	6249.5-6229.5

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Tb4, Cerros del Rio Basalt	Basalt, medium light gray (N5) to dark reddish brown (10R 3/4). WR: 60% medium light gray, massive basalt with 40% dark reddish brown, weakly vesicular basalt. 10+F: 70% gray basalt, 1-2% olivine phenocrysts; 15% reddish brown basalt with orange clay adhering to surfaces, 1-2% olivine phenocrysts, weakly vesicular to vesicular; 5% intermediate composition volcanic clasts; trace clay; trace pumice. 35+F: 75% red basalt with orange clay; 15% gray aphanitic basalt; 10% intermediate composition volcanic clasts, felsic crystals, and pumice fragments.	805-810	6229.5-6224.5
	No cuttings returned; no sample available for examination.	810-815	6224.5-6219.5
	Basalt, moderate reddish brown (10R 4/6). WR: massive to vesicular basalt. 10+F: 40% reddish vesicular basalt with 1-2% olivine phenocrysts; 30% vitric pumice, felsic phenocrysts; 20% gray aphanitic basalt; 10% intermediate composition volcanic clasts. 35+F: finer fraction as described for 10+F.	815-820	6219.5-6214.5
	Basalt, medium gray (N5) to moderate reddish brown (10R 4/6). WR: basalt, massive with trace vesicular basalt, trace clay. 10+F: aphanitic basalt, 1-2% olivine phenocrysts, trace vesicular basalt, trace clay. 35+F: 50-70% black massive basalt; 30-60% reddish vesicular basalt; trace lithic fragments, clay, felsic crystals (broken and faceted surfaces present), and pumice.	820-840	6214.5-6194.5
	Basalt, medium light gray (N6). WR: massive basalt. 10+F: basalt, aphanitic, 2% pale green olivine phenocrysts up to 4mm. 35+F: 80-95% basalt; 5-10% lithic fragments and clay; 5% vitric pumice; 5-10% felsic crystals (broken and faceted surfaces present).	840-860	6194.5-6174.5
	Basalt, medium light gray (N6). WR: massive basalt, porphyritic with aphanitic groundmass, trace clay. 10+F: massive basalt, 2-3% phenocrysts including plagioclase, pale green and dark reddish brown olivine; trace reddish brown basalt; trace clay; pumice. 35+F:85% black and reddish brown basalt, very weakly vesicular; 5-10% felsic crystals, broken and faceted surfaces; 5% clay.	860-875	6174.5-6159.5

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Tb4, Cerros del Rio Basalt	Basalt, medium gray (N5). WR: massive basalt with trace vesicles, weakly porphyritic, aphanitic; trace clay; trace pumice. 10+F: 75-85% basalt, some rounding and weathering, rounding on vesicle edges, 1-2% plagioclase and olivine phenocrysts, trace clay; 10% rounded intermediate volcanic composition clasts. 35+F: 65-70% basalt; 10-20% felsic crystals, broken and faceted surfaces; 15% clay.	875-890	6159.5-6144.5
	Basalt, light gray (N7). WR: 70% massive basalt, 20% pumice, 5% clay. 10+F: 55% massive basalt, aphanitic, 1-2% olivine phenocrysts; 45% white to orange vitric pumice; trace clay. 35+F: 65% basalt; 15% clay; 15% pumice; 10% felsic crystals.	890-895	6144.5-6139.5
	Basalt, medium gray (N5). WR: massive basalt; trace rounded intermediate composition volcanic clasts; trace pumice. 10+F: basalt, 1-2% olivine phenocrysts; trace pumice. 35+F: 75% basalt; 15% felsic crystals, broken and faceted surfaces; 5-10% pumice; 5% clay.	895-900	6139.5-6134.5
	Basalt, medium gray (N5). WR: massive basalt trace vesicles, olivine phenocrysts; trace clay; 1-10% pumice increasing across interval. 10+F: basalt, 1-2% olivine phenocrysts, trace alteration; trace clay; trace pumice. 35+F: 85-90% basalt; 10-15% pumice, felsic crystals, and clay.	900-910	6134.5-6124.5
	No cuttings returned; no sample available for examination.	910-915	6124.5-6119.5
	Basalt, medium dark gray (N4). WR: massive basalt; 5-10% clay; trace pumice. 10+F: massive basalt, weakly vesicular, 1% olivine phenocrysts; 5-15% clay; trace pumice. 35+F: 65-80% basalt, minor red basalt; 10-15% clay; 5-10% felsic crystals, angular; 5-10% pumice.	915-935	6119.5-6099.5
	Basalt, light gray (N7). WR: massive basalt with olivine phenocrysts; clay; pumice. 10+F: 85% massive to weakly vesicular gray basalt; minor reddish basalt; 10% pumice; minor clay. 35+F: 65% basalt; 20% pumice; 10% felsic crystals, broken and faceted surfaces; 5% clay.	935-940	6099.5-6094.5
	Basalt, medium gray (N5). WR: basalt, massive to weakly vesicular, 1-2% olivine phenocrysts. 10+F: basalt; trace clay. 35+F: basalt; 10% felsic crystals, angular, broken and faceted surfaces; 5% clay.	940-945	6094.5-6089.5

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Tb4, Cerros del Rio Basalt	Basalt and pumice, very light gray (N8). WR: pumice and basalt; trace clay. 10+F: 70% white to orange vitric pumice with fibrous texture, rounded to angular felsic phenocrysts; 30% massive, gray basalt, 1-2% olivine phenocrysts. 35+F: 30% basalt; 30% pumice; 30% felsic crystals, broken and faceted surfaces; trace obsidian and clay; trace intermediate composition volcanic clasts.	945-950	6089.5-6084.5
	Basalt, medium light gray (N6). WR: massive basalt and pumice. 10+F: 70% basalt, 1% olivine phenocrysts; 20% white to moderate orange vitric pumice, fibrous texture, felsic phenocrysts; 10% free felsic crystals, broken and faceted surfaces. Increasing pumice percentage across interval to 50%. 35+F: 40-50% basalt; 20-30% felsic crystals, broken and faceted surfaces; 10-30% pumice; 10% subrounded intermediate composition volcanic clasts.	950-960	6084.5-6074.5
	Basalt, medium light gray (N6). WR: basalt, weakly vesicular, and pumice fragments. 10+F: 50-75% basalt, weakly vesicular, 1% olivine phenocrysts; 25-50% white to orange vitric pumice with felsic phenocrysts, pumice decreasing across interval. 35+F: 55-60% basalt; 25-30% felsic crystals, broken and faceted surfaces; 10% pumice; 5% intermediate composition volcanic clasts; trace obsidian.	960-970	6074.5-6064.5
Tpf, Puye Formation (fanglomerate)	No cuttings returned; no sample available for examination. **Note: The base of the Cerros del Rio Basalt (Tb4) and the contact with the underlying Puye Formation (Tpf) is interpreted to be at 974 ft bgs based on geophysical logs. Drill cuttings examined from the Puye Formation reflect intermixing of returns with overlying formations as interpreted from the similar lithologies of constituents to overlying formations, and borehole instability encountered during drilling.**	970-975	6064.5-6059.5
	Volcaniclastic sediment, poor returns, medium light gray (N6) to moderate orange pink (5YR 8/4) clasts of 80% basalt fragments, 15-20% pumice, trace felsic crystals with minor very pale orange (10YR 8/2) fines. No 10+F. No 35+F.	975-980	6059.5-6054.5
	Volcaniclastic sediments, intermixed cuttings, medium light gray (N6). WR: Clasts of weakly vesicular basalt and pumice fragments. 10+F: 60-80% basalt, weakly vesicular; 20-40% white to orange vitric pumices up to 2cm. 35+F: 55-65% basalt; 15-25% felsic crystals; 15% pumice; 5% intermediate composition volcanic clasts.	980-990	6054.5-6044.5

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Tpf, Puye Formation (fanglomerate)	Volcaniclastic sediments, gravel with sand to poorly-sorted sand with gravel, very light gray (N8). WR: 40-50% gravel; 40-50% sand; 10% fines. 10+F: 40-80% white to orange, rounded, vitric pumice; 5-40% basalt, decreasing to 5% across interval; 5-35% intermediate composition volcanic clasts, including biotite dacite, up to 1cm, varied colored, generally light colored with occasional medium gray and moderate red, subangular to rounded, larger clasts broken with rounded surfaces. 35+F: 40-50% felsic crystals, broken and faceted surfaces; 15-40% basalt, decreasing across interval; 10-30% white to orange pumice; 10-25% rounded intermediate composition volcanic clasts.	990-1010	6044.5-6024.5
	Volcaniclastic sediments, silty sand with gravel, medium gray (N5). WR: silty sand with gravel; moderately-sorted sands (predominately very fine to fine), minor gravels. 10+F: 60% basalt; 40% pumice; trace silt and clay. 35+F: 40% basalt; 40% felsic crystals, predominately broken fragments; 15% pumice; 5% intermediate composition volcanic clasts.	1010-1015	6024.5-6019.5
	Volcaniclastic sediments, silty sand with gravel, light gray (N7). WR: poorly-sorted sands (very fine to coarse), rounded to subangular, composed of pumice, felsic crystals, basalt and trace intermediate composition volcanic clasts. 10+F (poor returns): 50-60% subrounded to angular pumice, vitric, felsic phenocrysts; 35% varied clasts of intermediate composition volcanics, including hornblende dacite, rounded to subrounded; 15% basalt, massive and small rounded moderately vesicular basalt clasts. 35+F: 35-40% felsic crystals, angular and faceted surfaces; 25-35% pumice; 25-35% intermediate composition volcanic clasts; 5-10% basalt.	1015-1030	6019.5-6004.5
	Volcaniclastic sediments, silty sand with gravel, light gray (N7). WR: 50-65% poorly-sorted sand; 25-30% silt; 10-15% well-sorted small gravel of pumice and intermediate composition volcanic clasts. 10+F: 45-65% rounded to subrounded intermediate composition volcanic clasts up to 1cm; 30-50% vitric pumice, rounded clasts frequent; 0-5% felsic crystals; 0-5% basalt. 35+F: 35-45% rounded to angular felsic crystals, frosted surfaces; 25-35% pumice; 25-35% rounded to subrounded intermediate composition volcanic clasts.	1030-1045	6004.5-5989.5

Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Tpf, Puye Formation (fanglomerate)	Volcaniclastic sediment, sandy gravel with silt, medium light gray (N6). WR: moderately-sorted gravels (fine to medium) composed of predominantly pumice and intermediate composition volcanic clasts; poorly-sorted sands. 10+F: 50% vitric pumice with felsic phenocrysts, rounded to subrounded; 50% intermediate composition volcanic clasts, varied colored, aphanitic, generally <1cm, including dacite and possible rhyolitic clast, rounded to subrounded. 35+F: 40% intermediate composition volcanic clasts; 30% felsic crystals, subangular, broken, and faceted surfaces; 30% pumice.	1045-1050	5989.5-5984.5
	TOTAL BOREHOLE DEPTH (TD) IS AT 1050 FT BGS.		

NOTES:

Descriptions presented in this lithologic log are primarily based on those made during visual examination of drill cuttings and core material as follows: 0 to 300 ft bgs - drill cuttings; 300 to 727.3 ft bgs - drill core; and, 727.3 to 1050 ft bgs - drill cuttings.

Descriptions of drill chips and drill core from sedimentary units such as the Quaternary Alluvium, Cerro Toledo Interval and the Puye Formation utilized principles outlined in *Petrology of Sedimentary Rocks* by Robert L. Folk. Color Descriptions were determined using The Geological Society of America, *Rock-Color Chart.*

Cuttings were collected at nominal 5 or 10-ft intervals and divided into three sample splits: (1) unsieved, or whole rock (WR), sample; (2) 10+F sieved fraction (No. 10 sieve equivalent to 2.0 mm); and (3) 35+F sieved fraction (No. 35 sieve equivalent to 0.5 mm). When cuttings were overall finer grained, then cuttings were divided into a 35+F sieved fraction and a 60+F sieved fraction.

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

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

REFERENCES:

Folk, Robert L., 1980, Petrology of Sedimentary Rocks, Hemphill Publishing Company

The Geological Society of America, 1991, Rock-Color Chart.

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Borehole Viaio log 0-4600 ft bgs 1/8/05

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Coremole Video log 0-725ft bgs 11/11/04

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1-1 Borehole Video log 0-838 ft bgs 12/18/04

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1-5 boreholes Video log [illegible] ft Lgs

10/21/04

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I-Walls Final Completion Report - Appendix A

1-4 Borehole Video Log 0-541 ft bgs 11/03/04

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T. Wells Final Completion Report - 1-10 Borehole

Video log 0-1043.7 ft bgs 1/27/05

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I-Wells Final Completion Report - Appendix A 1-8

Borehole Video log 0-740 ft bgs 1/04/05