

TA03

ENTERED



Environmental Programs
P.O. Box 1663, MS M991
Los Alamos, New Mexico 87545
(505) 606-2337/FAX (505) 665-1812



National Nuclear Security Administration
Los Alamos Site Office, MS A316
Environmental Restoration Program
Los Alamos, New Mexico 87544
(505) 667-4255/FAX (505) 606-2132

Date: May 30, 2009
Refer To: EP2009-0255

James P. Bearzi, Bureau Chief
Hazardous Waste Bureau
New Mexico Environment Department
2905 Rodeo Park Drive East, Building 1
Santa Fe, NM 87505-6303

Subject: Submittal of the Completion Report for Regional Aquifer Well R-45

Dear Mr. Bearzi:

Enclosed please find two hard copies with electronic files of the Completion Report for Regional Aquifer Well R-45.

If you have any questions, please contact Mark Everett at (505) 667-5931 (meverett@lanl.gov) or Nancy Werdel at (505) 665-3619 (nwerdel@doeal.gov).

Sincerely,

Michael J. Graham, Associate Director
Environmental Programs
Los Alamos National Laboratory

Sincerely,

David R. Gregory, Project Director
Environmental Operations
Los Alamos Site Office



MG/DG/PH/ME/SW:sm

Enclosures: Two hard copies with electronic files – Completion Report for Regional
Aquifer Well R-45 (LA-UR-09-3065)

Cy: (w/enc.)

Neil Weber, San Ildefonso Pueblo
Nancy Werdel, DOE-LASO, MS A316
Mark Everett, EP-LWSP, MS M992
RPF, MS M707 (with two CDs)
Public Reading Room, MS M992

Cy: (Letter and CD only)

Laurie King, EPA Region 6, Dallas, TX
Steve Yanicak, NMED-OB, White Rock, NM
Steve White, EP-LWSP, MS T005
Kristine Smeltz, EP-WES, MS M992
EP-LWSP File, MS M992

Cy: (w/o enc.)

Tom Skibitski, NMED-OB, Santa Fe, NM
Keyana DeAgüero, DOE-LASO (date-stamped letter emailed)
Michael J. Graham, ADEP, MS M991
Alison M. Dorries, EP-WES, MS M992
Paul Huber, EP-LWSP, MS M992
IRM-RMMSO, MS A150 (date-stamped letter emailed)

LA-UR-09-3065
May 2009
EP2009-0255

Completion Report for Regional Aquifer Well R-45

Prepared by the Environmental Programs Directorate

Los Alamos National Laboratory, operated by Los Alamos National Security, LLC, for the U.S. Department of Energy under Contract No. DE-AC52-06NA25396, has prepared this document pursuant to the Compliance Order on Consent, signed March 1, 2005. The Compliance Order on Consent contains requirements for the investigation and cleanup, including corrective action, of contamination at Los Alamos National Laboratory. The U.S. government has rights to use, reproduce, and distribute this document. The public may copy and use this document without charge, provided that this notice and any statement of authorship are reproduced on all copies.

Completion Report for Regional Aquifer Well R-45

May 2009

Responsible project leader:

Mark Everett		Project Leader	Environmental Programs	5-26-09
Printed Name	Signature	Title	Organization	Date

Responsible LANS representative:

Michael Graham		Associate Director	Environmental Programs	5/27/09
Printed Name	Signature	Title	Organization	Date

Responsible DOE representative:

David R. Gregory		Project Director	DOE-LASO	5/26/09
Printed Name	Signature	Title	Organization	Date

EXECUTIVE SUMMARY

This well completion report describes the drilling, installation, development, and aquifer testing of regional aquifer well R-45, located in Mortandad Canyon, Technical Area 05, at Los Alamos National Laboratory in Los Alamos County, New Mexico. This report was written in accordance with the requirements in Section IV.A.3.e.iv of the March 1, 2005, Compliance Order on Consent. The well was installed at the direction of the New Mexico Environment Department (NMED) to monitor groundwater quality and contaminant movement and to define the eastern limit of chromium contamination in the vicinity of R-28 and R-42 (which have consistently elevated concentrations of chromium in the regional aquifer at the Laboratory).

The R-45 borehole was drilled using dual-rotary air-drilling methods. Drilling fluid additives included potable water and foam. Foam-assisted drilling was used only in the vadose zone and ceased approximately 100 ft above the regional aquifer; only small amounts of potable water were added to the air within the regional aquifer. Additive-free drilling provides minimal impacts to the groundwater and formation. The R-45 borehole was successfully completed to total depth using casing-advance and open-hole drilling methods.

A retractable 16-in. casing was advanced through the Bandelier Tuff, Guaje Pumice Bed, and basaltic volcanoclastic sediments to a depth of 314.7 ft below ground surface (bgs). A 15-in. open borehole was advanced with fluid-assisted air-rotary methods and a downhole hammer bit through the Cerros del Rio basalt and into the Puye Formation sediments to a depth of 762.8 ft bgs. Then 12-in. casing was advanced with an 11 5/8-in. tricone bit to a total depth of 1057.2 ft bgs in Miocene pumiceous and riverine sediments.

Well R-45 was completed as a dual-screen well to evaluate water quality and measure water levels at two discrete depth intervals within the regional aquifer. Well screens will be separated by packers, as part of the permanent sampling system to ensure isolation of each groundwater bearing zone. The upper 10-ft-long screened interval had the top of the screen set at 880 ft bgs within the Puye Formation and the lower 20-ft long screened interval had the top of the screen set at 974.9 ft bgs within Miocene pumiceous sediments. The composite depth to water after well installation and well development was 868.6 ft bgs.

The well was completed in accordance with an NMED-approved well design and was thoroughly developed and met target water-quality parameters. Hydrogeologic testing indicated that monitoring well R-45 is highly productive and will perform effectively to meet the planned objectives. Water-level transducers will be placed in the upper and lower well screens in the R-45 well, and groundwater sampling will be performed as part of the facility-wide groundwater-monitoring program.

CONTENTS

1.0	INTRODUCTION	1
2.0	PRELIMINARY ACTIVITIES	1
2.1	Administrative Preparation	2
2.2	Site Preparation	2
3.0	DRILLING ACTIVITIES	2
3.1	Drilling Approach	2
3.2	Chronology of Drilling Activities	3
4.0	SAMPLING ACTIVITIES	4
4.1	Cuttings Sampling	4
4.2	Water Sampling	4
5.0	GEOLOGY AND HYDROGEOLOGY	5
5.1	Stratigraphy	5
5.2	Groundwater	6
6.0	BOREHOLE LOGGING	7
6.1	Video Logging	7
6.2	Geophysical Logging	7
7.0	WELL INSTALLATION	7
7.1	Well Design	7
7.2	Well Construction	8
8.0	POSTINSTALLATION ACTIVITIES	9
8.1	Well Development	9
8.1.1	Well Development Field Parameters	9
8.2	Aquifer Testing	10
8.2.1	Aquifer Testing Field Parameters	10
8.3	Dedicated Sampling System Installation	11
8.4	Wellhead Completion	11
8.5	Geodetic Survey	11
8.6	Waste Management and Site Restoration	11
9.0	DEVIATIONS FROM PLANNED ACTIVITIES	12
10.0	ACKNOWLEDGMENTS	12
11.0	REFERENCES	12

Figures

Figure 1.0-1	Regional aquifer well R-45 with respect to surrounding regional wells	15
Figure 5.1-1	R-45 borehole stratigraphy	16
Figure 7.2-1	R-45 as-built well construction diagram	17
Figure 8.3-1a	As-built schematic for regional well R-45	18
Figure 8.3-1b	As-built technical notes for R-45	19

Tables

Table 3.1-1 Fluid Quantities Used during Drilling and Well Construction 21
Table 4.2-1 Summary of Groundwater Screening Samples Collected during Drilling,
Well Development, and Aquifer Testing of Well R-45..... 22
Table 6.0-1 R-45 Video and Geophysical Logging Runs 23
Table 7.2-1 R-45 Annular Fill Materials..... 23
Table 8.5-1 R-45 Survey Coordinates..... 23
Table 8.6-1 Summary of Waste Samples Collected during Drilling and Development of R-45 24

Appendixes

Appendix A Well R-45 Lithologic Log
Appendix B Groundwater Analytical Results
Appendix C Aquifer Testing Report
Appendix D Borehole Video Logging (on DVD included with this document)
Appendix E Schlumberger Geophysical Logging Report (on CD included with this document)

Acronyms and Abbreviations

µS/cm	microsiemen per centimeter
amsl	above mean sea level
BETCO	barometric and Earth tide correction
bgs	below ground surface
CNT	Compensated Neutron Tool
cu	capture unit
DO	dissolved oxygen
ECS	Elemental Capture Sonde
EES-14	Environmental and Earth Sciences Group
ENV-MAQ	Environmental Stewardship–Meterology and Air Quality Group
EP	Environmental Programs
gAPI	American Petroleum Institute gamma ray
IC	ion chromatography
ICPMS	inductively coupled (argon) mass spectrometry
ICPOES	inductively coupled (argon) plasma optical emissison spectroscopy
I.D.	inside diameter
IDW	investigation-derived waste
IWD	integrated work document
LANL	Los Alamos National Laboratory

lbf	pound force
mV	millivolt
NMED	New Mexico Environment Department
NTU	nephelometric turbidity unit
O.D.	outside diameter
ORP	oxygen-reduction potential
PTO	power takeoff
PVC	polyvinyl chloride
Qal	Quaternary alluvium
Qbo	Quaternary Otowi Member of the Bandelier Tuff
Qbog	Quaternary Guaje Pumice Bed of Otowi Member of the Bandelier Tuff
RPF	Records Processing Facility
SOP	standard operating procedure
SWL	static water level
TA	technical area
Tb 4	Tertiary Cerros del Rio basalt
TD	total depth
TDL	Triple Detector Litho-Density
TOC	total organic carbon
Tpf	Tertiary Puye formation
Tjfp	Tertiary (Miocene) pumiceous sediments
Tsfu	Tertiary Santa Fe Group undifferentiated
wt%	weight percent
WCSF	waste characterization strategy form
WES-EDA	Waste and Environmental Services Division–Environmental Data and Analysis

1.0 INTRODUCTION

This completion report summarizes the site preparation, drilling, well construction, well development, and aquifer testing for well R-45. The report is written in accordance with the requirements in Section IV.A.3.e.iv of the March 1, 2005, Compliance Order on Consent (the Consent Order). Well R-45 was drilled from November 25, 2008, to January 8, 2009, and the well was completed from January 13, 2009, to January 24, 2009 at Los Alamos National Laboratory (LANL or the Laboratory) for the LANL Water Stewardship Program.

The R-45 project site is located in Mortandad Canyon in the vicinity of well R-28 within Technical Area 05 (TA-05), Los Alamos County, New Mexico (Figure 1.0-1). The purposes of the R-45 monitoring well are to monitor potential releases of contaminants from Mortandad and Sandia Canyon sources, assess the conceptual model for contaminant fate and transport of known chromium contamination in the vicinity of well R-28, monitor water levels within the regional aquifer, and measure pumping effects from municipal production well PM-5 and other wells in the vicinity.

The primary objective of the drilling activities at R-45 was to drill and install a dual-screen regional aquifer monitoring well in the uppermost part of the regional groundwater system. The two-screen approach was designed to determine the vertical extent of possible chromium contamination so that pathways and potential future impacts to regional groundwater may be assessed. Water-level transducers will be placed in upper and lower well screens to evaluate hydraulic connections between this monitoring well, other monitoring wells, and nearby water supply well PM-5. Secondary objectives were to collect drill-cutting samples, conduct borehole geophysical logging, and investigate potential perched groundwater zones.

The R-45 borehole was drilled to a total depth (TD) of 1057.2 ft below ground surface (bgs). A monitoring well was installed with two screens. Currently, a temporary packer is being used to isolate the two well screens until the permanent sampling system that is being built by an off-site contractor can be installed. The permanent sampling system will isolate the two screens with a packer when installed after receipt from the manufacturer. The upper 10-ft-long screened interval is between 880.0 and 890.0 ft bgs and the lower 20-ft-long screened interval is between 974.9 and 994.9 ft bgs. The composite depth to water after well installation and well development was 868.6 ft bgs on February 24, 2009. Cuttings samples were collected at 5-ft intervals in the borehole from ground surface to TD. Postinstallation activities included well development, aquifer testing, surface completion, and a geodetic survey. Future activities include dedicated sampling system installation, site restoration, and waste management.

The information presented in this report was compiled from field reports and daily activity summaries. Records, including field reports, field logs, and survey information, are on file at the Laboratory's Records Processing Facility (RPF). This report contains brief descriptions of activities and supporting figures, tables, and appendixes completed to date associated with the R-45 project.

2.0 PRELIMINARY ACTIVITIES

Preliminary activities included preparing administrative planning documents and preparing the drill site. All preparatory activities were completed in accordance with Laboratory policies and procedures and regulatory requirements.

2.1 Administrative Preparation

The following documents helped guide the implementation of the scope of work for well R-45: "Final Drilling Plan for Regional Aquifer Wells R-44 and R-45" (TerranearPMC 2008, 105083); "Integrated Work Document for Regional and Intermediate Aquifer Well Drilling" (LANL 2007, 100972); "Storm Water Pollution Prevention Plan Addendum" (LANL 2006, 092600); and "Waste Characterization Strategy Form for the R-38, R-41, R-44, R-45, and R-46 Regional Groundwater Well Installation and Corehole Drilling" (LANL 2008, 103916).

2.2 Site Preparation

The drill pad had been prepared by Laboratory personnel several weeks before mobilizing the drill rig, air compressors, trailers, and support vehicles to the drill site on November 23 and 24. This included staging of alternative drilling tools and construction materials at the Pajarito Road lay-down yard.

Potable water was obtained predominantly from the Puye Road fire hydrant and, as back-up, from a fire hydrant near the Los Alamos County landfill on East Jemez Road. Safety barriers and signs were installed around the borehole cuttings containment pit and along the perimeter of the work area.

3.0 DRILLING ACTIVITIES

This section describes the drilling strategy and approach and provides a chronological summary of field activities conducted at monitoring well R-45.

3.1 Drilling Approach

The drilling methodology and selection of equipment and drill-casing sizes for R-45 were designed to retain the ability to case off perched groundwater and ensure reaching TD with a sufficiently sized casing to allow well installation with the required 2-in. minimum annular filter pack thickness for a 5.56-in.-outside diameter (O.D.) well. It was anticipated that if perched groundwater was encountered at R-45, the perched zone would be isolated and sealed off either with casing or by cementing to avoid commingling perched groundwater with the regional aquifer.

Dual-rotary drilling methods using a Foremost DR-24HD drill rig were employed to drill the R-45 borehole. Dual-rotary drilling has the advantage of simultaneously advancing and casing the borehole. The Foremost DR-24HD drill rig was equipped with conventional drilling rods, tricone bits, downhole hammer bits, one deck-mounted 900 ft³/min air compressor, and general drilling equipment. Auxiliary equipment included two Sullair 1150 ft³/min trailer-mounted air compressors. Two sizes of A53 grade B flush-welded mild carbon-steel casing (16-in. and 12-in.) were used for the R-45 project. The dual-rotary technique used filtered air and fluid-assisted air to evacuate cuttings from the borehole. Cuttings samples were collected at 5-ft intervals in the borehole from ground surface to TD to characterize the hydrostratigraphy of rock units encountered in the borehole.

Drilling fluids, other than air, used in the vadose zone included municipal water and a mixture of municipal water with Baroid AQF-2 foaming agent. The fluids were used to cool the bit and help lift cuttings from the borehole. Use of foaming agents was terminated at 762.8 ft bgs, approximately 100 ft above the predicted regional aquifer. No additives other than municipal water were used for drilling within the regional aquifer. Total amounts of drilling fluids introduced into the borehole and those recovered are recorded and presented in Table 3.1-1.

3.2 Chronology of Drilling Activities

Mobilization of drilling equipment and supplies to the R-45 site occurred from November 23 to November 24, 2008. The well was initiated the next day, November 25, 2008, at 0901 h, using dual-rotary methods with 16-in. drill casing and a 15-in. tricone bit. There was a slight delay in drilling because the rig needed to be modified to meet fall protection requirements. Drilling and advancing 16-in. casing proceeded normally through alluvium and the Otowi Member of the Bandelier Tuff until refusal was met in the Cerros del Rio basalt. The 16-in casing was landed at 314.7 ft bgs at the base of a cinder-rich interval in the upper Cerros del Rio basalt at 1805 h on December 8, 2008.

Open-hole drilling with a 15-in. hammer bit commenced early in the day of December 10, 2008 (0745 h). The open-hole section was drilled fairly smoothly. However, below 510 ft bgs circulation was poor, but the borehole remained clear of cuttings. Essentially, no borehole returns (i.e., no drilling fluid or cuttings) were recorded from 510 ft bgs to the base of the Cerros del Rio/Puye Formation sediments contact at 687 ft bgs. The lack of returns persisted into the Puye Formation sediments to a depth of 762.8 ft bgs, which was reached at 0855 h on December 15, 2008. Poor weather conditions (snow and ice) forced closure of the road into Mortandad Canyon mid-day of December 15, 2008, and work was stopped as a result.

Activities resumed on December 17, 2008, and the decision was made to suspend further open-hole drilling. Jet West Geophysical services logged the open-hole section early in the morning of December 18, 2008. Very little water inflow was observed in the video. A brecciated interval of basalt noted on the video log at 495–510 ft bgs was probably the cause of the lost circulation. Drilling recommenced, but minor problems with the rig's power takeoff (PTO) system slowed progress. The 16-in. casing was cut to detach the welded drive shoe the next day at 311.0 ft bgs, and the installation of 12-in. drill casing was started. Two water samples were obtained by bailer and the bottom of the hole was tagged at 742.8 ft bgs on December 21, 2008. To create a seal, if the sampled water represented a potential perched water zone, 22.5 ft of bentonite chips would be placed at TD and hydrated that day. Because of the Laboratory holiday closure, drilling operations ceased, the drill site and equipment were winterized, and the site was secured the next day (December 22, 2008).

Dual-rotary drilling using 12-in. casing and an 11 5/8-in. tricone bit began at 720.7 ft bgs after the holiday closure on January 5, 2009. Drilling proceeded without incident through the evening of January 8, 2009, when rounded fluvial clasts were observed in cuttings samples at a depth of 1057.2 ft. During this phase of drilling that used only air for circulation, regional groundwater was detected as each joint of casing and drill rod was added to the drill string. The interval from 954 to 1038 ft bgs, where no potable water was used, showed prolific water production. Water samples were collected at nominal 20-ft-depth intervals from the discharge line as the borehole was advanced through the regional aquifer. Borehole TD of 1057.2 ft bgs was achieved at 1650 h on January 8, 2009.

A Schlumberger field crew conducted multiple cased-hole logging runs on January 9, 2009, after the tools had been tripped out of the borehole. Later that day, the drilling tools were rerun to clean out 50 ft of formation heave to a depth of 1030 ft bgs. The 12-in. casing was then cut at 1025 ft bgs. The drill rig was moved off of the borehole at 0430 h on January 10, 2009.

The field crews typically worked two 12-h shifts per day (24 h operation), 7 d/wk. Daily activities were briefly interrupted twice by weather delays caused by snow and ice and were suspended from December 23 to January 4, 2009, due to the Laboratory holiday shutdown. Minor mechanical delays with the rig's PTO system slowed drilling progress slightly.

4.0 SAMPLING ACTIVITIES

This section describes the cuttings and groundwater-sampling activities at well R-45. All sampling activities were conducted in accordance with applicable quality procedures.

4.1 Cuttings Sampling

Cuttings samples were collected from the R-45 borehole at 5-ft intervals from ground surface to the TD of 1057.2 ft bgs. At each interval, approximately 500 mL of bulk cuttings were collected from the discharge hose, placed in resealable plastic bags, labeled, and archived in core boxes. Sieved fractions (>#10 and >#35 mesh) were also collected from ground surface to bottom depth and placed in chip trays along with unsieved (whole rock) cuttings. Laboratory radiation control technicians screened cuttings before removal from the site. All screening measurements were within the range of background values.

Drilling and sample collection methods used at R-45 did not retain a majority of the fine fraction (silt and clay) of the drill cuttings, and much of the fine material throughout the borehole stratigraphy was lost. The volume of compressed air and water required for circulation made catching samples difficult, and fines were selectively lost during sample collection. Site geologists manually collected samples with a wire mesh basket directly from the discharge hose where discharge velocities commonly forced the fine fraction of sample through the basket. Recovery of the coarser fraction of the cuttings samples was excellent in most of the borehole when drilling circulation was not lost. No cuttings returns, a result of lost circulation, occurred at R-45 in the lower Cerros del Rio–Puye Formation interval between 510 and 762.5ft bgs. It is assumed that a highly permeable zone (fractured and/or brecciated) in the basalt was responsible for the loss of drilling circulation. The borehole lithologic log for R-45 is summarized in section 5.1 and detailed in Appendix A.

4.2 Water Sampling

Groundwater-screening samples were collected from the drilling discharge hose at approximate 20-ft intervals starting at 742.3 ft bgs to evaluate a potential perched zone and continued to the top of the regional aquifer to TD at 1057.2 ft bgs in the R-45 borehole. Typically, upon reaching the bottom of a 20-ft run of casing, the driller would stop water circulation (if injecting water) and circulate air to clean out the borehole. As the discharge cleared, a water sample was collected directly from the discharge hose. Not all depth intervals yielded water at the end of each casing run. Alternatively, some water samples were collected upon start-up of the next casing run after the borehole equilibrated. Refer to Table 4.2-1 for a summary of screening samples collected at well R-45.

Twelve groundwater screening samples, from depths of 742.3 to 1038.5 ft bgs, were collected during drilling operations by bailing or air-lifting water samples through the drill string. Drilling screening samples were analyzed for anions and metals, and three samples were analyzed for tritium.

Four regional groundwater screening samples were collected during well development: two from the upper screen interval (880.0–890.0 ft bgs) and two from the lower screen interval (974.9–994.9 ft bgs). Development screening samples were analyzed for anions, metals, and total organic carbon (TOC).

Twelve regional groundwater screening samples were collected at regular intervals (approximately one sample per 4 h) during aquifer testing. Six screening samples were collected from the upper screen interval (880.0–890.0 ft bgs), and six screening samples were collected from the lower screen interval (974.9–994.9 ft bgs). The groundwater samples were collected from a stainless-steel riser pipe that was connected to the discharge port of the submersible pump. Aquifer-testing screening samples were analyzed for dissolved anions, metals, and TOC.

Groundwater characterization samples were collected from the completed well at the end of the aquifer test from each screen in accordance with the Consent Order. The samples were analyzed for the full suite of constituents, including radioactive elements, anions/cations, general inorganic chemicals, volatile and semivolatile organic compounds, and stable isotopes of hydrogen, nitrogen, and oxygen. These groundwater analytical results will be reported in the annual update to the "Interim Facility-Wide Groundwater Monitoring Plan."

5.0 GEOLOGY AND HYDROGEOLOGY

A brief description of the geologic and hydrogeologic features encountered at R-45 is presented below. The Laboratory's geology task leader and site geologists examined cuttings and geophysical logs to determine geologic contacts and hydrogeologic conditions. Drilling observations, video logging, water-level measurements, and geophysical logs were used to characterize groundwater occurrences encountered at R-45.

5.1 Stratigraphy

The stratigraphy for the R-45 borehole is presented below in order of youngest to oldest geologic units. Lithologic descriptions are based on cuttings samples collected from the discharge hose. Cuttings and borehole geophysical logs were used to identify geologic contacts. Figure 5.1-1 illustrates the stratigraphy at R-45. A detailed lithologic log based on analysis of drill cuttings is presented in Appendix A.

Quaternary Alluvium, Qal (0–80 ft bgs)

Quaternary alluvium, consisting of unconsolidated tuffaceous silty sand to sandy silt with pebble gravels containing pumice and volcanic detritus, occurs from 0 to 80 ft bgs. No evidence of alluvial groundwater was observed.

Otowi Member of the Bandelier Tuff, Qbo (80–233 ft bgs)

The Otowi Member of the Bandelier Tuff was intersected from 80 to 233 ft bgs, as interpreted from natural gamma ray geophysical log. The Otowi Member is a poorly welded, pumiceous, lithic-bearing to locally lithic-rich, crystal-bearing ash-flow tuff. Otowi Member drill cuttings commonly contain abundant pumice lapilli that are orange-tan to white, glassy, fibrous-textured and quartz- and sanidine-phyric enclosed in a matrix of vitric ash. Locally abundant volcanic lithic fragments, or xenoliths (locally up to 18 mm in diameter) are commonly subangular to subrounded gray and light pinkish gray, coarsely porphyritic hornblende- and biotite-phyric dacites.

Guaje Pumice Bed of the Otowi Member of the Bandelier Tuff, Qbog (233–248 ft bgs)

The Guaje Pumice Bed occurs from 233 to 248 ft bgs, based on interpretation of the natural gamma ray log. Locally, the Guaje is a pumice-rich, lithic- and crystal-poor fall deposit that contains predominantly (up to 97% by volume) white, glassy, pumice lapilli that typically are phenocryst-poor and have a fresh pristine appearance. Trace amounts of volcanic lithics, quartz and sanidine crystals and fine ash are present.

Cerros del Rio Basalt, Tb4 (248–687 ft bgs)

The Cerros del Rio basalt section, encountered from 248 to 687 ft bgs, locally includes pyroclastic lapilli tuff deposits of basalt cinders and scoria and at least three distinct basalt lavas separated by intervals of interflow breccia. The upper part of the Tb4 section, from 248 to 315 ft bgs, is made up of unconsolidated

red ferruginous (i.e., strongly hematite-stained) basaltic cinders and black vitric scoria. The presence of this thick accumulation of ejecta suggests proximity to a local basaltic eruptive center. The uppermost of three basalt flows identified in the Tb4 section, including an inferred 28-ft-thick basal agglomerate interval, or interflow breccia, occurs from 315 to 408 ft bgs. The basalt in this upperflow is vesicular to massive, phenocryst-poor, weakly olivine-, and clinopyroxene-phyric and exhibits an aphanitic groundmass that is commonly altered. No cuttings were returned from the breccia interval.

The interval from 408 ft to 506 ft bgs contains a basalt flow with underlying 10-ft-thick interflow breccia. This basalt is weakly porphyritic with phenocrysts of olivine, plus minor clinopyroxene and plagioclase, set in an aphanitic groundmass that is conspicuously altered and bleached. The lowermost basalt flow in the Cerros del Rio section, from 506 to 687 ft bgs, is defined by the open-borehole video log and by the natural gamma ray log. No cuttings were returned to characterize the interflow breccia and lowermost basalt.

Puye Formation, Tpf (687–965 ft bgs)

Volcaniclastic sediments of the Puye Formation were encountered in from 687 ft to 965 ft bgs. Cuttings in the upper 55 ft (687 to 742 ft) of the Puye Formation section were unrecovered because of lost circulation. The open borehole video log shows that the Puye Formation from 687 to 698 ft bgs is made up of alternating silt, sandy silt, and pebble gravels. From 698 to 741 ft bgs, the Puye Formation is made up of crudely stratified coarse-grained lithic sand, gravel, cobble, and boulder deposits. Below 742 ft bgs, cuttings recovered from the Puye Formation consist of texturally variable gray, grayish brown and pinkish tan, poorly sorted, fine to coarse gravels, gravelly sandstones and silty sandstones with gravel. Detrital constituents are generally subangular to subrounded. They are composed predominantly of gray, coarsely porphyritic biotite- and hornblende-dacites and they occur in abundance throughout the section. Other clasts locally include olivine-basalt, white dacite with abundant acicular biotite, rhyodacite, weathered pumice, scoria and dark colored vitrophyre.

Miocene Pumiceous Sediments, Tjfp (965–1042 ft bgs)

A section of pumice-rich volcaniclastic sediments occurs in R-45 from 965 ft to 1042 ft bgs. These deposits are made up of fine- to coarse-grained sandstones with pebble gravels. White, glassy, phenocryst-poor detrital pumices generally make up a large percent (typically as much as 70% by volume) of granule and pebble-size clasts. Additional constituents include abundant subangular to subrounded dacites, lesser amounts of basalt scoria, flow-banded rhyodacite, vitrophyre, and andesite.

Miocene Riverine Sediments, Tcar (1042–1057 ft bgs)

Pebble gravels and fine- to medium-grained riverine deposits (equivalent to the Hernandez Member of the Chamita Formation of the Santa Fe Group) were encountered from 1042 to 1057.2 ft bgs borehole TD. These deposits are characterized by subrounded to well rounded detrital clasts composed of mixed volcanic and Precambrian lithologies ranging from basalt, andesite, dacite and minor pumice, quartzite, and granite.

5.2 Groundwater

Potential groundwater was first encountered during drilling at approximately 742 ft bgs on December 19, 2008 and again at approximately 887 ft bgs (with a composite regional water level of 868 ft; the 887-ft water occurrence cannot be a potential perched zone) on January 7, 2009. Water samples were collected.

Groundwater was first recognized in the regional aquifer (estimated at 5-10 gpm flow) at approximately 944 ft bgs in the Puye Formation on January 7, 2009. After the well was drilled to final depth of 1057.2 ft bgs, the water level was measured at 868.4 ft bgs in the borehole.

Groundwater-screening samples collected during drilling, well development, and aquifer testing are discussed in section 4.2. Groundwater chemistry and field water quality parameters are discussed in Appendix B. Aquifer testing data and analysis are discussed in Appendix C.

6.0 BOREHOLE LOGGING

Several video logs were collected during the R-45 drilling project by Jet West Geophysical logging crews and a suite of cased-hole geophysical logs was recorded by Schlumberger Wireline Services. A summary of video and geophysical logging runs is presented in Table 6.0-1.

6.1 Video Logging

Video logs were run in the uncased borehole to check for the presence of perched groundwater on December 18, 2008. Minor indications of perched water were observed in the video in the lower portion of the Cerros del Rio basalt at 646–647 ft bgs, approximately 40 ft above the Cerros del Rio/Puye Formation contact. A second video log was recorded on January 16, 2009 to verify successful cutting of the 12-in. drill casing. The December 18, 2008, video log from the borehole is presented on a DVD as part of Appendix D included with this document. Table 6.0-1 provides details of individual video logging runs.

6.2 Geophysical Logging

A suite of Schlumberger geophysical logs was run inside the drill casing on January 9, 2009. At the time of logging, the terminations of the two casing strings in the borehole were located at the following depths: 16-in. casing at 314.7 ft bgs and the 12-in. casing at 1057.2 ft bgs (borehole TD). The geophysical suite included Triple Detector Litho-Density (TDL) tool, Compensated Neutron Tool (CNT), Natural and Spectral Gamma Ray Logs, and Elemental Capture Sonde (ECS). Interpretation and details of the logging are presented on CD in the Geophysical Logging Report as part of Appendix E.

Details of the logging operations are presented in Table 6.0-1. The results of the geophysical logging are presented on plots in Appendix E.

7.0 WELL INSTALLATION

R-45 well casing and annular fill were installed between January 13, 2009, and January 24, 2009.

7.1 Well Design

The R-45 well was designed in accordance with the approved drilling work plan. NMED approved the well design before installation. The well was designed with dual-screens to monitor groundwater quality near the top of the regional aquifer within Puye Formation sediments and deeper in the aquifer within Miocene pumiceous sediments.

7.2 Well Construction

The R-45 monitoring well was constructed of 5.0-in.-I.D./5.56-in.-O.D., type A304 stainless-steel beveled casing fabricated to American Society for Testing and Materials A312 standards. Screened sections utilized three (3) 10-ft lengths to make up 10-ft-long upper and 20-ft-long lower 5.0-in.-I.D. rod-based 0.020-in. wire-wrapped well screens. Welding, using compatible stainless-steel welding rods, was used to join all individual casing and screen sections. All casing and screen were steam and pressure washed on-site before installation. A 2-in. I.D. steel threaded/coupled tremie pipe string (decontaminated before use) was utilized for delivery of backfill and annular fill materials during well construction. The placement of annular materials typically had two components: (1) installing materials and (2) retracting the drill casing and raising the tremie pipe. As each section of drill casing was cut off the string, it was picked up and laid down. During this part of the process, the well casing was hung under full tension on a wireline in the borehole while the drill casing was supported by a ring and slips. Short lengths of 12-in. (32.2-ft casing and shoe) and 16-in. (3.7-ft casing and shoe) drill casing remain in the borehole. The 12-in. casing stub was encased in formation slough and backfill and isolated by the lowermost bentonite seal, while the 16-in. casing stub was set in bentonite to avoid unwanted impacts in the future.

Two screened intervals were chosen for the R-45 well design. The lower nominal 20-ft-long screen interval had the top of the screen set at 974.9 ft bgs, while the upper nominal 10-ft-long screen interval had the top of the screen set at 880 ft bgs. A 21.1-ft stainless-steel sump was placed below the bottom of the lower well screen. Stainless-steel centralizers (four sets of four) were welded to the well casing approximately 2.0 ft above and below each screen. A Pulstar work-over rig was used for well construction activities. Figure 7.2-1 presents an as-built schematic showing construction details for the completed well.

The work-over rig was moved on location January 12, 2009. Decontamination of the stainless-steel well casing and screens took place that day along with mobilization of initial well construction materials to the site. On January 13, the 5-in. well casing was started in the wellbore. Welders from Right Bit, Inc., welded each joint as it went into the borehole, using careful welding techniques and covering the borehole to avoid slag falling into the annular void.

After landing the casing at 1016 ft bgs, the process of installing annular materials began early in the morning of January 14, 2009. However, before significant 10/20 silica sand backfill was added, Jet West Geophysical was called on-site on January 16 to verify (via video logging) that the 12-in. casing was indeed cut after it refused to budge with the capable Pulstar rig. As a result, the dual-rotary drill rig was briefly moved onto the borehole to rotate the 12-in. casing to loosen it up a bit before video logging. After a clean cut was verified on the video, the remaining 10/20 silica sand (total, 31.7 ft³) was added to bring the top of the backfill up to 1011.2 ft bgs late on January 16. Next, a lower seal composed of ¼-in. bentonite pellets (3.4 ft³) was placed from 1000.3 to 1011.2 ft bgs.

The lower screen 10/20 silica sand filter pack was then installed from 969.0 to 1000.3 ft bgs. After this, the dual-rotary rig was swapped out for the Pulstar work-over rig and casing jacks, and the sand pack surged to promote compaction. A 20/40 silica sand transition was placed on top of the lower filter sand pack from 964.9 to 969.0 ft bgs.

A seal separating the two screened intervals was added from 895.6 to 964.9 ft bgs consisting of ¼-in. bentonite pellets (19.4 ft³), followed by ⅜-in. bentonite chips (40.2 ft³). The upper screen filter pack of 10/20 silica sand was then installed and surged at 874.8–895.6 ft bgs. The upper filter pack was then capped with a transition 20/40 silica sand from 872.7 to 874.8 ft bgs.

The well's upper bentonite seal (3/8-in. chips) was installed on January 19–22 from 299.4 to 872.7 ft bgs using a total of 636.7 ft³ of bentonite chips. The final surface seal, a mix of 97–98 wt% (Portland cement with 2–3 wt% bentonite) was placed above the upper bentonite seal from 3.0 to 299.4 ft bgs. Well construction was completed on January 24, 2009. Table 7.2-1 summarizes volumes of all materials used during well construction.

Operationally, well construction proceeded smoothly, 24 h/d, 7 d/wk, from January 13 to January 24, 2009. No significant problems slowed progress.

8.0 POSTINSTALLATION ACTIVITIES

Following well installation, the well was developed and aquifer pumping tests were conducted. Total groundwater removed during development and aquifer testing was 90,149 gal. A dedicated dual-zone submersible pump system, including an isolation packer and two transducers, will be installed in the near future. The wellhead and surface pad are complete and a geodetic survey of the wellhead was performed. Site restoration activities will be completed, following final disposition of contained drill cuttings, and groundwater is determined in accordance with the NMED-approved waste decision trees and regulatory requirements.

8.1 Well Development

Well development was conducted between January 26 and January 29, 2009. Initially, the screen intervals were bailed and swabbed to remove formation fines in the filter pack and well sump. Bailing and swabbing continued until water clarity visibly improved. Final development was then performed with a submersible pump. The swabbing tool was a 4.5-in.-O.D. 1-in.-thick nylon disc attached to a weighted steel rod. The swabbing tool was lowered by wireline and drawn repeatedly in both directions across the screen intervals. Each interval of swabbing was followed by an interval of bailing to remove fines. After bailing and swabbing, a 7.5-hp, 4-in.-Grundfos submersible pump was installed in the well for the final stage of well development.

During the pumping stage of well development, turbidity, temperature, pH, dissolved oxygen (DO), oxidation-reduction potential (ORP), and specific conductance parameters were measured. In addition, water samples for total organic carbon (TOC) analysis were collected. The required values for TOC and turbidity to determine adequate well development are less than 2.0 ppm and less than 5 nephelometric turbidity units (NTUs), respectively. The TOC measurements at the end of R-45 well development were less than 0.8 ppm, and the final turbidity values were 0.0 NTU for both screen intervals.

Approximately 14,559 gal. of groundwater was purged during well development activities. A discussion of water removed during well development, field water-quality parameters, and analytical results for samples collected during development is summarized below in section 8.1.1 and detailed in Table B.1.2.1-1 of Appendix B.

8.1.1 Well Development Field Parameters

Field parameters, including pH, temperature, DO, ORP, specific conductance, and turbidity, were measured at regular time intervals during well development. Results and further discussion are provided in Appendix B. Field parameters were measured by collecting aliquots of groundwater from the discharge pipe without the use of a flow-through cell, allowing the samples to be exposed to the atmosphere. This condition probably resulted in a slight variation of field parameters during well development and during the pumping test, most notably, temperature, pH, and DO.

Measurements of pH varied from 8.16 to 9.03 in the upper screened interval and 8.59 to 8.65 in the lower screened interval. Measurements of temperature varied from 17.24°C to 18.37°C in the upper screened interval and 18.60°C to 18.99°C in the lower screened interval. These uncorrected ORP measurements performed on groundwater samples pumped from well R-45 during development are not consistent with known overall oxidizing conditions characteristic of the regional aquifer beneath the Pajarito Plateau. Positive, uncorrected ORP measurements, however, were recorded during aquifer performance testing, suggesting that groundwater at well R-45 is relatively oxidizing. Concentrations of DO varied from 11.40 to 13.15 mg/L in the upper screened interval and from 7.80 to 10.79 mg/L in the lower screened interval. Uncorrected ORP measurements varied from -125.1 to -132.5 millivolts (mV) in the upper screened interval and -112.5 to -148.7 mV in the lower screened interval during well development. These DO measurements taken during well development are not consistent with the noncorrected and nonrepresentative negative ORP values; however, detectable concentrations of redox-sensitive solutes including chromium, nitrate, sulfate, and uranium (discussed in Appendix B) suggest the groundwater at R-45 is relatively oxidizing. Specific conductance ranged from 164 to 174 microsiemens per centimeter ($\mu\text{S}/\text{cm}$) in the upper screened interval and from 171 to 181 $\mu\text{S}/\text{cm}$ in the lower screened interval. Values of turbidity of nonfiltered samples measured were all 0.0 NTU for the upper screen and ranged from 66.3 to 0.0 NTUs for the lower screen. Four of the 22 turbidity measurements recorded during well development exceeded 5 NTUs.

8.2 Aquifer Testing

Aquifer pumping tests were conducted at R-45 between February 25 and March 5, 2009. Several short-duration tests with short-duration recovery periods were performed on the first day of testing each of the two screen intervals. A 24-h test followed by a 24-h recovery period completed the testing of each screen interval. A 10-hp Grundfos pump was used to perform the aquifer tests. Approximately 75,590 gal. of groundwater was purged during aquifer testing activities. The results of the R-45 aquifer tests are presented in Appendix C.

8.2.1 Aquifer Testing Field Parameters

Field parameters, including pH, temperature, DO, ORP, specific conductance, and turbidity, were measured at regular time intervals during aquifer testing in the same manner as during well development. Parameters were measured by collecting aliquots of groundwater from the discharge pipe without the use of a flow-through cell, allowing the samples to be exposed to the atmosphere. This condition probably resulted in a slight variation of field parameters during well development and during the pumping test, most notably, temperature, pH, and DO. Results are provided in Appendix B.

Measurements of pH and temperature varied from 7.95 to 8.01 and from 8.30°C to 20.13°C, respectively, for groundwater samples pumped from the upper screen. The pH values for groundwater pumped from the lower screen varied between 8.07 and 8.19, while temperatures varied between 15.78°C and 21.97°C. Concentrations of DO ranged from 6.35 to 9.37 mg/L in groundwater pumped from the upper screen and from 6.10 to 18.18 mg/L in groundwater pumped from the lower screen. Positive uncorrected ORP values varied from 85 to 160.5 mV during aquifer performance testing of R-45 screen 1, suggesting that groundwater is relatively oxidizing at well R-45. Positive ORP values varied from 76.4 to 97.6 mV during aquifer performance testing of R-45 screen 2. The DO and uncorrected ORP measurements are in general agreement with each other and they are consistent with overall oxidizing groundwater conditions within the regional aquifer. Upper screen specific conductance ranged from 156 to 176 $\mu\text{S}/\text{cm}$. Lower screen specific conductance varied from 123 to 171 $\mu\text{S}/\text{cm}$. Values of turbidity ranged from 1.0 to 3.8 NTUs for the nonfiltered groundwater samples in the upper screen. Turbidities varied between 1.1 and 4.1 NTUs for similar samples in the lower screen interval.

8.3 Dedicated Sampling System Installation

The dedicated sampling system for R-45 has been designed. The sampling system is on order from the manufacturer and will be installed upon delivery. The system will be a Baski Inc.-manufactured system that will utilize a single 3-hp, 4-in.-O.D. environmentally retrofitted Grundfos submersible pump capable of purging each screen interval discretely via pneumatically actuated access port valves. The system will include a viton-wrapped isolation packer between the screen intervals. Pump riser pipe will consist of threaded and coupled nonannealed 1-in.diameter stainless steel. Two 1-in.-diameter polyvinyl chloride (PVC) tubes will be installed along with and banded to the pump riser for dedicated transducers. The tubes will be 1.0-in.-I.D. flush-threaded schedule 80 PVC pipe. The upper PVC transducer tube will be equipped with a 6-in. section of 0.010-in. slot screen with a threaded end cap at the bottom of the tube. The lower PVC transducer tube will be equipped with a flexible nylon tube that will extend from a threaded end cap at the bottom of the PVC tube through the isolation packer to measure water levels in the lower screen interval. Two In-Situ Level Troll 500 transducers will be installed in the PVC tubes to monitor water levels in each screen interval. Postinstallation construction and sampling system component installation details for R-45 are presented in Figure 8.3-1a. Figure 8.3-1b presents technical notes.

8.4 Wellhead Completion

A reinforced concrete surface pad, 10 ft × 10 ft × 6 in. thick, was installed at the R-45 well head on March 16, 2009. The pad will provide long-term structural integrity for the well. A brass survey monument imprinted with well identification information was placed in the northwest corner of the pad. A 10-in.-I.D. steel protective casing with a locking lid was installed around the stainless-steel well riser. A weep hole was installed to prevent water buildup inside the protective casing. The concrete pad is slightly elevated above the ground surface to promote runoff. A total of four bollards, painted yellow for visibility, are set at the outside corners of the pad to protect the well from traffic. All of the four bollards are designed for easy removal to allow access to the well. Details of the wellhead completion are presented in Figure 8.3-1a.

8.5 Geodetic Survey

A New Mexico licensed professional land surveyor conducted a geodetic survey on February 10, 2009, (Table 8.5-1). The survey data collected conforms to Laboratory Information Architecture project standards IA-CB02, "GIS Horizontal Spatial Reference System," and IA-D802, "Geospatial Positioning Accuracy Standard for A/E/C and Facility Management." All coordinates are expressed as New Mexico State Plane Coordinate System Central Zone (NAD 83); elevation is expressed in feet above mean sea level using the National Geodetic Vertical Datum of 1929. Survey points include ground-surface elevation near the concrete pad, the top of the brass pin in the concrete pad, the top of the well casing, and the top of the protective casing. Survey results are summarized in Figure 8.3-1b.

8.6 Waste Management and Site Restoration

Waste generated from the R-45 project includes decontamination water, drilling fluids, purged groundwater, drill cuttings, and contact waste. A summary of the waste characterization samples collected from the R-45 well is presented in Table 8.6-1.

All waste streams produced during drilling and development activities were sampled in accordance with "Waste Characterization Strategy Form for the R-38, R-41, R-44, R-45, and R-46 Regional Groundwater Well Installation and Corehole Drilling" (LANL 2008, 103916).

Fluids produced during drilling and well development are expected to be land-applied after a review of associated analytical results per the waste characterization strategy form and the EP-Directorate Standard Operating Procedure (SOP) 010.0, Land Application of Groundwater. If it is determined that drilling fluids are nonhazardous but cannot meet the criterion for land application, the drilling fluids will be evaluated for treatment and disposal at one of the Laboratory's six wastewater treatment facilities. If analytical data indicate that the drilling fluids are hazardous/nonradioactive or mixed low-level waste, the drilling fluids will be disposed of at an authorized facility.

Cuttings produced during drilling are anticipated to be land-applied after a review of associated analytical results per the WCSF and ENV-RCRA SOP-011.0, Land Application of Drill Cuttings. If the drill cuttings do not meet the criterion for land application, they will be removed from the pit and disposed of at an authorized facility. Characterization of contact waste will be based upon acceptable knowledge, pending analyses of the waste samples collected from the drill cuttings, and purge water. Decontamination fluid used for cleaning the drill rig and equipment is containerized. The fluid waste was sampled and will be disposed of at an authorized facility.

Site restoration activities will include removing drilling fluids and cuttings from the pit and managing the fluids and cuttings in accordance with SOP-010.06, removing the polyethylene liner, removing the containment area berms, and backfilling and regrading the containment area, as appropriate.

9.0 DEVIATIONS FROM PLANNED ACTIVITIES

Drilling, sampling, and well construction at R-45 were performed as specified in "Final Drilling Plan for Regional Aquifer Wells R-44 and R-45" (TerranearPMC 2008, 105083).

10.0 ACKNOWLEDGMENTS

Patrick Longmire wrote Appendix B, Groundwater Analytical Results.

Boart Longyear drilled the R-45 borehole and installed the well.

Jet West Geophysical ran all downhole video equipment.

Right Bit Services and Equipment Repair welded the stainless well screen and casing.

Schlumberger Wireline Services performed the final geophysical logging of the borehole.

TerranearPMC provided oversight on all preparatory and field-related activities.

11.0 REFERENCES

The following list includes all documents cited in the main text of this report. Parenthetical information following each reference provides the author(s), publication date, and ER ID number. This information is also included in text citations. ER ID numbers are assigned by the Environmental Programs Directorate's Records Processing Facility (RPF) and are used to locate the document at the RPF and, where applicable, in the master reference set.

Copies of the master reference set are maintained at the NMED Hazardous Waste Bureau; the U.S. Department of Energy–Los Alamos Site Office; U.S. Environmental Protection Agency, Region 6; and the Directorate. The set was developed to ensure that the administrative authority has all material needed to review this document, and it is updated with every document submitted to the administrative authority. Documents previously submitted to the administrative authority are not included.

LANL (Los Alamos National Laboratory), March 2006. "Storm Water Pollution Prevention Plan for SWMUs and AOCs (Sites) and Storm Water Monitoring Plan," Los Alamos National Laboratory document LA-UR-06-1840, Los Alamos, New Mexico. (LANL 2006, 092600)

LANL (Los Alamos National Laboratory), October 4, 2007. "Integrated Work Document for Regional and Intermediate Aquifer Well Drilling (Mobilization, Site Preparation and Setup Stages)," Los Alamos National Laboratory, Los Alamos, New Mexico. (LANL 2007, 100972)

LANL (Los Alamos National Laboratory), October 2008. "Waste Characterization Strategy Form for the R-38, R-41, R-44, R-45, and R-46 Regional Groundwater Well Installation and Corehole Drilling," Los Alamos, New Mexico. (LANL 2008, 103916)

TerranearPMC, December 2008. "Drilling Plan for Regional Aquifer Well R-46," plan prepared for Los Alamos National Laboratory, Los Alamos, New Mexico. (TerranearPMC 2008, 105083)

Map Data Sources for R-45 Completion Report Location Map

Point Feature Locations of the Environmental Restoration Project Database; Los Alamos National Laboratory, Waste and Environmental Services Division, EP2008-0109; February 28, 2008.

Hypsography, 100 and 20 Foot Contour Interval; Los Alamos National Laboratory, ENV Environmental Remediation and Surveillance Program; 1991.

Surface Drainages, 1991; Los Alamos National Laboratory, ENV Environmental Remediation and Surveillance Program, ER2002-0591; 1:24,000 Scale Data; Unknown publication date.

Paved Road Arcs; Los Alamos National Laboratory, KSL Site Support Services, Planning, Locating and Mapping Section; 06 January 2004; as published January 4, 2008.

Dirt Road Arcs; Los Alamos National Laboratory, KSL Site Support Services, Planning, Locating and Mapping Section; 06 January 2004; as published January 4, 2008.

Structures; Los Alamos National Laboratory, KSL Site Support Services, Planning, Locating and Mapping Section; 06 January 2004; as published January 4, 2008.

Technical Area Boundaries; Los Alamos National Laboratory, Site Planning & Project Initiation Group, Infrastructure Planning Division; September 19, 2007.

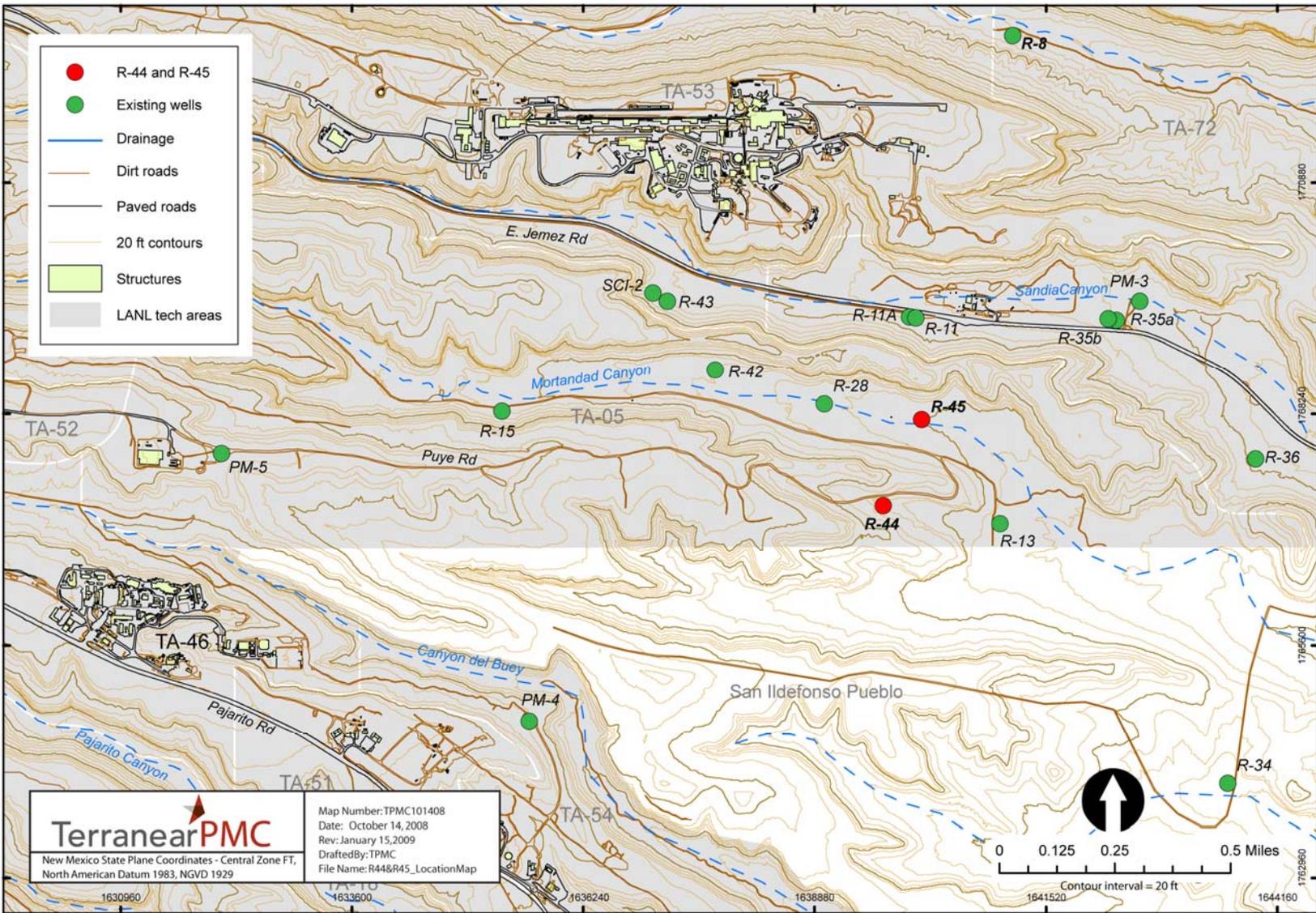


Figure 1.0-1 Regional aquifer well R-45 with respect to surrounding regional wells

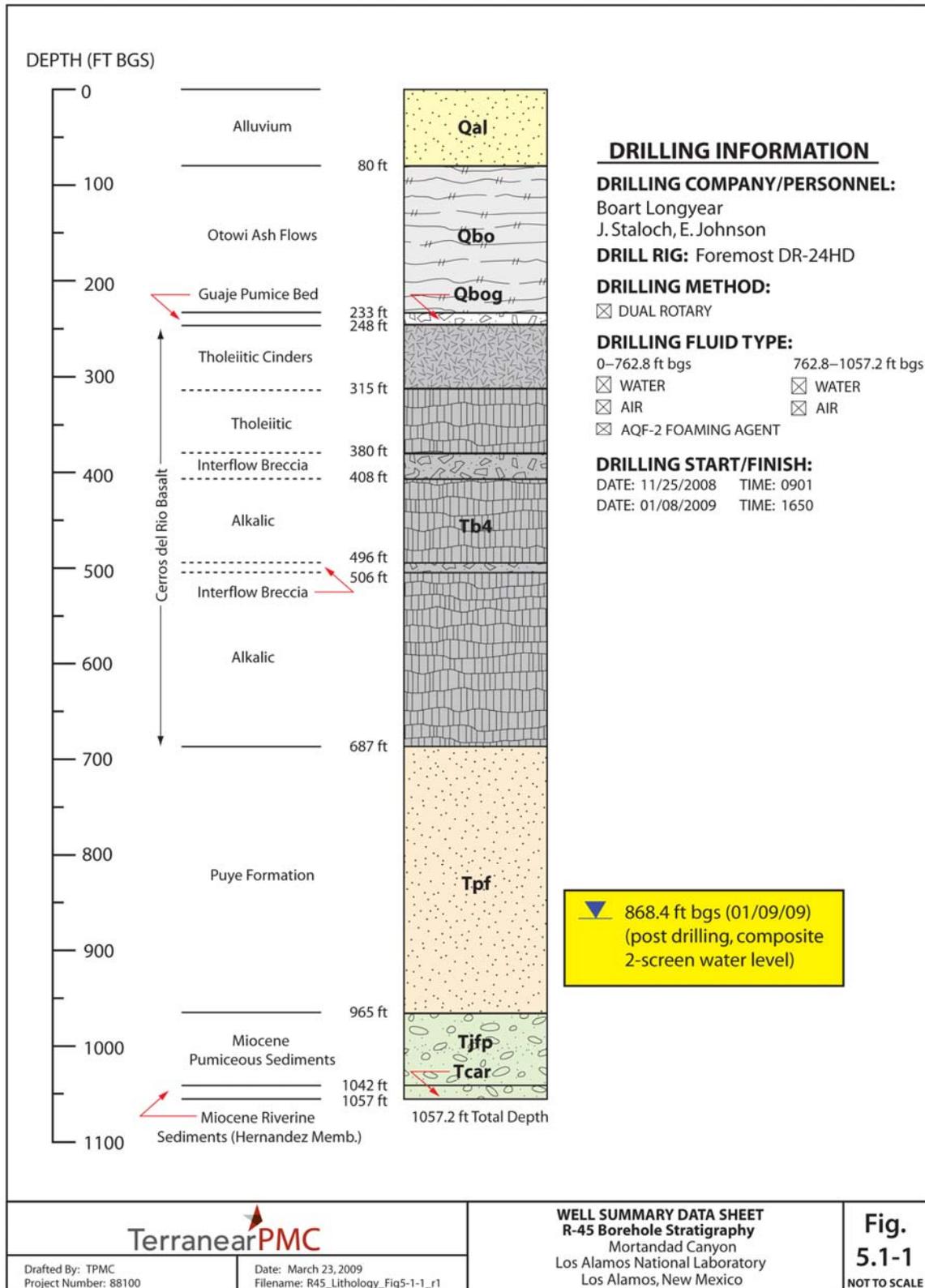


Figure 5.1-1 R-45 borehole stratigraphy

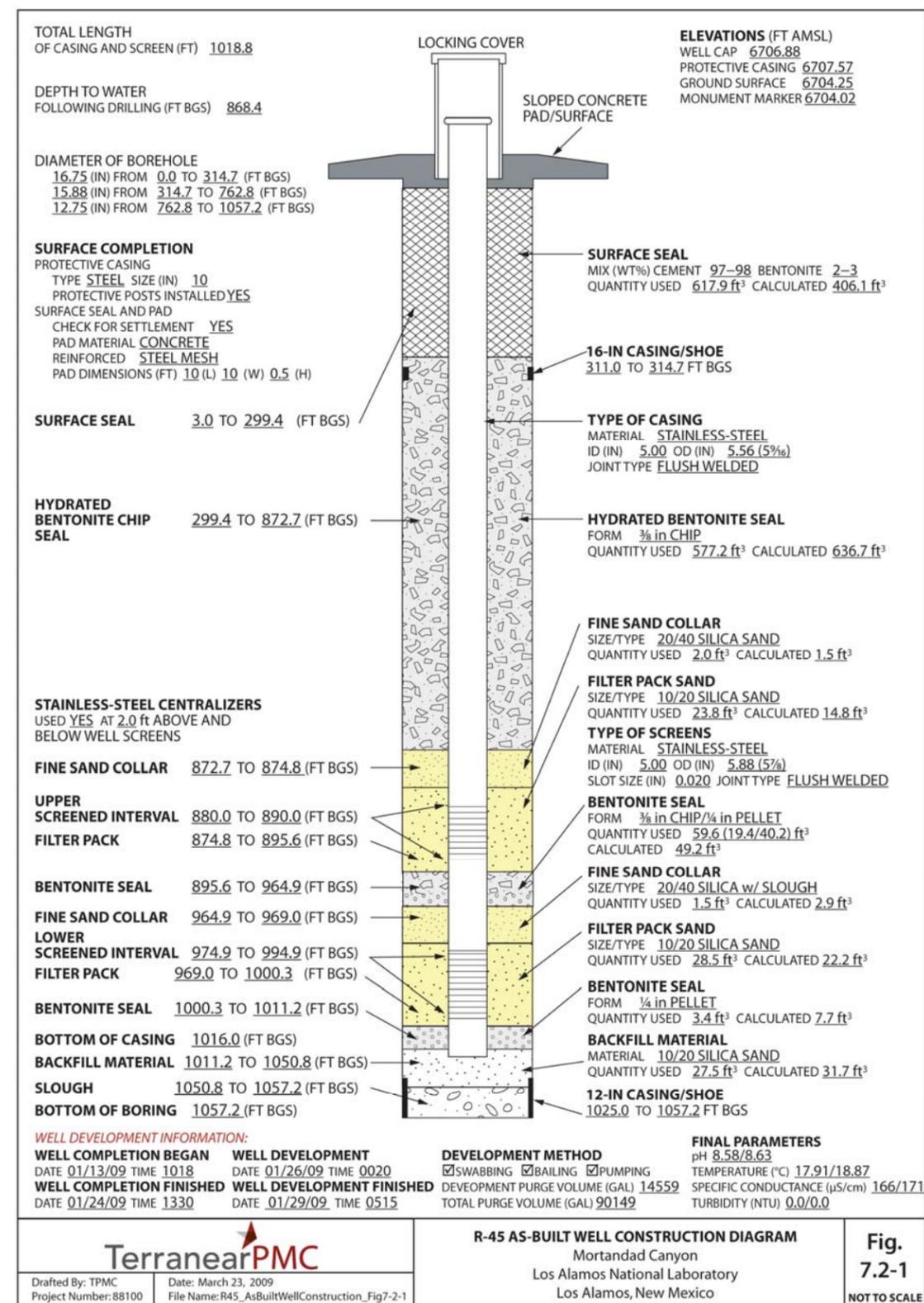


Figure 7.2-1 R-45 as-built well construction diagram

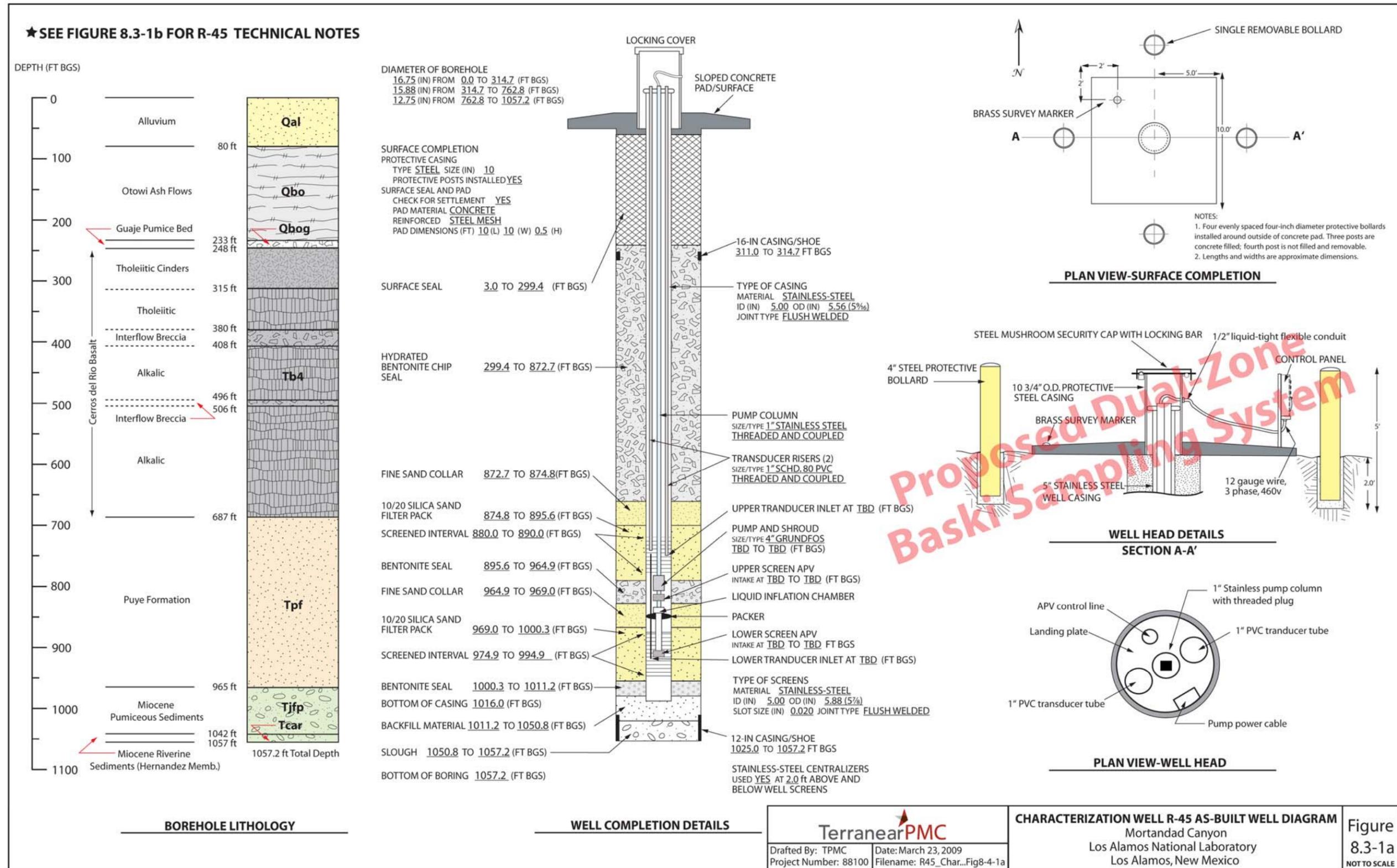


Figure 8.3-1a As-built schematic for regional well R-45

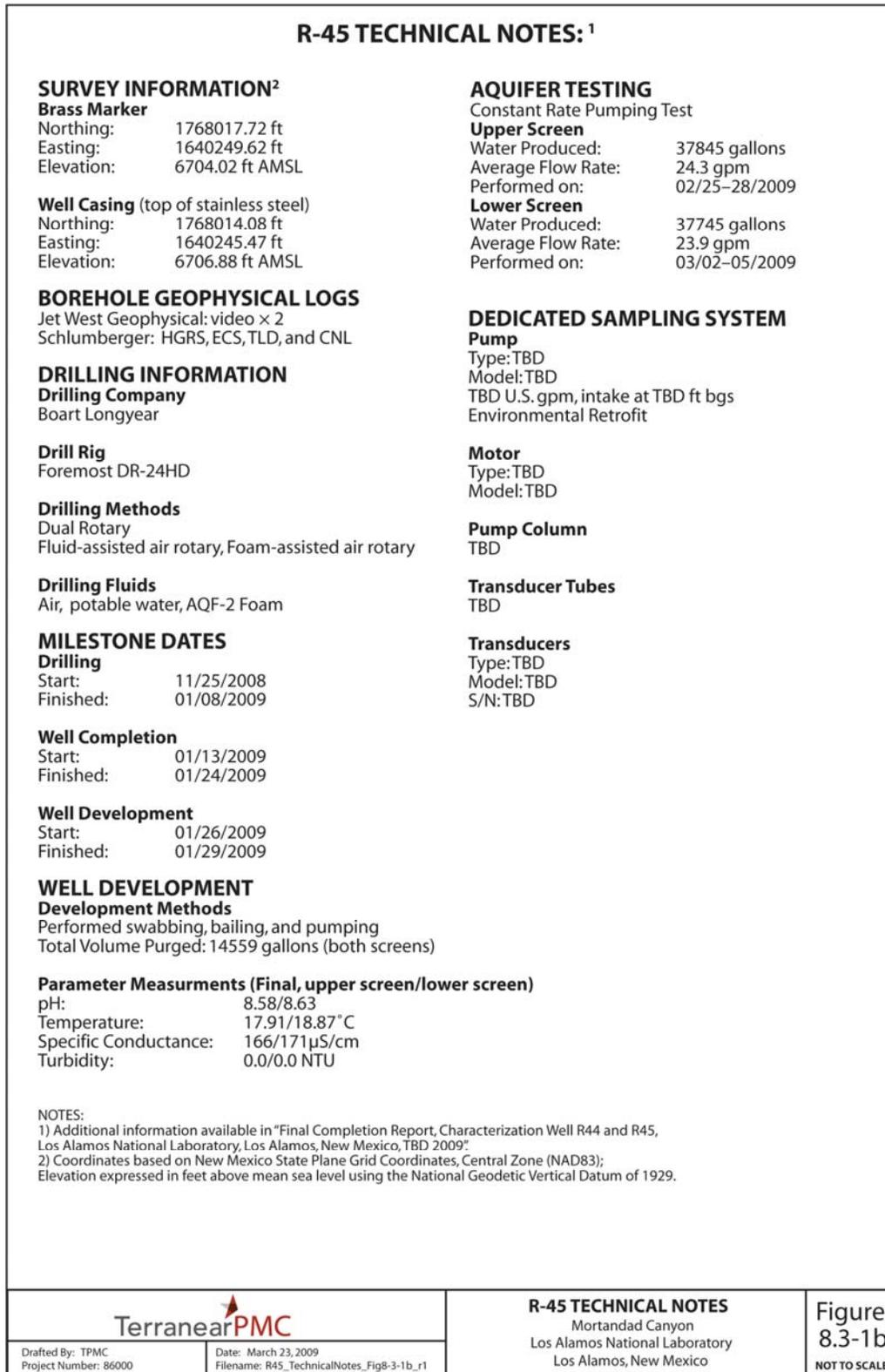


Figure 8.3-1b As-built technical notes for R-45

**Table 3.1-1
Fluid Quantities Used during Drilling and Well Construction**

Date	Water (gal.)	Cumulative Water (gal.)	AQF-2 Foam (gal.)	Cumulative AQF-2 Foam (gal.)
Drilling				
12/06/08	1800	1800	5	5
12/07/08	4200	6000	5	10
12/08/08	3600	9600	5	15
12/10/08	9000	18,600	5	20
12/11/08	4450	23,050	20	40
12/12/08	6200	29,250	35	75
12/13/08	16000	45,250	85	160
12/14/08	16000	61,250	66	226
12/15/08	1000	62,250	5	231
12/21/08	220	62,470	0	231
01/06/09	4100	66,570	0	231
01/07/09	2000	68,570	0	231
Well Construction				
01/15/09	1500	70,070	n/a*	231
01/16/09	4000	74,070	n/a	231
01/17/09	5500	79,570	n/a	231
01/18/09	13200	92,770	n/a	231
01/19/09	18000	110,770	n/a	231
01/20/09	6800	117,570	n/a	231
01/21/09	4400	121,970	n/a	231
01/22/09	1630	123,600	n/a	231
01/23/09	1400	125,000	n/a	231
01/24/09	1250	126,250	n/a	231

*n/a = Not applicable. Foam use and pit use discontinued after drilling activities; therefore, no additional fluids were produced.

**Table 4.2-1
Summary of Groundwater Screening Samples Collected during
Drilling, Well Development, and Aquifer Testing of Well R-45**

Location ID	Sample ID	Date Collected	Collection Depth (ft bgs)	Sample Type	Analysis
Drilling					
R-45	GW45-09-1337	12/19/08	742.3	Groundwater	Anions, metals
R-45	GW45-09-1357	12/19/08	742.3	Groundwater	Tritium
R-45	GW45-09-1338	01/07/09	887	Groundwater	Anions, metals
R-45	GW45-09-1358	01/07/09	887	Groundwater	Tritium
R-45	GW45-09-1340	01/07/09	924.0–924.5	Groundwater	Anions, metals
R-45	GW45-09-1359	01/07/09	924.0–924.5	Groundwater	Tritium
R-45	GW45-09-1341	01/07/09	944.0–944.5	Groundwater	Anions, metals
R-45	GW45-09-1342	01/08/09	962	Groundwater	Anions, metals
R-45	GW45-09-1343	01/08/09	982	Groundwater	Anions, metals
R-45	GW45-09-1344	01/08/09	1000.0–1000.5	Groundwater	Anions, metals
R-45	GW45-09-1345	01/08/09	1020.0–1020.6	Groundwater	Anions, metals
R-45	GW45-09-1346	01/08/09	1038.0–1038.5	Groundwater	Anions, metals
Development					
R-45	GW45-09-1317	01/27/09	880.0–890.0	Groundwater, upper screen	Anions, metals, TOC
R-45	GW45-09-1318	01/27/09	880.0–890.0	Groundwater, upper screen	Anions, metals, TOC
R-45	GW45-09-1319	01/29/09	974.9–994.9	Groundwater, lower screen	Anions, metals, TOC
R-45	GW45-09-1320	01/29/09	974.9–994.9	Groundwater, lower screen	Anions, metals, TOC
Pump Testing					
R-45	GW45-09-1321	02/27/09	880.0–890.0	Groundwater, upper screen	Anions, metals, TOC
R-45	GW45-09-1322	02/27/09	880.0–890.0	Groundwater, upper screen	Anions, metals, TOC
R-45	GW45-09-1323	02/27/09	880.0–890.0	Groundwater, upper screen	Anions, metals, TOC
R-45	GW45-09-1324	02/28/09	880.0–890.0	Groundwater, upper screen	Anions, metals, TOC
R-45	GW45-09-1325	02/28/09	880.0–890.0	Groundwater, upper screen	Anions, metals, TOC
R-45	GW45-09-1326	02/28/09	880.0–890.0	Groundwater, upper screen	Anions, metals, TOC
R-45	GW45-09-1327	03/04/09	974.9–994.9	Groundwater, lower screen	Anions, metals, TOC
R-45	GW45-09-1328	03/04/09	974.9–994.9	Groundwater, lower screen	Anions, metals, TOC
R-45	GW45-09-1329	03/04/09	974.9–994.9	Groundwater, lower screen	Anions, metals, TOC
R-45	GW45-09-1330	03/05/09	974.9–994.9	Groundwater, lower screen	Anions, metals, TOC
R-45	GW45-09-1331	03/05/09	974.9–994.9	Groundwater, lower screen	Anions, metals, TOC
R-45	GW45-09-1332	03/05/09	974.9–994.9	Groundwater, lower screen	Anions, metals, TOC

Table 6.0-1
R-45 Video and Geophysical Logging Runs

Date	Depth (ft bgs)	Description
12/18/08	762.8	Jet West Geophysical video logging of 16-in. cased and open hole section of borehole. Video revealed brecciated basalt at 495–510 ft bgs, slight water inflow at 646–647 ft bgs, and fairly common vertical fracturing in zones of massive basalt. The video below 741 ft bgs was obscured.
01/09/09	1057.2	Schlumberger Well Services, at final borehole TD, multiple cased hole trips and ran Hostile Natural Gamma-Ray, ECS, TLD, and Compensation Neutron Log.
01/16/09	1022.2	Jet West Geophysical, video logging inside 12-in. casing to confirm casing cut. Cut verified at 1016.1 ft bgs (bottom of lifted 12-in. casing).

Table 7.2-1
R-45 Annular Fill Materials

Material	Volume
Surface seal: cement slurry	617.9 ft ³
Upper seal: bentonite chips	577.2 ft ³
Upper fine sand collar: 20/40 silica sand	2.0 ft ³
Upper filter pack: 10/20 silica sand	23.8 ft ³
Middle seal: bentonite (pellets/chips)	59.6 (19.4/40.2) ft ³
Lower fine sand collar: 20/40 silica sand	1.5 ft ³
Lower filter pack: 10/20 silica sand	28.5 ft ³
Lower seal: bentonite pellets	3.4 ft ³
Backfill material: 10/20 silica sand	27.5 ft ³
Backfill material: formation slough	5.0 ft ³
Potable water used in the regional aquifer (drilling and well construction)	126,250 gal.

Table 8.5-1
R-45 Survey Coordinates

North	East	Elevation	Identification
1768017.72	1640249.62	6704.02	R-45 brass pin embedded in pad
1768014.81	1640245.50	6704.25	R-45 ground surface near pad
1768014.34	1640245.22	6707.57	R-45 top of 10-in. protective casing
1768014.08	1640245.47	6706.88	R-45 top of stainless-steel well casing

Notes: All coordinates are expressed as New Mexico State Plane Coordinate System Central Zone (NAD 83). Elevation is expressed in feet above mean sea level using the National Geodetic Vertical Datum of 1929.

Table 8.6-1
Summary of Waste Samples Collected during Drilling and Development of R-45

Location ID	Sample ID	Date Collected	Description	Sample Type
R-45	RC05-09-2859	12/12/08	Contact Waste	Solid
R-45	RC05-09-2860	12/12/08	Contact Waste	Solid
R-45	RC05-09-2859	01/26/09	Drill Cuttings	Solid
R-45	RC05-09-2860	01/26/09	Drill Cuttings	Solid
R-45	RC05-09-1531	01/26/09	Drilling Fluid	Liquid
R-45	RC05-09-1532	01/26/09	Drilling Fluid	Liquid
R-45	RC05-09-1533	01/26/09	Drilling Fluid	Liquid
R-45	RC05-09-1534	01/26/09	Drilling Fluid	Liquid
R-45	RC05-09-4867	03/04/09	Purge Water	Liquid
R-45	RC05-09-4868	03/04/09	Purge Water	Liquid
R-45	RC05-09-4869	03/04/09	Purge Water	Liquid
R-45	RC05-09-4870	03/04/09	Purge Water	Liquid

Appendix A

Well R-45 Lithologic Log

**Los Alamos National Laboratory
Regional Hydrogeologic Characterization Project
Borehole Lithologic Log**

corehole Identification (ID): R-45		Technical Area (TA): 5	Page: 1 of 18
DRILLING COMPANY: Boart Longyear Company		Start Date/Time: 11/25/2008: 0901	End Date/Time: 01/08/2009: 1650
Drilling Method: Dual Rotary		MACHINE: Foremost DR24 HD	Sampling Method: Grab
Ground Elevation:			TOTAL DEPTH: 1057 ft below ground surface (bgs)
DRILLERS: J. Staloch, C. Johnson, D. McCurdy		SITE GEOLOGISTS: A. Miller, J. R. Lawrence	
Depth (ft bgs)	Lithology	Lithologic Symbol	Notes
0–40	<p>ALLUVIUM:</p> <p>Unconsolidated tuffaceous sediments—light pinkish gray (5YR 6/1) to pinkish tan (5YR 7/6) medium to coarse sand and silty fine to medium sand; loose detritus derived from tuff.</p> <p>0–7 ft WR/+10F: silty gravels, pebbles of mixed quartzite and volcanic rocks indicating surficial construction fill.</p> <p>7–20 ft WR/+10F: medium to coarse sand; grains predominantly quartz and sanidine crystals, minor volcanic lithics, minor pumice.</p> <p>20–40 ft WR/+10F: silty fine to medium sand; grains predominantly quartz and sanidine crystals, minor volcanic lithics, minor pumice.</p>	Qal	<p>Note: Drill cuttings for microscopic and descriptive analysis were collected at 5-ft intervals from 0 to borehole total depth (TD) at 1057 ft bgs.</p> <p>Quaternary alluvial sediments, from 0 to 80 ft bgs, are estimated to be 80 ft thick.</p>
40–55	<p>Unconsolidated tuffaceous sediments— light pinkish gray (5YR 7/2) to pinkish tan (5YR 7/6) silty fine to medium sand with gravel; detritus derived from tuff.</p> <p>40–55 ft +10F: detritus composed of weathered pumice, various volcanic lithics, quartz and sanidine crystals, indurated fragments of crystal-rich tuff.</p>	Qal	
55–80	<p>Unconsolidated tuffaceous sediments— light pinkish gray (5YR 7/2) to reddish tan (5YR 6/4) silty fine to medium sand with gravel; detritus derived from tuff.</p> <p>55–80 ft WR: abundant silt matrix. +10F: detritus composed of indurated/welded crystal-rich tuff, various volcanic lithics, quartz and sanidine crystals, minor weathered tuff.</p>	Qal	Estimated Qal–Qbo contact at 80 ft bgs, based on interpreted natural gamma log data.

Borehole Lithologic Log (continued)

Borehole ID: R-45		TA: 5	Page: 2 of 18
Depth (ft bgs)	Lithology	Lithologic Symbol	Notes
80–100	<p>OTOWI MEMBER OF THE BANDELIER TUFF:</p> <p>Tuff—light pinkish gray (5YR 7/2) to pale tan (5YR 8/3), poorly welded, pumiceous, lithic- and crystal-bearing.</p> <p>80–100 ft WR: abundant silty ash matrix.+10F: 80%–90% quartz and sanidine crystals; 10%–20% small (up to 5 mm in diameter) dacitic lithic fragments, minor weathered pumice fragments.</p>	Qbo	The Otowi Member, encountered from 80 to 233 ft bgs, is estimated to be 153 ft thick.
100–115	<p>Tuff—light pinkish gray (7.5YR 7/2), poorly welded, strongly pumiceous, lithic- and crystal-bearing.</p> <p>80–100 ft WR: abundant silty ash matrix.+10F: 95%–98% pumice fragments (orange tan, quartz- and sanidine-phyric, glassy, with spots of black secondary Fe-oxide); 2%–5% volcanic lithic fragments, predominantly dacite. +35F: 30%–40% quartz and sanidine crystals; 25%–35% pumice particles; 25%–35% dacitic lithic fragments.</p>	Qbo	
115–120	<p>Tuff—pinkish white (7.5YR 8/2), poorly welded, strongly pumiceous, lithic- and crystal-poor.</p> <p>115–120 ft WR: predominantly pumice fragments, no ash preserved. +10F: 99%–100% pumice fragments (up to 18 mm in diameter), white to locally yellowish brown (i.e., limonite stained), glassy, quartz- and sanidine-phyric.</p>	Qbo	
120–140	<p>Tuff—pinkish white (7.5YR 8/2), poorly welded, strongly pumiceous, lithic- and crystal-poor.</p> <p>120–125 ft +10F: 30–40% white to yellowish (Fe-oxide stained) pumice fragments (up to 10 mm in diameter) that are glassy, fibrous-textured and quartz- and sanidine-phyric; 40%–50% volcanic lithic fragments (up to 3 mm in diameter) predominantly light gray and pinkish dacites and gray vitrophyre; trace quartz and sanidine crystals. +35F: 40%–50% pumice, 20%–30% quartz and sanidine crystals; 20%–30% volcanic lithics.</p> <p>125–140 ft +10F: 50%–60% vitric pumice fragments; 40%–50% volcanic lithics.</p>	Qbo	

Borehole Lithologic Log (continued)

Borehole ID: R-45		TA: 5	Page: 3 of 18
Depth (ft bgs)	Lithology	Lithologic Symbol	Notes
140–150	<p>Tuff—pinkish white (7.5YR 8/2), poorly welded, strongly pumiceous, lithic- and crystal-bearing.</p> <p>140–150 ft +10F: very little sample volume preserved. +35F: 80%–85% white vitric pumice fragments; 10%–15% quartz and sanidine crystals; 3%–5% volcanic lithic fragments (dacite, obsidian, andesite).</p>	Qbo	
150–160	<p>Tuff—light pinkish white (7.5YR 8/2), poorly welded, strongly pumiceous, lithic-bearing, crystal-poor.</p> <p>150–155 ft+10F: 98%–99% white to yellowish (i.e., limonite stained) vitric, quartz- and sanidine-phyric pumice fragments (up to 7 mm in diameter); 1%–2% volcanic lithic fragments.</p> <p>155–160 ft +10F: 85%–90% vitric pumice fragments; 10%–15% volcanic lithic fragments, predominantly pinkish to gray dacites.</p>	Qbo	
160–180	<p>Tuff—varicolored, pinkish white (7.5YR 8/2) to light gray (GLE Y1 7/0), poorly welded, pumiceous, lithic-rich, crystal-poor.</p> <p>160–165 ft +10F: 15%–20% vitric pumices; 30%–40% quartz and sanidine crystals; 30%–40% dacitic lithic fragments (up to 3 mm in diameter).</p> <p>165–170 ft No cuttings present; lost circulation.</p> <p>170–175 ft+10F: 60%–70% volcanic lithic fragments (up to 5 mm in diameter), predominantly gray to pink dacites, trace black vitrophyre; 20%–30% white to yellowish, vitric, quartz- and sanidine-phyric pumices.</p> <p>175–180 ft +10F: 65%–75% vitric pumice fragments (up to 10 mm in diameter), commonly limonite-stained; 25%–35% dacitic lithic fragments.</p>	Qbo	

Borehole Lithologic Log (continued)

Borehole ID: R-45		TA: 5	Page: 4 of 18
Depth (ft bgs)	Lithology	Lithologic Symbol	Notes
180–200	<p>Tuff—pinkish white (7.5YR 8/2), poorly welded, strongly pumiceous, lithic- and crystal-bearing.</p> <p>180–185 +10F: 90%–95% yellowish orange to white vitric pumice fragments (up to 8 mm in diameter) containing phenocrysts of quartz and sanidine plus minor clinopyroxene; 5%–10% white to light gray dacitic lithic fragments. +35F: 30%–40% pumice fragments 30%–35a% lithics (dacite, andesite); 35%–45% quartz and sanidine crystals.</p> <p>185–190 ft +10F: 90% pumices; 7%–10% dacite lithics; 1%–2% quartz and sanidine crystals.</p> <p>190–200 ft +10F: 98-99% pumice fragments; 1%–2% dacitic lithic fragments.</p>	Qbo	
200–220	<p>Tuff—pinkish white (7.5YR 8/2), poorly welded, strongly pumiceous, lithic- and crystal-bearing.</p> <p>200–205 ft+10F: 99% yellowish (i.e., limonite-stained) to white glassy pumices (up to 12 mm in diameter) that are quartz- and sanidine-phyric; trace volcanic lithic fragments (dacite, obsidian). +35F: 30%–35% quartz and sanidine crystals; 30%–35% volcanic lithic fragments (dacite, vitrophyre); 30%–35% yellowish pumice fragments.</p> <p>205–210 ft +10F: 85%–90% yellowish pumice fragments; 10%–15% volcanic lithics; trace quartz and sanidine crystals.</p> <p>210–215 ft +10F: 40%–50% yellowish to white pumice fragments; 40%–50% volcanic lithic fragments.</p> <p>215–220 ft+10F; 80%–85% white and minor pinkish glassy pumices; 15%–20% dacitic lithic fragments.</p>	Qbo	

Borehole Lithologic Log (continued)

Borehole ID: R-45		TA: 5	Page: 5 of 18
Depth (ft bgs)	Lithology	Lithologic Symbol	Notes
220–233	<p>Tuff—white (7.5YR 8/2) to medium gray (GLEY1 6/0), poorly welded, pumiceous, lithic-rich.</p> <p>200–225 ft+10F: 60%–70% white to yellowish (i.e., limonite-stained) glassy pumices; 30%–40% volcanic lithic fragments (white to gray and pinkish dacites, black porphyritic vitrophyre).</p> <p>225–233 ft+10F: 80%–95% white and partly yellowish vitric, quartz- and sanidine-phyric pumices; 20%–25% volcanic lithic fragments (pinkish and gray dacites, flow-banded rhyolite).</p>	Qbo	<p>The Qbo-Qbog contact is placed at 233 ft bgs, based on interpretation of natural gamma geophysical log data.</p>
233–248	<p>GUAJE PUMICE BED:</p> <p>Tuff— white (5YR 8/1) to very pale orange (7.5YR 7/6), pumice-rich, lithic-poor, crystal-poor, no apparent volcanic ash matrix.</p> <p>296–305 ft WR/+10F: 97%–98% white to locally yellowish (i.e., weak limonite staining) vitric pumices (up to 22 mm in diameter); 2%–3% dacitic lithic fragments (up to 20 mm in diameter).</p> <p>305–315 ft WR/+10F: 100% white and locally pinkish vitric pumices (up to 22 mm in diameter); phenocryst-poor, having pristine, very fresh appearance.</p> <p>310–315 ft +35F: no returns of this sample size fraction.</p>	Qbog	<p>The Guaje Pumice Bed, from 233 to 248 ft bgs, is estimated to be 15 ft thick.</p> <p>The Qbog-Tb4 contact is placed at 248 ft bgs, based on cuttings analysis and interpretation of natural gamma geophysical log data.</p>
248–255	<p>CERROS DEL RIO BASALT:</p> <p>Basaltic tuff/cinder deposits—varicolored, white 5YR 8/1) to light gray (GLEY1 7/0) mixed pumice fragments, detrital dacite granules and cinder fragments.</p> <p>248–255 ft WR/+10F: 60%–70% white glassy phenocryst-poor pumice fragments that are locally Fe-oxide stained (probable residual Otowi cuttings); 30%–40% subangular dacite granules (up to 4 mm in diameter). 10%–15% lapilli cinders of ferruginous scoria and black vitrophyric scoria.</p>	Tb4	<p>The Cerros del Rio basalt (in total), occurring from 248 to 687 ft bgs, is estimated to be 439 ft thick.</p> <p>Pyroclastic cinder deposits of basaltic lapilli tuff, encountered from 248 ft to 315 ft bgs, are estimated to be 67 ft thick.</p>

Borehole Lithologic Log (continued)

Borehole ID: R-45		TA: 5	Page: 6 of 18
Depth (ft bgs)	Lithology	Lithologic Symbol	Notes
255–270	<p>Basaltic tuff/cinder deposits—reddish brown (2.5YR 5/8) to black (GLE Y1 2.5/0), unconsolidated ferruginous cinders and scoriaceous vitrophyre.</p> <p>255–270 ft WR/+10F: 90%–95% angular fragments/chips of red ferruginous scoria (i.e., cinders) and black vitric scoria; 5%–10% white glassy pumice fragments; trace subangular dacite granules and quartz crystal grains.</p>	Tb4	
270–295	<p>Basaltic tuff/cinder deposits—reddish brown (2.5YR 5/8) to black (GLE Y1 2.5/0), unconsolidated lapilli tuff, cinders of ferruginous (i.e., strongly hematite stained) and black glassy scoria; minor pumice fragments.</p> <p>270–280 ft WR/+10F: 95%–97% lapilli-size (up to 10 mm in diameter) red ferruginous basalt cinders and black glassy scoria; 3%–5% white pumice fragments; trace subangular dacitic granules.</p> <p>280–295 ft +10F: similar to 270–280 ft; abundance of black glassy scoria decreases downward with respect to red hematitic cinders.</p>	Tb4	
295–315	<p>Basaltic tuff/cinder deposits—reddish brown (2.5YR 5/8) lapilli of ferruginous (i.e., hematitic) scoriaceous basaltic cinders and minor glassy scoria.</p> <p>295–310 ft WR/+10F: 99%–100% lapilli-size cinders and fragments (up to 6 mm) of strongly hematite-stained basaltic scoria and minor black vitrophyre; up to 1% white pumice fragments; trace dacitic granules.</p> <p>310–315 ft WR/+10F: 99%–100% lapilli-size (up to 20 mm in diameter) ferruginous scoriaceous basalt cinders, clinopyroxene(cpx)-phyric.</p>	Tb4	The contact between Tb4 cinder deposits and underlying massive basaltic lava is placed at 315 ft bgs, based on interpretation of natural gamma geophysical log data.

Borehole Lithologic Log (continued)

Borehole ID: R-45		TA: 5	Page: 7 of 18	
Depth (ft bgs)	Lithology	Lithologic Symbol	Notes	
315–325	<p>Basalt lava—medium gray (GLE Y1 6/0) and reddish brown (2.5YR 5/8), predominantly basalt scoria and minor massive basalt chips.</p> <p>315–320 ft WR/+10F: 95–98% lapilli (up to 8 mm in diameter) of ferruginous red and gray basalt scoria; 2%–5% angular massive cpx-phyric basalt chips; trace granules of pumice and dacite.</p> <p>320–325 ft no cuttings preserved; lost circulation.</p>	Tb4		
325–335	<p>Basalt lava—medium gray (GLE Y1 6/0) and reddish brown (2.5YR 5/8), predominantly chips of massive to vesicular basalt, phenocryst-poor with aphanitic groundmass; minor basalt cinders.</p> <p>325–335 ft WR/+10F: 80%–85% angular chips of strongly vesicular and nonvesicular basalt, phenocrysts (up to 1% by volume) small (up to 1 mm in diameter) black cpx, groundmass weakly altered; 10%–15% ferruginous scoriaceous lapilli.</p>	Tb4		
335–355	<p>Basalt lava—dark reddish brown (2.5YR 4/4) to medium gray (GLE Y1 5/0), chips of massive and vesicular basalt, phenocryst-poor with aphanitic groundmass.</p> <p>335–340 ft WR/+10F: 45%–55% reddish to yellowish brown chips of strongly vesicular to scoriaceous basalt exhibiting strong Fe-oxide alteration; 45%–55% chips of massive basalt with phenocrysts (up to 1% by volume) green-amber olivine and minor small clinopyroxene).</p> <p>340–355 ft WR: silty matrix. +10F: similar to 335–340 ft with proportionally less abundant reddish vesicular basalt; olivine phenocrysts subhedral (up to 3 mm in diameter) are weakly iddingsitized.</p>	Tb4		

Borehole Lithologic Log (continued)

Borehole ID: R-45		TA: 5	Page: 8 of 18
Depth (ft bgs)	Lithology	Lithologic Symbol	Notes
355–365	Basalt lava—dark reddish brown (2.5YR 4/4) to medium gray (GLE Y1 5/0), mixed angular chips of gray massive and brick red vesicular basalt, phenocryst-poor with aphanitic groundmass that is weakly to moderately altered. 355–365 ft WR: abundant silt due to milling of altered basalt groundmass. +10F: 50%–60% gray massive basalt chips, phenocrysts (up to 1% by volume) of olivine, trace cpx; groundmass altered.	Tb4	
365–380	Basalt lava—medium gray (GLE Y1 5/0) to locally yellow brown (7.5YR 7/8), mixed massive cpx- and olivine-phyric basalt and lesser abundant reddish vesicular basalt, local yellow Fe-oxide (i.e., limonite) staining. 365–380 ft WR: abundant silt-size particles. +10F: 90% massive cpx- and olivine-phyric basalt, phenocrysts (1%–2% by volume) anhedral black cpx (up to 4 mm in diameter) and subhedral; green-amber olivines (up to 2 mm in diameter) that are commonly iddingsitized; 10% reddish vesicular basalt chips; local limonite staining on fracture surfaces.	Tb4	365–370 ft WR: dusty appearance is caused by abundant silt-size particles generated during drilling and indicating moderately altered basalt groundmass.
380–408	Basaltic interflow breccia—medium gray (GLE Y1 5/0) to locally yellow brown (7.5YR 7/8), mixed massive cpx- and olivine-phyric basalt and lesser abundant reddish vesicular basalt, local yellow Fe-oxide (i.e., limonite) staining. 380–385 ft WR/+10F: similar to 365'–380'. 385–408 ft No cuttings available; no sample recovery.	Tb4	Note: Tb4 interflow breccia occurs from 380 ft to 408 ft bgs, as interpreted from natural gamma log data. Cuttings from most of this interval are unavailable because of lost circulation while drilling.

Borehole Lithologic Log (continued)

Borehole ID: R-45		TA: 5	Page: 9 of 18
Depth (ft bgs)	Lithology	Lithologic Symbol	Notes
408–435	<p>Basalt lava–medium gray (GLE Y1 5/0), massive to weakly vesicular, phenocryst-poor with aphanitic groundmass, GM weakly altered.</p> <p>408–410 ft No cuttings available; lost circulation.</p> <p>410–415 ft+10F: very low sample volume preserved; massive phenocryst-poor olivine- and cpx-phyric basalt.</p> <p>415–425 ft +10F: 99% angular chips of massive, phenocryst-poor basalt, phenocrysts (1% by volume) of small (up to 2 mm in diameter) black cpx and green olivine, aphanitic groundmass weakly altered; trace red Fe-oxide-stained basalt chips.</p> <p>425–435 ft No cuttings available; lost circulation.</p>	Tb4	
408–435	<p>Basalt lava–medium gray (GLE Y1 5/0), massive to weakly vesicular, phenocryst-poor with aphanitic groundmass, GM weakly altered.</p> <p>408–410 ft No cuttings available; lost circulation.</p> <p>410–415 ft+10F: very low sample volume preserved; massive phenocryst-poor olivine- and cpx-phyric basalt.</p> <p>415–425 ft +10F: 99% angular chips of massive, phenocryst-poor basalt, phenocrysts (1% by volume) of small (up to 2 mm in diameter) black cpx and green olivine, aphanitic groundmass weakly altered; trace red Fe-oxide-stained basalt chips.</p> <p>425–435 ft No cuttings available; lost circulation.</p>	Tb4	
435–455	<p>Basalt lava– medium gray (GLE Y1 5/0) to light gray (GLE Y1 7/0), chips of weakly porphyritic, cpx- and olivine-phyric basalt with weakly altered groundmass.</p> <p>435–455 ft WR/+10F: 100% angular to subrounded (i.e., milled during drilling) basalt chips, phenocrysts (2%–3% by volume) of amber-green olivine and black anhedral to resorbed cpx (up to 2 mm in diameter) plus small white plagioclase; groundmass moderately altered; cpx exhibits apparent olivine as overgrowths.</p>		

Borehole Lithologic Log (continued)

Borehole ID: R-45		TA: 5	Page: 10 of 18
Depth (ft bgs)	Lithology	Lithologic Symbol	Notes
455–480	Basalt lava–light gray (GLE Y1 7/0) chips of massive, weakly porphyritic, olivine- and cpx-phyric basalt with aphanitic groundmass, GM conspicuously altered and bleached. 455–475 ft WR/+10F: 100% subrounded (i.e., milled during drilling) basalt chips, phenocrysts (3%–4% by volume) of pale amber-green olivine, dark brown opaque cpx, minor white plagioclase; groundmass altered and bleached. 475–480 ft No cuttings available; lost circulation.	Tb4	
480–496	Basalt lava–light gray (GLE Y1 7/0) basalt, weakly porphyritic with aphanitic groundmass, GM altered and bleached. 480–496 ft WR/+10F: 100% angular to subrounded (i.e., milled during drilling) basalt chips, phenocrysts (2%–4% by volume) of small (up to 2 mm in diameter) anhedral to subhedral pale green olivine, plagioclase and minor clinopyroxene; groundmass altered and bleached.	Tb4	
496–506	Basaltic interflow breccia–light gray (GLE Y1 7/0) basalt chips, weakly porphyritic with aphanitic groundmass, predominantly cpx-phyric basalt, GM weakly to moderately altered and bleached, minor vesicular basalt. 496–500 ft similar to 480 ft 496 ft. 500–505 ft WR/+10F: 95%–97% angular basalt chips, phenocrysts (2%–4% by volume) predominantly small (1–2 mm in diameter) black cpx, minor greenish olivine; 3%–5% glassy basalt scoria, vesicles in-filled with brown clay and fine white grains (unidentified). 505–506 ft No cuttings available; lost circulation.	Tb4	Note: Tb4 interflow breccia occurs from 496 ft to 506 ft bgs, as interpreted from natural gamma log data. Some cuttings from this interval are unavailable because of lost circulation while drilling.
506–687	Basalt lava– 506–687 ft No cuttings available; lost circulation.	Tb4	506–687 ft No sample recovery due to lost fluid circulation while drilling in Tb4 basalt through this extensive interval. The contact between Tb4 lavas and underlying Puye volcanoclastic sediments is placed at 687 ft bgs, based on interpretation of natural gamma geophysical log data and open-borehole video.

Borehole Lithologic Log (continued)

Borehole ID: R-45		TA: 5	Page: 11 of 11	
Depth (ft bgs)	Lithology	Lithologic Symbol	Notes	
687–740	<p>PUYE FORMATION:</p> <p>Volcaniclastic sediments—</p> <p>687–740 No cuttings available, no recovery in this drilled interval.</p>	Tpf	Puye Formation volcaniclastic sediments, encountered from 687 to 965 ft bgs, are estimated to be 278 ft thick.	
740–760	<p>Volcaniclastic sediments—varicolored, medium gray (GLE Y1 5/0) to pale tan (5YR 8/2), mixed basalt chips and volcaniclastic detrital grains.</p> <p>740–745 ft WR: 35%–45% small angular/broken chips of weakly vesicular ol- and cpx-phyric basalt; 55%–65% subangular sand grains and granules of diverse volcanic rocks (fine-grained white and gray hbn-phyric dacites, black vitrophyre, quartz crystal, white pumices, andesite). +10F: 60%–70% small chips ol-cpx-basalt; 30%–40% grains of various volcanic rocks (as above).</p> <p>745–760 ft No cuttings available; lost circulation.</p>	Tpf		
760–765	<p>Volcaniclastic sediments—light gray (GLE Y1 7/0) to light pinkish gray (2.5YR 6/4), fine to coarse gravels with fine- to medium-grained sandstone, detritus of gray to pink coarsely porphyritic dacites.</p> <p>760–765 ft WR/+10F: broken and subrounded clasts (up to 17 mm in diameter) made up uniquely of coarse-porphyritic hbn-plagioclase dacite.</p>	Tpf		
765–775	<p>Volcaniclastic sediments—light gray (GLE Y1 7/0) to pinkish gray (2.5YR 6/4), fine gravel with fine- to coarse-grained sandstone, detritus dominantly of gray to pink coarse-porphyritic dacites.</p> <p>765–775 ft WR/+10F: subangular granules and small pebbles mainly composed of gray and pink hbn-dacites plus minor white fine-grained bt-dacite, andesite and glassy dacite.</p>	Tpf		

Borehole Lithologic Log (continued)

Borehole ID: R-45		TA: 5	Page: 12 of 12	
Depth (ft bgs)	Lithology	Lithologic Symbol	Notes	
775–790	<p>Volcaniclastic sediments—light pinkish white (5YR 8/2), medium to coarse gravel with fine- to coarse-grained sandstone and silt, detritus mostly of gray to pink dacites, minor additional volcanic rocks.</p> <p>775–785 ft WR: clasts coated with pink silt. +10F: subangular to subrounded pebbles predominantly of gray and pink-orange hbn-dacite, trace bt-dacite and white to black porphyritic vitrophyre.</p> <p>785–790 ft WR: abundant silt matrix. +10F: similar to 775–78 ft.</p>	Tpf		
790–810	<p>Volcaniclastic sediments—light gray (GLE Y1 7/0) and pink tan (2.5YR 6/4), coarse to fine gravels with fine- to coarse-grained sandstone, detritus predominantly dacitic.</p> <p>790–800 ft +10F: broken (up to 23 mm in diameter) and subangular to subrounded clasts predominantly gray to pink coarse-porphyrific hbn-dacite, also minor white bt-dacite, rhyodacite.</p> <p>800–810 ft +10F: clasts/fragments of hbn- and bt-phyric dacites, trace local dark.</p>	Tpf		
810–830	<p>Volcaniclastic sediments—light gray (GLE Y1 7/0) coarse to fine gravels with silty fine- to coarse-grained sandstone, detritus of various volcanic rocks, predominantly dacite.</p> <p>810–820 ft WR: clasts coated with silt. +10F: broken and subangular clasts (up to 15 mm in diameter) composed of various volcanic lithologies: light gray cpx-dacite, hbn-dacite, pumices, andesite.</p> <p>820–830 ft WR: very silty matrix. +10F: broken (up to 22 mm in diameter) and subangular to subrounded clasts composed of cpx-phyric dacites, hbn-dacite (gray coarse porphyritic and white fine-grained varieties).</p>	Tpf		

Borehole Lithologic Log (continued)

Borehole ID: R-45		TA: 5	Page: 13 of 13	
Depth (ft bgs)	Lithology	Lithologic Symbol	Notes	
830–840	<p>Volcaniclastic sediments—light gray (GLE Y1 7/0) fine gravel with fine- to coarse-grained sandstone, detritus predominantly gray to pinkish dacites.</p> <p>830–835 ft +10F: subangular small pebbles and granules composed mostly of hbn- and bt-phyric dacites; minor dacite with small green cpx.</p> <p>835–840 ft +10F: similar to 830–835 ft; also present pink-orange rhyodacite, minor dark brown vitrophyre.</p>	Tpf		
840-865	<p>Volcaniclastic sediments—light gray (GLE Y1 7/0) fine to medium gravels with fine to coarse sand and silt, coarse-grained sandstone, detritus predominantly gray to pinkish dacites.</p> <p>840–845 ft WR: moderately silty matrix. +10F: broken chips and subangular to subrounded small pebbles (up to 12 mm in diameter) composed of gray and pinkish hbn- and bt-phyric dacites, black vitrophyre and pink-orange quartz-rhyodacite.</p> <p>845–855 ft +10F: abundant subrounded pebbles and granules of light gray hbn-dacite, minor white dacite with fine acicular hornblende phenocrysts.</p> <p>855–865 ft WR: matrix silty to very silty. +10F: subangular to subrounded clasts (up to 14 mm) mainly of light gray coarsely porphyritic hbn-dacite, local pink rhyodacite and fragments of silty fine-grained sandstone.</p>	Tpf		
865-885	<p>Volcaniclastic sediments—light pinkish gray (5YR 8/2) coarse gravels with fine to coarse sand and silt; detrital clasts primarily dacite.</p> <p>865-875 ft +10F: broken and subangular to subrounded pebble-size clasts (up to 16mm) composed almost entirely of gray and pinkish gray hbn-bt-phyric dacites (monolithologic sample). dacites and granules of light gray hbn-dacite.</p> <p>875–880 ft +10F: 80% gray hbn-dacites; 20% white bt-phyric dacite.</p> <p>880–885 ft +10F: 96%–97% subangular to subrounded porphyritic dacite clasts (up to 18 mm in diameter); 3%–5% clasts of indurated silty coarse-grained volcaniclastic sandstone.</p>	Tpf		

Borehole Lithologic Log (continued)

Borehole ID: R-45		TA: 5	Page: 14 of 18	
Depth (ft bgs)	Lithology	Lithologic Symbol	Notes	
885-905	<p>Volcaniclastic sediments—pale pinkish gray (5YR 7/2) coarse gravels with fine to coarse sand and some silt; detrital clasts primarily light gray porphyritic dacite.</p> <p>885-890 ft +10F: broken and subangular to subrounded clasts (up to 15 mm) mostly of gray coarsely porphyritic hbn-dacite and minor white bt-dacite.</p> <p>890-90 ft +10F: clasts predominantly gray hbn-dacite and minor white bt-dacite; trace white glassy bt-phyric pumices; local minor indurated fragments of fine- to medium-grained sandstone.</p>	Tpf		
905-915	<p>Volcaniclastic sediments—light pinkish gray (5YR 7/3) fine to coarse gravels with fine to coarse sand and silt; detrital clasts primarily of medium gray porphyritic dacite.</p> <p>905-915 ft WR: silty matrix. +10F: 99% broken and subangular clasts (up to 10 mm in diameter) of grayish hbn-dacites and minor white bt-dacite, 1% indurated fragments of reddish fine-grained sandstone.</p>	Tpf		
915-925	<p>Volcaniclastic sediments—light pinkish gray (5YR 7/3) coarse to medium gravels with silt and fine to coarse sand; detrital clasts almost exclusively of light gray porphyritic dacite.</p> <p>915-925 ft WR: silty matrix. +10F: broken and subangular clasts (up to 20 mm in diameter) predominantly of grayish hbn-dacites; trace white bt-dacite. +35F: abundant fragments of indurated silty fine- to medium grained sandstone.</p>	Tpf		
925-930	<p>Volcaniclastic sediments—light gray (GLE Y1 7/0) to pale pinkish gray (5YR 7/3) medium to coarse gravels fine to coarse sand and minor silt; detrital clasts gray porphyritic dacite.</p> <p>925-930 ft +10F: angular to subangular 95%–97% light gray hbn-dacites; 3%–5% fragments of indurated silty fine-grained sandstone containing granules of dacite, pumice, and obsidian. +35F: contains moderate abundances of indurated silty sandstone grains and white pumices.</p>	Tpf		

Borehole Lithologic Log (continued)

Borehole ID: R-45		TA: 5	Page: 15 of 18
Depth (ft bgs)	Lithology	Lithologic Symbol	Notes
930–940	<p>Volcaniclastic sediments—pinkish white (5YR 8/2) coarse to fine gravels with silt and fine to coarse sand; detrital clasts of porphyritic dacite.</p> <p>930–935 ft WR: silty (fines 10%–20%) matrix. +10F: broken and subangular clasts (up to 15 mm in diameter) light gray and pinkish hbn-dacites. +35F: contains moderate abundances of indurated silty.</p> <p>935–940 ft +10F: clasts predominantly of gray and pinkish dacites; white fine-grained bt dacite; trace white glassy pumices.</p>	Tpf	
940–965	<p>Volcaniclastic sediments—medium to light gray (GLE Y1 7/0) coarse to medium gravels with medium to coarse sand; angular to subangular detrital clasts composed predominantly of porphyritic dacites.</p> <p>940–945 ft+10F: broken and subangular clasts (up to 19 mm in diameter) of bt- and hbn-phyric dacites; minor white fine-grained bt-dacite; minor glassy bt-phyric pumices.</p> <p>945–960 ft+10F: 80% subangular clasts of light gray dacites; 20% subrounded clasts of white bt-phyric dacite; trace glassy white pumices.</p> <p>960–965 ft +10F: 50% subrounded clasts of white bt-dacite; 50% subangular clasts of light gray hbn-dacites; minor white glassy bt-phyric pumices.</p>	Tpf	Estimated contact between Puye volcaniclastic sediments and underlying Miocene pumiceous sediments is placed at 965 ft bgs.
965–970	<p>Miocene Pumiceous Sediments:</p> <p>Pumiceous volcaniclastic sediments—light gray (GLE Y1 7/0) to pinkish white (5YR 8/2) coarse to medium gravels with medium to coarse sand; subangular to subrounded detrital clasts of mixed porphyritic dacites and pumice.</p> <p>965–970 ft +10F: 35% light gray coarsely porphyritic hbn-dacite (clasts up to 23 mm in diameter); 35% white fine-grained bt-phyric dacite; 30% white glassy, phenocryst-poor bt-bearing pumices.</p>	Tjfp	Miocene pumiceous deposits, encountered from 965 to 1042 ft bgs, are estimated to be 77 ft thick.

Borehole Lithologic Log (continued)

Borehole ID: R-45		TA: 5	Page: 16 of 18
Depth (ft bgs)	Lithology	Lithologic Symbol	Notes
970–980	<p>Pumiceous volcanoclastic sediments— varicolored, pinkish tan (5YR 7/4) to white (5YR 8/1) medium to very coarse sand; granular detritus of mixed pumice and dacite.</p> <p>970–980 ft WR/+10F: generally angular grains/granules (up to 5 mm in diameter); 50%–60% white glassy phenocryst-poor pumices; 25%–35% dacites; 10%–15% indurated sandstone; trace obsidian grains.</p>	Tjfp	
980–985	<p>Pumiceous volcanoclastic sediments— varicolored, pinkish gray (5YR 7/1) to white (5YR 8/1) medium to fine gravels with fine to coarse sand; subangular clasts composed mostly of glassy pumices and lesser dacites.</p> <p>980–985 ft WR/+10F: 60%–70% white glassy phenocryst-poor pumices; 30%–40% coarsely porphyritic dacite.</p>	Tjfp	
985–995	<p>Pumiceous volcanoclastic sediments— varicolored, pinkish tan (5YR 7/4) to white (5YR 8/1) medium to coarse sand with fine (pebble-size) to medium gravels, detritus composed of diverse volcanic lithologies and pumice.</p> <p>985–995 ft WR/+10F: subangular granules and larger clasts (up to 20 mm in diameter) composed of 35%–45% pumices; 55%–65% mixed volcanic rocks including medium gray and white dacites, red basaltic scoria, bt-dacite vitrophyre and flow-banded rhyodacite.</p>	Tjfp	
995–1010	<p>Pumiceous volcanoclastic sediments— varicolored, light medium gray (GLE Y1 6/0) to pinkish tan (5YR 7/3) fine (pebble-size) to medium gravels and fine to coarse sand, detritus composed of diverse volcanic lithologies and pumice.</p> <p>995–1005 ft WR/+10F: broken and subangular to subrounded clasts (up to 18 mm in diameter) composed of 40% white vitric, phenocryst-poor pumices; 60% various volcanic lithologies including dark brown vesicular andesite, lithic tuff(?), flow banded dacite, various dacites, dark colored vitrophyre.</p> <p>1005–1010 ft+10F: 80%–85% subangular to subrounded dacite clasts (up to 18 mm in diameter); 15%–20% indurated fragments of pumiceous fine-grained sandstone.</p>	Tjfp	

Borehole Lithologic Log (continued)

Borehole ID: R-45		TA: 5	Page: 17 of 18	
Depth (ft bgs)	Lithology	Lithologic Symbol	Notes	
1010–1020	<p>Pumiceous volcanoclastic sediments— varicolored, light pinkish tan (5YR 7/3) to white (5YR 8/1) coarse to fine sand with silt to silty sand with minor pebble gravel, detritus composed of pumice and varieties of intermediate volcanic lithologies.</p> <p>1010–1020 ft WR: matrix of silty fine sand. +10F: 40%–50% white pumice fragments; 15%–20% dacite and other volcanic detritus; 30%–40% fragments of indurated fine-grained volcanoclastic sandstone.</p>	Tjfp		
1020–1025	<p>Pumiceous volcanoclastic sediments— varicolored, light gray (GLE Y1 7/0) to white (5YR 8/1) pebble gravel and fine to coarse sand; angular to subangular detritus of pumice and diverse volcanic rocks.</p> <p>1020–1025 ft WR: matrix of silty fine sand. +10F: 60%–70% white glassy, phenocryst-poor pumice fragments; 30%–40% various volcanic rocks (dacites, dark brown andesites).</p>	Tjfp		
1025–1042	<p>Pumiceous volcanoclastic sediments— varicolored, light pinkish tan (5YR 7/3) to white (5YR 8/1) fine to medium sand with pebble gravel; detritus composed of mixed pumice and various volcanic rocks.</p> <p>1025–1030 ft +10F: 60%–70% white vitric pumice fragments; 20%–30% volcanic rocks (dacite, andesite) 10%–15% fragments of fine-grained pumice-rich volcanoclastic sandstone.</p> <p>1030–1035 ft +10F: strongly pumice-rich interval; 85%–90% white vitric pumice fragments, 10%–15% fragments of fine-grained pumiceous sandstone; 2%–5% dacite fragments.</p> <p>1035–1040 ft +10F: 40-50% white vitric, phenocryst-poor pumice fragments, 20%–30% fragments of fine- to medium-grained pumiceous sandstone; 20%–30% dacite and other volcanic rock detritus.</p>	Tjfp	Estimated contact between Miocene pumiceous sediments and underlying Miocene riverine sediments is placed at 1042 ft bgs.	

Borehole Lithologic Log (continued)

Borehole ID: R-45		TA: 5	Page: 18 of 18	
Depth (ft bgs)	Lithology	Lithologic Symbol	Notes	
1042–1045	<p>Miocene riverine sediments:</p> <p>Axial-river gravel deposits—pale yellowish tan (7.5YR 8/4) fine to medium sand with silt and pebble gravel; detritus of angular white pumices and subrounded to well-rounded clasts of diverse volcanic and Precambrian lithologies.</p> <p>1042–1045 ft+10F: 10%–15% white vitric pumice fragments, 10%–15% indurated fragments of reddish tan fine-grained volcanic sandstone; 70%–80% rounded pebbles and broken clasts vesicular basalt, andesite, dacite, and quartzite.</p>	Tcar	Miocene riverine gravel deposits were intersected from 1042 ft to the bottom of the R-45 borehole at 1057 ft bgs (TD).	
1045–1050	<p>Axial-river gravel deposits—medium brown (7.5YR 8/4) pebble gravel and fine to medium sand; rounded to well-rounded clast (up to 32 mm in diameter) of diverse mixed volcanic and Precambrian lithologies.</p> <p>1045–1050 ft+10F: detritus composed of 50% quartzite, granite; 5% white vitric pumice fragments, 10%–15% indurated fragments of fine-grained sandstone; 20%–30% volcanic lithologies (andesite, dacite).</p>	Tcar		
1050–1057	<p>Axial-river gravel deposits—medium to light brown (7.5YR 8/4) fine to medium sand and local pebble gravels; rounded to well-rounded pebbles (up to 23 mm in diameter) composed of mixed volcanic and Precambrian lithologies.</p> <p>1050–1057 ft+10F: 20%–30% quartzites and granite; 60%–70% various volcanic rocks (andesite, dacite); locally up to 10% pumice fragments.</p>	Tcar	Note: R-45 borehole drilling was concluded at a total depth of 1057 ft bgs.	

Borehole Lithologic Log (continued)

ABBREVIATIONS

5YR 8/1 = Munsell soil color notation where hue (e.g., 5YR), value (e.g., 8), and chroma (e.g., 1) are expressed. Hue indicates soil color's relation to red, yellow, green, blue, and purple. Value indicates soil color's lightness. Chroma indicates soil color's strength.

% = estimated per cent by volume of a given sample constituent

bgs = below ground surface

bt = biotite

cpx = clinopyroxene

ft = feet

GM = groundmass

hbn = hornblende

ol = olivine

Qal = Quaternary Alluvium

Qct = Cerro Toledo Interval

Qbo = Otowi Member of Bandelier Tuff

Qbog = Guaje Pumice Bed

Tb4 = Cerros del Rio Basalt

Tpf = Puye Formation

N/S = no assigned symbol for geologic unit

Y = Yellow

YR = Yellow red

+10F = plus No. 10 sieve sample fraction

+35F = plus No. 35 sieve sample fraction

Appendix B

Groundwater Analytical Results

B-1.0 SAMPLING AND ANALYSIS OF GROUNDWATER AT R-45

A total of 13 groundwater samples were collected during drilling (9 samples) and well development (4 samples) at the regional aquifer well R-45. One groundwater sample potentially was collected from the vadose zone (742.3 ft bgs) and eight from the regional aquifer during drilling. The vadose zone sample most likely consists of municipal water used during drilling, based on very small volumes of water produced from groundwater inflow within the borehole. In addition, low concentrations of key contaminants, including chloride, chromium, nitrate, and sulfate measured in the borehole sample, were not consistent with those measured at wells MCOI-4, MCOI-5, MCOI-6, SCI-1, SCI-2, R-28, and R-42. Perched intermediate-depth groundwater was not encountered during drilling at R-42, R-44, and R-28. The vadose zone water sample was analyzed for tritium and the analytical result is pending. During aquifer performance (pumping) testing, six groundwater samples were collected from screen 1 between a depth interval ranging from 880 to 890 ft below ground surface (bgs) and six groundwater samples were collected from screen 2 between a depth interval of 975 and 995 ft bgs. All of the groundwater samples were collected within the Puye Formation. The filtered samples were analyzed for cations, anions, perchlorate, and metals. A total of 14,559 gal. of groundwater was pumped from well R-45 during development before emplacing packers to seal off screens 1 and 2. During the pumping tests conducted at well R-45, a total of 75,590 gal. of groundwater was pumped from screens 1 and 2.

B-1.1 Field Preparation and Analytical Techniques

Chemical analyses of groundwater-screening samples collected from well R-45 were performed at Los Alamos National Laboratory's (LANL's, or the Laboratory's) Earth and Environmental Sciences Group 14 (EES-14). Groundwater samples were filtered (0.45- μ m membranes) before preservation and chemical analyses. Samples were acidified at the EES-14 wet chemistry laboratory with analytical grade nitric acid to a pH of 2.0 or less for metal and major cation analyses.

Groundwater samples were analyzed using techniques specified in the U.S. Environmental Protection Agency SW-846 manual. Ion chromatography (IC) was the analytical method for bromide, chloride, fluoride, nitrate, nitrite, oxalate, perchlorate, phosphate, and sulfate. The instrument detection limits for perchlorate were 0.002 and 0.005 ppm, depending on the sample type (borehole water versus developed well water) and analyte interferences due to the presence of drilling fluid (AQF-2) used during drilling. Inductively coupled (argon) plasma optical emission spectroscopy (ICPOES) was used for analyses of dissolved aluminum, barium, boron, calcium, total chromium, iron, lithium, magnesium, manganese, potassium, silica, sodium, strontium, titanium, and zinc. Dissolved aluminum, antimony, arsenic, barium, beryllium, boron, cadmium, cesium, chromium, cobalt, copper, iron, lead, lithium, manganese, mercury, molybdenum, nickel, rubidium, selenium, silver, thallium, thorium, tin, vanadium, uranium, and zinc were analyzed by inductively coupled (argon) plasma mass spectrometry (ICPMS). The precision limits (analytical error) for major ions and trace elements were generally less than $\pm 7\%$ using ICPOES and ICPMS. Concentrations of total organic carbon (TOC) in nonfiltered groundwater samples collected during well development and aquifer performance testing were determined by using an organic carbon analyzer. Charge balance errors for total cations and anions were generally less than $\pm 10\%$ for complete analyses of the above inorganic chemicals. The negative cation-anion charge balance values indicate excess anions for the filtered samples. Total carbonate alkalinity was measured using standard titration techniques.

B-1.2 Field Parameters

B-1.2.1 Well Development

Results of field parameters, consisting of pH, temperature, dissolved oxygen (DO), oxidation-reduction potential (ORP), specific conductance, and turbidity, measured during well development and aquifer performance testing conducted at R-45 are provided in Table B-1.2.1-1. Twelve measurements of pH and temperature varied from 8.16 to 9.03 and from 17.24°C to 18.07°C, respectively, in groundwater pumped from well R-45 screen 1 during development. Concentrations of DO varied from 11.40 to 13.15 mg/L during this phase of pumping at well R-45 screen 1. Noncorrected ORP values varied from -132.5 to -125.1 millivolts (mV) during well development of R-45 screen 1 (Table B-1.2.1-1), which are not reliable and consistent with known overall oxidizing conditions characteristic of the regional aquifer beneath the Pajarito Plateau. These DO measurements taken during well development are not consistent with the reported ORP values. Detectable concentrations of redox-sensitive solutes, including chromium, nitrate, sulfate, and uranium provided in Table B-1.3.1-1, suggest the groundwater at R-45 is relatively oxidizing. Specific conductance generally decreased from 174 to 164 microsiemens per centimeter ($\mu\text{S}/\text{cm}$) and turbidity values were zero nephelometric turbidity unit (NTU) during well development of R-45 screen 1 (Table B-1.2.1-1).

Ten measurements of pH and temperature slightly varied from 8.59 to 8.65 and from 18.60°C to 18.99°C, respectively, in groundwater pumped from well R-45 screen 2 during development (Table B-1.2.1-1). Concentrations of DO generally decreased from 10.79 to 7.80 mg/L during this phase of pumping at R-45 screen 2. Noncorrected ORP values generally decreased from -148.7 to -112.5 mV (Table B-1.2.1-1) during well development of R-45 screen 2. These nonrepresentative and uncorrected ORP values are not consistent with known overall oxidizing conditions characteristic of the regional aquifer beneath the Pajarito Plateau. Specific conductance decreased from 181 to 171 $\mu\text{S}/\text{cm}$ in groundwater pumped from R-45 screen 2 during well development, and turbidity decreased from 66.3 to 0 NTUs. Four of the 10 measurements had turbidity greater than 5 NTUs during well development of R-45 screen 2.

B-1.2.2 Aquifer Performance Testing

During aquifer performance testing, 22 measurements of pH and temperature varied from 7.95 to 8.01 and from 8.30°C to 20.13°C, respectively, at well R-45 screen 1 (Table B-1.2.1-1). The cooler temperatures are reflective of atmospheric-land surface conditions at the site during sampling. Concentrations of DO varied from 6.35 to 9.37 mg/L at R-45 screen 1 during aquifer performance testing. Positive, uncorrected ORP values varied from 85 to 160.5 mV during aquifer performance testing of R-45 screen 1. The DO and uncorrected ORP measurements are in general agreement with each other, confirming that the regional aquifer is relatively oxidizing beneath the Pajarito Plateau. Specific conductance generally decreased from 176 to 159 $\mu\text{S}/\text{cm}$ and turbidity varied from 1.0 to 3.8 NTUs for groundwater pumped from R-45 screen 1 during aquifer performance testing (Table B-1.2.1-1).

Twenty measurements of pH and temperature varied from 8.07 to 8.19 and from 12.74°C to 21.97°C, respectively, during aquifer performance testing conducted at well R-45 screen 2 (Table B-1.2.1-1). Concentrations of DO varied from 6.10 to 18.18 mg/L at R-45 screen 2 during aquifer performance testing. Positive ORP values varied from 76.4 to 97.6 mV during aquifer performance testing of R-45 screen 2. Specific conductance varied from 171 to 123 $\mu\text{S}/\text{cm}$ for the R-45 screen 2 samples measured during aquifer performance testing. Turbidity varied from 1.1 to 4.1 NTUs in groundwater pumped from R-45 screen 2 during this phase of testing (Table B-1.2.1-1).

B-1.3 Analytical Results for R-45 Groundwater-Screening Samples

B-1.3.1 Well Development

Analytical results for groundwater-screening samples collected at well R-45 during drilling, well development, and aquifer performance testing are provided in Table B-1.3.1-1. Four groundwater samples were collected from R-45 screens 1 and 2 during well development and selected analytical results for these samples are combined in the following discussion. Calcium and sodium are the dominant cations in regional aquifer groundwater pumped from well R-45. During well development, dissolved concentrations of calcium ranged from 15.58 to 16.11 ppm (15.58 to 16.11 mg/L) and from 12.34 to 13.26 ppm, respectively. Dissolved concentrations of chloride and fluoride varied from 4.77 to 5.39 ppm and from 0.37 to 0.45 ppm, respectively, during development conducted at well R-45 (Table B-1.3.1-1). Dissolved concentrations of nitrate(N) and sulfate ranged from 0.43 to 1.51 ppm and from 6.10 to 7.44 ppm, respectively, during development at well R-45. Dissolved concentrations of chloride, nitrate(N), and sulfate exceeded Laboratory median background for regional aquifer groundwater (LANL 2007, 095817). Median background concentrations for dissolved chloride, nitrate plus nitrite(N), and sulfate in the regional aquifer are 2.17 mg/L, 0.31 mg/L, and 2.83 mg/L, respectively (LANL 2007, 095817). Detectable concentrations of TOC ranged from 0.52 to 0.84 mgC/L in groundwater-screening samples collected during development conducted at well R-45 (Table B-1.3.1-1). The median background concentration of TOC is 0.34 mgC/L for regional aquifer groundwater (LANL 2007, 095817). Concentrations of perchlorate were less than analytical detection (<0.002 ppm, IC method) in groundwater-screening samples collected from well R-45 during development (Table B-1.3.1-1).

During well development conducted at R-45, dissolved concentrations of iron ranged from 0.110 to 0.140 ppm (110 to 140 µg/L, or 110 to 140 ppb) using ICPOES (Table B-1.3.1-1), which do not exceed the maximum background value of 147 µg/L for regional aquifer groundwater (LANL 2007, 095817). Dissolved concentrations of manganese ranged from 0.150 to 0.170 ppm (Table B-1.3.1-1), which exceeded the median background value of 1.0 µg/L for regional aquifer groundwater (LANL 2007, 095817). A carbon-steel discharge pipe was used during well development at R-45, which contributed iron and manganese in the form of colloidal rust to the filtered groundwater samples. Dissolved concentrations of boron ranged from 0.020 to 0.025 ppm (Table B-1.3.1-1) at well R-45, which is below the maximum background value of 51.6 µg/L for the regional aquifer (LANL 2007, 095817). Dissolved concentrations of nickel generally were less than analytical detection (0.001 ppm, ICPMS method) (Table B-1.3.1-1) in four groundwater-screening samples collected during well development conducted at R-45. Dissolved concentrations of zinc ranged from 0.001 to 0.008 ppm in groundwater-screening samples collected at well R-45 during development (Table B-1.3.1-1). The background median concentration of zinc in filtered samples is 1.45 µg/L for the regional aquifer (LANL 2007, 095817). Total dissolved concentrations of chromium were 0.003 and 0.005 ppm (3 to 5 µg/L) at well R-45, with the higher concentrations of this metal measured in groundwater samples collected from screen 1 (Table B-1.3.1-1). Background mean, median, and maximum concentrations of total dissolved chromium are 3.07 µg/L, 3.05 µg/L, and 7.20 µg/L, respectively, for the regional aquifer (LANL 2007, 095817).

B-1.3.2 Aquifer Performance Testing

Dissolved concentrations of calcium and sodium ranged from 15.88 to 16.19 ppm and from 9.98 to 10.75 ppm, respectively, during aquifer performance testing conducted at R-45 screen 1 (Table B-1.3.1-1). Dissolved concentrations of chloride and fluoride varied from 3.73 to 3.91 ppm and from 0.36 to 0.38 ppm, respectively, during this phase of testing conducted at well R-45 screen 1 (Table B-1.3.1-1). Dissolved concentrations of nitrate(N) and sulfate slightly varied from 1.67 to 1.70 ppm and from 4.98 to 5.24 ppm, respectively, during aquifer performance testing performed at well R-45 screen 1. Dissolved concentrations of chloride, nitrate(N), and sulfate in groundwater-screening samples collected from R-45 screen 1

exceeded Laboratory median background within regional aquifer groundwater (LANL 2007, 095817). Median background concentrations for dissolved chloride, nitrate plus nitrite(N), and sulfate in the regional aquifer are 2.17 mg/L, 0.31 mg/L, and 2.83 mg/L, respectively (LANL 2007, 095817). Elevated above-background concentrations of chloride, nitrate(N), and sulfate at well R-45 screen 1 suggest the presence of a contaminant plume(s) consisting, in part, of treated sewage effluent most likely released from Technical Area 03 (TA-03) discharges and possibly from other sewage/industrial waste streams released within Mortandad Canyon. Concentrations of TOC measured in groundwater-screening samples ranged from 0.22 to 0.25 mgC/L during aquifer performance testing at well R-45 screen 1 (Table B-1.3.1-1). Concentrations of perchlorate were less than detection (<0.002 ppm, IC method) in groundwater-screening samples collected from well R-45 screen 1 during aquifer performance testing (Table B-1.3.1-1).

During aquifer performance testing conducted at R-45 screen 1, dissolved concentrations of iron were less than analytical detection (0.010 ppm) using ICPOES (Table B-1-3-1). A stainless-steel discharge pipe was used during aquifer performance testing at R-45 screens 1 and 2, which is much less corrosive than carbon steel. Dissolved concentrations of manganese varied from 0.003 to 0.006 ppm (Table B-1.3.1-1) at well R-45 screen 1 during this phase of testing. Dissolved concentrations of boron ranged from 0.017 to 0.033 ppm (Table B-1.3.1-1) in groundwater-screening samples collected from well R-45 screen 1, which is below the maximum background value of 51.6 µg/L for the regional aquifer (LANL 2007, 095817). Dissolved concentrations of nickel were less than analytical detection (0.001 ppm, ICPMS method) (Table B-1.3.1-1) in six groundwater-screening samples collected from R-45 screen 1 during aquifer performance testing. Dissolved concentrations of zinc were 0.003 and 0.006 ppm in groundwater-screening samples collected from R-45 screen 1 during this phase of testing (Table B-1.3.1-1). The background median concentration of zinc in filtered samples is 1.45 µg/L for the regional aquifer (LANL 2007, 095817). Total dissolved concentrations of chromium were 0.007 and 0.008 ppm (7 and 8 µg/L) in six groundwater-screening samples collected from R-45 screen 1 during aquifer performance testing (Table B-1.3.1-1). Background mean, median, and maximum concentrations of total dissolved chromium are 3.07 µg/L, 3.05 µg/L, and 7.20 µg/L, respectively, for the regional aquifer (LANL 2007, 095817). The most likely source of dissolved chromium measured in groundwater samples collected from well R-44 screen 1 is from past releases associated with the TA-03 cooling towers, in which potassium dichromate was used as a corrosion inhibitor from 1956 to 1972. Chromate (CrO_4^{2-}) is mobile in groundwater under oxidizing and basic pH conditions characteristic of most perched intermediate saturated zones and the regional aquifer at Los Alamos.

During aquifer performance testing of R-45 screen 2, dissolved concentrations of calcium and sodium ranged from 15.90 to 16.25 ppm and from 10.73 to 11.56 ppm, respectively, which are slightly higher than those measured in groundwater-screening samples collected from R-45 screen 1. Dissolved concentrations of chloride and fluoride varied slightly from 3.70 to 3.98 ppm and from 0.44 to 0.46 ppm, respectively, during aquifer performance testing at well R-45 screen 2 (Table B-1.3.1-1). Dissolved concentrations of nitrate(N) varied slightly from 0.48 to 0.53 ppm, which are less than dissolved concentrations of nitrate(N) measured in groundwater-screening samples collected from R-45 screen 1. Dissolved concentrations of sulfate decreased from 5.49 to 4.32 ppm during aquifer performance testing at well R-45 screen 2, which are similar with those measured in groundwater-screening samples collected from R-45 screen 1. Dissolved concentrations of chloride, nitrate(N), and sulfate at well R-45 slightly exceeded Laboratory median background within regional aquifer groundwater (LANL 2007, 095817). Concentrations of TOC fluctuated from 0.30 to 2.11 mgC/L during aquifer performance testing at well R-45 screen 2 (Table B-1.3.1-1). Concentrations of perchlorate were less than detection (<0.002 ppm, IC method) in groundwater-screen samples collected from well R-45 screen 2 during aquifer performance testing (Table B-1.3.1-1).

During aquifer performance testing conducted at R-45 screen 2, dissolved concentrations of iron were less than analytical detection (0.010 ppm) using ICPOES (Table B-1.3.1-1). Dissolved concentrations of manganese decreased from 0.009 to 0.004 ppm (Table B-1.3.1-1) during aquifer performance testing conducted at well R-45 screen 2. Dissolved concentrations of boron ranged from 0.021 to 0.037 ppm (Table B-1.3.1-1) at well R-45 screen 2, which is below the maximum background value of 51.6 µg/L for the regional aquifer (LANL 2007, 095817). Dissolved concentrations of boron are similar in groundwater-screening samples collected from both screens at R-45 (Table B-1.3.1-1). Detectable dissolved concentrations of nickel were 0.001 ppm in groundwater-screening samples collected from R-45 screen 2 during aquifer performance testing (Table B-1.3.1-1). Dissolved concentrations of zinc slightly varied from 0.003 to 0.005 ppm in groundwater-screening samples collected from R-45 screen 2 during aquifer performance testing (Table B-1.3.1-1). Total dissolved concentrations of chromium ranged from 0.004 to 0.006 ppm (4 to 6 µg/L) at well R-45 screen 2 (Table B-1.3.1-1). Background mean, median, and maximum concentrations of total dissolved chromium are 3.07 µg/L, 3.05 µg/L, and 7.20 µg/L, respectively, for the regional aquifer (LANL 2007, 095817). Total dissolved concentrations of chromium are lower in groundwater-screening samples collected from screen 2 compared with those pumped from screen 1 at well R-45.

B-2.0 REFERENCES

The following list includes all documents cited in this appendix. Parenthetical information following each reference provides the author(s), publication date, and ER ID. This information is also included in text citations. ER IDs are assigned by the Environmental Programs Directorate's Records Processing Facility (RPF) and are used to locate the document at the RPF and, where applicable, in the master reference set.

Copies of the master reference set are maintained at the NMED Hazardous Waste Bureau and the Directorate. The set was developed to ensure that the administrative authority has all material needed to review this document, and it is updated with every document submitted to the administrative authority. Documents previously submitted to the administrative authority are not included.

LANL (Los Alamos National Laboratory), May 2007. "Groundwater Background Investigation Report, Revision 3," Los Alamos National Laboratory document LA-UR-07-2853, Los Alamos, New Mexico. (LANL 2007, 095817)

**Table B-1-2.1-1
Well Development Volumes, Aquifer Pump Test Volumes,
and Associated Field Water-Quality Parameters for R-45**

Date	pH	Temp (°C)	DO (mg/L)	ORP (mV)	Specific Conductivity (µS/cm)	Turbidity (NTU)	Purge Volume between Samples (gal.)	Cumulative Purge Volume (gal.)
Well Development								
01/25/09	n/r, bailing - both screens open						532	532
01/26/09	n/r, bailing - both screens open						502	1034
01/27/09	n/r, pumping/swabbing - both screens open						3750	4784
01/27/09 (upper screen only)	8.16	17.24	13.05	-128.6	174	0.0	788	5572
	8.20	17.55	13.15	-127.0	173	0.0	262	5834
	8.20	17.42	13.10	-126.6	172	0.0	263	6097
	8.19	17.45	12.89	-126.3	171	0.0	262	6359
	8.17	17.75	12.50	-125.1	170	0.0	263	6622
	8.18	17.76	12.35	-130.4	169	0.0	262	6884
	9.03	17.66	12.11	-130.3	168	0.0	263	7147
	8.79	18.37	11.82	-132.5	170	0.0	262	7409
	8.64	17.85	11.72	-131.9	166	0.0	263	7672
	8.63	17.42	11.84	-132.0	164	0.0	262	7934
	8.61	18.07	11.40	-130.1	166	0.0	263	8197
8.58	17.91	11.77	-126.2	166	0.0	262	8459	
01/28/09	n/r, pumping/swabbing - both screens open						3900	12,359
01/29/09 (lower screen only)	8.65	18.60	10.36	-148.7	181	66.3	283	12,642
	8.61	18.64	10.79	-138.9	181	43.1	213	12,855
	8.59	18.64	9.69	-129.7	179	20.2	213	13,068
	8.60	18.78	9.42	-123.8	178	8.3	213	13,281
	8.62	18.81	9.26	-121.2	177	1.2	213	13,494
	8.64	18.81	9.48	-117.6	176	0.0	213	13,707
	8.59	18.99	8.74	-115.2	175	0.0	213	13,920
	8.60	18.81	8.63	-113.2	172	0.0	213	14,133
	8.62	18.89	8.10	-114.6	172	0.0	213	14,346
	8.63	18.87	7.80	-112.5	171	0.0	213	14,559

Table B-1-2.1-1 (continued)

Date	pH	Temp (°C)	DO (mg/L)	ORP (mV)	Specific Conductivity (µS/cm)	Turbidity (NTU)	Purge Volume between Samples (gal.)	Cumulative Purge Volume (gal.)
Aquifer Pumping Test Volumes								
02/25/09	n/r, step-tests, upper screen						2892	2892
02/027– 28/09 (upper screen)	8.01	18.47	8.57	85.0	176	3.8	485	3377
	7.97	19.42	8.19	98.6	170	2.6	971	4348
	7.96	19.64	8.80	98.3	170	3.2	1456	5804
	7.96	20.03	8.63	95.3	168	1.9	1456	7260
	7.96	20.13	8.58	94.5	167	1.0	1456	8716
	7.96	19.73	8.56	93.8	166	2.0	1456	10,172
	7.95	19.82	8.53	93.7	166	3.4	1456	11,628
	7.95	19.99	8.55	94.2	166	2.4	1456	13,084
	7.96	17.97	8.77	92.6	166	1.0	1456	14,540
	7.97	15.85	9.37	87.5	166	1.2	1456	15,996
	7.95	13.02	8.83	138.9	165	1.3	1456	17,452
	7.97	12.73	8.88	139.4	162	2.0	1456	18,908
	7.95	12.01	9.06	146.4	161	2.5	1456	20,364
	8.00	16.51	8.22	148.0	161	1.4	5825	26,189
	7.99	15.34	8.65	150.0	159	1.9	1456	27,645
	7.97	15.91	8.49	149.4	160	1.9	1456	29,101
	7.98	15.37	6.35	151.1	161	1.8	1456	30,557
	8.00	9.36	9.09	153.4	159	3.1	1456	32,013
	7.98	8.41	7.76	153.3	157	3.7	1456	33,469
	7.96	8.30	7.63	160.5	156	3.6	1456	34,925
7.98	10.53	9.20	156.7	162	3.3	1456	36,381	
7.97	12.81	8.76	151.1	159	1.1	1214	37,595	
	n/r						250	37,845
03/01/09	n/r, pumping, lower screen						411	38,256
03/02/09	n/r, step-tests, lower screen						2892	41,148
03/04– 05/09 (lower screen)	8.19	19.74	8.18	n/r	171	4.1	2870	44,018
	8.15	19.87	7.00	n/r	152	2.0	1435	45,453
	8.12	20.66	6.66	n/r	150	1.6	1435	46,888
	8.11	20.42	6.75	n/r	149	3.4	1435	48,323
	8.10	21.97	6.46	n/r	149	1.4	1435	49,758
	8.10	21.21	6.43	n/r	148	1.1	1435	51,193
	8.09	20.57	6.62	90.5	147	2.0	1435	52,628
	8.10	19.70	6.56	83.9	145	3.1	1435	54,063
	8.15	16.28	6.55	97.8	141	3.0	5741	59,804
	8.14	16.97	6.59	84.6	142	3.5	1435	61,239
	8.12	12.74	6.75	88.4	141	1.1	1435	62,674

Table B-1-2.1-1 (continued)

Date	pH	Temp (°C)	DO (mg/L)	ORP (mV)	Specific Conductivity (µS/cm)	Turbidity (NTU)	Purge Volume between Samples (gal.)	Cumulative Purge Volume (gal.)
	8.14	18.21	6.31	76.4	141	2.1	1435	64,109
	8.13	18.03	6.25	86.2	140	2.1	1435	65,544
	8.13	17.49	6.41	86.2	141	1.8	1435	66,979
	8.07	18.99	6.27	93.4	123	1.6	1435	68,414
	8.10	15.78	6.63	93.6	140	1.6	1435	69,849
	8.13	16.72	6.55	91.8	140	1.7	1435	71,284
	8.11	17.63	6.32	97.6	139	2.3	1435	72,719
	8.13	17.30	6.44	94.3	138	3.3	1435	74,154
	8.12	19.82	6.10	90.8	142	3.5	1196	75,350
	n/r						240	75,590

Note: Cumulative pump test volumes calculated using average pump discharge rate of 24.3/ 23.9 (upper screen/lower screen) gpm.

*n/r = Not recorded.

Table B.1.3.1-1
Analytical Results for Groundwater Screening Samples Collected from Well R-45, Mortandad Canyon

Sample ID	Date Received	ER/RRES-WQH	Sample Type	Screen	Depth (feet)	Ag rslt (ppm)	stdev (Ag)	Al rslt (ppm)	stdev (Al)	As rslt (ppm)	stdev (As)	B rslt (ppm)	stdev (B)
GW45-09-1337	12/22/2008	09-557	Borehole	Not Applicable	742.3	0.001	U	0.14	0.00	0.0003	0.0000	0.039	0.000
GW45-09-1338	1/9/2009	09-594	Borehole	Not Applicable	887	0.001	U	0.05	0.00	0.0002	0.0000	0.021	0.000
GW45-09-1340	1/9/2009	09-594	Borehole	Not Applicable	924-924.5	0.001	U	0.04	0.00	0.0003	0.0000	0.026	0.000
GW45-09-1341	1/9/2009	09-594	Borehole	Not Applicable	944-944.5	0.001	U	0.14	0.03	0.0004	0.0000	0.020	0.000
GW45-09-1342	1/9/2009	09-594	Borehole	Not Applicable	962	0.001	U	0.02	0.00	0.0002	U	0.016	0.001
GW45-09-1343	1/9/2009	09-594	Borehole	Not Applicable	982	0.001	U	0.04	0.00	0.0002	U	0.014	0.001
GW45-09-1344	1/9/2009	09-594	Borehole	Not Applicable	1000-1000.5	0.001	U	0.09	0.01	0.0003	0.0000	0.017	0.000
GW45-09-1345	1/9/2009	09-594	Borehole	Not Applicable	1020-1020.6	0.001	U	0.40	0.00	0.0004	0.0000	0.020	0.001
GW45-09-1346	1/9/2009	09-594	Borehole	Not Applicable	1038-1038.5	0.001	U	0.07	0.00	0.0003	0.0000	0.028	0.001
GW45-09-1317	1/28/2009	09-751	Well, development	1	880-890	0.001	U	0.004	0.000	0.0009	0.0000	0.025	0.000
GW45-09-1318	1/28/2009	09-751	Well, development	1	880-890	0.001	U	0.005	0.000	0.0009	0.0000	0.020	0.000
GW45-09-1319	2/2/2009	09-773	Well, development	2	974.9-994.9	0.001	U	0.006	0.000	0.0011	0.0000	0.023	0.001
GW45-09-1320	2/2/2009	09-773	Well, development	2	974.9-994.9	0.001	U	0.005	0.000	0.0011	0.0000	0.022	0.000
GW45-09-1321	2/27/2009	Not provided	Well, pumping test	1	880-890	0.001	U	0.002	U	0.0008	0.0000	0.019	0.001
GW45-09-1322	2/27/2009	Not provided	Well, pumping test	1	880-890	0.001	U	0.002	U	0.0008	0.0000	0.019	0.000
GW45-09-1323	2/28/2009	Not provided	Well, pumping test	1	880-890	0.001	U	0.002	U	0.0009	0.0000	0.018	0.000
GW45-09-1324	2/28/2009	Not provided	Well, pumping test	1	880-890	0.001	U	0.002	U	0.0009	0.0000	0.017	0.000
GW45-09-1325	2/28/2009	Not provided	Well, pumping test	1	880-890	0.001	U	0.002	0.000	0.0009	0.0001	0.022	0.001
GW45-09-1326	2/28/2009	Not provided	Well, pumping test	1	880-890	0.001	U	0.002	U	0.0009	0.0000	0.033	0.001
GW45-09-1327	3/4/2009	Not provided	Well, pumping test	2	974.9-994.9	0.001	U	0.005	0.000	0.0010	0.0000	0.031	0.001
GW45-09-1328	3/5/2009	Not provided	Well, pumping test	2	974.9-994.9	0.001	U	0.005	0.000	0.0009	0.0000	0.024	0.001
GW45-09-1329	3/4/2009	Not provided	Well, pumping test	2	974.9-994.9	0.001	U	0.003	0.000	0.0010	0.0000	0.022	0.000
GW45-09-1330	3/5/2009	Not provided	Well, pumping test	2	974.9-994.9	0.001	U	0.009	0.000	0.0010	0.0000	0.021	0.000
GW45-09-1331	3/5/2009	Not provided	Well, pumping test	2	974.9-994.9	0.001	U	0.006	0.000	0.0010	0.0000	0.037	0.000
GW45-09-1332	3/5/2009	Not provided	Well, pumping test	2	974.9-994.9	0.001	U	0.006	0.000	0.0010	0.0000	0.031	0.001

Table B.1.3.1-1
Analytical Results for Groundwater Screening Samples Collected from Well R-45, Mortandad Canyon

Sample ID	Date Received	ER/RRES-WQH	Ba rslt (ppm)	stdev (Ba)	Be rslt (ppm)	stdev (Be)	Br(-) ppm	TOC rslt (ppm)	Ca rslt (ppm)	stdev (Ca)	Cd rslt (ppm)	stdev (Cd)	Cl(-) ppm	ClO4(-) ppm	ClO4(-) (U)
GW45-09-1337	12/22/2008	09-557	0.018	0.000	0.001	U	0.06	Not applicable	16.72	0	0.001	U	15.52	0.005	U
GW45-09-1338	1/9/2009	09-594	0.012	0.000	0.001	U	0.06	Not applicable	3.31	0	0.001	U	12.04	0.002	U
GW45-09-1340	1/9/2009	09-594	0.015	0.000	0.001	U	0.02	Not applicable	9.78	0	0.001	U	11.10	0.002	U
GW45-09-1341	1/9/2009	09-594	0.020	0.000	0.001	U	0.06	Not applicable	11.54	0	0.001	U	6.41	0.002	U
GW45-09-1342	1/9/2009	09-594	0.012	0.000	0.001	U	0.09	Not applicable	13.42	0	0.001	U	12.00	0.002	U
GW45-09-1343	1/9/2009	09-594	0.011	0.000	0.001	U	0.06	Not applicable	11.93	0	0.001	U	6.49	0.002	U
GW45-09-1344	1/9/2009	09-594	0.020	0.000	0.001	U	0.05	Not applicable	12.22	0	0.001	U	4.99	0.002	U
GW45-09-1345	1/9/2009	09-594	0.035	0.000	0.001	U	0.07	Not applicable	12.97	0	0.001	U	6.85	0.002	U
GW45-09-1346	1/9/2009	09-594	0.037	0.000	0.001	U	0.09	Not applicable	15.40	0	0.001	U	5.38	0.002	U
GW45-09-1317	1/28/2009	09-751	0.039	0.000	0.001	U	0.03	0.5, U	15.65	0	0.001	U	5.01	0.002	U
GW45-09-1318	1/28/2009	09-751	0.037	0.000	0.001	U	0.03	0.52	15.94	0	0.001	U	4.77	0.002	U
GW45-09-1319	2/2/2009	09-773	0.040	0.001	0.001	U	0.02	0.77	16.11	0	0.001	U	5.39	0.002	U
GW45-09-1320	2/2/2009	09-773	0.038	0.000	0.001	U	0.03	0.84	15.58	0	0.001	U	4.99	0.002	U
GW45-09-1321	2/27/2009	Not provided	0.030	0.000	0.001	U	0.05	0.23	16.09	0	0.001	U	3.91	0.002	U
GW45-09-1322	2/27/2009	Not provided	0.028	0.000	0.001	U	0.05	0.25	16.04	0	0.001	U	3.83	0.002	U
GW45-09-1323	2/28/2009	Not provided	0.027	0.001	0.001	U	0.05	0.24	15.99	0	0.001	U	3.73	0.002	U
GW45-09-1324	2/28/2009	Not provided	0.027	0.000	0.001	U	0.05	0.22	15.88	0	0.001	U	3.76	0.002	U
GW45-09-1325	2/28/2009	Not provided	0.027	0.000	0.001	U	0.04	0.22	16.19	0	0.001	U	3.73	0.002	U
GW45-09-1326	2/28/2009	Not provided	0.027	0.000	0.001	U	0.04	0.23	16.10	0	0.001	U	3.75	0.002	U
GW45-09-1327	3/4/2009	Not provided	0.032	0.000	0.001	U	0.05	0.44	15.95	0	0.001	U	3.98	0.002	U
GW45-09-1328	3/5/2009	Not provided	0.026	0.001	0.001	U	0.05	1.44	16.10	0	0.001	U	3.76	0.002	U
GW45-09-1329	3/4/2009	Not provided	0.030	0.000	0.001	U	0.05	2.11	15.95	0	0.001	U	3.72	0.002	U
GW45-09-1330	3/5/2009	Not provided	0.029	0.001	0.001	U	0.05	0.30	15.90	0	0.001	U	3.72	0.002	U
GW45-09-1331	3/5/2009	Not provided	0.029	0.000	0.001	U	0.04	1.31	16.25	0	0.001	U	3.70	0.002	U
GW45-09-1332	3/5/2009	Not provided	0.029	0.000	0.001	U	0.05	0.64	16.25	0	0.001	U	3.73	0.002	U

Table B.1.3.1-1
Analytical Results for Groundwater Screening Samples Collected from Well R-45, Mortandad Canyon

Sample ID	Date Received	ER/RRES-WQH	Co rslt (ppm)	stdev (Co)	Alk-CO3 rslt (ppm)	ALK-CO3 (U)	Cr rslt (ppm)	stdev (Cr)	Cs rslt (ppm)	stdev (Cs)	Cu rslt (ppm)	stdev (Cu)	F(-) ppm	Fe rslt (ppm)	stdev (Fe)
GW45-09-1337	12/22/2008	09-557	0.001	U	0.8	U	0.002	0.000	0.001	U	0.005	0.000	0.60	0.10	0.00
GW45-09-1338	1/9/2009	09-594	0.001	U	0.8	U	0.001	U	0.001	U	0.001	0.000	0.79	0.02	0.00
GW45-09-1340	1/9/2009	09-594	0.001	U	0.8	U	0.001	U	0.001	U	0.001	0.000	0.73	0.04	0.00
GW45-09-1341	1/9/2009	09-594	0.001	U	0.8	U	0.002	0.000	0.001	U	0.001	U	0.68	0.36	0.06
GW45-09-1342	1/9/2009	09-594	0.001	U	0.8	U	0.001	U	0.001	U	0.001	U	0.72	0.01	0.00
GW45-09-1343	1/9/2009	09-594	0.001	U	0.8	U	0.001	U	0.001	U	0.001	U	0.84	0.04	0.00
GW45-09-1344	1/9/2009	09-594	0.001	U	0.8	U	0.002	0.001	0.001	U	0.001	U	0.69	0.20	0.00
GW45-09-1345	1/9/2009	09-594	0.001	U	0.8	U	0.002	0.001	0.001	U	0.003	0.000	1.25	0.21	0.00
GW45-09-1346	1/9/2009	09-594	0.001	U	0.8	U	0.002	0.000	0.001	U	0.001	U	0.78	0.24	0.00
GW45-09-1317	1/28/2009	09-751	0.001	U	0.8	U	0.005	0.000	0.001	U	0.001	U	0.37	0.11	0.00
GW45-09-1318	1/28/2009	09-751	0.001	U	0.8	U	0.005	0.000	0.001	U	0.001	U	0.37	0.12	0.00
GW45-09-1319	2/2/2009	09-773	0.001	U	0.8	U	0.003	0.000	0.001	U	0.001	U	0.44	0.14	0.00
GW45-09-1320	2/2/2009	09-773	0.001	U	0.8	U	0.003	0.000	0.001	U	0.001	U	0.45	0.13	0.00
GW45-09-1321	2/27/2009	Not provided	0.001	U	0.8	U	0.007	0.000	0.001	U	0.001	U	0.36	0.01	U
GW45-09-1322	2/27/2009	Not provided	0.001	U	0.8	U	0.007	0.000	0.001	U	0.001	U	0.37	0.01	U
GW45-09-1323	2/28/2009	Not provided	0.001	U	0.8	U	0.008	0.000	0.001	U	0.001	U	0.37	0.01	U
GW45-09-1324	2/28/2009	Not provided	0.001	U	0.8	U	0.007	0.000	0.001	U	0.001	U	0.37	0.01	U
GW45-09-1325	2/28/2009	Not provided	0.001	U	0.8	U	0.007	0.000	0.001	U	0.001	U	0.37	0.01	U
GW45-09-1326	2/28/2009	Not provided	0.001	U	0.8	U	0.007	0.000	0.001	U	0.001	U	0.38	0.01	U
GW45-09-1327	3/4/2009	Not provided	0.001	U	0.8	U	0.005	0.000	0.001	U	0.001	U	0.44	0.01	U
GW45-09-1328	3/5/2009	Not provided	0.001	U	0.8	U	0.004	0.000	0.001	U	0.002	0.000	0.46	0.01	U
GW45-09-1329	3/4/2009	Not provided	0.001	U	0.8	U	0.005	0.000	0.001	U	0.001	0.000	0.46	0.01	U
GW45-09-1330	3/5/2009	Not provided	0.001	U	0.8	U	0.005	0.000	0.001	U	0.002	0.000	0.46	0.01	U
GW45-09-1331	3/5/2009	Not provided	0.001	U	0.8	U	0.006	0.000	0.001	U	0.001	U	0.46	0.01	U
GW45-09-1332	3/5/2009	Not provided	0.001	U	0.8	U	0.006	0.000	0.001	U	0.001	0.000	0.46	0.01	U

Table B.1.3.1-1
Analytical Results for Groundwater Screening Samples Collected from Well R-45, Mortandad Canyon

Sample ID	Date Received	ER/RRES-WQH	Alk-CO3+HCO3 rslt (ppm)	Hg rslt (ppm)	stdev (Hg)	K rslt (ppm)	stdev (K)	Li rslt (ppm)	stdev (Li)	Mg rslt (ppm)	stdev (Mg)	Mn rslt (ppm)	stdev (Mn)	Mo rslt (ppm)	stdev (Mo)
GW45-09-1337	12/22/2008	09-557	136	0.00006	0.00000	2.74	0.0	0.034	0.000	5.52	0.02	0.095	0.000	0.026	0.000
GW45-09-1338	1/9/2009	09-594	97	0.00007	0.00000	1.33	0.0	0.024	0.000	1.10	0.00	0.067	0.000	0.154	0.001
GW45-09-1340	1/9/2009	09-594	123	0.00039	0.00000	1.77	0.0	0.028	0.000	2.65	0.01	0.033	0.000	0.053	0.000
GW45-09-1341	1/9/2009	09-594	95	0.00012	0.00000	0.75	0.0	0.024	0.000	3.59	0.02	0.044	0.000	0.010	0.000
GW45-09-1342	1/9/2009	09-594	84	0.00010	0.00000	1.59	0.0	0.024	0.000	4.06	0.03	0.108	0.001	0.030	0.000
GW45-09-1343	1/9/2009	09-594	89	0.00017	0.00001	1.79	0.0	0.024	0.000	3.31	0.01	0.063	0.000	0.041	0.000
GW45-09-1344	1/9/2009	09-594	88	0.00035	0.00000	1.40	0.0	0.024	0.000	3.83	0.03	0.063	0.000	0.013	0.000
GW45-09-1345	1/9/2009	09-594	95	0.00642	0.00005	2.69	0.0	0.046	0.000	3.51	0.02	0.045	0.000	0.111	0.000
GW45-09-1346	1/9/2009	09-594	100	0.00059	0.00001	1.94	0.0	0.034	0.001	4.08	0.01	0.032	0.000	0.034	0.000
GW45-09-1317	1/28/2009	09-751	97	0.00005	U	1.27	0.00	0.025	0.000	4.31	0.03	0.017	0.000	0.001	0.000
GW45-09-1318	1/28/2009	09-751	92	0.00005	U	1.25	0.00	0.025	0.000	4.32	0.03	0.016	0.000	0.001	0.000
GW45-09-1319	2/2/2009	09-773	102	0.00005	U	1.47	0.02	0.025	0.000	4.62	0.03	0.016	0.000	0.001	0.000
GW45-09-1320	2/2/2009	09-773	105	0.00005	U	1.42	0.01	0.025	0.000	4.50	0.04	0.015	0.000	0.001	0.000
GW45-09-1321	2/27/2009	Not provided	87	0.00005	U	1.20	0.0	0.024	0.000	4.33	0.0	0.006	0.000	0.001	U
GW45-09-1322	2/27/2009	Not provided	85	0.00005	U	1.17	0.0	0.024	0.000	4.26	0.0	0.004	0.000	0.001	U
GW45-09-1323	2/28/2009	Not provided	85	0.00005	U	1.17	0.0	0.025	0.000	4.31	0.0	0.004	0.000	0.001	U
GW45-09-1324	2/28/2009	Not provided	85	0.00005	U	1.15	0.0	0.024	0.000	4.21	0.0	0.004	0.000	0.001	U
GW45-09-1325	2/28/2009	Not provided	85	0.00005	U	1.21	0.0	0.024	0.000	4.37	0.0	0.003	0.000	0.001	U
GW45-09-1326	2/28/2009	Not provided	84	0.00005	U	1.18	0.0	0.024	0.000	4.30	0.0	0.003	0.000	0.001	0.000
GW45-09-1327	3/4/2009	Not provided	94	0.00005	U	1.33	0.0	0.023	0.000	4.42	0.0	0.009	0.000	0.001	U
GW45-09-1328	3/5/2009	Not provided	93	0.00005	U	1.27	0.0	0.020	0.001	4.44	0.1	0.006	0.000	0.002	0.001
GW45-09-1329	3/4/2009	Not provided	92	0.00005	U	1.26	0.0	0.024	0.000	4.46	0.0	0.006	0.000	0.001	U
GW45-09-1330	3/5/2009	Not provided	92	0.00005	U	1.24	0.0	0.023	0.000	4.44	0.0	0.005	0.000	0.001	U
GW45-09-1331	3/5/2009	Not provided	91	0.00005	U	1.26	0.0	0.024	0.000	4.41	0.0	0.005	0.000	0.001	U
GW45-09-1332	3/5/2009	Not provided	91	0.00005	U	1.24	0.0	0.023	0.000	4.45	0.0	0.004	0.000	0.001	U

Table B.1.3.1-1
Analytical Results for Groundwater Screening Samples Collected from Well R-45, Mortandad Canyon

Sample ID	Date Received	ER/RRES-WQH	Na rslt (ppm)	stdev (Na)	Ni rslt (ppm)	stdev (Ni)	NO2(ppm)	NO2-N rslt	NO3 ppm	NO3-N rslt	C2O4 rslt (ppm)	Pb rslt (ppm)	stdev (Pb)	Lab pH	PO4(-3) rslt (ppm)
GW45-09-1337	12/22/2008	09-557	30.25	0	0.008	0.000	0.01	0.003, U	0.03	0.01	0.14	0.0002	U	6.93	0.01, U
GW45-09-1338	1/9/2009	09-594	41.16	0	0.001	U	0.27	0.082	3.31	0.75	0.01, U	0.0002	U	6.92	0.01, U
GW45-09-1340	1/9/2009	09-594	33.04	0	0.001	U	0.01	0.003, U	2.15	0.49	0.01, U	0.0002	U	7.27	0.01, U
GW45-09-1341	1/9/2009	09-594	18.11	0	0.001	0.000	0.03	0.009	4.67	1.05	0.01, U	0.0002	U	7.11	0.01, U
GW45-09-1342	1/9/2009	09-594	16.71	0	0.002	0.000	0.10	0.030	7.38	1.67	0.01, U	0.0002	U	7.14	0.01, U
GW45-09-1343	1/9/2009	09-594	14.55	0	0.001	0.000	0.47	0.142	3.49	0.79	0.01, U	0.0002	U	7.06	0.01, U
GW45-09-1344	1/9/2009	09-594	12.25	0	0.001	0.000	0.01	0.003, U	1.90	0.43	0.01, U	0.0002	U	7.24	0.01, U
GW45-09-1345	1/9/2009	09-594	14.80	0	0.001	U	0.01	0.003, U	1.66	0.37	0.01, U	0.0007	0.0000	7.36	0.01, U
GW45-09-1346	1/9/2009	09-594	9.69	0.1	0.001	U	0.01	0.003, U	2.03	0.46	0.02	0.0008	0.0000	7.35	0.01, U
GW45-09-1317	1/28/2009	09-751	12.89	0	0.001	U	0.01	0.003, U	6.54	1.48	0.01, U	0.0002	U	7.86	0.04
GW45-09-1318	1/28/2009	09-751	12.54	0	0.001	U	0.01	0.003, U	6.70	1.51	0.01, U	0.0002	U	7.73	0.04
GW45-09-1319	2/2/2009	09-773	13.26	0	0.001	0.000	0.01	0.003, U	1.89	0.43	0.01, U	0.0002	U	7.88	0.03
GW45-09-1320	2/2/2009	09-773	12.34	0	0.001	U	0.01	0.003, U	1.90	0.43	0.01, U	0.0002	U	8.04	0.04
GW45-09-1321	2/27/2009	Not provided	10.75	0	0.001	0.000	0.01	0.003, U	7.53	1.70	0.01, U	0.0002	U	7.79	0.03
GW45-09-1322	2/27/2009	Not provided	10.37	0	0.001	U	0.01	0.003, U	7.52	1.70	0.01, U	0.0002	U	7.79	0.05
GW45-09-1323	2/28/2009	Not provided	10.28	0	0.001	U	0.01	0.003, U	7.39	1.67	0.01, U	0.0002	U	7.85	0.05
GW45-09-1324	2/28/2009	Not provided	9.98	0	0.001	U	0.01	0.003, U	7.43	1.68	0.01, U	0.0002	U	7.79	0.05
GW45-09-1325	2/28/2009	Not provided	10.35	0	0.001	U	0.01	0.003, U	7.39	1.67	0.01, U	0.0002	U	7.79	0.05
GW45-09-1326	2/28/2009	Not provided	10.18	0	0.001	U	0.01	0.003, U	7.38	1.67	0.01, U	0.0002	U	7.74	0.05
GW45-09-1327	3/4/2009	Not provided	11.56	0	0.001	0.000	0.01	0.003, U	2.12	0.48	0.01, U	0.0002	U	7.98	0.07
GW45-09-1328	3/5/2009	Not provided	11.10	0	0.001	U	0.01	0.003, U	2.18	0.49	0.01, U	0.0002	U	8.01	0.03
GW45-09-1329	3/4/2009	Not provided	10.78	0	0.001	0.000	0.01	0.003, U	2.23	0.50	0.01, U	0.0002	U	7.96	0.03
GW45-09-1330	3/5/2009	Not provided	10.70	0	0.001	0.000	0.01	0.003, U	2.25	0.51	0.01, U	0.0002	U	7.95	0.03
GW45-09-1331	3/5/2009	Not provided	10.80	0	0.001	U	0.01	0.003, U	2.32	0.52	0.01, U	0.0002	U	7.98	0.05
GW45-09-1332	3/5/2009	Not provided	10.73	0	0.001	U	0.01	0.003, U	2.35	0.53	0.01, U	0.0002	U	7.94	0.04

Table B.1.3.1-1
Analytical Results for Groundwater Screening Samples Collected from Well R-45, Mortandad Canyon

Sample ID	Date Received	ER/RRES-WQH	Rb rslt (ppm)	stdev (Rb)	Sb rslt (ppm)	stdev (Sb)	Se rslt (ppm)	stdev (Se)	Si rslt (ppm)	stdev (Si)	SiO2 rslt (ppm)	stdev (SiO2)	Sn rslt (ppm)	stdev (Sn)	SO4(-2) rslt (ppm)
GW45-09-1337	12/22/2008	09-557	0.004	0.000	0.001	U	0.001	U	28	0.3	60.6	0.7	0.001	U	8.32
GW45-09-1338	1/9/2009	09-594	0.002	0.000	0.001	U	0.001	U	7	0.0	14.0	0.1	0.001	U	25.37
GW45-09-1340	1/9/2009	09-594	0.002	0.000	0.001	U	0.001	U	11	0.1	23.6	0.1	0.001	U	14.03
GW45-09-1341	1/9/2009	09-594	0.001	0.000	0.001	U	0.001	U	23	0.2	48.5	0.3	0.001	U	9.61
GW45-09-1342	1/9/2009	09-594	0.002	0.000	0.001	U	0.001	U	14	0.1	29.4	0.1	0.001	U	15.01
GW45-09-1343	1/9/2009	09-594	0.002	0.000	0.001	U	0.001	U	13	0.1	28.2	0.2	0.001	U	7.07
GW45-09-1344	1/9/2009	09-594	0.002	0.000	0.001	U	0.001	U	26	0.1	55.6	0.2	0.001	U	5.60
GW45-09-1345	1/9/2009	09-594	0.003	0.000	0.001	U	0.001	U	18	0.1	39.1	0.2	0.001	U	8.79
GW45-09-1346	1/9/2009	09-594	0.002	0.000	0.001	U	0.001	U	24	0.3	52.0	0.6	0.001	U	5.17
GW45-09-1317	1/28/2009	09-751	0.002	0.000	0.001	U	0.001	U	33	0	71.7	0.5	0.001	U	6.32
GW45-09-1318	1/28/2009	09-751	0.002	0.000	0.001	U	0.001	U	34	0	72.1	0.5	0.001	U	6.10
GW45-09-1319	2/2/2009	09-773	0.002	0.000	0.001	U	0.001	U	34	1	72.8	1.1	0.001	U	7.44
GW45-09-1320	2/2/2009	09-773	0.002	0.000	0.001	U	0.001	U	34	0	73.0	0.6	0.001	U	6.71
GW45-09-1321	2/27/2009	Not provided	0.002	0.000	0.001	U	0.001	U	34	0	73.5	0.2	0.001	U	5.24
GW45-09-1322	2/27/2009	Not provided	0.002	0.000	0.001	U	0.001	U	34	0	73.1	1.0	0.001	U	5.13
GW45-09-1323	2/28/2009	Not provided	0.002	0.000	0.001	U	0.001	U	35	0	74.1	0.4	0.001	U	4.98
GW45-09-1324	2/28/2009	Not provided	0.002	0.000	0.001	U	0.001	U	34	0	72.2	0.6	0.001	U	5.02
GW45-09-1325	2/28/2009	Not provided	0.002	0.000	0.001	U	0.001	U	35	0	74.5	0.7	0.001	U	4.98
GW45-09-1326	2/28/2009	Not provided	0.002	0.000	0.001	U	0.001	U	34	0	73.8	0.8	0.001	U	5.00
GW45-09-1327	3/4/2009	Not provided	0.002	0.000	0.001	U	0.001	U	36	0	76.8	0.1	0.001	U	5.49
GW45-09-1328	3/5/2009	Not provided	0.002	0.000	0.001	U	0.001	U	36	0	77.3	0.3	0.001	U	5.08
GW45-09-1329	3/4/2009	Not provided	0.002	0.000	0.001	U	0.001	U	37	0	78.1	0.4	0.001	U	4.56
GW45-09-1330	3/5/2009	Not provided	0.002	0.000	0.001	U	0.001	U	36	0	77.4	0.4	0.001	U	4.50
GW45-09-1331	3/5/2009	Not provided	0.002	0.000	0.001	U	0.001	U	36	0	78.0	0.5	0.001	U	4.34
GW45-09-1332	3/5/2009	Not provided	0.002	0.000	0.001	U	0.001	U	37	0	78.7	0.6	0.001	U	4.32

Table B.1.3.1-1
Analytical Results for Groundwater Screening Samples Collected from Well R-45, Mortandad Canyon

Sample ID	Date Received	ER/RRES-WQH	Sr rslt (ppm)	stdev (Sr)	Th rslt (ppm)	stdev (Th)	Ti rslt (ppm)	stdev (Ti)	Tl rslt (ppm)	stdev (Tl)	U rslt (ppm)	stdev (U)	V rslt (ppm)	stdev (V)	Zn rslt (ppm)
GW45-09-1337	12/22/2008	09-557	0.08	0.00	0.001	U	0.008	0.000	0.001	U	0.0006	0.0000	0.001	0.000	0.008
GW45-09-1338	1/9/2009	09-594	0.02	0.00	0.001	U	0.002	U	0.001	U	0.0002	U	0.001	U	0.003
GW45-09-1340	1/9/2009	09-594	0.04	0.00	0.001	U	0.002	U	0.001	U	0.0009	0.0000	0.001	U	0.002
GW45-09-1341	1/9/2009	09-594	0.05	0.00	0.001	U	0.002	U	0.001	U	0.0007	0.0000	0.001	U	0.002
GW45-09-1342	1/9/2009	09-594	0.05	0.00	0.001	U	0.002	U	0.001	U	0.0004	0.0000	0.001	U	0.003
GW45-09-1343	1/9/2009	09-594	0.04	0.00	0.001	U	0.002	U	0.001	U	0.0004	0.0000	0.001	U	0.003
GW45-09-1344	1/9/2009	09-594	0.04	0.00	0.001	U	0.005	0.000	0.001	U	0.0005	0.0000	0.001	U	0.004
GW45-09-1345	1/9/2009	09-594	0.04	0.00	0.001	U	0.024	0.000	0.001	U	0.0010	0.0000	0.001	0.000	0.005
GW45-09-1346	1/9/2009	09-594	0.05	0.00	0.001	U	0.033	0.000	0.001	U	0.0011	0.0000	0.001	0.000	0.006
GW45-09-1317	1/28/2009	09-751	0.07	0.00	0.001	U	0.002	U	0.001	U	0.0011	0.0000	0.005	0.000	0.001
GW45-09-1318	1/28/2009	09-751	0.07	0.00	0.001	U	0.002	U	0.001	U	0.0010	0.0000	0.005	0.000	0.001
GW45-09-1319	2/2/2009	09-773	0.08	0.00	0.001	U	0.002	U	0.001	U	0.0010	0.0000	0.006	0.000	0.008
GW45-09-1320	2/2/2009	09-773	0.08	0.00	0.001	U	0.002	U	0.001	U	0.0010	0.0000	0.006	0.000	0.007
GW45-09-1321	2/27/2009	Not provided	0.07	0.00	0.001	U	0.002	U	0.001	U	0.0008	0.0000	0.005	0.000	0.006
GW45-09-1322	2/27/2009	Not provided	0.07	0.00	0.001	U	0.002	U	0.001	U	0.0008	0.0000	0.005	0.000	0.006
GW45-09-1323	2/28/2009	Not provided	0.07	0.00	0.001	U	0.002	U	0.001	U	0.0007	0.0000	0.005	0.000	0.006
GW45-09-1324	2/28/2009	Not provided	0.07	0.00	0.001	U	0.002	U	0.001	U	0.0007	0.0000	0.005	0.000	0.006
GW45-09-1325	2/28/2009	Not provided	0.07	0.00	0.001	U	0.002	U	0.001	U	0.0007	0.0000	0.005	0.000	0.003
GW45-09-1326	2/28/2009	Not provided	0.07	0.00	0.001	U	0.002	U	0.001	U	0.0007	0.0000	0.005	0.000	0.003
GW45-09-1327	3/4/2009	Not provided	0.07	0.00	0.001	U	0.002	U	0.001	U	0.0008	0.0000	0.007	0.000	0.005
GW45-09-1328	3/5/2009	Not provided	0.06	0.00	0.001	U	0.002	U	0.001	U	0.0007	0.0001	0.007	0.000	0.003
GW45-09-1329	3/4/2009	Not provided	0.06	0.00	0.001	U	0.002	U	0.001	U	0.0007	0.0000	0.008	0.000	0.004
GW45-09-1330	3/5/2009	Not provided	0.06	0.00	0.001	U	0.002	U	0.001	U	0.0008	0.0000	0.007	0.000	0.004
GW45-09-1331	3/5/2009	Not provided	0.06	0.00	0.001	U	0.002	U	0.001	U	0.0007	0.0000	0.008	0.000	0.003
GW45-09-1332	3/5/2009	Not provided	0.06	0.00	0.001	U	0.002	U	0.001	U	0.0007	0.0000	0.007	0.000	0.003

Table B.1.3.1-1
Analytical Results for Groundwater Screening Samples Collected from Well R-45, Mortandad Canyon

Sample ID	Date Received	ER/RRES-WQH	stdev (Zn)	TDS (ppm)	Cations	Anions	Balance
GW45-09-1337	12/22/2008	09-557	0.001	278.0	2.68	2.90	-0.04
GW45-09-1338	1/9/2009	09-594	0.001	201.1	2.09	2.59	-0.11
GW45-09-1340	1/9/2009	09-594	0.001	223.2	2.20	2.73	-0.11
GW45-09-1341	1/9/2009	09-594	0.001	200.5	1.68	2.08	-0.11
GW45-09-1342	1/9/2009	09-594	0.001	185.6	1.78	2.22	-0.11
GW45-09-1343	1/9/2009	09-594	0.000	168.0	1.55	1.92	-0.11
GW45-09-1344	1/9/2009	09-594	0.001	187.6	1.50	1.79	-0.09
GW45-09-1345	1/9/2009	09-594	0.001	187.9	1.66	2.05	-0.11
GW45-09-1346	1/9/2009	09-594	0.001	198.2	1.58	2.01	-0.12
GW45-09-1317	1/28/2009	09-751	0.001	222.4	1.73	2.02	-0.08
GW45-09-1318	1/28/2009	09-751	0.001	217.7	1.73	1.93	-0.05
GW45-09-1319	2/2/2009	09-773	0.001	226.4	1.81	2.06	-0.07
GW45-09-1320	2/2/2009	09-773	0.001	226.7	1.73	2.08	-0.09
GW45-09-1321	2/27/2009	Not provided	0.000	210.6	1.66	1.81	-0.04
GW45-09-1322	2/27/2009	Not provided	0.000	208.3	1.64	1.78	-0.04
GW45-09-1323	2/28/2009	Not provided	0.000	208.4	1.64	1.77	-0.04
GW45-09-1324	2/28/2009	Not provided	0.000	205.8	1.61	1.77	-0.05
GW45-09-1325	2/28/2009	Not provided	0.000	209.1	1.65	1.77	-0.03
GW45-09-1326	2/28/2009	Not provided	0.000	207.5	1.64	1.76	-0.04
GW45-09-1327	3/4/2009	Not provided	0.000	216.8	1.70	1.85	-0.04
GW45-09-1328	3/5/2009	Not provided	0.000	215.6	1.69	1.82	-0.04
GW45-09-1329	3/4/2009	Not provided	0.000	214.3	1.67	1.79	-0.04
GW45-09-1330	3/5/2009	Not provided	0.000	213.3	1.66	1.79	-0.04
GW45-09-1331	3/5/2009	Not provided	0.000	213.7	1.68	1.78	-0.03
GW45-09-1332	3/5/2009	Not provided	0.000	214.0	1.68	1.77	-0.03

Appendix C

Aquifer Testing Report

C-1.0 INTRODUCTION

This appendix describes the hydraulic analysis of pumping tests at well R-45 screens 1 and 2 located in Mortandad Canyon near the edge of the existing chromium plume beneath the canyon. The tests were conducted in conjunction with testing of nearby well R-44 screens 1 and 2. The primary objective of the analysis was to determine the hydraulic properties of the zones screened in R-45, as well as the intervening sediments between the two screen zones. A secondary objective was to look for cross-connection between R-45 and surrounding wells R-44, R-11, R-13, and R-28.

Testing consisted primarily of constant-rate pumping tests conducted on R-45 screens 1 and 2. During the tests on each screen, water levels were monitored in the nonpumped screen zone in R-45 to examine the properties of the intervening tight sediments and in R-44 screens 1 and 2 to monitor cross-connection between the wells. In addition, water levels were monitored in adjacent wells R-11, R-13, and R-28.

Consistent with most of the R-well pumping tests conducted on the plateau, an inflatable packer system was used in R-45 to isolate the screens and eliminate the effects of casing storage on the test data.

Conceptual Hydrogeology

R-45 is a dual-screen well completed in the Puye Formation and the Miocene pumiceous deposits. Screen 1 is 10 ft long, screened from 880.0 to 890.0 ft below ground surface (bgs) within the Puye Formation. Screen 2 is 20 ft long, screened from 974.9 to 994.9 bgs within the Miocene pumiceous sediments. Thus, the screens are separated by 84.9 ft of intervening sediments. The composite static water level measured on February 13 at the onset of testing R-44 and R-45 was 868.27 ft bgs. When the zones were isolated with inflatable packers, the water level in screen 1 rose 0.04 to 868.23 ft bgs, while the level in screen 2 dropped 0.07 to 868.34 ft bgs. Thus, the initial water level in screen 1 was 0.11 ft higher than in screen 2, implying a slight downward gradient. The head difference between the two screen zones in R-45 was modest (0.0011 ft/ft downward gradient from the center of screen 1 to the center of screen 2) compared with differences measured at other multiscreen wells on the plateau, which show head differences of feet or tens of feet in most cases. The brass cap elevation at R-45 is 6704.02 ft above mean sea level (amsl), making the approximate static water-level elevations in screens 1 and 2 5836 ft.

Well R-44, also a dual-screen well, is located about 1000 ft south of R-45 and is completed at the top of the regional aquifer in the Puye Formation, just above the Miocene pumiceous sediments, with 10 ft of screen from 895.0 to 905.0 ft bgs (screen 1) and 9.9 ft of screen from 985.3 to 995.2 ft bgs (screen 2). The composite water level in R-44 measured at the outset of testing R-44 and R-45 was 878.86 ft bgs. When the zones were isolated with inflatable packers, the water level in screen 1 rose from 0.06 to 878.80 ft bgs, while the level in screen 2 dropped from 0.14 to 879.00 ft bgs. Thus, the initial water level in screen 1 was 0.2 ft above that in screen 2. The brass cap elevation at R-44 is 6714.91 ft amsl, making the approximate static water-level elevations in screens 1 and 2 5836 ft, nearly identical to those in R-45 at the time of testing.

R-44 Screen 1 Testing

R-45 screen 1 was tested from February 24 to March 1, 2009. Testing consisted of brief pumping to fill the drop pipe and verify equipment operation on February 24, trial pumping on February 25, background data collection, and a 24-h constant-rate pumping test that was begun on February 27.

Two trial tests were conducted on February 25. Trial 1 was conducted at an average discharge rate of 24.3 gpm for 60 min from 8:00 to 9:00 a.m. and was followed by 60 min of recovery until 10:00 a.m. Trial 2 was conducted for 120 min from 10:00 a.m. to 12:00 p.m. at 24.1 gpm. Following shutdown, recovery/background was monitored for 44 h until 8:00 a.m. on February 27.

At 8:00 a.m. on February 27, the 24-h pumping test begun at a rate of 24.3 gpm. Pumping continued until 8:00 am on February 28. Following shutdown, recovery measurements were recorded for 24 h until 8:00 a.m. on March 1.

R-45 Screen 2 Testing

R-45 screen 2 was tested from March 1 to March 6, 2009. Testing consisted of brief pumping to fill the drop pipe and verify equipment operation on March 1, trial pumping on March 2, background data collection, and a 24-h constant-rate pumping test that began on March 4.

Two trial tests were conducted on March 2. Trial 1 was conducted at an average discharge rate of 24.2 gpm for 60 min from 8:00 to 9:00 a.m. and was followed by 60 min of recovery until 10:00 a.m. Trial 2 was conducted for 60 min from 10:00 to 11:00 a.m. at 24.2 gpm. Following shutdown, recovery/background was monitored for 45 h until 8:00 a.m. on March 4.

At 8:00 a.m. on March 4, the 24-h pumping test began at a rate of 23.9 gpm. Pumping continued until 8:00 a.m. on March 5. Following shutdown, recovery measurements were recorded for 24 h until 8:00 a.m. on March 6.

Leaky Drop Pipe Joints

Similar to what occurred earlier at R-44 during the R-45 testing, there was leakage through the threaded joints on the 1 ½-in. stainless-steel drop pipe (1.90-in. outside diameter × 1.61-in. inside diameter), creating downhole voids inside the drop pipe beneath the check valves. This allowed initial pump operation against reduced head until the voids were refilled. The result was an elevated pumping rate for a brief period at the beginning of most of the tests. This effect corrupted the early startup data and added uncertainty to the analyses of the early drawdown data. The leaks were caused either by worn or improperly manufactured threads, as well as by the need to avoid wrenching the pipe extremely as a precaution against galling the stainless-steel threads.

Screen 1 Storage Effects

Initial testing of R-45 screen 1 did not show storage effects. However, the final test (24-h test) did show a minor storage effect, probably associated with dewatering a small portion of the filter pack. As-built drawings of R-45 estimate the top of the filter pack to be at a depth of 872.7 ft bgs, about 4.5 ft below the screen 1 static water level. The drawdown during pumping was around 5.7 ft during the trial tests and 6.4 ft during the 24-h test. If the interface between the top of the filter pack and the bentonite seal were slightly deeper than estimated (say a foot or so), it is possible that the filter pack could have remained mostly saturated during the trial tests but drained slightly during the 24-h test.

C-2.0 BACKGROUND DATA

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

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

Previous pumping tests on the plateau have demonstrated a barometric efficiency for most wells of between 90% and 100%. 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 on the early R-wells, downhole pressure was monitored using a *vented* pressure 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 R-45, have used *nonvented* transducers. These devices simply record 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 in a barometrically efficient well. Take as an example a 90% barometrically efficient well. When monitored using a vented transducer, an *increase* in barometric pressure of 1 unit causes a *decrease* in recorded downhole pressure of 0.9 unit because the water level is forced downward 0.9 unit by the barometric pressure change. However, using a nonvented transducer, the total measured pressure *increases* by 0.1 unit (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 Technical Area 54 (TA-54) tower site from the Waste and Environmental Services Division-Environmental Data and Analysis (WES-EDA). The TA-54 measurement location is at an elevation of 6548 ft amsl, whereas the wellhead elevation is approximately 6704 ft amsl. The static water levels of the two zones were about 868 ft below land surface, making the water-table elevation roughly 5836 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 R-45.

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

$$P_{WT} = P_{TA54} \exp \left[- \frac{g}{3.281R} \left(\frac{E_{R44} - E_{TA54}}{T_{TA54}} + \frac{E_{WT} - E_{R44}}{T_{WELL}} \right) \right] \quad \text{Equation C-1}$$

Where, P_{WT} = barometric pressure at the water table inside R-44

P_{TA54} = barometric pressure measured at TA-54

g = acceleration of gravity, in m/sec² (9.80665 m/sec²)

R = gas constant, in J/Kg/degree Kelvin (287.04 J/Kg/degree Kelvin)

E_{R44} = land-surface elevation at R-45 site, in feet (6715 ft)

E_{TA54} = elevation of barometric pressure measuring point at TA-54, in feet (6548 ft)

E_{WT} = elevation of the water level in R-45, in feet (approximately 5836 ft)

T_{TA54} = air temperature near TA-54, in degrees Kelvin (assigned a value of 34.2 degrees Fahrenheit, or 284.4 degrees Kelvin)

T_{WELL} = air temperature inside R-44, in degrees Kelvin (assigned a value of 62.1 degrees Fahrenheit, or 289.9 degrees Kelvin)

This formula is an adaptation of an equation WES-EDA provided. 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 with the water-level hydrographs to discern the correlation between the two.

C-3.0 IMPORTANCE OF EARLY DATA

When pumping or recovery first begins, the vertical extent of the cone of depression is limited to approximately the well screen length, the filter pack length, or the aquifer thickness in relatively thin permeable strata. For many pumping tests on the plateau, the early pumping period is the only time that the effective height of the cone of depression is known with certainty. Thus, the early data often offer the best opportunity to obtain hydraulic conductivity information because conductivity would equal the earliest-time transmissivity divided by the well screen length.

Unfortunately, in many pumping tests, casing-storage effects dominate the early-time data, hindering the effort to determine the transmissivity of the screened interval. The duration of casing-storage effects can be estimated using the following equation (Schafer 1978, 098240).

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

Equation C-2

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 gallons per minute

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 before conducting the test. Therefore, this option has been implemented for the R-well testing program, including the R-45 pumping tests.

C-4.0 TIME-DRAWDOWN METHODS

Time-drawdown data can be analyzed using a variety of methods. Among them is the Theis method (1934-1935, 098241). The Theis equation describes drawdown around a well as follows:

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

Equation C-3

Where,

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

Equation C-4

and

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

Equation C-5

and where, s = drawdown, in feet

Q = discharge rate, in gallons per minute

T = transmissivity, in gallons per day per foot

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:

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

Equation C-6

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

Equation C-7

Where, T = transmissivity, in gallons per day per foot

S = storage coefficient

Q = discharge rate, in gallons per minute

$W(u)$ = 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, 098236), a simplification of the Theis equation that is mathematically equivalent to the Theis equation for most pumped well data. The Cooper–Jacob equation describes drawdown around a pumping well as follows:

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

Equation C-8

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 most or all measured drawdown values. Thus, for the pumped well, the Cooper–Jacob equation usually can be considered a valid approximation of the Theis equation.

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

$$T = \frac{264Q}{\Delta s} \quad \text{Equation C-9}$$

Where, T = transmissivity, in gallons per day per foot

Q = discharge rate, in gallons per minute

Δs = change in head over one log cycle of the graph, in feet

Because the R-wells are severely partially penetrating, an alternate solution considered for assessing aquifer conditions is the Hantush equation for partially penetrating wells (Hantush 1961, 098237; Hantush 1961, 106003). The Hantush equation is as follows:

Equation C-10

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

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

b = aquifer thickness

d = distance from top of aquifer to top of well screen in pumped well

l = distance from top of aquifer to bottom of well screen in pumped well

d' = distance from top of aquifer to top of well screen in observation well

l' = distance from top of aquifer to bottom of well screen in observation well

K_z = vertical hydraulic conductivity

K_r = horizontal hydraulic conductivity

In this equation, $W(u)$ is the Theis well function and $W(u,\beta)$ is the Hantush well function for leaky aquifers where:

$$\beta = \sqrt{\frac{K_z}{K_r}} \frac{n\pi r}{b} \quad \text{Equation C-11}$$

Note that for single-well tests, $d = d'$ and $l = l'$.

C-5.0 RECOVERY METHODS

Recovery data were analyzed using the Theis recovery method. This is a semilog analysis method similar to the Cooper–Jacob procedure.

In this method, residual drawdown is plotted on a semilog 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:

$$T = \frac{264Q}{\Delta s} \quad \text{Equation C-12}$$

The recovery data are particularly useful compared with 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. This was of paramount importance in the R-45 pumping tests because of the entrained air-induced discharge rate fluctuations.

C-6.0 SPECIFIC CAPACITY METHOD

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

For fully penetrating wells, the Cooper–Jacob equation can be 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 and Marting (1961, 098235) and augmented by Bradbury and Rothchild (1985, 098234).

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

$$s_p = \frac{1 - \frac{L}{b}}{\frac{L}{b}} \left[\ln \frac{b}{r_w} - 2.948 + 7.363 \frac{L}{b} - 11.447 \left(\frac{L}{b} \right)^2 + 4.675 \left(\frac{L}{b} \right)^3 \right] \quad \text{Equation C-13}$$

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

$$K = \frac{264Q}{sb} \left(\log \frac{0.3Tt}{r_w^2 S} + \frac{2s_p}{\ln 10} \right) \quad \text{Equation C-14}$$

To apply this procedure, a storage coefficient value must be assigned. Unconfined conditions were assumed for screen 1, while confined to leaky-confined conditions were applied to screen 2. Storage coefficient values for confined conditions can be expected to range from about 10^{-5} to 10^{-3} , depending on

aquifer thickness, while those for unconfined conditions can be expected to range from about 0.01 to 0.25 (Driscoll 1986, 104226). The calculation result is not particularly sensitive to the choice of storage coefficient value, so a rough estimate of the storage coefficient is generally adequate to support the calculations. An assumed value of 0.1 was used in the calculations for screen 1, while values of 10^{-3} and 10^{-2} were used for screen 2. For screen 2, a storage coefficient value of 10^{-3} was deemed appropriate for the assumption of confined conditions (with perhaps very minor leakage from above), while 10^{-2} was used to simulate leaky-confined conditions.

The analysis also requires assigning a value for the saturated aquifer thickness, b . For calculation purposes, the screen 1 zone was assumed to extend from the water table, at 868 ft bgs, to the midpoint of the blank pipe section between the two screens, at approximately 932 ft bgs. This resulted in an assigned aquifer thickness of 64 ft for screen 1. This was equivalent to assuming that the resistive zone between screens 1 and 2 was at the midpoint of the intervening blank section, even though the actual location was not known. However, the computed result is not particularly sensitive to the exact aquifer thickness because sediments far above or below the screen have little effect on yield and drawdown response. Therefore, the calculation based on the assumed aquifer thickness value was deemed to be adequate. For screen 2, an arbitrary thickness of 200 ft was assigned in the calculations.

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

C-7.0 BACKGROUND DATA ANALYSIS

Background aquifer pressure data collected during the R-45 tests were plotted along with barometric pressure to determine the barometric effect on water levels and to look for pumping response in the surrounding observation wells. The four screen zones in R-44 and R-45 were monitored using nonvented pressure transducers, while the remaining wells—R-11, R-13, and R-28—were monitored using vented transducers.

Figure C-7.0-1 shows aquifer pressure data from R-45 screen 1 along with barometric pressure data from TA-54 that have been corrected to equivalent barometric pressure in feet of water at the water table. The R-45 data are referred to in the figure as the “apparent hydrograph” because the measurements reflect the sum of water pressure and barometric pressure, having been recorded using a nonvented pressure transducer. The times of the pumping periods for the screen 1 and screen 2 pumping tests are included on the figure for reference.

The screen 1 data recorded during the screen 2 tests showed substantial scatter. This resulted from the transducer having to be located adjacent to the pump power cable (inevitable when pumping screen 2 and monitoring screen 1), which interfered with transducer operation when the pump was running. To minimize the data scatter in Figure C-7.0-1, a rolling average of the data was plotted in Figure C-7.0-2. The average included data over a 1-h interval.

It is clear from Figure C-7.0-2 that pumping R-45 screen 2 (March 4 to 5) induced drawdown in screen 1. The estimated effect was about 0.06 ft.

It appeared in Figures C-7.0-1 and C-7.0-2 that changes in barometric pressure had no discernible effect on water levels suggesting high barometric efficiency. Previous results from testing R-44 had indicated 100% barometric efficiency for R-45. This was best illustrated by the R-45 screen 1 hydrograph recorded at that time shown in Figure C-7.0-3. Inspection of Figure C-7.0-3 shows that large changes in barometric pressure had essentially no effect on total aquifer pressure.

Figure C-7.0-4 shows the R-45 screen 2 apparent hydrograph during the testing of R-45 screens 1 and 2. The figure showed that large barometric pressure changes did not significantly alter the aquifer pressure. Note that the very significant rise in barometric pressure beginning on February 27 had no discernible effect on the hydrograph. The prominent diurnal effect in the signal having a magnitude of about two to three hundredths of a foot was likely Earth tide response. The induced drawdown in screen 2 during pumping screen 1 was estimated at about 0.04 ft from the graph.

Figure C-7.0-5 shows a plot of the R-45 screen 2 apparent hydrograph recorded during previous testing of R-44. Again, large barometric pressure changes had negligible effect on aquifer pressure. Both Figures C-7.0-4 and C-7.0-5 confirmed the barometric efficiency estimate of near 100%.

The R-45 screen 2 apparent hydrograph was plotted along with run times for the Los Alamos County production wells to check the data for a correlation. Figure C-7.0-6 shows the resulting data plot.

There was no correlation between the hydrograph and the cycling of PM-3, PM-5, and O-4. However, the ongoing continuous operation of PM-4 may have caused the slight decline seen in the hydrograph in February 24 and 25.

Figure C-7.0-7 shows the apparent hydrograph for R-44 screen 1 recorded during the R-45 tests. To minimize the data scatter, a rolling average of the aquifer pressure data was plotted as shown in Figure C-7.0-8.

Several observations were made from the R-44 screen 1 hydrograph. First, the very large change in barometric pressure on February 27 to 28 had negligible effect on aquifer pressure indicating a barometric efficiency near 100%. Second, there was an overall downward trend in the data set. This was probably ongoing drawdown response to continuous operation of PM-4. Finally, each of the R-45 pumping tests appeared to have a subtle effect on R-44 screen 1 water levels. The hydrograph steepened slightly during each 24-h pumping period and then flattened following pump shutdown. Rough estimates of the magnitude of the effects were about 0.02 ft and 0.01 ft in R-44 screen 1 and screen 2, respectively. Because the effect was so small, it was not possible to be certain that it was a direct pumping effect.

Figure C-7.0-9 shows the apparent hydrograph for R-44 screen 2 recorded during the R-45 tests. To minimize the data scatter, a rolling average of the aquifer pressure data was plotted as shown in Figure C-7.0-10.

Several observations were made from the R-44 screen 2 hydrograph. First, the very large change in barometric pressure on February 27 to 28 had negligible effect on aquifer pressure, indicating a barometric efficiency near 100%. Second, there was an overall downward trend in the data set. This was probably ongoing drawdown response to continuous operation of PM-4. Third, there was a clear response to pumping R-45 screen 2 but no apparent effect to pumping screen 1. An estimate of the R-45 screen 2 drawdown effect during 24-h pumping test was about 0.06 ft.

Finally, there was a distinct water-level rise beginning late on March 4 during the R-45 screen 2 pumping test. This effect was explained by comparing the hydrograph with the pumping times associated with Los Alamos County production well operation, as shown in Figure C-7.0-11.

Similar to the BETCO plot, the corrected hydrograph in Figure C-7.0-17 showed a clear response to pumping R-45 screen 2. The magnitude of the drawdown effect was estimated at about 0.02 ft. It was not possible to identify a response to pumping R-45 screen 1, however.

Similar to the R-13 response, the corrected hydrograph in Figure C-7.0-17 showed an overall decline in water level, probably in response to the continuous operation of PM-4.

C-8.0 R-45 SCREEN 1 DATA ANALYSIS

This section presents the data obtained from the R-45 screen 1 pumping tests and the results of the analytical interpretations. Data are presented for drawdown and recovery for trials 1 and 2 and the 24-h constant-rate pumping test.

R-45 Screen 1 Trial 1

Figure C-8.0-1 shows a semilog plot of the trial 1 drawdown data. The pumping rate during the test was 24.3 gpm. The transmissivity calculated from the early data was 2860 gpd/ft. Based on the well screen length of 10 ft, the computed hydraulic conductivity of the screened interval was 286 gpd/ft², or 38.2 ft/d.

Within a minute of pumping, the data trace flattened in response to a combination of delayed yield of the presumed unconfined aquifer and vertical expansion of the cone of depression.

It is likely that shutdown of PM-4 accounted for the water-level reversal that occurred during the R-45 screen 2 pumping test as well as the rise in water level through March 5 and 6 above the starting level before the pumping test.

There was no correlation between the hydrograph and the cycling of the other production wells. The diurnal fluctuations in the water levels in R-44 screen 2 were likely responses to Earth tides.

Figure C-7.0-12 shows the hydrograph obtained from well R-11 located in Sandia Canyon just under 1300 ft north of R-45. The data were recorded using the permanently installed vented transducer, so the hydrograph fluctuated with barometric pressure rather than showing the more flat-line response typical of nonvented transducers. The times of the pumping tests on R-45 screens 1 and 2 are included on the graph for reference. The screen at R-11 is located approximately 20 ft below the regional water table.

Visual examination of the hydrograph and barometric pressure curves showed that they nearly coincided. The only exceptions to this were slight downward deviations of the hydrograph relative to the barometric pressure curve during and following each of the R-45 24-hour pumping tests. This suggested a subtle response in R-11 to pumping both screens in R-45.

Because the barometric pressure fluctuations in the hydrograph were large, it was necessary to correct the water level data by removing the barometric effect. This was done in two ways. One procedure involved correcting the data using BETCO (barometric and Earth tide correction) software, a mathematically complex correction algorithm that uses regression deconvolution (Toll and Rasmussen 2007, 104799) to modify the data. The BETCO correction not only removes barometric pressure effects, but Earth tides as well. The BETCO corrected data are shown in Figure C-7.0-12.

The BETCO plot showed an irregular sinusoidal pattern. During the R-45 screen 1 pumping test, the corrected water level dropped more than in antecedent cycles. Following shutdown, the levels appeared to gradually recover over the next couple of days. It was difficult to discern a response in the BETCO curve to pumping R-45 screen 2.

A second correction approach was applied to the hydrograph data by correcting directly for the change in barometric pressure assuming 100% barometric efficiency and immediate response. Figure C-7.0-13 shows the hydrograph corrected in this manner. The BETCO correction was retained on the graph for comparison.

The direct correction showed a “sag” in the hydrograph during and a few days following the R-45 screen 1 pumping test. It was surmised that this was a possible response to the pumping test, although it was difficult to know for certain. The magnitude of the deflection in the hydrograph was estimated to be roughly 0.02 ft. The corrected hydrograph also showed a slight decline and recovery during and following the R-44 screen 2 pumping test. The estimated magnitude of the effect was only about 0.01 ft, so it was not possible to be certain that the screen 2 pumping test induced the effect.

Figure C-7.0-14 shows the hydrograph obtained from R-13 located roughly 1300 ft southeast of R-45. Again, the times of the R-45 pumping tests and the BETCO hydrograph correction were included on the graph. The screen at R-13 is located approximately 120 ft below the regional water table.

Visual examination of the hydrograph and barometric pressure curve showed that they nearly coincided except for a gradual downward trend in the hydrograph relative to the barometric pressure curve. This was likely ongoing drawdown response to continuous operation of PM-4.

The BETCO plot showed a clear drawdown and recovery response to pumping R-45 screen 2. Possible response to pumping screen 1 was less certain, however. There was a slight drop in level toward the end of the screen 1 pumping period, followed by a gradual rise over the next few days. It was difficult to know whether this was a response to pumping screen 1 or some other effect.

A second correction was performed, this time using the direct approach of correcting for barometric pressure only, assuming 100% barometric efficiency and immediate response. Figure C-7.0-15 shows the resulting corrected hydrograph. The BETCO hydrograph was retained on the figure for comparison purposes.

Similar to the BETCO plot, the corrected hydrograph in Figure C-7.0-15 showed a clear response to pumping R-45 screen 2. The magnitude of the drawdown effect was about 0.03 ft. It was not possible to identify a response to pumping R-45 screen 1, however.

The corrected hydrograph in Figure C-7.0-15 showed effects of operating and shutting down PM-4. The general overall decline in level appeared to be ongoing response to PM-4 operation. Subsequently, during the 24-h R-45 screen 2 pumping period, the water level began rising, despite continued pumping of screen 2. This could have a recovery response to shutting down PM-4 on March 4. Alternatively, because the effect was absent on the BETCO plot, it may have been a delayed barometric response.

Figure C-7.0-16 shows the hydrograph obtained from R-18 located roughly 1300 ft southeast of R-45. Again, the times of the R-45 pumping tests and the BETCO hydrograph correction were included on the graph.

Visual examination of the hydrograph and barometric pressure curve showed that they nearly coincided except for a gradual downward trend in the hydrograph relative to the barometric pressure curve. This was likely ongoing drawdown response to continuous operation of PM-4.

The BETCO plot showed a slight drawdown and recovery response to pumping R-45 screen 2. Possible response to pumping screen 1 was less certain, however. As observed in R-13, there was a slight drop in the R-28 water level toward the end of the screen 1 pumping period, followed by a gradual rise over the next few days. It was difficult to know whether this was a response to pumping screen 1 or some other effect.

A second correction was performed, this time using the direct approach of correcting for barometric pressure only, assuming 100% barometric efficiency and immediate response. Figure C-7.0-17 shows the resulting corrected hydrograph. The BETCO hydrograph was retained in the figure for comparison purposes.

Figure C-8.0-2 shows an expanded-scale plot of the late data from trial 1. The final slope on the graph revealed a transmissivity value of 27,900 gpd/ft. Because of the brevity of the test, there was no way to know whether delayed yield had affected the result or what the effective height of the cone of depression was that corresponded to the observed drawdown slope and transmissivity.

Figure C-8.0-3 shows a semilog plot of the trial 1 recovery data. The transmissivity value computed from the early data was 3150 gpd/ft. Based on the screen length of 10 ft, the computed hydraulic conductivity was 315 gpd/ft², or 42.1 ft/d.

The recovery curve began flattening within a minute of pump shutoff because of delayed yield effects and vertical expansion of the cone of impression. Figure C-8.0-4 shows an expanded-scale plot of the late-recovery data.

The late-recovery data trace was essentially flat—different than observed on the drawdown plot. The flat slope likely reflected delayed yield of the unconfined aquifer. The different response during recovery compared with pumping was probably a result of sluggish recovery of the water table compared with the original rate of decline during pumping, hysteresis effects common to unconfined aquifers.

R-45 Screen 1 Trial 2

Figure C-8.0-5 shows a semilog plot of the trial 2 drawdown data. The discharge rate for trial 2 was 24.1 gpm. The transmissivity value computed from the early data was 3230 gpd/ft, making the computed hydraulic conductivity 323 gpd/ft², or 43.2 ft/d.

Note that the early data showed the effects of a minimal amount of antecedent drainage of the drop pipe through leaky coupling joints. Also, the data within the first minute of pumping showed more of an s-shape than seen in trial 1, possibly indicating a small storage effect. It is possible that predrainage of a portion of the filter pack just beneath the bentonite seal during trial 1 may have trapped a small amount of air in the filter, contributing a small storage effect upon subsequent pumping.

Figure C-8.0-6 shows an expanded-scale plot of the trial 2 drawdown data. The final slope suggested a transmissivity value of 33,500 gpd/ft. As with the trial 1 late-recovery data, there was no way to know the sediment thickness corresponding to the computed transmissivity value.

During the final minute of pumping, from 119 to 120 min, there was an abrupt increase in the recorded drawdown as shown in Figure C-8.0-6. This corresponded to the exact time (119 min) when the data collection scheme in the transducer shifted from 1-min intervals to ¼-s intervals. It was possible that the odd result was an artifact of changes in the transducer operation associated with rapid data collection. The pumping rate was stable during this transition.

Figure C-8.0-7 shows a semilog plot of the trial 2 recovery data. The first couple of data points showed brief and temporary “overrecovery” that was likely associated with inertial effects. Also, the subtle s-shape was observed in the data set, similar to what was seen in the drawdown data. Again, this may have been related to storage effects.

The transmissivity value computed from the early data was 3160 gpd/ft, making the computed hydraulic conductivity 316 gpd/ft², or 42.2 ft/d.

The recovery curve began flattening within a minute of pump shutoff because of delayed yield effects and vertical expansion of the cone of impression. Figure C-8.0-8 shows an expanded-scale plot of the late-recovery data.

Except for probable Earth tide effects, the late-recovery data trace was essentially flat, different than observed on the drawdown plot. The flat slope likely reflected delayed yield of the unconfined aquifer. The different response during recovery compared with pumping was probably a result of sluggish recovery of the water table compared with the original rate of decline during pumping, hysteresis effects common to unconfined aquifers.

C-8.1 R-45 Screen 1 24-H Constant-Rate Pumping Test

Figure C-8.1-1 shows a semilog plot of the drawdown data recorded during the 24-h constant-rate pumping test conducted at a discharge rate of 24.3 gpm. The early data showed the effects of significant antecedent drainage of the drop pipe. This precluded a rigorous analysis of the early-time drawdown data.

Figure C-8.1-2 shows an expanded-scale graph of the late drawdown data. The transmissivity computed from the bulk of the late data was 28,300 gpd/ft. There was no way to know the effective height of the cone of depression corresponding to this value.

The drawdown data in Figure C-8.1-2 after about 1000 min showed a flat trace. This may have indicated great transmissivity of the zone penetrated by the cone of depression at that time, or it may have been an artifact of delayed yield of the unconfined aquifer.

Figure C-8.1-3 shows the recovery data measured following the 24-h constant-rate pumping test. The transmissivity calculated from the early data was 2100 gpd/ft, making the hydraulic conductivity 210 gpd/ft², or 28.1 ft/d. These values were substantially lower than those obtained from the trial tests.

The early data in Figure C-8.1-3 showed a prominent storage-type effect, greater than seen in the trial test plots. It appeared that the storage effect worsened from test to test during the screen 1 investigation. The storage effect likely led to an underestimate of transmissivity and hydraulic conductivity, explaining the discrepancy between these results and those obtained from the trial tests.

Figure C-8.1-4 shows an expanded-scale graph of the late-recovery data. The middle data showed the effects of delayed yield and vertical expansion of the cone of impression. After some time, the data curve began steepening again, possibly signaling the cessation of delayed yield.

The latest slope on Figure C-8.1-4 supported calculation of a transmissivity value of 42,000 gpd/ft. There was no way to know what sediment thickness (height of the cone of impression) corresponded to that transmissivity value.

R-45 Screen 1 Specific Capacity Data

Specific capacity data were used along with well geometry to estimate a lower-bound conductivity value for the R-45 screen 1 zone for comparison to the pumping test values. In addition to specific capacity, other input values used in the calculations included the assumed aquifer thickness of 64 ft (from the static water level to the midpoint of the blank pipe section between screens 1 and 2), a storage coefficient of 0.1 and a borehole radius of 0.51 ft. The calculations are somewhat insensitive to the assigned aquifer thickness, as long as the selected value is substantially greater than the screen length.

R-45 screen 1 produced 24.3 gpm with a drawdown of 6.38 ft after 24 h of pumping for a specific capacity of 3.81 gpm/ft. Applying the Brons and Marting method to these inputs yielded a lower-bound hydraulic conductivity value for the screened interval of 288 gpd/ft², or 38.5 ft/d. This result was consistent with (slightly less than) the values computed from the pumping test data.

R-45 Screen 1 Summary

Table C-8.1-1 summarizes the hydraulic conductivity values obtained from the R-45 screen 1 pumping test analyses. The average hydraulic conductivity computed from the test data was 41.4 ft/d. The computed average did not include the 24-h pumping test recovery results because those data appeared to be storage-affected and yielded a hydraulic conductivity value that deviated from the other calculations

The specific capacity obtained from screen 1 suggested a lower-bound hydraulic conductivity of 38.5 ft/d. This result was consistent with the hydraulic conductivity values from the pumping tests and provided corroboration of those results. It also suggested a fairly efficient screen zone. In all tests, the drawdown and/or recovery data trace began flattening within 1 min of startup/shutdown in response to delayed yield and vertical expansion of the cone of depression.

C-9.0 R-45 SCREEN 2 DATA ANALYSIS

This section presents the data obtained from the R-45 screen 2 pumping tests and the results of the analytical interpretations. Data are presented for drawdown and recovery for trials 1 and 2 and the 24-h constant-rate pumping test.

R-45 Screen 2 Trial 1

Figure C-9.0-1 shows a semilog plot of the drawdown data collected from trial 1 conducted at a discharge rate of 24.2 gpm. The early data showed exaggerated drawdown because the pumping rate was elevated temporarily as it refilled a void in the drop pipe that had been created by antecedent drainage through leaky coupling joints. The varying pumping rate associated with filling the drop pipe precluded analysis of the early drawdown data.

The data following refilling of the drop pipe were plotted on an expanded scale as shown in Figure C-9.0-2. The slope of the graph became continuously flatter throughout the trial test. This was caused by a combination of vertical expansion of the cone of depression and leakage from the screen 1 zone. It is also possible that the data included indirect effects of delayed yield of the overlying unconfined screen 1 interval.

As shown in the figure, the earliest analyzable data (from 1 to 4 min after pumping began) produced a transmissivity value of 19,700 gpd/ft. Dividing this value by the screen length of 20 ft yielded a hydraulic conductivity value of 985 gpd/ft², or 132 ft/d. Subsequent analyses, presented below, showed that the actual hydraulic conductivity was just a fraction of this value. This meant that the data measured immediately after the void in the drop pipe had refilled was already affected by vertical expansion of the cone of depression and could not be used to determine a valid hydraulic conductivity value.

During the last half of the trial test, the water level rose slightly. This may have been a response to a tiny discharge rate decline over time. It is possible also that the efficiency of the well may have increased slightly. The discharge rate applied during testing was greater than that used for developing the well, so it is possible that the larger entrance velocities achieved during testing may have dislodged a small amount of sediment and improved the efficiency by a trivial amount.

Figure C-9.0-3 shows the recovery data collected following shutdown of the trial 1 pumping test. The transmissivity computed from the early data on the graph was 3300 gpd/ft. Dividing this value by the screen length of 20 ft yielded a hydraulic conductivity estimate of 165 gpd/ft², or 22.1 ft/d.

Within seconds of pump shutoff, the recovery curve began flattening in response to partial penetration effects (vertical expansion of the cone of depression). The late-recovery data were plotted on an expanded-scale graph as shown in Figure C-9.0-4.

The slope of the recovery curve continued to flatten throughout the monitored period, becoming essentially flat at late time. The flat curve suggests large aquifer transmissivity as well as delayed yield contribution from the overlying sediments.

R-45 Screen 2 Trial 2

Figure C-9.0-5 shows a semilog plot of the drawdown data collected from trial 2 conducted at a discharge rate of 24.2 gpm. The data from the first few seconds of pumping showed exaggerated drawdown associated with minor antecedent drainage of a portion of the drop pipe through a leaky coupling joint. This precluded capturing the very early data for analysis.

The data following refilling of the void in the drop pipe were plotted on an expanded scale as shown in Figure C-9.0-6. The transmissivity computed from the graph was 5280 gpd/ft. Dividing this value by the screen length of 20 ft yielded a hydraulic conductivity estimate of 264 gpd/ft², or 35.3 ft/d. This was nearly double the conductivity value obtained from the trial 1 recovery.

It was likely that the cone of depression had already expanded beyond the thickness of screened sediment so the hydraulic conductivity value computed based on the screen length of 20 ft was considered an overestimate of the actual value. This was confirmed by subsequent analyses, described below. Thus, the snapshot of the early data associated with initial lateral expansion of the cone of depression was masked by the discharge rate fluctuations caused by changing head conditions applied to the pump as the void in the drop pipe refilled. By the time postrefill data were collected, the cone of depression had expanded vertically.

The slope of the data plot in Figure C-9.0-6 progressively decreased, eventually flattening completely at late time. This suggested a large transmissivity for the aquifer at the R-45 location. It also implied the likelihood that the screen 2 response was affected by delayed yield of the overlying unconfined sediments.

Figure C-9.0-7 shows the recovery data recorded following the trial 2 test on R-45 screen 2. The transmissivity computed from the early-recovery data was 3100 gpd/ft, making the hydraulic conductivity 155 gpd/ft², or 20.7 ft/d.

Within seconds of the start of recovery, the data trace began flattening in response to vertical growth of the cone of impression. Figure C-9.0-8 shows an expanded-scale plot of the late trial 2 recovery data.

As with previous graphs of late drawdown or recovery data, the slope of the data trace flattened continuously throughout the recovery period, becoming essentially horizontal at the end of the monitoring period. The continuous flattening resulted from partial penetration effects, including both vertical expansion of the cone of impression and leakage from the upper zone, and also including possible delayed yield effects. The data also indicated a large overall aquifer transmissivity at the R-45 location.

C-9.1 R-45 Screen 2 24-H Constant-Rate Pumping Test

Figure C-9.1-1 shows a semilog plot of the drawdown data recorded during the 24-h constant-rate pumping test conducted at a discharge rate of 23.9 gpm. The early data showed that antecedent drainage of the drop pipe had occurred during the background monitoring period.

The effective discharge rate during the time that the void in the drop pipe was being refilled was estimated by comparing the maximum drawdown observed during that time with the reduced drawdown that occurred once the pump operated against maximum head after the pipe was refilled. The measured discharge rate (23.9 gpm) was multiplied by that drawdown ratio yielding an estimated fill rate of 35 gpm. This rate was used to analyze the data collected during the refill event.

The transmissivity computed from the refill data was 2670 gpd/ft, yielding a hydraulic conductivity of 134 gpd/ft², or 17.8 ft/d. This value was in reasonable agreement with previous results, considering the limitations of the estimate of discharge rate on which the calculations were based.

The late-drawdown data were examined by replotting them on an expanded-scale graph as shown on Figure C-9.1-2. The data set was quite noisy, having been affected by random changes in discharge rate caused by inconsistent operation of the generator and submersible pump. One of the dips in the pumping water level, identified in the figure, was caused by temporarily reducing the discharge hose elevation. All other fluctuations were all associated with equipment operation. The erratic water levels precluded an analysis of the late-drawdown data.

Figure C-9.1-3 shows the recovery data measured following the 24-h constant-rate pumping test. The transmissivity calculated from the early data was 3040 gpd/ft, making the computed hydraulic conductivity 152 gpd/ft², or 20.3 ft/d. This result was in good agreement with previous results.

Within seconds of the start of recovery, the data trace began flattening in response to vertical growth of the cone of impression. Figure C-9.1-4 shows an expanded-scale plot of the late-recovery data.

As with previous graphs of late drawdown or recovery data, the slope of the data trace flattened continuously throughout the recovery period, becoming essentially horizontal at the end of the monitoring period. The continuous flattening resulted from partial penetration effects including both vertical expansion of the cone of impression and leakage from the upper zone, including possible delayed yield effects from the overlying unconfined aquifer. The data also indicated a large overall aquifer transmissivity at the R-45 location.

R-45 Screen 2 Specific Capacity Data

Specific capacity data were used along with well geometry to estimate a lower-bound conductivity value for the R-45 screen 2 zone for comparison to the pumping test values. In addition to specific capacity, other input values used in the calculations included the assumed an arbitrarily assigned aquifer thickness of 200 ft, storage coefficient values of 0.01 and 0.001 (for leaky-confined and confined conditions, respectively), and a borehole radius of 0.51 ft.

R-45 screen 2 produced 23.9 gpm with a drawdown of 7.14 ft after 24 h of pumping for a specific capacity of 3.35 gpm/ft. Applying the Brons and Marting method to these inputs yielded lower-bound hydraulic conductivity values for the screened interval of 155 gpd/ft², or 20.7 ft/d, for leaky-confined conditions and 159 gpd/ft², or 21.3 ft/d, for confined conditions.

These values were similar to the pumping test values and provided good corroboration of those analyses.

R-45 Screen 2 Summary

Table C-9.1-1 summarizes the hydraulic conductivity values obtained from the R-45 screen 2 pumping test analyses.

The average hydraulic conductivity computed from the recovery test data was 21.0 ft/d. The computed average did not include the drawdown analyses, because these data were affected by discharge rate fluctuations due to antecedent drainage of the drop pipe, as described above.

The specific capacity obtained from screen 2 suggested a lower-bound hydraulic conductivity of about 21 ft/d, matching the pumping test value average. This suggested an efficiency well completion and provided good corroboration of the pumping test values.

C-10.0 LEAKANCE/RESISTANCE OF SEDIMENTS BETWEEN SCREENS 1 AND 2

Data from the pumping tests were used to estimate the leakance of the sediments separating R-45 screen 1 from screen 2. Each of the 24-hour tests supported estimation of this parameter.

Pumping R-45 screen 1 at 24.3 gpm produced approximately 0.04 ft of drawdown in screen 2, while pumping screen 2 at 23.9 gpm resulted in about 0.06 ft of drawdown in screen 1. These responses to pumping were simulated analytically using Equations C-10 and C-11, assuming uniform aquifer properties, including a uniform vertical anisotropy ratio. For each pumping test, the vertical anisotropy was adjusted until the observed drawdown in the non-pumped zone matched the field observation. The assumption of uniform conditions was an oversimplification, but the analysis served useful in providing a rough idea of the vertical resistance to flow.

The following assumptions were used in the calculations:

- aquifer thickness = 300 ft
- hydraulic conductivity = 31 ft/d (the average from the pumping tests)
- storage coefficient ranged from 0.002 to 0.05
- pumping rate = 24.2 gpm/23.9 gpm
- static water level = 868 ft
- screen 1: 880 to 890 ft
- screen 2: 974.9 to 994.9 ft
- pumping time = 1440 min

Using the above inputs, Equation C-10 was solved for anisotropy ratio by adjusting the ratio until the drawdown at 1440 minutes was equal to the measured value. The computations were repeated for a few values of storage coefficient ranging from 0.002 to 0.05. Figure C-10.0-1 shows the computed relationship between storage coefficient and vertical anisotropy ratio for the pumping tests on screen 1 and screen 2. The geometric mean is shown on the graph also.

The figure showed that there was insufficient data to determine the vertical anisotropy ratio accurately. Its value varied substantially as a function of storage coefficient and therefore its estimate was only as accurate as the estimate of storage coefficient.

For example, according to the geometric mean graph in Figure C-10.0-1, for an assumed storage coefficient value of 0.01, the computed vertical anisotropy ratio was 0.012. Based on the assumed average hydraulic conductivity of 31 ft/d, this made the estimated vertical permeability $0.012 \times 31 = 0.37$ ft/d. The corresponding leakance of the 85 ft of sediments separating the two screens was $0.37/85 = 0.00435$ inverse days and the computed resistance was $1/0.00435 = 230$ d. These calculations showed moderate vertical permeability, indicating the absence of a real aquitard. The results suggested good vertical movement of groundwater in the vicinity of R-45 screens 1 and 2.

These results implied a fairly conductive separating layer between screen 1 and screen 2, similar to formation characteristics at R-43 and R-44, but different than what has been observed at other locations on the Plateau where the head separation between the uppermost screens in multiscreened wells is greater than observed here. As a comparison, similar analysis at R-35a and R-35b yielded hydraulic resistance on an order of magnitude greater than computed for R-45, while analysis of R-10 screens 1 and 2 data showed resistance more than 2 orders of magnitude greater. Note that part of the greater resistance at the other locations was attributable to the greater distance between the well screens.

R-45 screens 1 and 2 are 85 ft apart, whereas the separation distance at R-35a/b is about 167 ft and that at R-10 is about 144 ft. From screen center to screen center, the downward gradients in R-35a/b and R-10 are 0.031 ft/ft and 0.083 ft/ft, respectively, compared with 0.0011 in R-45. Although computations like this have not been made for R-33, it is likely that the hydraulic resistance between screens 1 and 2 at that location is similar to what was determined for R-10 based on the large head difference between the screens in R-33. Thus, compared with other locations on the plateau, the potential for vertical groundwater movement at R-45 (as well as R-43 and R-44) is relatively favorable.

C-11.0 SUMMARY

Constant-rate pumping tests were conducted on R-45 screens 1 and 2 in Mortandad Canyon. The tests were conducted to gain an understanding of the hydraulic characteristics of the zones in which the screens were installed as well as the intervening sediments between the screens. Additionally, several surrounding wells were monitored to check for hydraulic cross connection to R-45.

Numerous observations and conclusions were drawn for the tests as summarized below.

1. The static water level in R-45 screen 1 was only 0.11 ft higher than in screen 2, suggesting minimal vertical hydraulic resistance of the intervening sediments. Consistent with this idea, analysis of interference effects between screen 1 and screen 2 (about 0.04 and 0.06 ft when pumping screen 1 and screen 2, respectively, after 24 h of pumping 24 gpm) suggested moderate leakage.
2. All monitored wells and screen zones (R-45 screens 1 and 2, R-44 screens 1 and 2, R-11, R-13, and R-28) showed immediate water-level response to barometric pressure with a barometric efficiency of essentially 100%.
3. There was no correlation between water levels in any of the monitored wells and cycling of production wells PM-3, PM-5, and O-4. PM-4, on the other hand, which was started up on February 11 and ran continuously until March 4, induced a small but steady drawdown trend in all of the monitored wells and screen zones except R-11. After shutdown of PM-4, a recovery effect was observed in R-44 screen 2 and R-13.
4. Leaky threaded joints in the drop pipe used to hang the submersible test pump allowed drainage of a portion of the pipe between pumping events. Pumping against reduced head briefly until the void in the drop pipe was refilled resulted in chaotic discharge rate changes at the onset of pumping, corrupting much of the early drawdown data and rendering it unusable for determining aquifer properties. The early-recovery data, however, were usable. The leaky joints were likely attributable to a combination of worn threads, improperly manufactured threads, and the need to avoid over-tightening the threads to avoid galling.
5. The estimated hydraulic conductivity for the sediments adjacent to screen 1 was 41.4 ft/d.
6. The estimated hydraulic conductivity for the sediments adjacent to screen 2 was 21.0 ft/d.
7. In addition to screens 1 and 2 affecting one another when pumping was performed, several of the monitored screen zones showed slight pumping response. Table C-11.0-1 summarizes the pumping effects induced by testing R-45 screens 1 and 2.
8. Specific capacity analysis showed that screen 1 produced 24.3 gpm with 6.4 ft of drawdown, for a specific capacity of 3.81 gpm/ft. The lower-bound hydraulic conductivity computed from this information was 38.5 ft/d. This result agreed with and corroborated the results of the pumping test analyses.

9. Specific capacity analysis showed that screen 2 produced 23.9 gpm with 7.14 ft of drawdown, for a specific capacity of 3.35 gpm/ft. The lower-bound hydraulic conductivity computed from this information was about 21 ft/d. This result agreed with and corroborated the results of the pumping test analyses.
10. All of the pumping tests showed immediate flattening of the drawdown and/or recovery curves. This reflected the effects of a combination of delayed yield and partial penetration (vertical expansion of the cone of depression). The fact that the drawdown and recovery curves remained flat at late time suggested the possibility of a large aquifer transmissivity or lingering delayed yield effects.

C-12.0 REFERENCES

The following list includes all documents cited in this appendix. Parenthetical information following each reference provides the author(s), publication date, and ER ID. This information is also included in text citations. ER IDs are assigned by the Environmental Programs Directorate's Records Processing Facility (RPF) and are used to locate the document at the RPF and, where applicable, in the master reference set.

Copies of the master reference set are maintained at the NMED Hazardous Waste Bureau and the Directorate. The set was developed to ensure that the administrative authority has all material needed to review this document, and it is updated with every document submitted to the administrative authority. Documents previously submitted to the administrative authority are not included.

- Bradbury, K.R., and E.R. Rothschild, March-April 1985. "A Computerized Technique for Estimating the Hydraulic Conductivity of Aquifers from Specific Capacity Data," *Ground Water*, Vol. 23, No. 2, pp. 240-246. (Bradbury and Rothschild 1985, 098234)
- Brons, F., and V.E. Marting, 1961. "The Effect of Restricted Fluid Entry on Well Productivity," *Journal of Petroleum Technology*, Vol. 13, No. 2, pp. 172-174. (Brons and Marting 1961, 098235)
- Cooper, H.H., Jr., and C.E. Jacob, August 1946. "A Generalized Graphical Method for Evaluating Formation Constants and Summarizing Well-Field History," *American Geophysical Union Transactions*, Vol. 27, No. 4, pp. 526-534. (Cooper and Jacob 1946, 098236)
- Driscoll, F.G., 1986. Excerpted pages from *Groundwater and Wells*, 2nd Ed., Johnson Filtration Systems Inc., St. Paul, Minnesota. (Driscoll 1986, 104226)
- Hantush, M.S., July 1961. "Drawdown around a Partially Penetrating Well," *Journal of the Hydraulics Division, Proceedings of the American Society of Civil Engineers*, Vol. 87, No. HY 4, pp. 83-98. (Hantush 1961, 098237)
- Hantush, M.S., September 1961. "Aquifer Tests on Partially Penetrating Wells," *Journal of the Hydraulics Division, Proceedings of the American Society of Civil Engineers*, pp. 171-195. (Hantush 1961, 106003)
- Schafer, D.C., January-February 1978. "Casing Storage Can Affect Pumping Test Data," *The Johnson Drillers Journal*, pp. 1-6, Johnson Division, UOP, Inc., St. Paul, Minnesota. (Schafer 1978, 098240)

Theis, C.V., 1934-1935. "The Relation Between the Lowering of the Piezometric Surface and the Rate and Duration of Discharge of a Well Using Ground-Water Storage," *American Geophysical Union Transactions*, Vol. 15-16, pp. 519-524. (Theis 1934-1935, 098241)

Toll, N.J., and T.C. Rasmussen, January–February 2007. "Removal of Barometric Pressure Effects and Earth Tides from Observed Water Levels," *Ground Water*, Vol. 45, No. 1, pp. 101–105. (Toll and Rasmussen 2007, 104799)

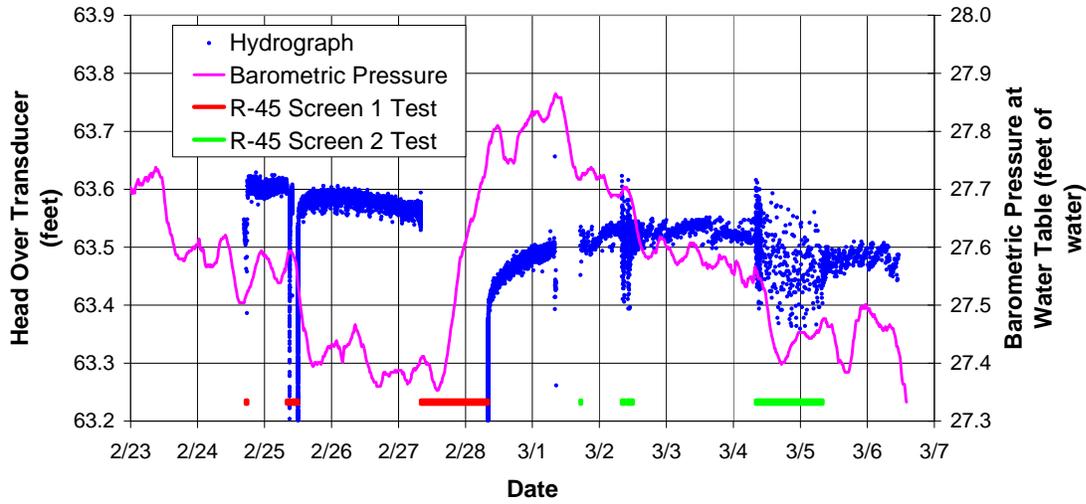


Figure C-7.0-1 R-45 Screen 1 apparent hydrograph during R-45 screen 1 and 2 tests

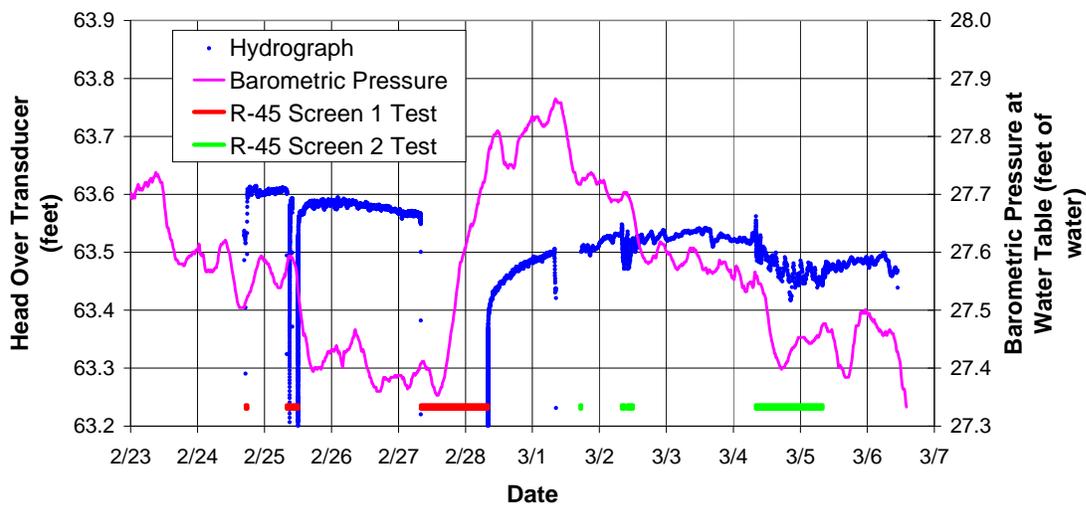


Figure C-7.0-2 R-45 screen 1 rolling average apparent hydrograph during R-45 screen 1 and 2 tests

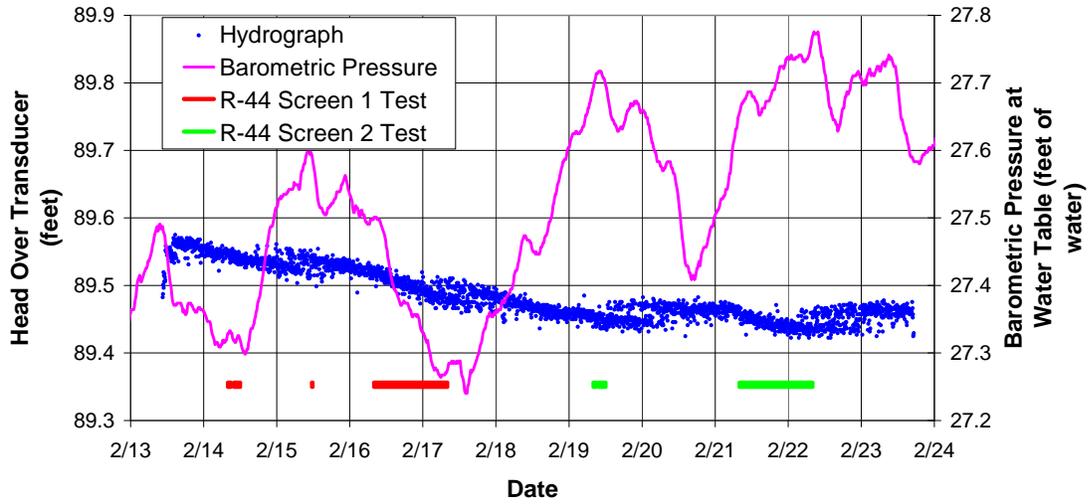


Figure C-7.0-3 R-45 screen 1 apparent hydrograph during R-44 screen 1 and 2 tests

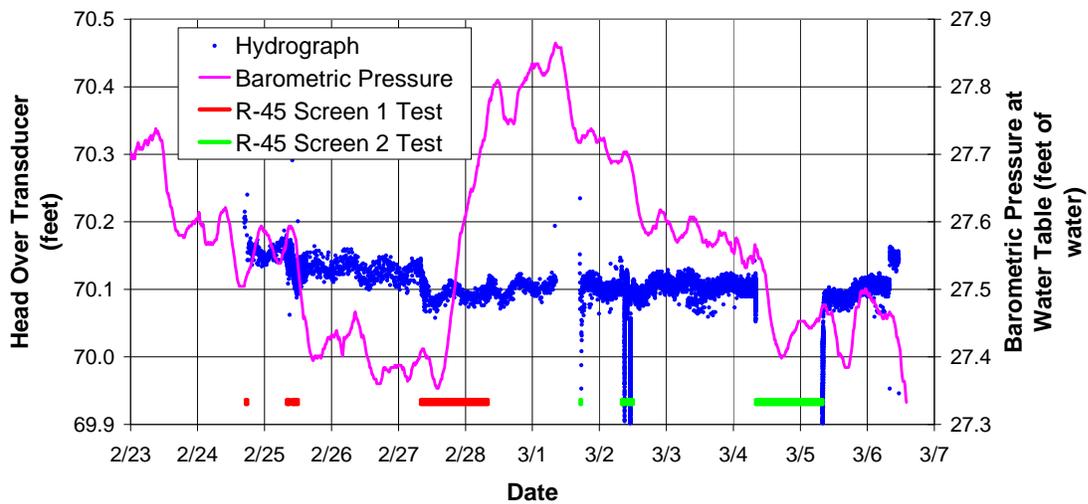


Figure C-7.0-4 R-45 Screen 2 apparent hydrograph during R-45 screen 1 and 2 tests

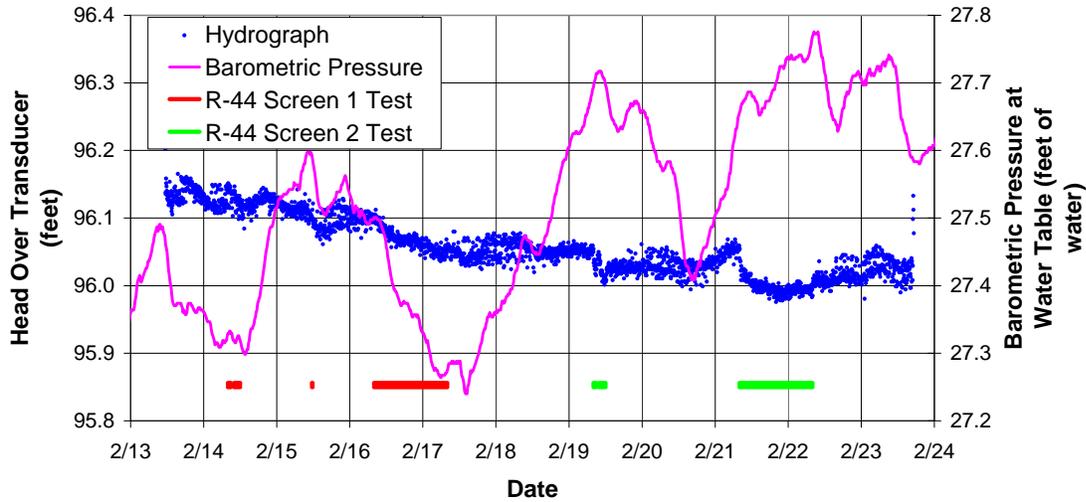


Figure C-7.0-5 R-45 screen 2 apparent hydrograph during R-44 screen 1 and 2 tests

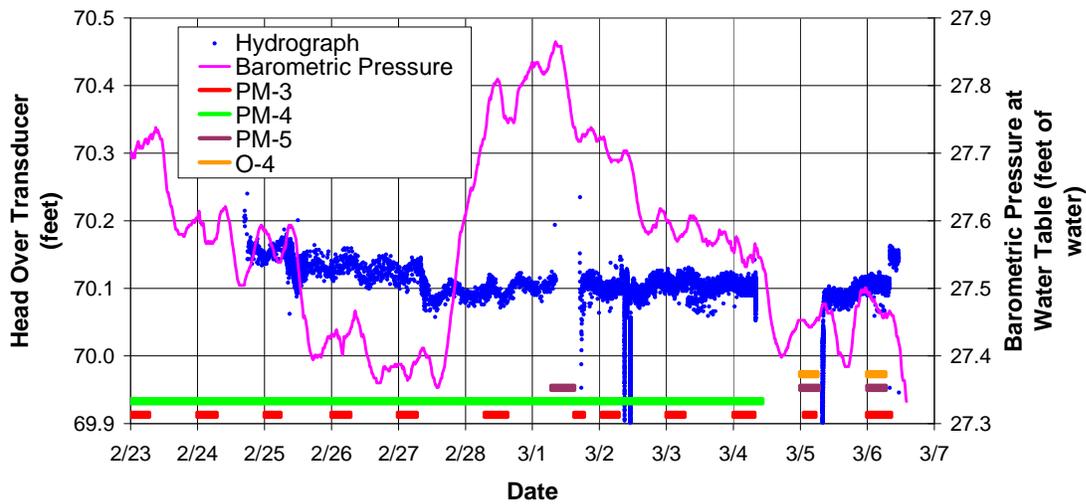


Figure C-7.0-6 R-45 screen 2 apparent hydrograph during R-45 screen 1 and 2 tests with County well operation

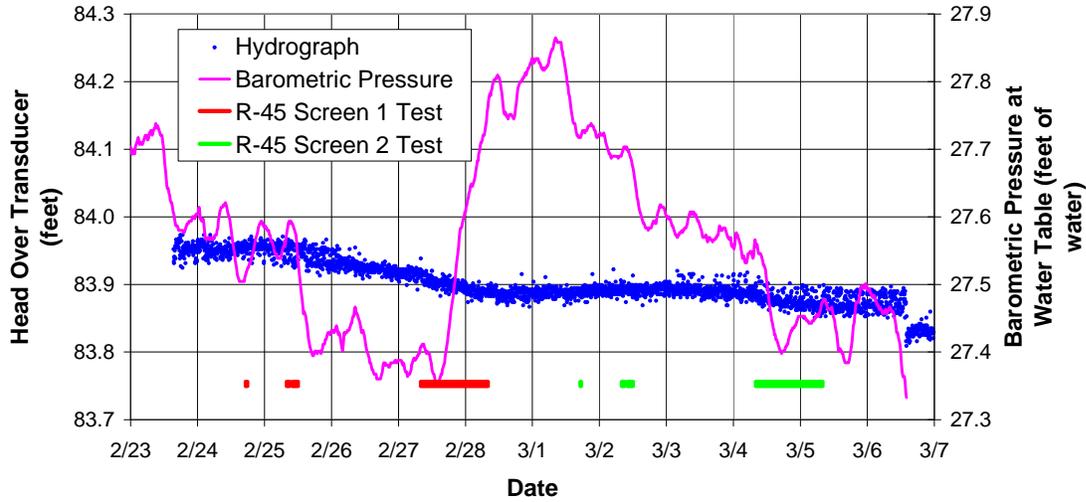


Figure C-7.0-7 R-44 screen 1 apparent hydrograph during R-45 screen 1 and 2 tests

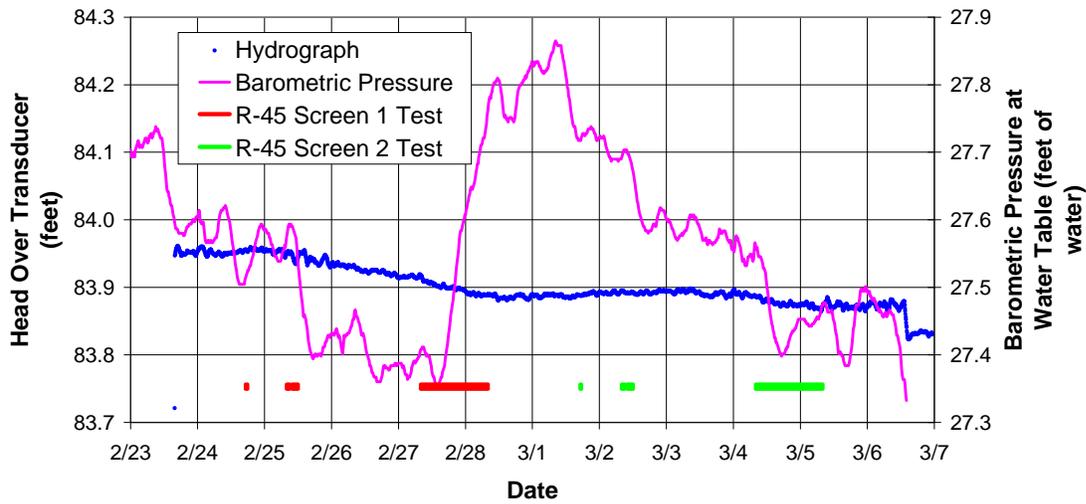


Figure C-7.0-8 R-44 screen 1 rolling average apparent hydrograph during R-45 screen 1 and 2 tests

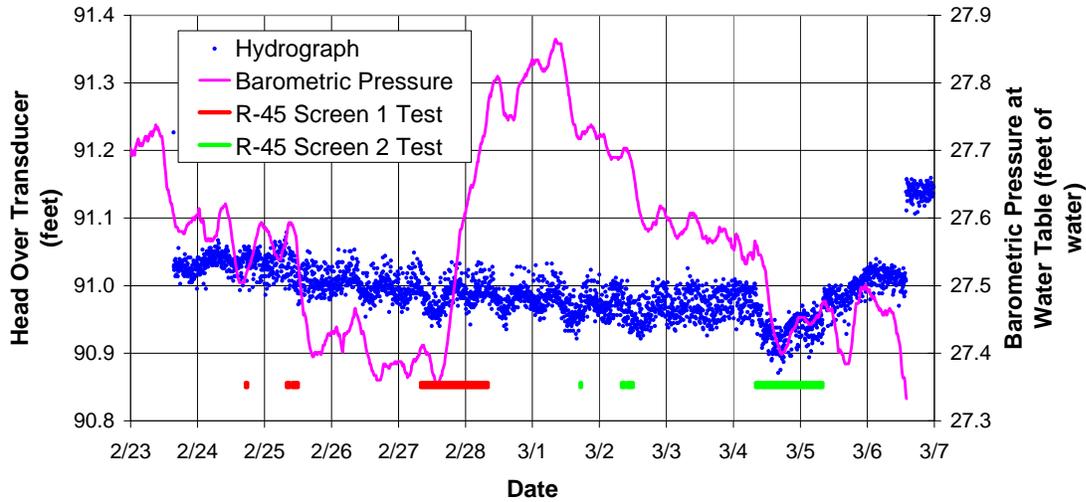


Figure C-7.0-9 R-44 screen 2 apparent hydrograph during R-45 screen 1 and 2 tests

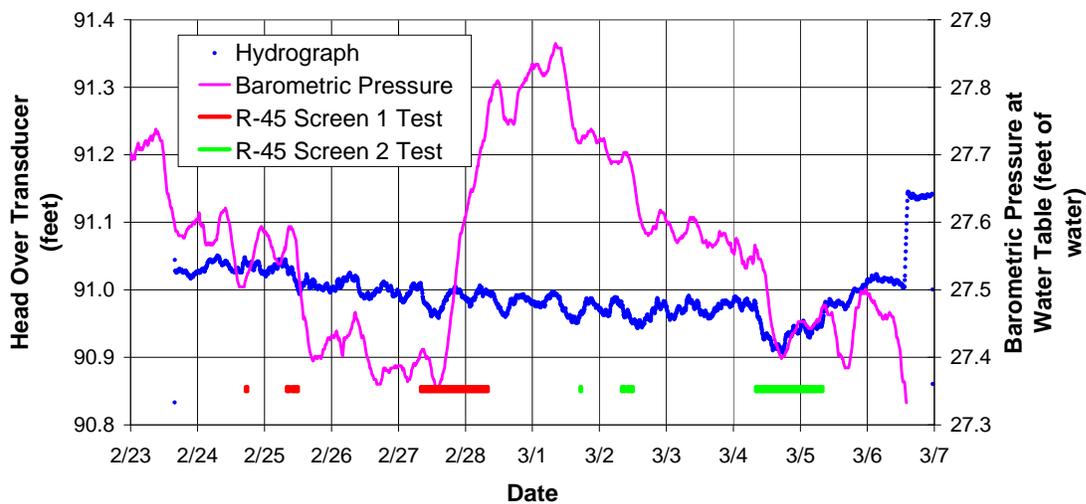


Figure C-7.0-10 R-44 screen 2 rolling average apparent hydrograph during R-45 screen 1 and 2 tests

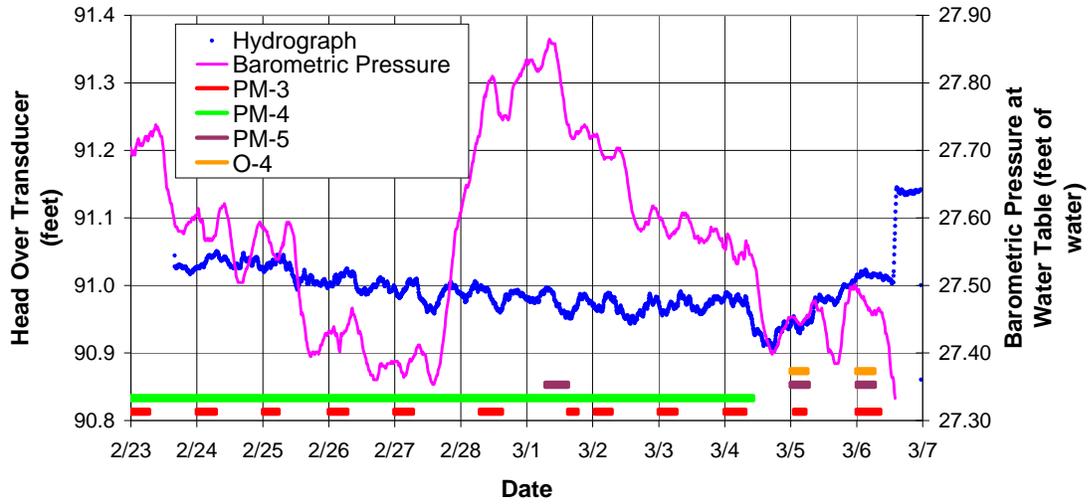


Figure C-7.0-11 R-44 screen 2 rolling average apparent hydrograph during R-45 screen 1 and 2 tests

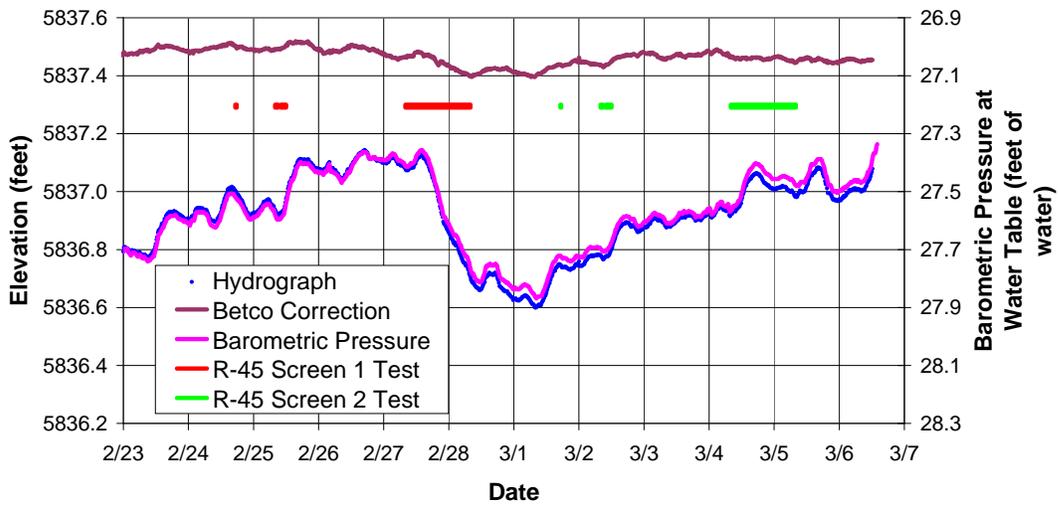


Figure C-7.0-12 R-11 apparent hydrograph during R-45 screen 1 and 2 tests

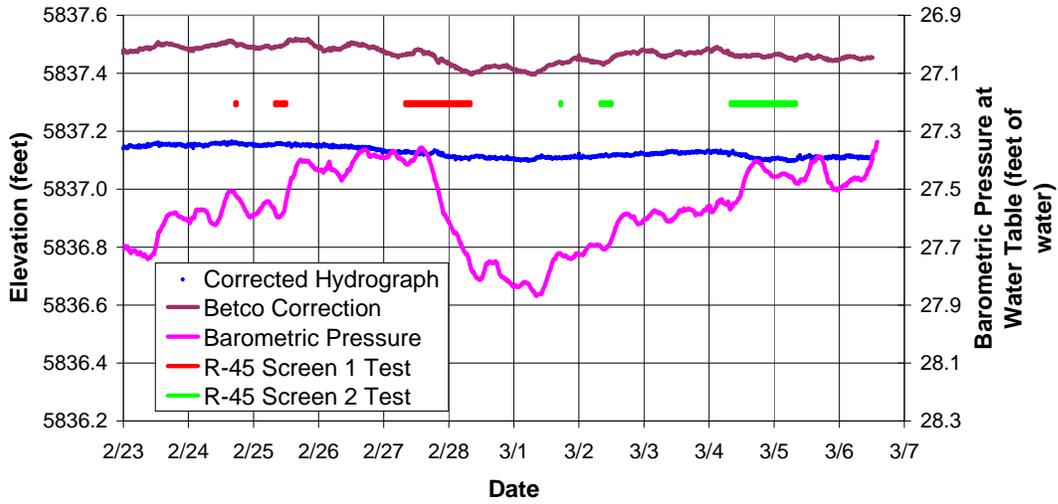


Figure C-7.0-13 R-11 corrected hydrograph during R-45 screen 1 and 2 tests

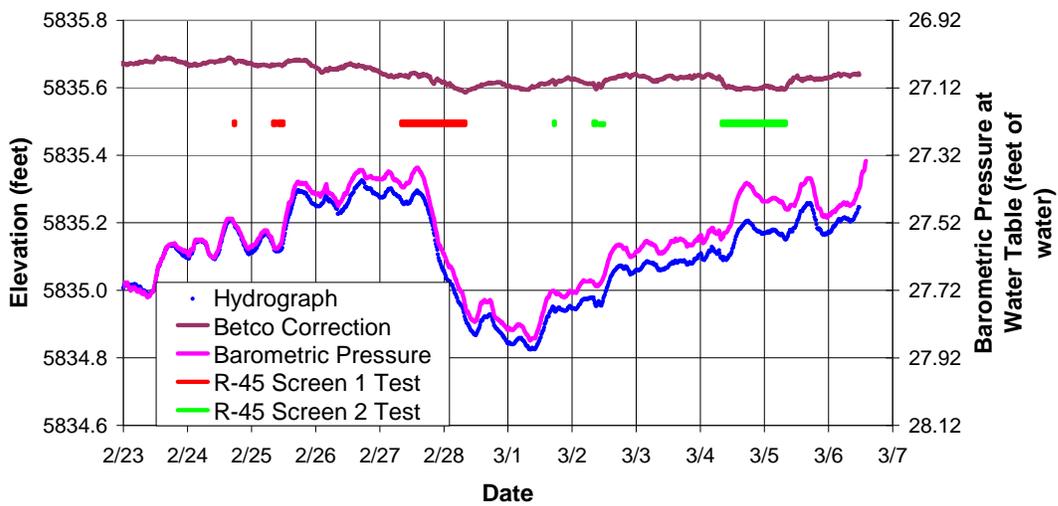


Figure C-7.0-14 R-13 apparent hydrograph during R-45 screen 1 and 2 tests

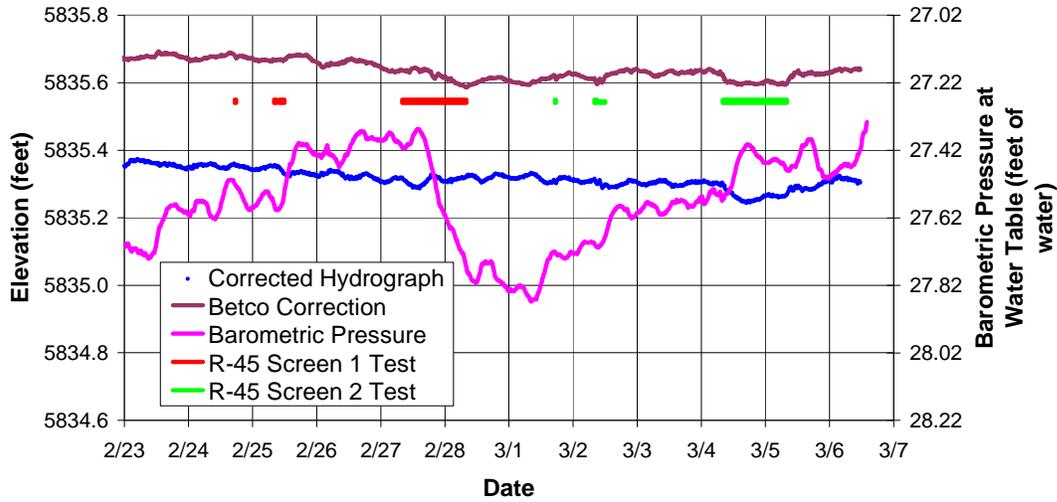


Figure C-7.0-15 R-13 corrected hydrograph during R-45 screen 1 and 2 tests

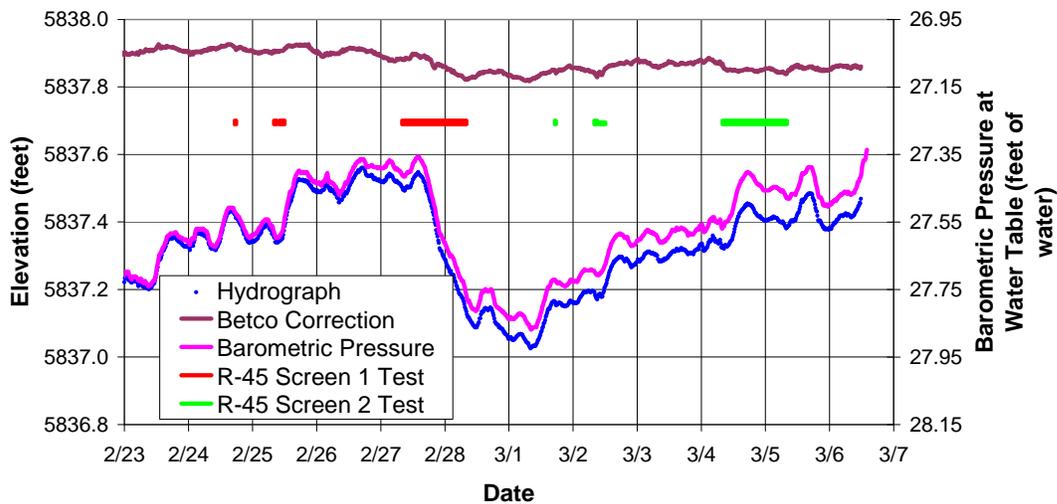


Figure C-7.0-16 R-28 apparent hydrograph during R-45 screen 1 and 2 tests

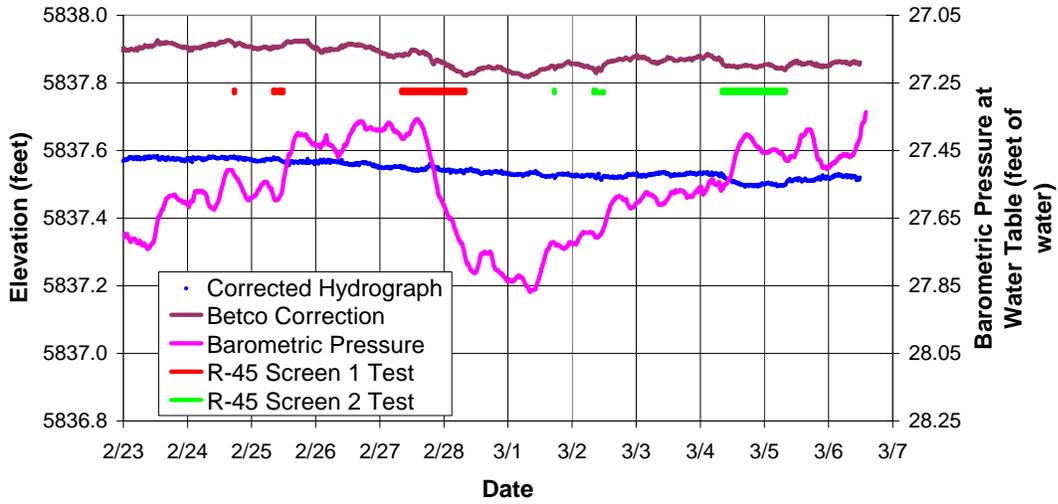


Figure C-7.0-17 R-28 corrected hydrograph during R-45 screen 1 and 2 tests

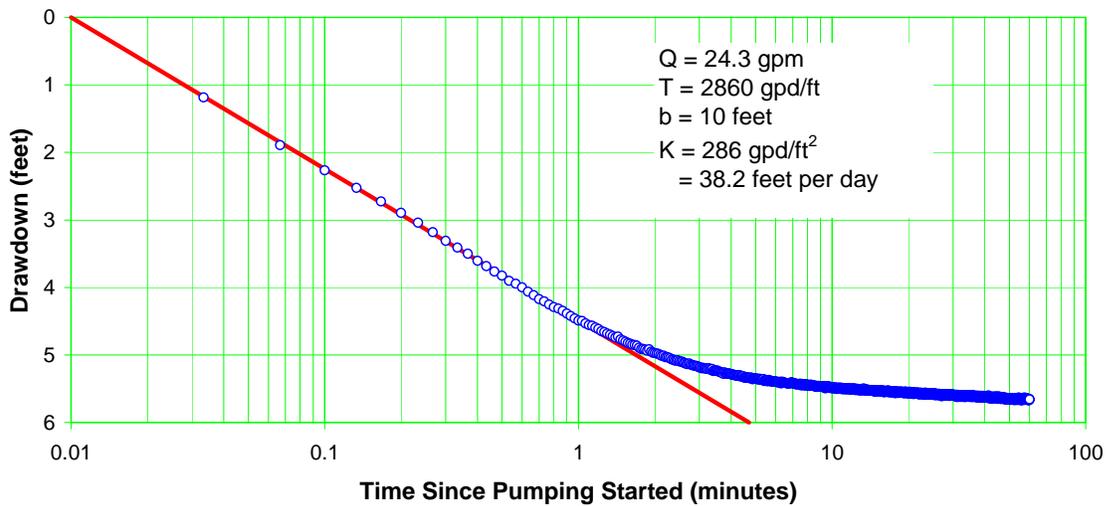


Figure C-8.0-1 Well R-45 screen 1 trial 1 drawdown

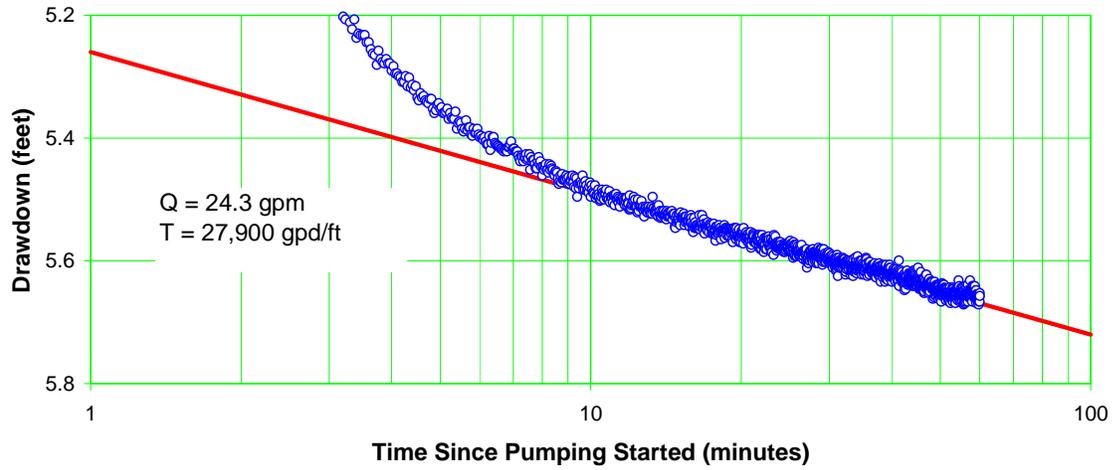


Figure C-8.0-2 Well R-45 screen 1 trial 1 drawdown—expanded scale

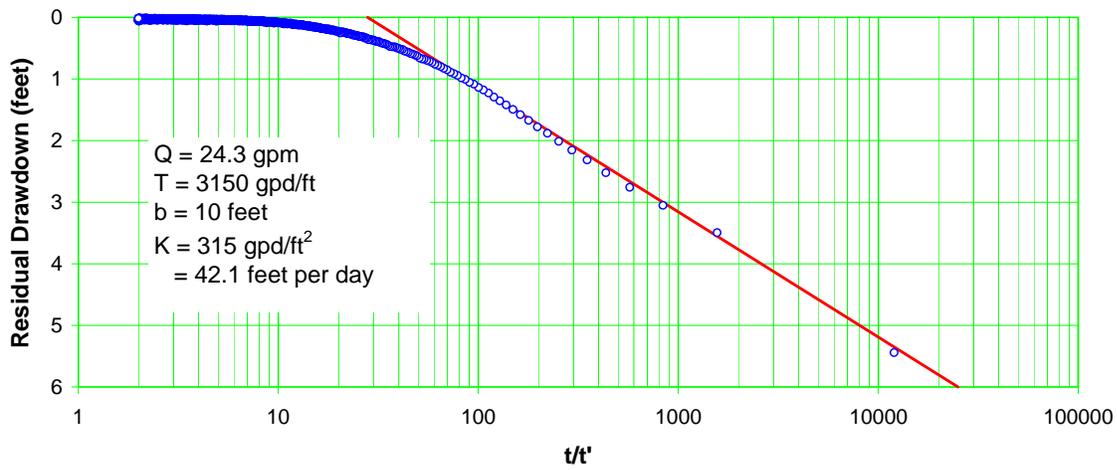


Figure C-8.0-3 Well R-45 screen 1 trial 1 recovery

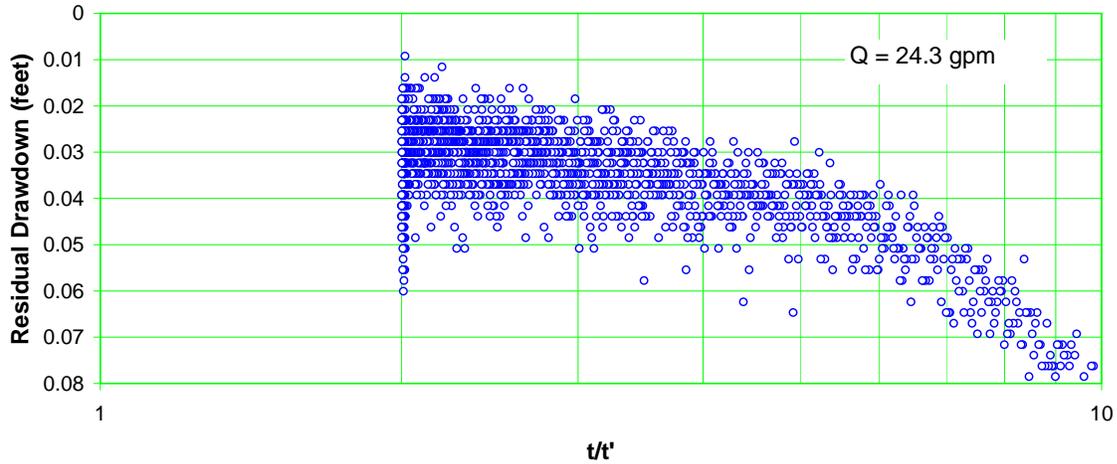


Figure C-8.0-4 Well R-45 screen 1 trial 1 recovery—expanded scale

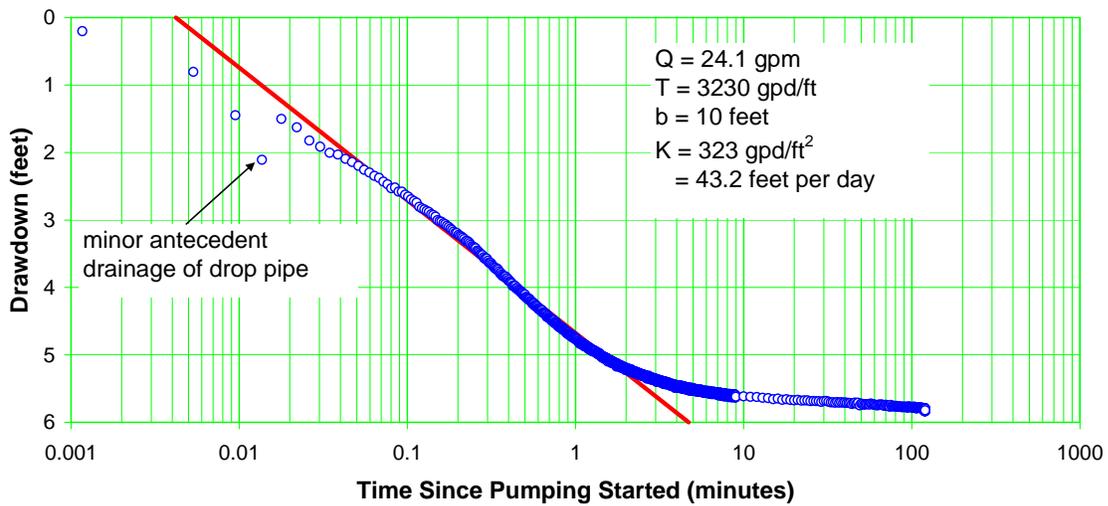


Figure C-8.0-5 Well R-45 Screen 1 Trial 2 Drawdown

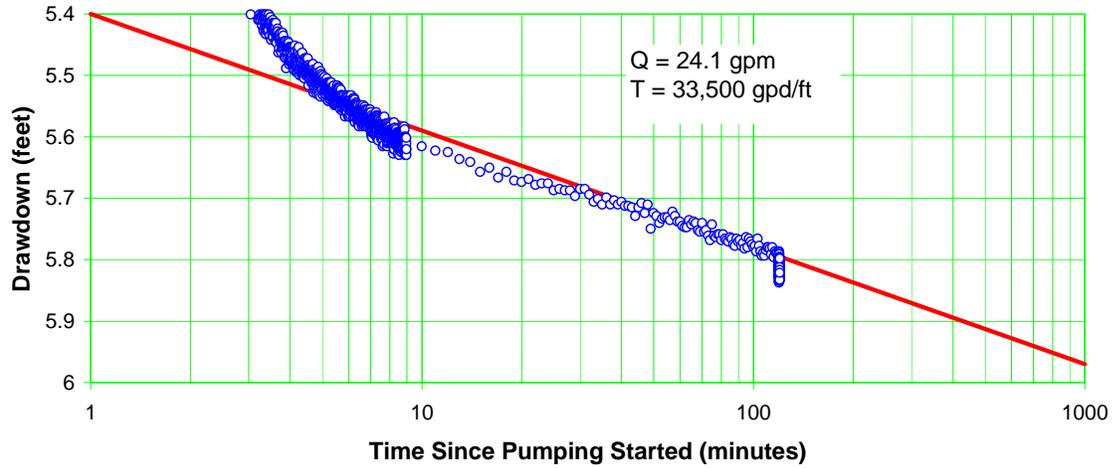


Figure C-8.0-6 Well R-45 screen 1 trial 2 drawdown—expanded scale

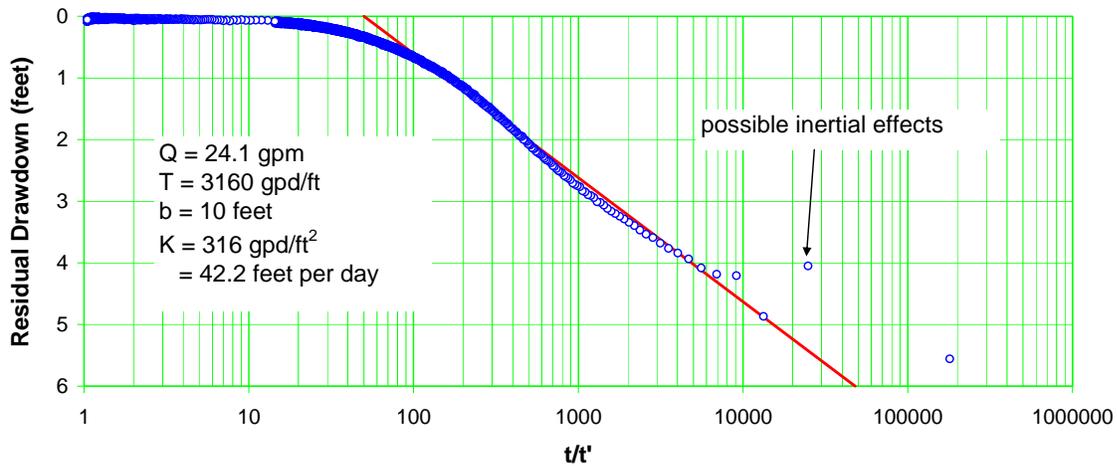


Figure C-8.0-7 Well R-45 screen 1 trial 2 recovery

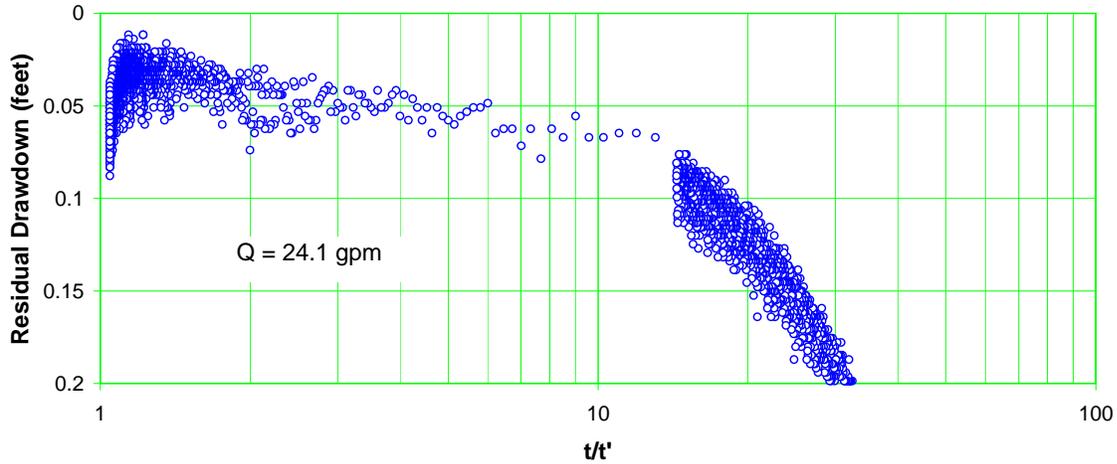


Figure C-8.0-8 Well R-45 screen 1 trial 2 recovery—expanded scale

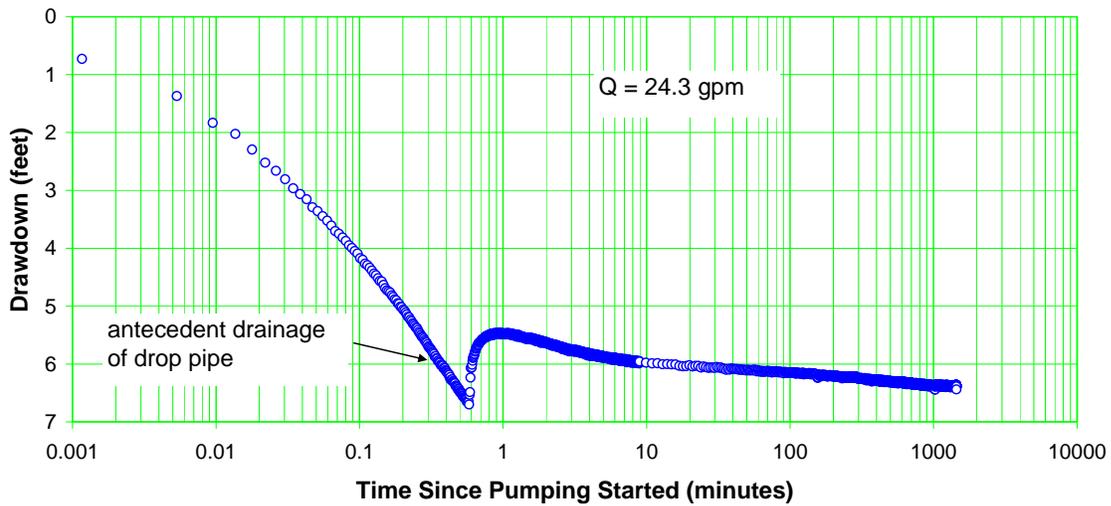


Figure C-8.1-1 Well R-45 screen 1 drawdown

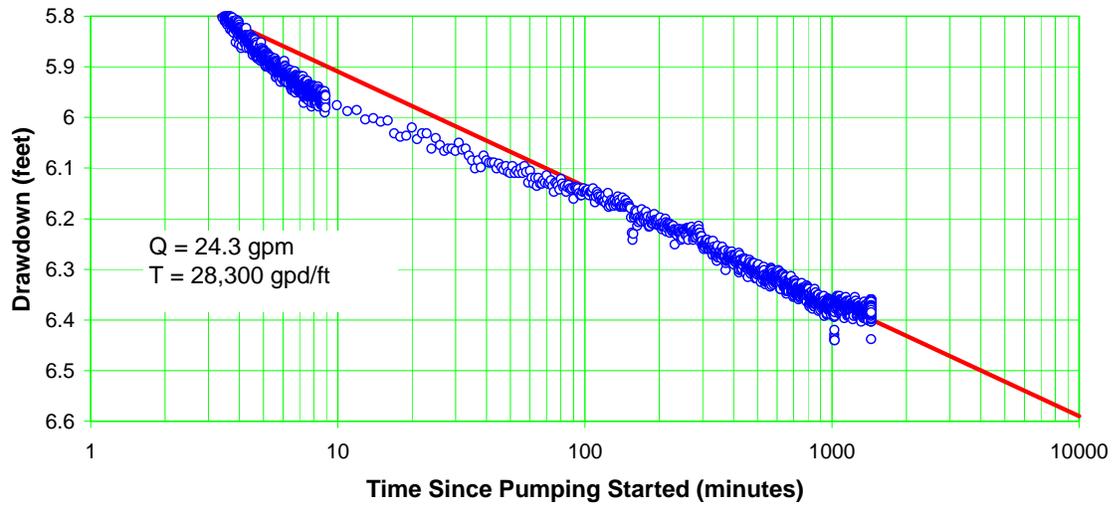


Figure C-8.1-2 Well R-45 screen 1 drawdown—expanded scale

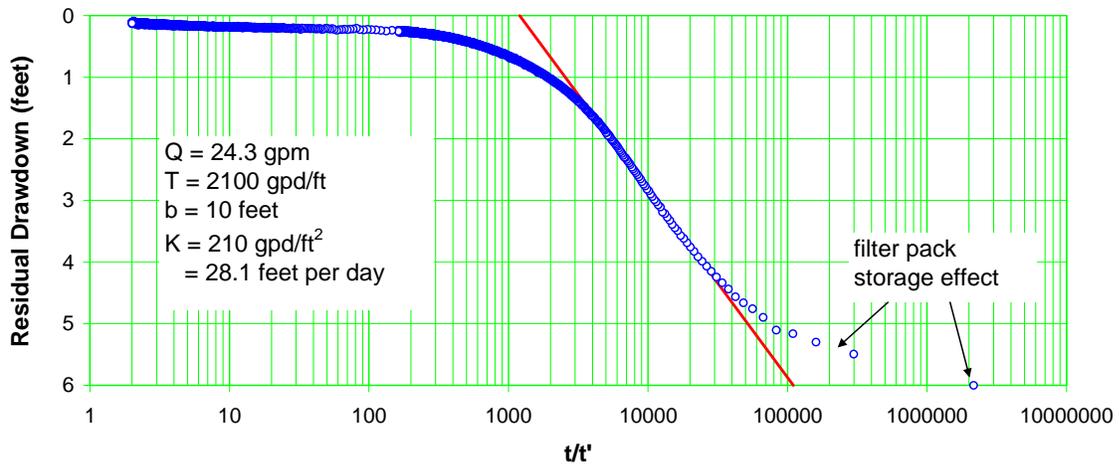


Figure C-8.1-3 Well R-45 screen 1 recovery

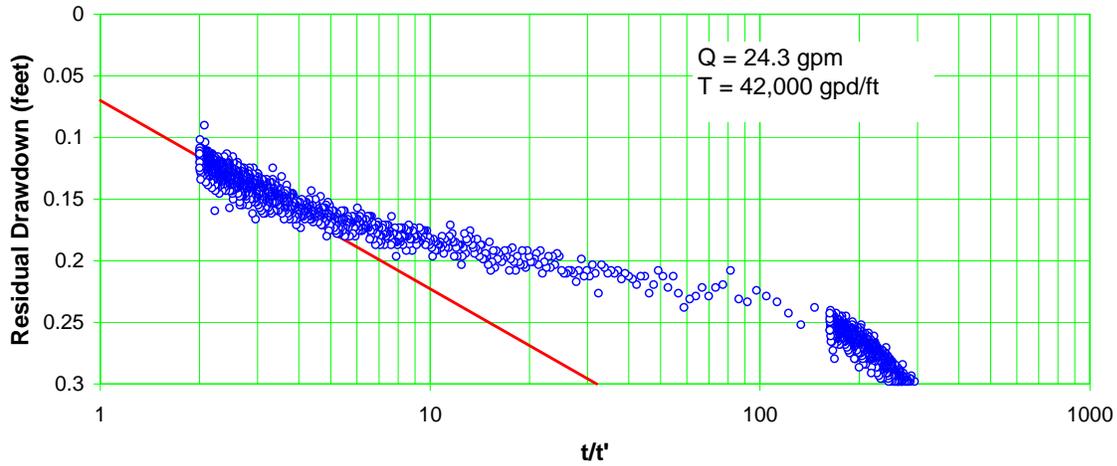


Figure C-8.1-4 Well R-45 screen 1 recovery—expanded scale

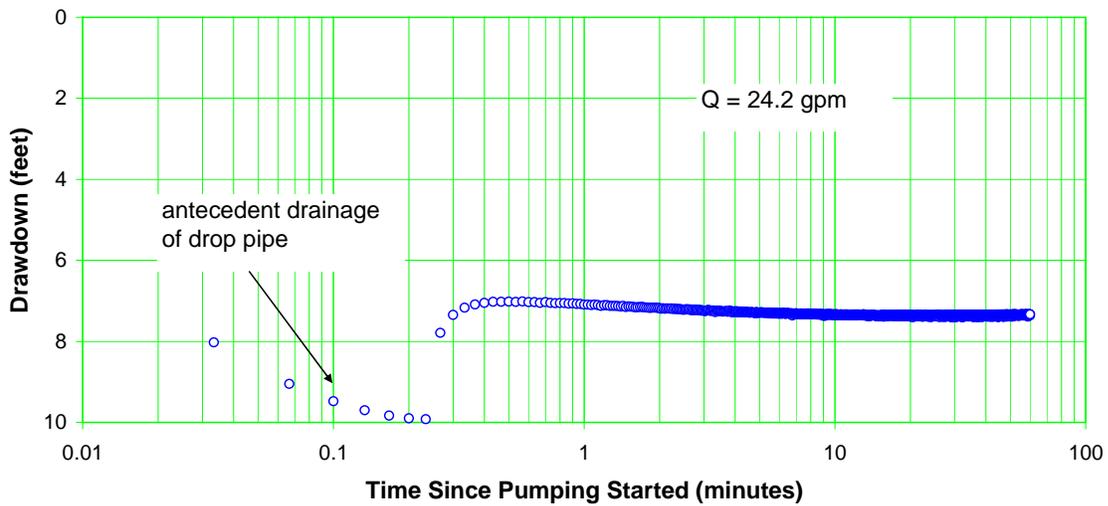


Figure C-9.0-1 Well R-45 screen 2 trial 1 drawdown

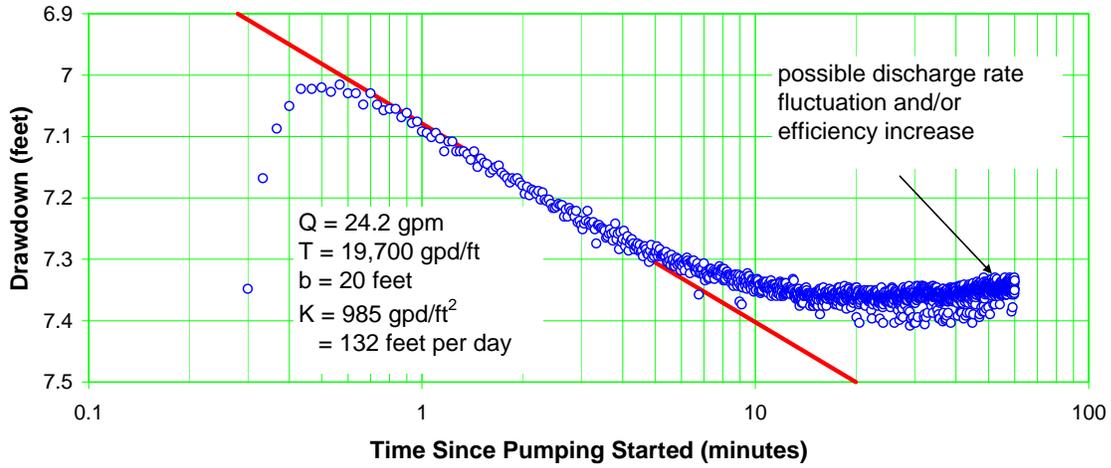


Figure C-9.0-2 Well R-45 Screen 2 trial 1 drawdown—expanded scale

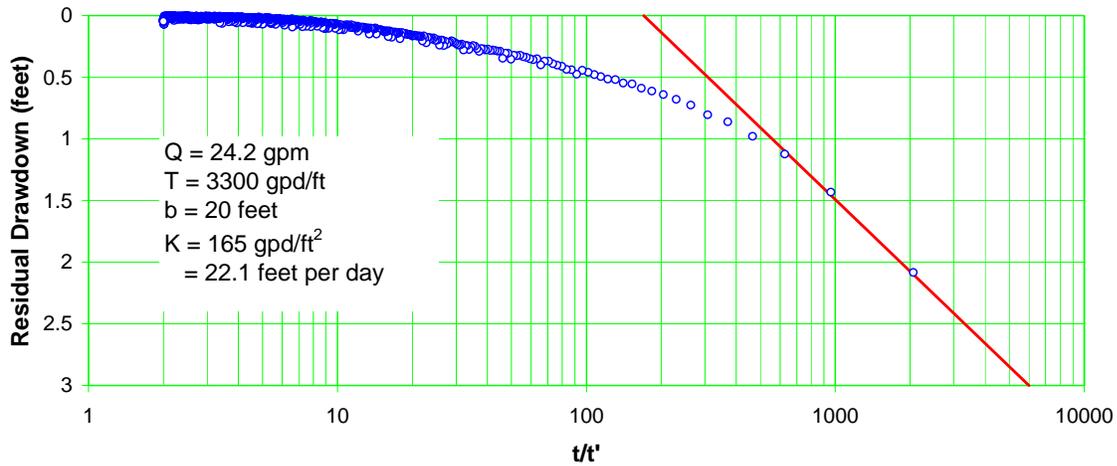


Figure C-9.0-3 Well R-45 screen 2 trial 1 recovery

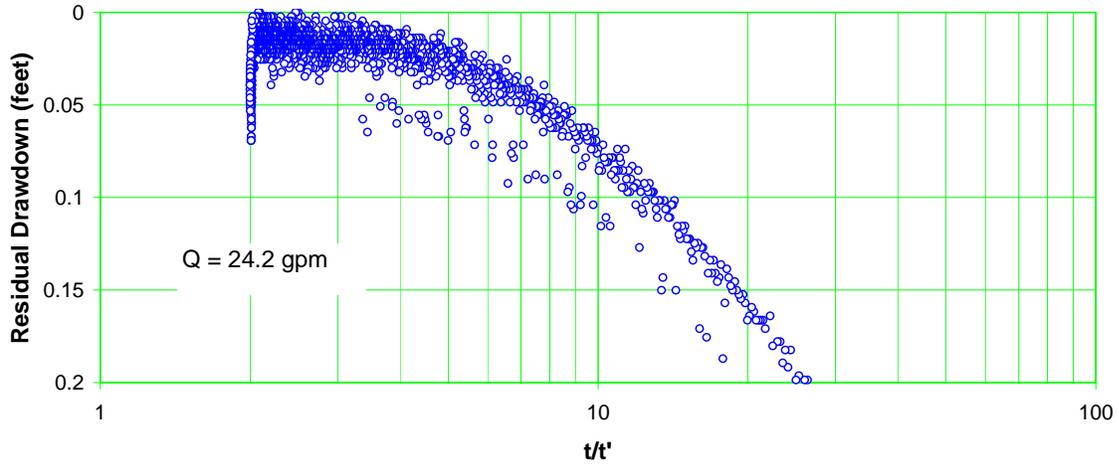


Figure C-9.0-4 Well R-45 screen 2 trial 1 recovery

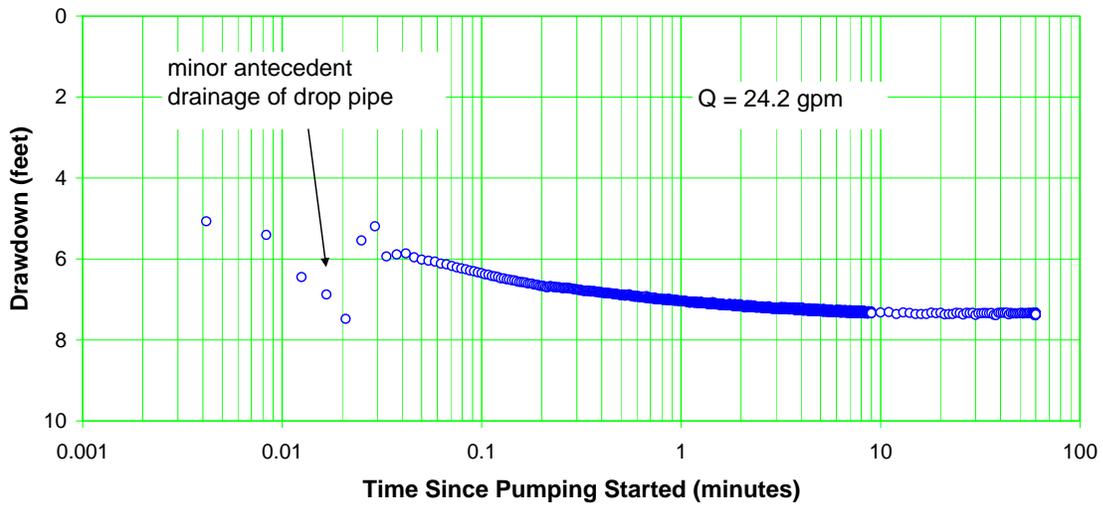


Figure C-9.0-5 Well R-45 screen 2 trial 2 drawdown

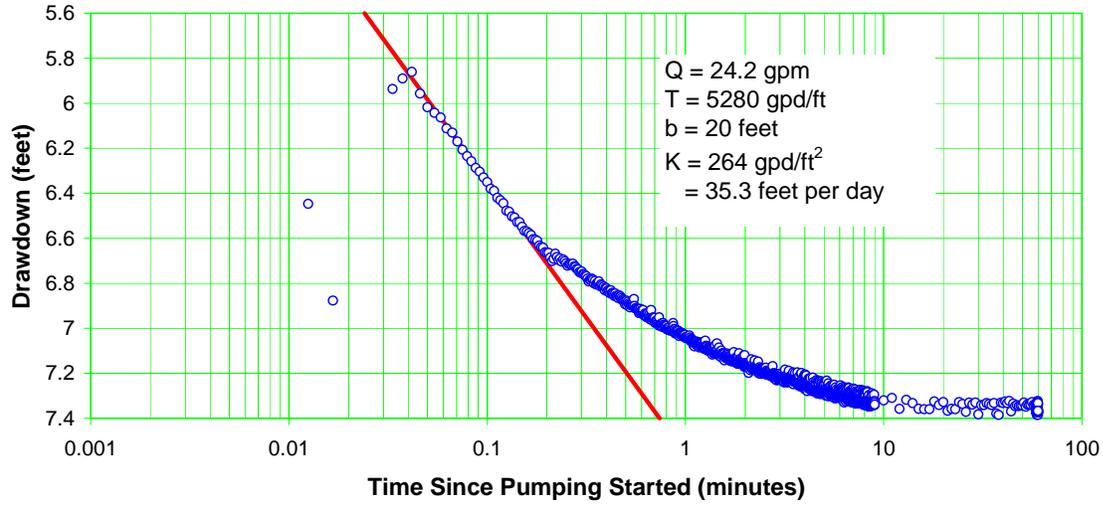


Figure C-9.0-6 Well R-45 screen 2 trial 2 drawdown

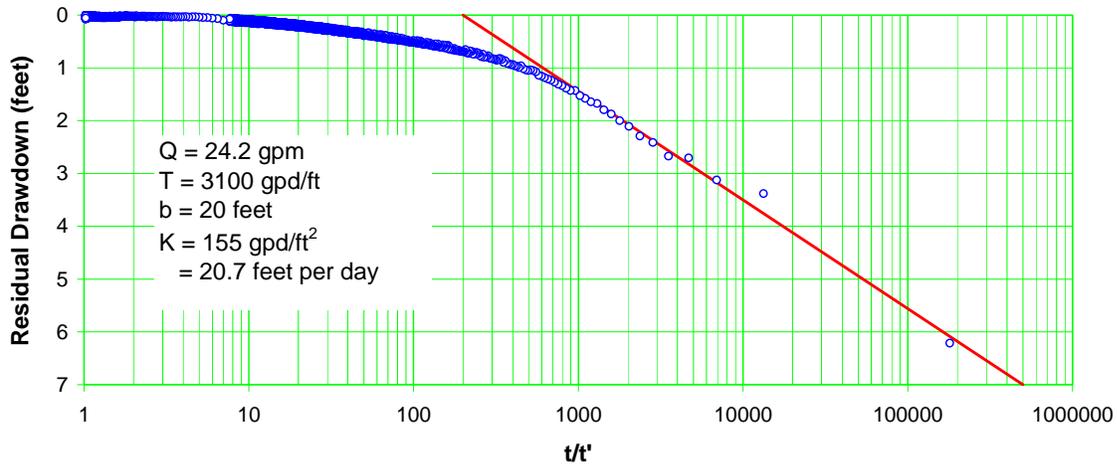


Figure C-9.0-7 Well R-45 screen 2 trial 2 recovery

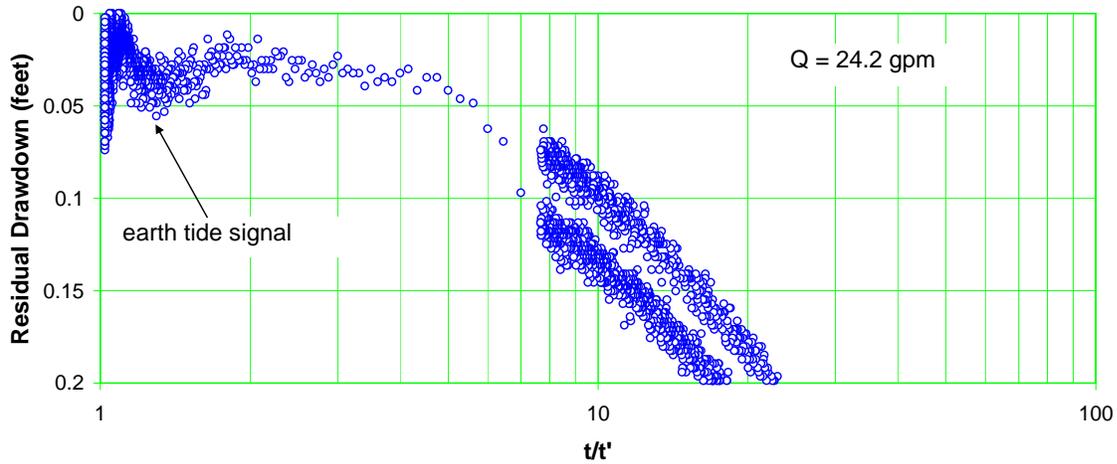


Figure C-9.0-8 Well R-45 screen 2 trial 2 recovery—expanded scale

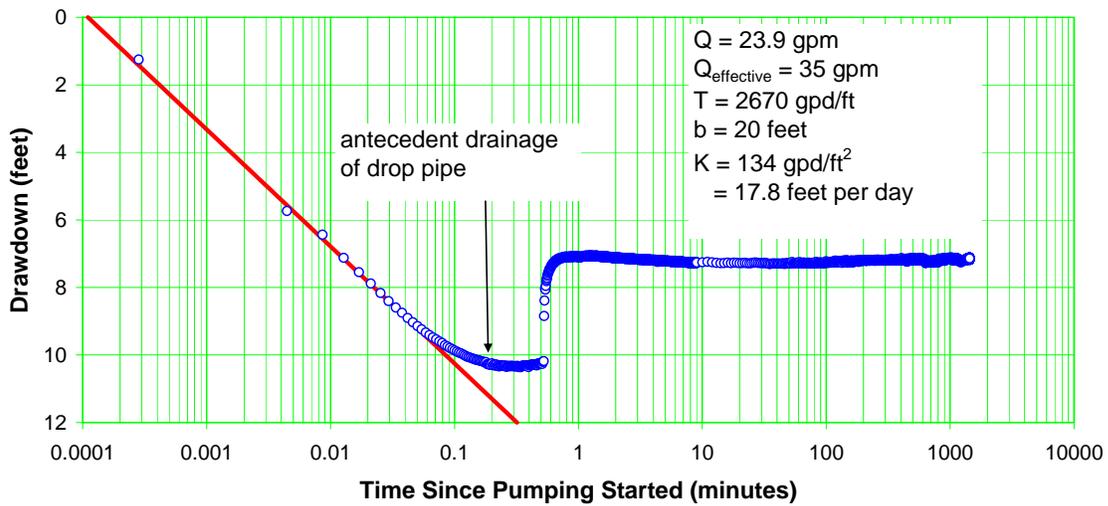


Figure C-9.1-1 Well R-45 Screen 2 trial 2 recovery—expanded scale

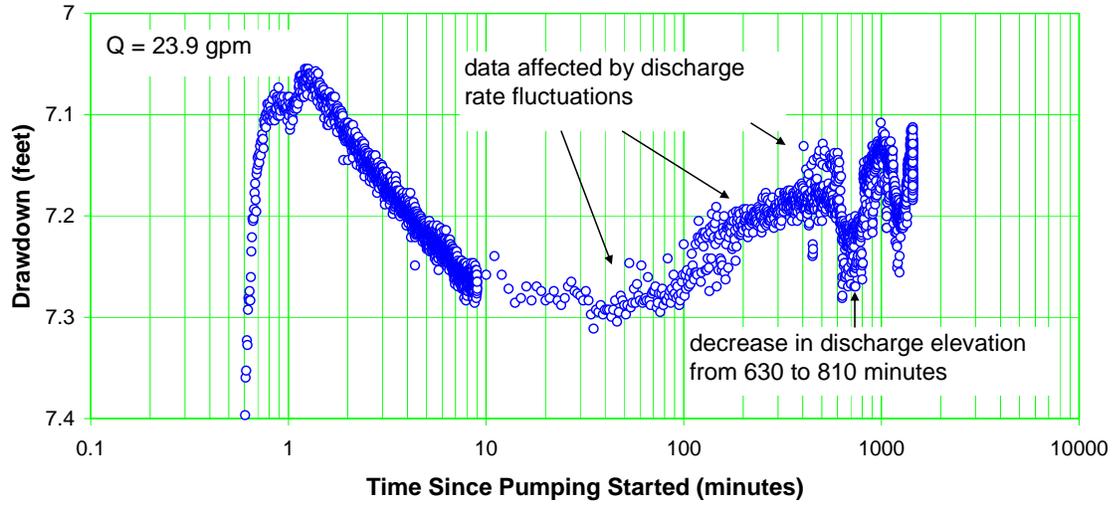


Figure C-9.1-2 Well R-45 screen 2 drawdown—expanded scale

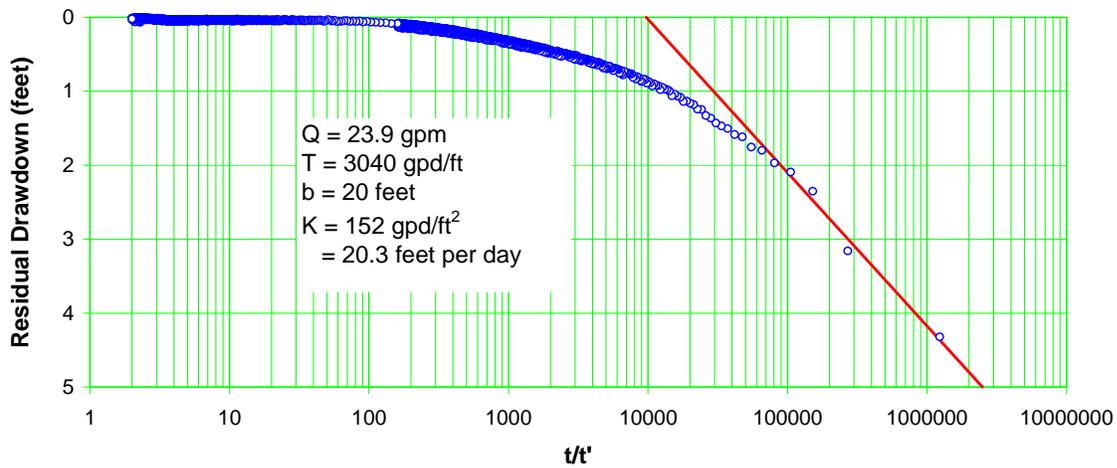


Figure C-9.1-3 Well R-45 screen recovery

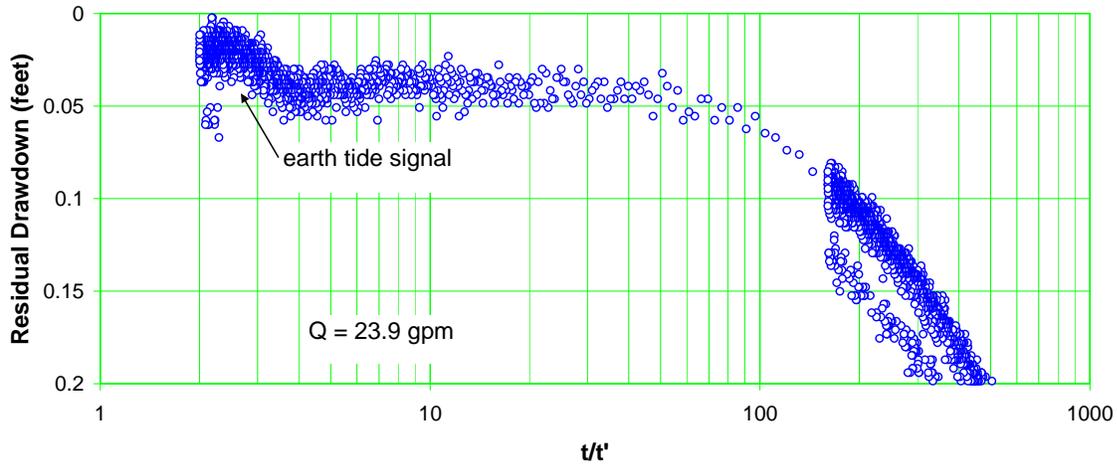


Figure C-9.1-4 Well R-45 screen 2 recovery—expanded scale

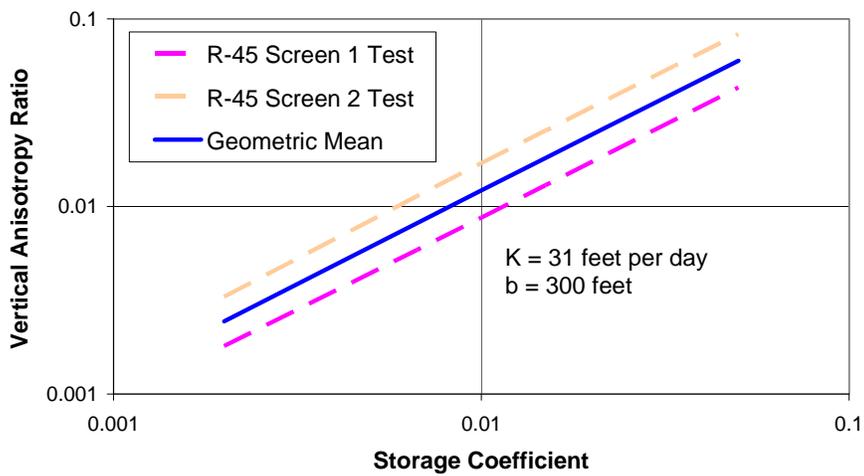


Figure C-10.0-1 Correlation of storage coefficient and anisotropy

Table C-8.1-1
R-45 Screen 1 Pumping Test Results

Analysis	Hydraulic Conductivity (ft/d)
Trial 1 Drawdown	38.2
Trial 1 Recovery	42.1
Trial 2 Drawdown	43.2
Trial 2 Recovery	42.2
24-H Drawdown	nd ^a
24-H Recovery	28.1 ^b
Average	41.4

^a nd = Not determined.

^b Not included in average.

Table C-9.1-1
R-45 Screen 2 Pumping Test Results

Analysis	Hydraulic Conductivity (ft/d)
Trial 1 Drawdown	132*
Trial 1 Recovery	22.1
Trial 2 Drawdown	35.3*
Trial 2 Recovery	20.7
24-H Drawdown	17.8*
24-H Recovery	20.3
Recovery Average	21.0

* Not included in average.

**Table C-11.0-1
R-45 Interference Effects**

Well Name (Screen ID)	Drawdown (ft)	
	Pump R-45 Screen 1	Pump R-45 Screen 2
R-45 (# 1)	n/a ^a	0.06
R-45 (# 2)	0.04	n/a
R-44 (# 1)	0.02 ^b	0.01 ^b
R-44 (# 2)	0.00	0.06
R-11	0.02 ^b	0.01 ^b
R-13	0.00	0.03
R-28	0.00	0.02

^a n/a = Not applicable.

^b Subtle effect.

Appendix D

Borehole Video Logging
(on DVD included with this document)

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

Appendix E

*Schlumberger Geophysical Logging Report
(on CD included with this document)*

Schlumberger Geophysical Report

TABLE OF CONTENTS

1.0	SUMMARY	1
2.0	INTRODUCTION	3
3.0	METHODOLOGY	4
3.1	Acquisition Procedure.....	5
3.2	Log QC and QA	5
3.3	Processing Procedure	6
	3.3.1 Environmental Corrections and Raw Measurement Reprocessing.....	6
	3.3.2 Depth-Matching and Reference	7
	3.3.3 Integrated Log Analysis.....	7
4.0	RESULTS	9
	4.1 Well Fluid Level	10
	4.2 Regional Aquifer.....	10
	4.3 Vadose Zone Perched Water.....	10
	4.4 Geology	11
4.5	Summary Logs.....	12
4.6	Integrated Log Montage	16
	4.6.1 Track 1—Depth	16
	4.6.2 Track 2—Basic Logs.....	16
	4.6.3 Track 3—Porosity.....	16
	4.6.4 Track 4—Density.....	17
	4.6.5 Track 5—HNGS Spectral Gamma	17
	4.6.6 Tracks 6 to 11—Geochemical Elemental Measurements.....	17
	4.6.7 Track 12—ELAN Mineralogy Model Results (Dry-Weight Fraction).....	17
	4.6.8 Track 13—ELAN Mineralogy and Pore Space Model Results (Wet-Volume Fraction)	18
	4.6.9 Track 14—Water Saturation.....	19
	4.6.11 Track 15—Hydraulic Conductivity	19
	4.6.12 Track 16—Predicted Flow (Production Potential) Profile.....	20
	4.6.13 Track 17—Summary Logs	20
	4.6.14 Track 18—Depth	20
5.0	REFERENCES	21

1.0 SUMMARY

Geophysical logging was performed by Schlumberger in characterization well R-45 in January 2009 before well completion. The logging measurements were acquired from 29 to 1,008 ft below ground surface (bgs), when the borehole contained 12-in. inside diameter (I.D.) freestanding steel casing from ground surface to 1084 ft, drilled with an approximately 12.75-in. diameter bit size.

The primary purpose of the geophysical logging was to characterize the geology and hydrogeology across the depth section where well screens were being considered, with emphasis on determining regional aquifer groundwater level, relative water saturation, depths of porous aquifer zones, and stratigraphy/lithology of geologic units. These objectives were accomplished by measuring, nearly continuously, along the length of the well (1) total water-filled porosity from which, in combination with lithologic composition estimated from the other logs, an indirect estimate of hydraulic conductivity (production capacity) is made; (2) bulk density (sensitive to total water plus air-filled porosity and grain density); (3) neutron-induced gamma ray spectroscopy, providing bulk concentrations of a number of important mineral-forming elements, as well as hydrogen; and (4) spectral natural gamma ray, including potassium, thorium, and uranium concentrations.

The following Schlumberger geophysical logging tools were used in the project (Table 1.1):

- Compensated Thermal/Epithermal Neutron Tool (CNT-G^{*})
- Triple Detector Litho-Density (TLD^{*}) tool
- Elemental Capture Spectroscopy (ECS^{*}) tool
- Hostile Natural Gamma Spectroscopy (HNGS^{*}) and gamma ray (GR)

Table 1.1
Geophysical Logging Tool, Technology, Corresponding Measured Properties

Tool	Technology	Properties Measured
Compensated Neutron Tool (CNT-G [*])	Epithermal and thermal neutron porosity	Water/moisture content, lithologic variations
Triple Detector Litho-Density (TLD [*])	Gamma-gamma bulk density	Bulk density, total porosity, lithology
Elemental Capture Spectroscopy (ECS [*])	Neutron induced gamma ray spectroscopy	Formation matrix geochemistry, lithology and mineralogy, formation hydrogen content
Hostile Natural Gamma Spectroscopy (HNGS [*]) and gamma ray (GR)	Gross and spectral natural gamma ray, including potassium, thorium, and uranium concentrations	Formation matrix geochemistry, lithology and mineralogy

Once the Terranear PMC well drilling project team provided Schlumberger final notification that R-45 was ready for geophysical well logging, the Schlumberger district in Farmington, New Mexico, mobilized a wireline logging truck, the appropriate wireline logging tools and associated equipment, and crew to the job site. Table 1.2 summarizes the geophysical logging runs performed in R-45.

^{*} Mark of Schlumberger.

Table 1.2
Geophysical Logging Services, Their Combined Tool Runs
and Intervals Logged, as Performed by Schlumberger in Well R-45

Date of Logging	Run #	Tool 1 (bottom)	Tool 2 (top)	Tool 3	Depth Interval (ft bgs)
9-Dec-2008	1	TLD	GR		29-1008
	2	HNGS			39-1074
	3	ECS	GR		29-1008
	4	CNT-G	GR		43-1008

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 (particularly casing) 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 provide consistent hydrogeologic and geologic results; 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, relative hydraulic conductivity, lithology).

The geophysical log measurements from well R-45 provide, overall, good quality results that are consistent with each other across the logged interval. However, the existence, extent, and effect on the geophysical logs of a water or air-filled annulus between the casing and the borehole wall (voids behind the casing) is difficult to determine and thus there is uncertainty about how well some of the log measurements represent true geologic formation conditions (unaffected by drilling). The distance between the logging tool sensor and formation is unknown and thus difficult to account or correct for. The measurements most affected by voids behind the casing were ones that have a shallow depth of investigation and that require close contact to the uncased borehole wall—the bulk density and the neutron porosity measurements (particularly the former). One indicator that the bulk density is being adversely affected by voids behind the casing is when the computed density porosity is unrealistically high. Where the total porosity estimated from the processed logs reaches above 55%, the bulk density measurement is likely being affected by voids. There are relatively few intervals in R-45 where the density porosity surpasses 55%.

Important results from the processed geophysical logs in R-45 include the following.

1. The well standing water level in R-45 was 880 ft bgs at the time of logging, and did not vary much between the different logging runs.
2. The processed logs indicate that the intersected geologic section is fully saturated with water from the bottom of the borehole (1008 ft bgs) to 880 ft bgs (well water level at time of logging) and likely as high as 866 ft bgs, which lies within alluvium/fanglomerate. Below 866 ft, the log-estimated water content and total porosity are high (greater than 20% of total rock/sediment volume 866–910 ft and mostly greater than 40% below that). Above 866 ft, the water content is much lower, mostly below 10%. Total porosity in the interval directly above 866 ft mostly ranges from 25% to 35%, resulting in an estimated water saturation that stays below 50% of total pore volume. Based on these results, the depth of the regional aquifer water level (depth at which there is full water saturation) is most likely in the vicinity of 866 ft, which is above the well water level at the time of logging.

3. Above 866 ft bgs, which the processed logs definitely show to be within the vadose zone (above the top of the regional aquifer), the estimated water content varies from less than 5% to 17% of total rock volume, mostly remaining at or below 10%. Estimated water saturation is mostly below 50% of total pore volume across the entire vadose zone. The highest vadose zone water saturation is in the following zones:
 - 756–770 ft, where water content averages about 15% and water saturation reaches 75%—located in a thick alluvium/fanglomerate sequence in a zone with lower estimated total porosity than the surrounding rock
 - 720–740 ft, where water content reaches 20 to 27% and water saturation is about 60%—located in the same alluvium/fanglomerate sequence, albeit total porosity is actually quite high in this zone
 - 455–480 and 635–650 ft, where water saturation peaks at 100% despite very low water content (5%)—located in a thick basalt lava sequence in zones where the total porosity is very low, likely corresponding to very competent, dense rock
 - 235–246 ft, where there is a slight, but notable increase in water content (15%) and saturation (30%)—located in the Guaje Pumice Bed directly above the same basalt lava sequence
4. The location of productive zones within the saturated section is difficult to determine because of the adverse cased well conditions. Higher porosity is not necessarily indicative of higher production capacity since fine-grained sediments often have higher porosity and lower productivity than coarser-grained sediments. The highest porosities are likely associated with washouts behind the casing. The predicted relative flow capacity profile generated from the integrated log analysis estimated permeability results suggest that the most productive intervals are 915–920 ft, 928–938 ft, 940–942 ft, 946–948 ft, 950–952 ft, 969–971 ft, 974–978 ft, 980–984 ft, 987–990 ft, and 995–997 ft.
5. The geophysical log results clearly delineate that the saturated/water-filled section of the borehole consists of alluvium/fanglomerate that extends well into the unsaturated section up to 686 ft bgs. Above 686 ft bgs, the processed logs strongly indicate a change in the matrix geochemical makeup and lithology to a thick basaltic lava sequence, which extends up to 246 ft (it is possible the sequence includes reworked/alterd basalt/breccia). The geophysical log response in the zone 233–246 ft is characteristic of the Guaje Pumice Bed, with very high total porosity and a large increase in thorium and uranium concentrations. The log results corroborate volcanic tuff overlying the pumice bed and extending to the top of the log interval (29 ft bgs), with zonal variations in porosity and geochemical signature, although it is possible the top section is alluvium composed of reworked tufflike material.

2.0 INTRODUCTION

Geophysical logging services were performed in characterization well R-45 by Schlumberger in January 2009 before initial well completion. The purpose of these services was to acquire in situ measurements to help characterize the near-borehole 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 used by scientists, engineers, and project managers in the Los Alamos Characterization and Monitoring Well Project to help design the well completion, better understand subsurface site conditions, and assist in overall decision-making.

The primary geophysical logging tools used by Schlumberger in well R-45 were the

- CNT-G, which measures, through casing and in water or air-filled hole, volumetric water content of the formation to evaluate moist/porous zones using both epithermal and thermal neutron measurements;
- TLD tool, which measures formation bulk density through casing to estimate total porosity;
- HNGS tool, which measures gross natural gamma and spectral natural gamma ray activity, including potassium, thorium, and uranium concentrations, to evaluate geology/lithology, particularly the amount of thorium and potassium-bearing minerals; and
- ECS tool, which measures neutron-induced spectral gamma ray activity; this determines elemental weight fraction concentrations of a number of key rock-forming elements used to characterize geochemistry, mineralogy, and lithology of the formation, as well as hydrogen content (closely related to water content).

In addition, calibrated gross GR was recorded with every service for the purpose of correlating depths between the different logging runs. Table 2.1 summarizes the geophysical logging runs performed in R-45.

**Table 2.1
Geophysical Logging Services, Their Combined Tool Runs
and Intervals Logged, as Performed by Schlumberger in Borehole R-45**

Date of Logging	Borehole Status	Run #	Tool 1 (bottom)	Tool 2 (top)	Tool 3	Depth Interval (ft bgs)
9-Dec-2009	Steel free-standing casing from surface to bottom. Single string of 12 in.-I.D. casing from surface to the bottom of the borehole at 1018 ft, with bit size of ~12.75 in.	1	TLD	GR		29-1008
	Same	2	HNGS			39-1074
	Same	3	ECS	GR		29-1008
	Same	4	CNT-G	GR		43-1008

A more detailed description of these geophysical logging tools can be found on the Schlumberger website (<http://www.slb.com/content/services/evaluation/index.asp?>).

3.0 METHODOLOGY

This section describes the methods Schlumberger employed for geophysical logging of well R-45, 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 R-45 was ready for geophysical well logging, the Schlumberger district in Farmington, New Mexico, mobilized a wireline logging truck, the appropriate wireline logging tools and associated equipment, and crew to the job site. Upon arriving at the Los Alamos National Laboratory (Laboratory) site, the crew completed site-entry paperwork and received a site-specific safety briefing.

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

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

Next, prelogging 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 ECS/CNT-G 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 before 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 were returned to their appropriate storage shields, thus eliminating any radiation hazards. Any postlogging measurement checks were performed as part of log quality control (QC) and quality assurance (QA). 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 on-site distribution and sent the data via satellite to the Schlumberger data storage center. The Schlumberger Water Services data processing center was alerted that the data were ready for postacquisition processing.

3.2 Log QC and QA

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 chemical and physical properties.

The base calibration for most Schlumberger tools is augmented through regular “master calibrations” typically performed every 1 to 6 mo in local Schlumberger shops (such as Farmington, New Mexico), 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 properties. 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, before and after on-site “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 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 postacquisition 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 website (<http://www.slb.com/content/services/evaluation/index.asp>).

3.3 Processing Procedure

After the geophysical logging job was completed in the field and the data was archived, the data were downloaded to the Schlumberger processing center. There the data were processed in the following sequence: (1) the measurements were corrected for near-wellbore environmental conditions and the measurement field processing for certain tools (in this case, the TLD and ECS) was redone using better processing algorithms and parameters; (2) the log curves from different logging runs were depth-matched and spliced, if required; and (3) the near-wellbore substrate lithology/mineralogy and pore fluids were modeled 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 R-45, the log measurements requiring these corrections are the CNT porosity, TLD bulk formation density, ECS elemental concentrations, and HNGS spectral gamma ray logs.

Two neutron porosity measurements are available from the CNT tool: 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

epithermal and thermal neutron measurements are valid. Both measurements can be environmentally corrected for a single string of steel-casing. The CNT measurements were reprocessed for casing, borehole fluid type (air versus water), and other environmental conditions. For further processing and analysis (e.g., integrated log analysis), the reprocessed neutron porosity was used.

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 this unwanted contribution from the raw normalized yield, 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 casing/fluid change. Casing corrections were applied to the ECS logs across the entire log interval, attempting to account for one string of steel casing throughout. At the time of the ECS logging in R-45 the borehole contained water from bottom to 880 ft; no hydrogen correction was required in the air-filled section above 880 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 HNGS spectral gamma ray is affected by the material (fluid, air, and casing) in the borehole because different types and amounts of these materials have different gamma ray shielding properties; the HNGS 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 HNGS logs from R-45 were reprocessed to account, as best as possible, for the environmental effects of the casing, borehole fluid (water below 880 ft and air above), and hole size.

The measurements cannot be fully corrected for borehole washouts or rugosity since the specific characteristics (e.g., geometry) of these features are unknown (especially in this scenario where they hidden by casing) 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 Reference

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, as needed, using the gross gamma ray log, acquired in all the logging runs, for depth correlation, or other logs that are well correlated (e.g., porosity). The depth reference for all field prints and processed logs, including those presented in this report, is ground surface.

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, 103867; Quirein et al. 1986, 098043)—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 itself¹. ELAN requires an a priori specification of the volume components present

^{*}Mark of Schlumberger.

¹Mathematically, 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.

within the formation, i.e., 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 g/cc.

The logging tool measurements, volume components, and measurement response parameters used in the ELAN analysis for R-45 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 (see Attachment 1), 6th 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, including geologic/hydrogeologic properties computed from the mineral-fluid volume model (see Attachment 2). To make best use of all the measurement data and to perform the analysis across as much of the well interval as possible (29 to 1008 ft bgs), 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.

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 its volcanic origins. For the ELAN analysis, the log interval from 29 to 246 ft bgs was assumed to be volcanic tuff or pumice, and a mineral suite considered representative of this volcanic tuff, based on Laboratory cuttings mineral analysis, was used (primary “minerals” silica glass/cristobalite/tridymite [indistinguishable from the log measurements], quartz, potassium feldspar, with accessory minerals augite, calcite and pyrite). The results of laboratory analyses of Bandelier Tuff and Puye Formation samples from around the Laboratory site were also used to constrain the proportion of quartz versus the combination of glass/cristobalite/tridymite in the ELAN analysis. The log interval 246 to 686 ft bgs was assumed to be basaltic lava flows/material with a possible mineral suite of plagioclase and potassium feldspar, augite, heavy mafic minerals (such as magnetite), and pyrite. The log interval 686 to 1008 ft bgs was assumed to be the Puye Formation, or fanglomerate/alluvium with similar composition, and a mineral suite considered representative of this geology, based on Laboratory cuttings mineral analysis, was used (primary “minerals” silica glass/cristobalite/tridymite [indistinguishable from the log measurements], plagioclase and potassium feldspar; quartz at a defined small fraction of the silica glass content; montmorillinite clay; with possible accessory/trace minerals biotite, hematite, augite, heavy mafic minerals, and pyrite).

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, despite the obvious influence on the log response of borehole washouts and annular voids behind the casing. There is no way to objectively correct for the adverse effect on the log measurements from these borehole conditions; therefore the decision was made to perform the ELAN analysis so as to honor the log measurements. Accordingly, 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 R-45 ELAN Analysis

Volume Tool Measurement	Air	Water	Albite	Hematite	Labradorite	Silica Glass, Cristo, Tridy.	Heavy Mafic Minerals	Augite	Montmorillinite	Biotite	Pyrite	Orthoclase	Calcite	Quartz
Bulk density (g/cc)	-0.19	1.00	2.58	5.161	2.68	2.33	5.08	3.08	2.02	3.04	4.99	2.54	2.71	2.64
Thermal neutron poro. (nonlinear) (ft ³ /ft ³)	0	1.00	-0.01	0.126	-0.01	-0.03	0.07	0.015	0.65	0.15	0.01	-0.01	0.0	-0.07
Epithermal neutron poro. (ft ³ /ft ³)	0	1.00	-0.01	0.0556	-0.01	0.0	0.022	-0.01	0.6	0.14	0.165	-0.01	0.0	-0.05
Dry weight silicon (lbf/lbf) [*]	0.0	0.0	0.32	0.0	0.247	0.468	0.184	0.225	0.242	0.178	0.0	0.3	0.0	0.468
Dry weight calcium (lbf/lbf)	0.0	0.0	0.0	0.0	0.09	0.0	0.0	0.10	0.012	0.007	0.0	0.0	0.405	0.0
Dry weight iron (lbf/lbf)	0.0	0.0	0.02	0.699	0.023	0.0	0.22	0.112	0.02	0.199	0.466	0.015	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	0.0	0.535	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	0.001	0.016	0.0	0.0	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	0.004	0.070	0.0	0.12	0.0	0.0
Weight hydrogen (lbf/lbf)	0.0	0.111	0.0	0.0	0.0	0.01	0.0	0.0	0.022	0.003	0.0	0.0	0.0	0.0
Wet weight thorium (ppm)	0	0	1.5	0	3	2	10	10	44	50	0	7	0	0

* lbf = Pound force.

4.0 RESULTS

Preliminary results from the wireline geophysical logging measurements acquired by Schlumberger in R-45 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 influence (from a measurement standpoint) of borehole and geologic conditions and are provided as separate, individual logs. The field log results have been processed to (1) correct/improve the measurements, as best as possible, for borehole/formation environmental conditions, and (2) ensure that all the logs from different tool runs are on depth. 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 Attachment 1). The summary log displays

address specific characterization needs, such as porosity, production capacity, 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 R-45 are described below.

4.1 Well Fluid Level

The standing water level in R-45 (within the freestanding 12-in. I.D. casing) was stable during the January 9, 2009 logging, residing at 880 ft bgs. The various measurements from all four logging runs concurred on this well water level.

4.2 Regional Aquifer

The processed geophysical logs definitively indicate that the intersected geologic section is fully saturated with water from the bottom of the borehole (1008 ft bgs) to 880 ft bgs (well water level at time of logging) and likely as high as 866 ft bgs, which lies within alluvium/fanglomerate (see porosity summary display in Figure 4.1 or integrated log montage in Attachment 1). Below 866 ft, the log estimated water content and total porosity are high (greater than 20% of total rock/sediment volume 866–910 ft and mostly greater than 40% below that). Above 866 ft, the water content is much lower, mostly below 10%. Total porosity in the interval directly above 866 ft mostly ranges from 25% to 35%, resulting in an estimated water saturation that stays below 50% of total pore volume.

Conclusions that can be drawn from these geophysical log results are that the regional aquifer water level (depth at which there is full water saturation) is most likely in the vicinity of 866 ft, which is above the well water level at the time of logging.

The location of productive zones within the saturated section is difficult to determine because of the adverse cased well conditions. Higher porosity is not necessarily indicative of higher production capacity since fine-grained sediments often have higher porosity and lower productivity than coarser-grained sediments. The highest porosities are likely associated with washouts behind the casing. The predicted relative flow capacity profile generated from the integrated log analysis estimated permeability results suggest that the most productive intervals are 915–920 ft, 928–938 ft, 940–942 ft, 946–948 ft, 950–952 ft, 969–971 ft, 974–978 ft, 980–984 ft, 987–990 ft, and 995–997 ft (see porosity summary display in Figure 4.1 or integrated log montage in Attachment 1).

4.3 Vadose Zone Perched Water

As mentioned above, the depth to the top of the regional aquifer and thus the extent of the vadose zone definitely extends above 866 ft bgs. Above 866 ft bgs, the estimated water content varies from less than 5% to 17% of total rock volume, mostly remaining at or below 10% (see porosity summary display in Figure 4.1 or integrated log montage in Attachment 1). Estimated water saturation is mostly below 50% of total pore volume (never above 75%) across the entire vadose zone. The highest vadose zone water saturation is in the following zones:

- 756–770 ft, where water content averages about 15% and water saturation reaches 75%—located in a thick alluvium/fanglomerate sequence in a zone with lower estimated total porosity than the surrounding rock)

- 720–740 ft, where water content reaches 20 to 27% and water saturation is about 60%—located in the same alluvium/fanglomerate sequence, albeit total porosity is actually quite high in this zone
- 455–480 and 635–650 ft, where water saturation peaks at 100% despite very low water content (5%)—located in a thick basalt lava sequence in zones where the total porosity is very low, likely corresponding to very competent, dense rock
- 235–246 ft, where there is a slight, but notable increase in water content (15%) and saturation (30%)—located in the Guaje Pumice Bed directly above the same basalt lava sequence

4.4 Geology

The processed geophysical log results, particularly the matrix geochemistry logs, provide information on lithology and potential formation contacts intersected by R-45 across the log interval (from 29 to 1008 ft bgs). The generalized geologic stratigraphy observed from the logs across the measured interval is as follows (depth below ground surface):

- **22–233 ft bgs: High porosity silicon- and thorium-rich volcanic tuff**—characterized by high, varying total porosity (30–45% of total rock volume); high silica glass/tridymite/cristobalite content; moderate potassium feldspar content; minor quartz content; and trace amounts of pyrite (or other sulfur-bearing minerals), calcite (or other calcium-bearing minerals), and augite (or similar minerals)
- **233–246 ft bgs: High porosity silicon-, thorium-, and uranium-rich volcanic tuff/pumice (likely Guaje Pumice Bed)**—characterized by high total porosity (40%–45% of total rock volume); high silica glass/tridymite/cristobalite content; moderate potassium feldspar content; minor quartz content; and trace amounts of pyrite (or other sulfur-bearing minerals), calcite (or other calcium-bearing minerals), and augite (or similar minerals)
- **246–450 ft bgs: High porosity iron-, calcium-, and titanium-rich volcanics (likely basalt)**—characterized by potentially (unrealistically) high total porosity (25% to over 60%, the highest likely elevated because of voids behind the casing); varying moderate to high plagioclase and augite (or similar minerals) content; variably minor to moderate alkali feldspars content; and variably trace to small amounts of pyrite
- **450–480 ft bgs: Low porosity iron-, calcium-, and titanium-rich volcanics (likely basalt)**—characterized by low to very low porosity (3%–20%); varying moderate to high plagioclase and augite (or similar minerals) content; variably minor to moderate alkali feldspars content; and variably trace to small amounts of pyrite
- **480–612 ft bgs: High porosity iron-, calcium-, and titanium-rich volcanics (likely basalt)**—characterized by potentially (unrealistically) high total porosity (25% to over 60%, the highest likely elevated because of voids behind the casing); varying moderate to high plagioclase and augite (or similar minerals) content; variably minor to moderate alkali feldspars content; and variably trace to small amounts of pyrite
- **612–660 ft bgs: Low porosity iron-, calcium-, and titanium-rich volcanics (likely basalt)**—characterized by low to very low porosity (3%–20%); varying moderate to high plagioclase and augite (or similar minerals) content; variably minor to moderate alkali feldspars content; and variably trace to small amounts of pyrite and biotite

- **660–686 ft bgs: High porosity iron-, calcium-, and titanium-rich volcanics (likely basalt)**—characterized by potentially high total porosity (25% to 50%, the highest likely elevated because of voids behind the casing); varying moderate to high plagioclase and augite (or similar minerals) content; variably minor to moderate alkali feldspars content; and variably trace to small amounts of pyrite
- **686–758 ft bgs: High to extremely high porosity (likely washouts), silicon- and potassium-rich and iron-deficient alluvium/fanglomerate**—characterized by potentially (unrealistically) high total porosity (30% to well over than 60%, likely elevated because of voids behind the casing); high silica glass/tridymite/cristobalite or quartz content; moderate potassium feldspar content; varying minor to high plagioclase feldspar content; varying minor to moderate amounts of montmorillinite and augite (or similar minerals); variably trace to minor amounts of pyrite and biotite
- **758–910 ft bgs: Low to moderate porosity, silicon- and potassium-rich and iron-deficient alluvium/fanglomerate**—characterized by low to moderate total porosity (mostly 20%–30% with spurious peaks); high silica glass/tridymite/cristobalite or quartz content; moderate potassium feldspar content; varying minor to high plagioclase feldspar content; varying minor to moderate amounts of montmorillinite and augite (or similar minerals); variably trace to minor amounts of pyrite and biotite
- **910–1002 ft bgs: Very high porosity, silicon- and potassium-rich and iron-deficient alluvium/fanglomerate**—characterized by very high total porosity (36% to 50%); high silica glass/tridymite/cristobalite or quartz content; moderate potassium feldspar content; varying minor to high plagioclase feldspar content; varying minor to moderate amounts of montmorillinite and augite (or similar minerals); variably trace to minor amounts of pyrite and biotite
- **1002–1008 ft bgs (bottom of log interval): Low porosity, silicon-rich and iron-deficient alluvium/fanglomerate** – characterized by low total porosity (15%); high silica glass/tridymite/cristobalite and potassium feldspar content; minor to moderate amounts of montmorillinite and plagioclase and/or; variably trace to minor amounts of pyrite, biotite and augite (or similar minerals)

4.5 Summary Logs

Three summary log displays have been generated for R-45 to highlight the key hydrogeologic and geologic information provided by the processed geophysical log results:

- Porosity and hydrogeologic properties summary log showing continuous hydrogeologic property logs, including total porosity (water and air), water-filled porosity, water saturation, estimated hydraulic conductivity, transmissivity, and relative producibility (production capacity); highlights key derived 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 estimated clay volume, highlights key geologic rock matrix information obtained from the log results (Figure 4.2)
- Spectral natural gamma ray and lithology summary showing a high vertical resolution, continuous volumetric analysis of formation mineral and pore fluid composition (based on an integrated analysis of the logs), and key lithologic/stratigraphic correlation logs from the spectral gamma ray measurement (concentrations of gamma-emitting elements); highlights the geologic lithology, stratigraphy, and correlation information obtained from the log results (Figure 4.3)

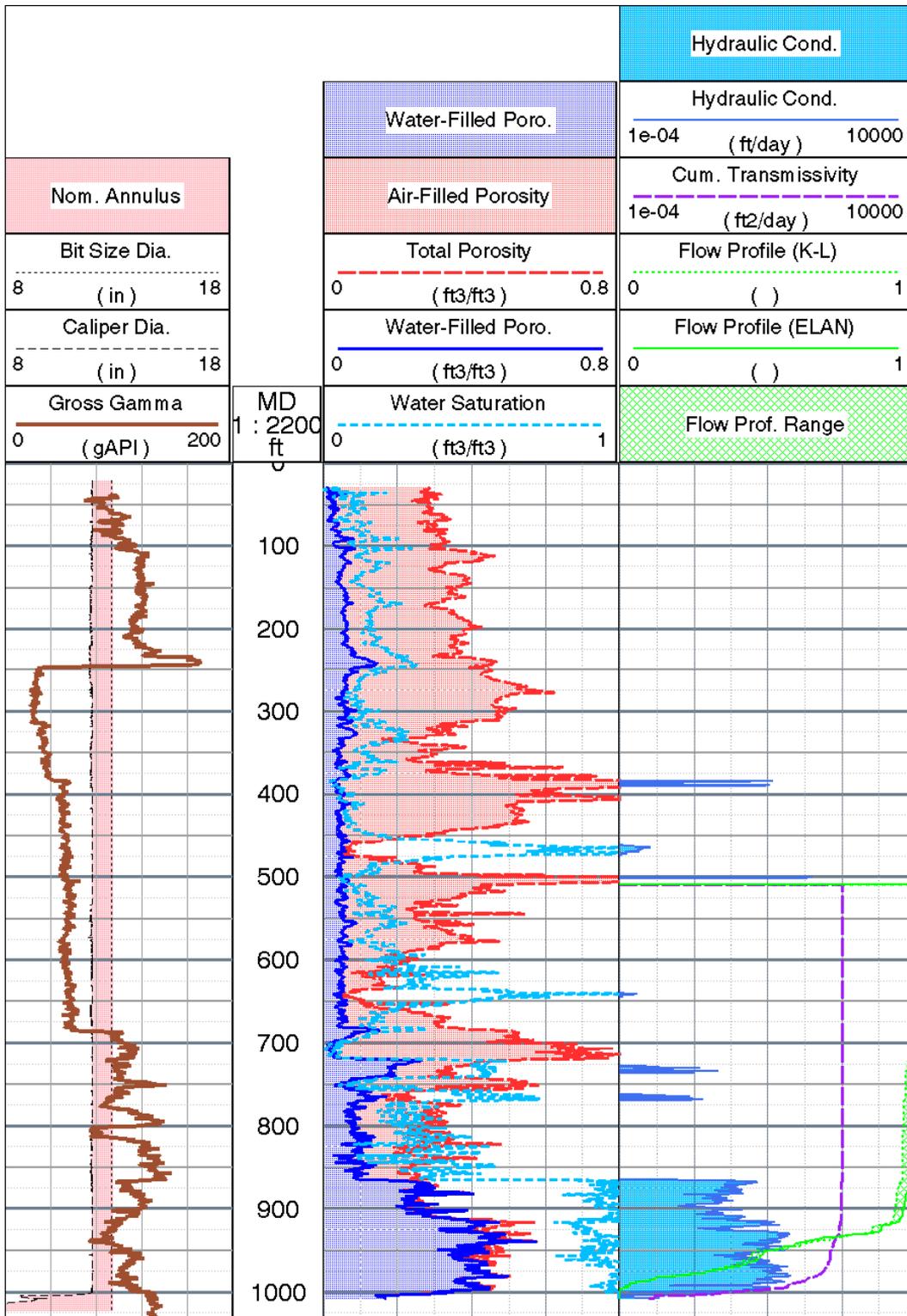


Figure 4.1 Summary of porosity logs in R-45 borehole from processed geophysical logs, interval of 29 to 1008 ft bgs, with caliper, gross gamma, water saturation, estimated relative flow capacity profile, hydraulic conductivity, and transmissivity logs also displayed. Porosity, water saturation, and hydraulic conductivity logs are derived from the ELAN-integrated log analysis.

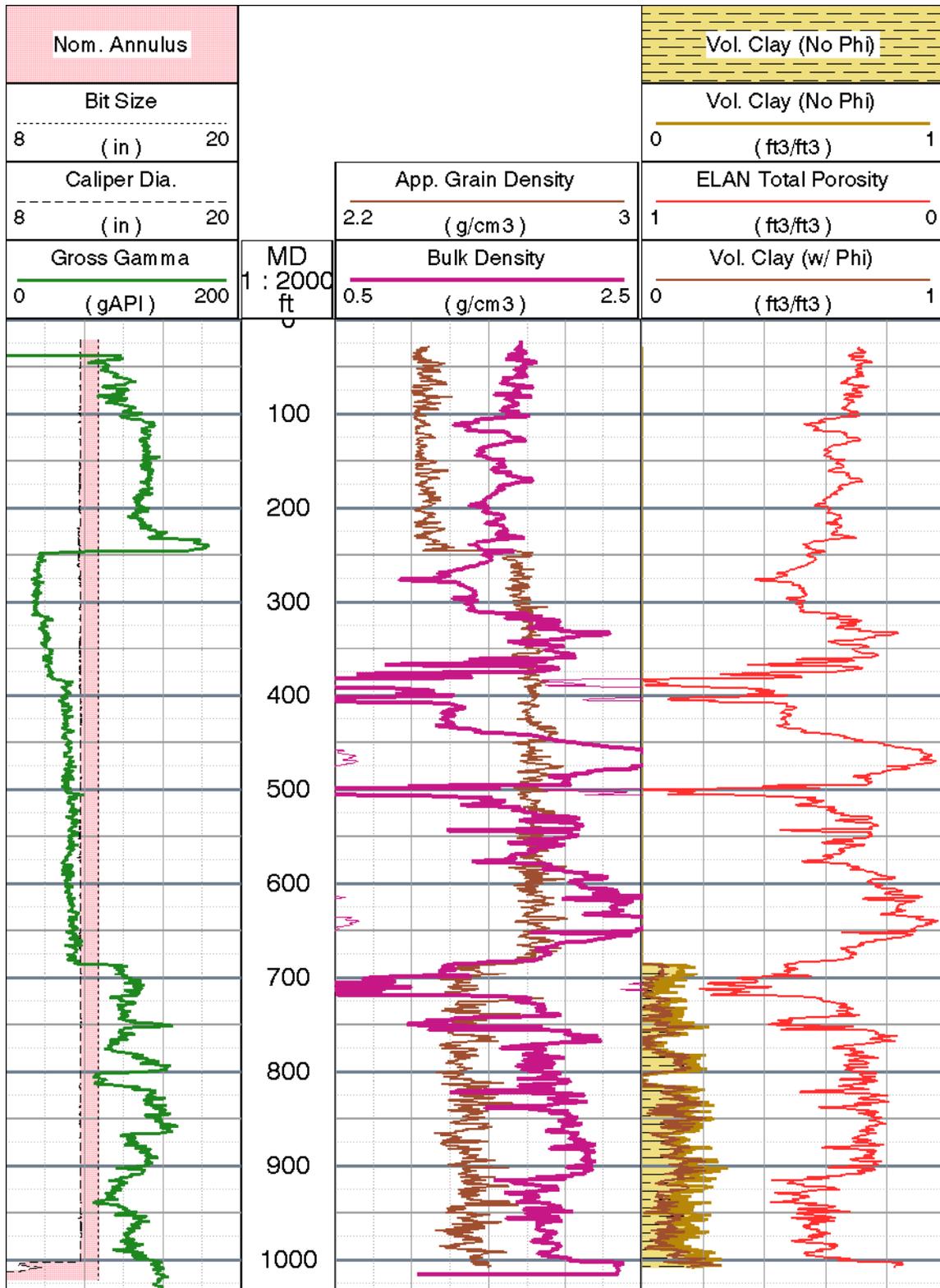


Figure 4.2 Summary of bulk density and apparent grain density logs in R-45 borehole from processed geophysical logs, interval of 29 to 1008 ft bgs. Also shown are caliper, gross gamma, volume of clay, and total porosity logs. (The latter two derived from the ELAN analysis. Note that clay was not solved for above 686 ft.)

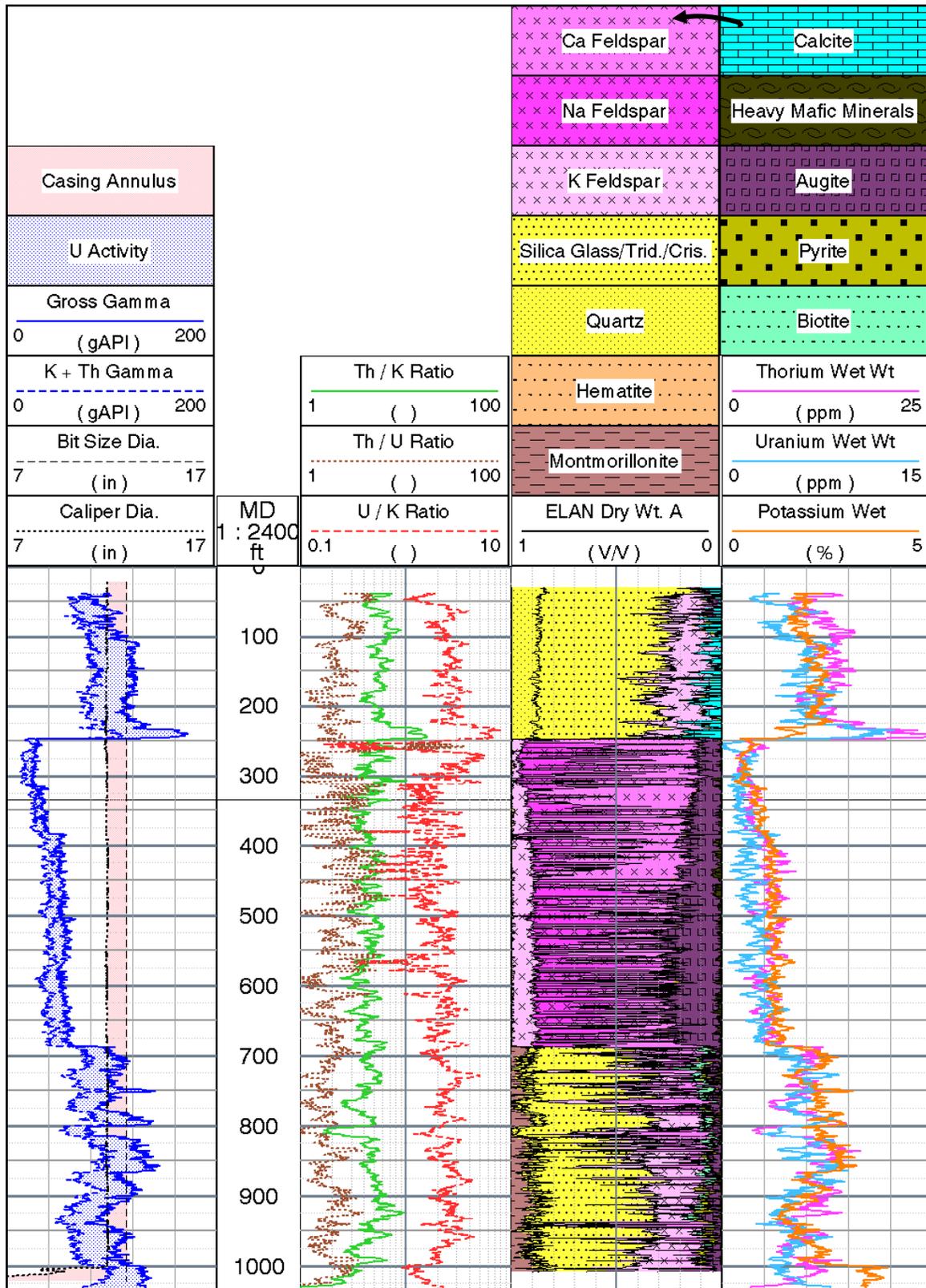


Figure 4.3 Summary of spectral natural gamma ray logs and ELAN mineralogy/lithology and pore fluid model volumes derived from the ELAN-integrated log analysis for R-45 borehole, interval 29 to 1008 ft bgs. Caliper log is also shown.

4.6 Integrated Log Montage

This section summarizes the integrated geophysical log montage for R-45. The montage is provided in Appendix 1. 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 R-45 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 CNT-G logging run. All the geophysical logs are depth-matched to the gross gamma log acquired 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 American Petroleum Institute gamma ray (gAPI) standard units and displayed on a scale of 0 to 200 gAPI units;
- single arm caliper from the TLD (thin solid pink) with nominal bit size as a reference (dashed-dotted black) to show nominal annular distance between inside of inner casing to borehole wall (pink shading), recorded as hole diameter in inches and displayed on a scale of 8 to 18 in.;
- cable tension (dashed-dotted dark red) recorded at logging truck and displayed to indicate tool pickup at bottom on a scale of 0 to 1000 lbf.

Two gamma ray curves from the HNGS are displayed:

- total gross gamma (thick solid black curve with thinner dashed black curve as backup representing the uncorrected SGT gamma ray displayed on a scale to match the corrected HNGS gamma)
- gross gamma minus the contribution of uranium (dotted black)
- yellow shading between the two curves to show uranium contribution to the total gamma ray response.

4.6.3 Track 3—Porosity

The third 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 (bold solid light blue curve) – processed for zoned air-filled and water-filled cased hole;
- CNT water-filled resolution enhanced thermal neutron porosity (solid dark blue curve) – thermal neutron porosity valid only in the fluid-filled borehole;

- ECS bulk volumetric water content derived from hydrogen weight concentration measurement, corrected for water in casing and converted to volume fraction (short-dashed sky blue);
- Total porosity derived from bulk density and ELAN water-filled porosity using a grain density of 2.4/2.65/2.45 g/cc (dashed red curve), 2.5/2.75/2.55 g/cc (long-dashed red curve), and 2.6/2.85/2.65 g/cc (dotted red curve)—with red shading between the 2.4/2.65/2.45 g/cc and 2.6/2.85/2.65 g/cc porosity curves to show the range (the lowest grain density range used across the tuff/pumice interval [29–246 ft], the highest grain density range used across the basalt interval [246–686 ft]), and middle grain density range used across the alluvium/fanglomerate interval [686–1,008 ft]; and
- ELAN water-filled porosity (bold dashed-dotted cyan with dark blue shading to right)—derived from the ELAN-integrated analysis of all log curves to estimate optimized matrix and pore volume constituents.

4.6.4 Track 4—Density

The fourth track displays the

- bulk density, corrected for single string of steel casing (thick solid maroon curve) on a wrapping scale of 1 to 3 g/cc, and
- apparent grain density (dashed brown curve), derived from the ELAN analysis, on a scale of 2.4 to 3.2 g/cc.

4.6.5 Track 5—HNGS Spectral Gamma

The fifth track from the left displays the spectral components of the HNGS measurement results as wet weight concentrations, corrected as best as possible for casing and borehole size and fluid:

- potassium (solid green curve) in units of percent weight fraction and on a scale of –5% to 5%;
- thorium (dashed brown) in units of parts per million and on a scale of 30 to –30 ppm; and
- uranium (dotted blue) in units of parts per million and on a scale of 20 to 0 ppm.

4.6.6 Tracks 6 to 11—Geochemical Elemental Measurements

The narrow tracks 6 to 11 present the geochemical measurements, along with their estimated one standard deviation uncertainty range: iron (Fe) and silicon (Si), sulfur (S) and calcium (Ca), estimated aluminum (Al) and potassium (K), titanium (Ti) and gadolinium (Gd), hydrogen (H) and apparent relative bulk chlorinity (Rela. Cl), and uranium (U) and carbon yield (C Yield)—from left to right respectively, in units of dry matrix weight fraction (except K and H in wet-weight fraction, Rela. Cl in ppk, U in wet-weight ppm, and C Yield in relative yield units).

4.6.7 Track 12—ELAN Mineralogy Model Results (Dry-Weight Fraction)

Track 12 displays the results from the ELAN-integrated log analysis (the matrix portion)—presented as dry-weight fraction of mineral types chosen in the model:

- montmorillinite clay (brown/tan)

- hematite (orange with small black dots)
- quartz (yellow with closely spaced small black dots)
- combined silica glass, tridymite, and cristobalite (yellow with widely spaced large black dots)
- orthoclase or other potassium feldspar (lavender)
- albite or similar sodium-rich plagioclase feldspar (bright pink)
- labradorite or similar calcium-rich plagioclase feldspar (pink)
- biotite (light green)
- pyrite (orange-tan with black squares)
- hypersthene (purple)
- augite (maroon)
- heavy mafic/ultramafic minerals, such as magnetite or olivine (dark green)
- calcite (cyan)

4.6.8 Track 13—ELAN Mineralogy and Pore Space Model Results (Wet-Volume Fraction)

Track 13 displays the results from the ELAN-integrated log analysis—presented as wet mineral and pore fluid volume fractions:

- montmorillinite clay (brown/tan)
- hematite (orange with small black dots)
- quartz (yellow with closely spaced small black dots)
- combined silica glass, tridymite, and cristobalite (yellow with widely spaced large black dots)
- orthoclase or other potassium feldspar (lavender)
- albite or similar sodium-rich plagioclase feldspar (bright pink)
- labradorite or similar calcium-rich plagioclase feldspar (pink)
- botite (light green)
- pyrite (orange-tan with black squares)
- hypersthene (purple)
- augite (maroon)
- heavy mafic/ultramafic minerals, such as magnetite or olivine (dark green)
- calcite (cyan)
- air (red)

- water (white)
- moved air (orange)
- moved water (blue)

4.6.9 Track 14—Water Saturation

Track 14 displays the continuous-in-depth water saturation logs estimated from the processed logs, recorded in units of volumetric fraction of pore space filled with water (ratio of cubic feet per cubic feet) and presented on a scale of 0 to 1 ft³/ft³ (left to right).

- Optimized estimate of water saturation (volumetric fraction of pore space filled with water) from the ELAN analysis (bold dashed-dotted purple curve with blue shading to the right and red shading to the left, corresponding to water-filled and air-filled pore space, respectively); and
- Water saturation as calculated directly from the bulk density and ELAN-estimated porosity using a grain density of 2.4/2.65/2.45 g/cc (dashed red curve), 2.5/2.75/2.55 g/cc (long-dashed red curve), and 2.6/2.85/2.65 g/cc (dotted red curve)—with red shading between the 2.4/2.65/2.45 g/cc and 2.6/2.85/2.65 g/cc porosity curves to show the range (the lowest grain density range used across the tuff/pumice interval [29–246 ft], the highest grain density range used across the basalt interval [246–686 ft]), and middle grain density range used across the alluvium/fanglomerate interval [686–1008 ft].

4.6.11 Track 15—Hydraulic Conductivity

Track 15 displays several estimates of hydraulic conductivity (K) derived from the ELAN-integrated log analysis (sensitive to the estimated porosities and mineral composition), presented on a logarithmic scale of 10⁻⁵ to 10⁵ ft/d:

- a K-versus-depth estimate derived from using the ELAN permeability equation with water-filled porosity and matrix mineral weight fraction values derived from the ELAN analysis, converted to hydraulic conductivity (bold solid blue curve with gradational coloring to represent the range of hydraulic conductivity relative to standard unconsolidated clastic sediments);
- a K-versus-depth estimate derived from using the k-Lambda permeability equation with water-filled porosity and matrix mineral weight fraction values derived from the ELAN analysis, converted to hydraulic conductivity (long-dashed sky blue curve); and
- an intrinsic K-versus-depth estimate (assuming full saturation) using the ELAN total porosity and mineral-based permeability equation with total porosity and matrix mineral weight fraction values derived from the ELAN analysis, converted to hydraulic conductivity (dotted purple).

In addition, an estimate of cumulative transmissivity from the bottom of the log interval is displayed for the ELAN mineral-based estimator (bold dashed-dotted bright green curve), computed by integrating from bottom to top the hydraulic conductivity estimates, presented on a logarithmic scale of 10⁻⁵ to 10⁵ ft²/d.

4.6.12 Track 16—Predicted Flow (Production Potential) Profile

Track 16 displays the integrated predicted relative flow (production potential) profile from the permeability (hydraulic conductivity) logs that mimics a flow meter (spinner) acquired under flowing conditions:

- predicted relative water flow profile derived from the k-Lambda water permeability log (long-dashed blue), displayed on a unitless linear scale of 0 to 1 relative volumetric flow rate (ratio of flow rate to flow rate);
- predicted relative water flow profile derived from the ELAN water permeability log (bold solid blue curve), displayed on a unitless linear scale of 0 to 1 relative volumetric flow rate;
- relative integrated intrinsic permeability profile derived by integrating the k-Lambda intrinsic permeability log (dashed-dotted red), displayed on a unitless linear scale of 0 to 1;
- relative integrated intrinsic permeability profile derived by integrating the ELAN intrinsic permeability log (dashed red), displayed on a unitless linear scale of 0 to 1; and
- predicted hypothetical well water flow versus depth profile for the entire log interval (dotted green), assuming a well radius of 4 in., entirely open to flow, and pumping is occurring under steady state conditions with a drawdown of 25 ft (incremental flow computed using the Thiem steady state flow equation) – derived from the k-Lambda water permeability log (bold solid blue), displayed on a scale of 0 to 100,000 gal./day.

4.6.13 Track 17—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:

- optimized estimate of total volume fraction water from the ELAN analysis (solid blue curve and blue plus cyan area shading);
- optimized estimate of volume fraction moveable water (non-clay bound moveable water-filled porosity) from the ELAN analysis (dashed cyan curve and cyan area shading);
- optimized estimate of total volume fraction of air-filled porosity from the ELAN analysis (solid red curve and dotted red area shading);and
- estimate of bulk volumetric water content from the ECS tool (thin dashed dark blue curve).

The porosity and volumetric water content scales are from 0 to 0.6 total volume fraction, left to right.

4.6.14 Track 18—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 HNGS logging run.

5.0 REFERENCES

- Mayer, C., and A. Sibbit, September 21–24, 1980. "Global, A New Approach to Computer-Processed Log Interpretation," 55th Annual Fall Technical Conference and Exhibition of the Society of Petroleum Engineers of AIME, September 21–24, 1980, Dallas, Texas. (Mayer and Sibbit 1980, 103867)
- Quirein, J., S. Kimminau, J. LaVigne, J. Singer, and F. Wendel, June 9–13, 1986. "A Coherent Framework for Developing and Applying Multiple Formation Evaluation Models," SPWLA 27th Annual Logging Symposium, June 9–13, 1986, Schlumberger Well Services, Houston, Texas. (Quirein et al. 1986, 098043)

Integrated Wireline Log

Processed Advanced Cased Hole Geophysical Logs

COMPANY: Teregar P&G (drilling contractor to LANL)

FIELD: Palm

STATE: New Mexico

COUNTRY: New Mexico

DATE LOGGED: 9-Jan-2009

DATE PROCESSED: May-2009

WELL LOCATION:

EXCHANGERS: K.B. <KBS> D.F. <DFS> G.L. <GL>

LOG NUMBER: J00 Number

GEOFRAME PROCESSED INTERPRETATION

Using the following logs: TLD, CNT, G, HNS, SGT, ESP

FOLD HERE The well name, location and borehole reference data were furnished by the customer.

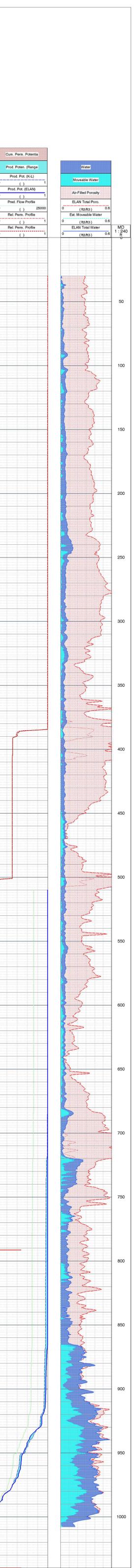
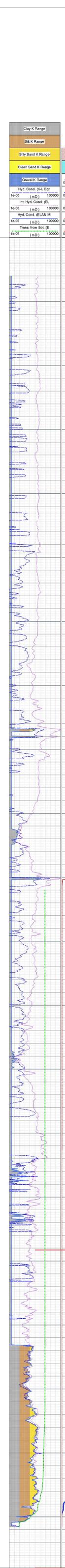
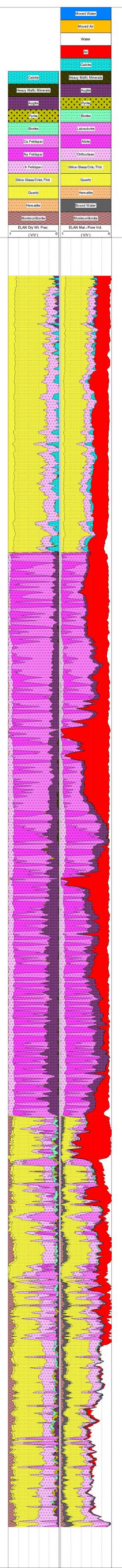
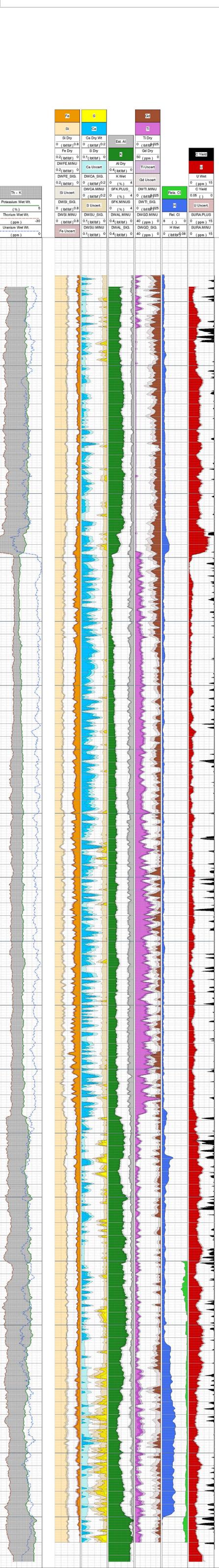
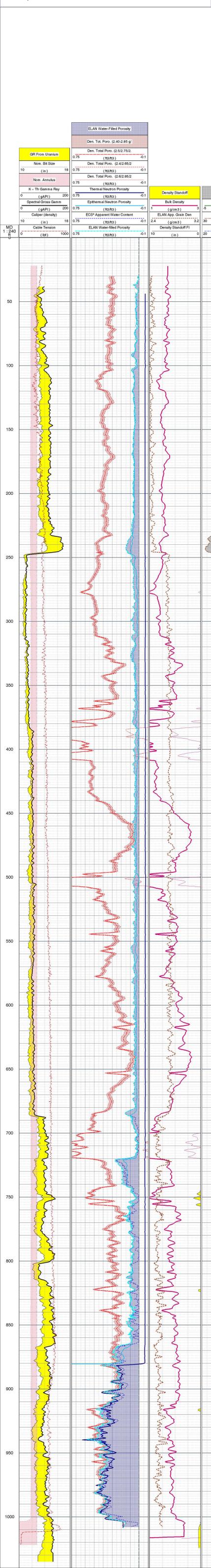
All interpretations are based on data from the well logs and other measurements and are subject to change without notice. The accuracy of these interpretations is not guaranteed. The user is responsible for any loss, damage or expense incurred as a result of any interpretation made by any party other than the provider of the logs.

Server: Ode # AXIM10 CP Vars: 1705-154 Process Date: May-2009 Center: BWS Barstow Baseline: GF-2 Log: Axi

Mud and Borehole Measurements:		
Rin @ Measured Temperature: -99.25 ohm	BHT: 713.556 degF	Blsize: 12.75 in
Rin @ Measured Temperature: -99.25 ohm	Type Fluid in Hole:	FGM:
Rin @ Measured Temperature: -99.25 ohm	Mud density: 0 lbm/gal	FGM:

Remarks:

Depth reference is ground surface.
Well contained one or more strings of casing (casing advance) during logging.
Well water level at 880' at time of logging.
ELAN* performed without porosity or water saturation constraints.
Interpretation should account for well conditions.





ELAN* Geophysical Log

Integrated Analysis

Optimized Mineral+Pore Volume Model

COMPANY: Terraneer PMC
WELL: R 45

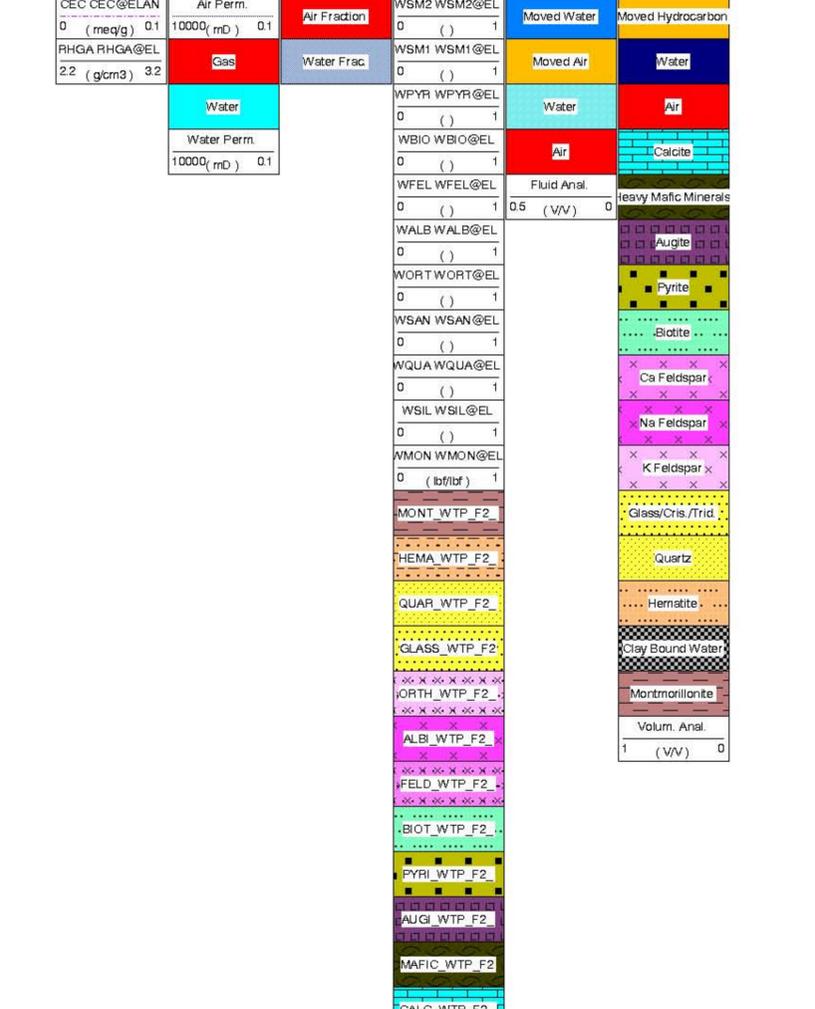
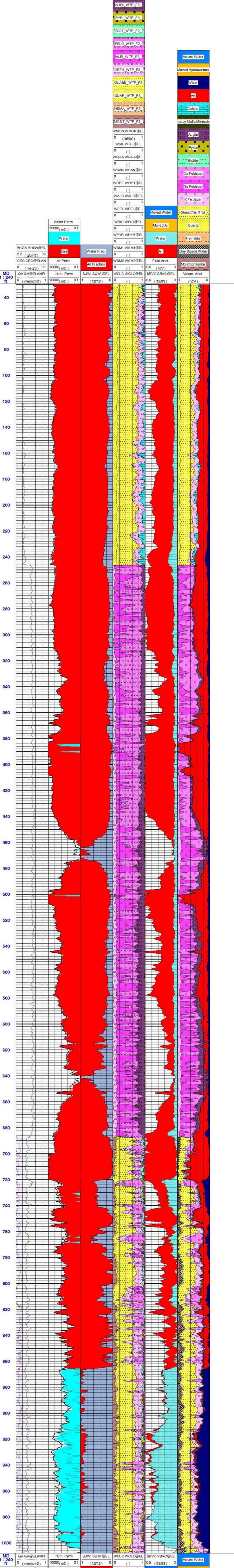
FIELD: LANL
State: New Mexico

COUNTRY: Elemental Log Analysis, Mark of Schlumberger

Date Processed: May-2009 Date Logged: 9-Jan-2009
Job Number: Processed at: SWS Sacramento
Well Location:
Latitude: Longitude:
Elevations: KB: 2041.86m DF: 1.17604e+07ft. 1.17604e+07ft.
FOLD HERE

All interpretations are opinions based on inferences from electrical or other measurements and we cannot, and do not guarantee the accuracy or correctness of any interpretation, and we shall not, except in the case of gross or willful negligence on our part, be liable or responsible for any loss, costs, damages or expenses incurred or sustained by anyone resulting from any interpretations made by any of our officers, agents or employees. These interpretations are also subject to Clause 4 of our General Terms and Conditions as set out in our current Price Schedule.

R45 [Fun_2]



R45 [Fun_2]