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Completion Report for Regional Aquifer Well R-57

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Prepared by the Environmental Programs Directorate

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EXECUTIVE SUMMARY

This well completion report describes the drilling, well construction, development, aquifer testing, and proposed dedicated sampling system installation for regional aquifer well R-57 located within Los Alamos National Laboratory (LANL or the Laboratory) Technical Area 54 (TA-54) in Los Alamos County, New Mexico. The
R-57 monitoring well is intended to provide hydrogeologic and groundwater quality data downgradient of Material Disposal Area G at the eastern end of TA-54. It was drilled in accordance with the Compliance Order on Consent (March 2005, revised June 2008) and the New Mexico Environment Department (NMED)-approved drilling work plan.

The R-57 monitoring well borehole was drilled using dual-rotary casing-advance air-drilling methods. Fluid additives used included potable water and foam. Foam-assisted drilling was used only above the anticipated regional aquifer; no drilling-fluid additives other than small amounts of potable water were used below 786 ft below ground surface (bgs), 100 ft above the expected top of the regional aquifer.

During drilling, a retractable 16-in. casing was advanced through alluvium, the Tshirege Member of the Bandelier Tuff, the Cerro Toledo interval, the Otowi Member of the Bandelier Tuff, the Guaje Pumice Bed, and stacked basaltic lava flows at the top of the Cerros del Rio volcanic series to a depth of 225.8 ft bgs. Then a 15-in. open borehole was advanced with fluid-assisted air-rotary methods and a downhole hammer bit into the Cerros del Rio volcanic series to a depth of 826.0 ft bgs. A retractable 12-in. casing was then advanced through the bottom of the Cerros del Rio volcanic series and into the Puye Formation to a total depth of 1081.6 ft bgs.

Well R-57 was completed as a dual-screen well allowing evaluation of water quality and water levels at two discrete depth intervals within the regional aquifer. The upper 20-ft-long screened interval is set between 910.0 and 930.5 ft bgs within the dacitic lava flows at the bottom of the Cerros del Rio volcanic series, while the lower 20-ft-long screened interval is set between 971.5 and 992.1 ft bgs within the Puye Formation. The composite depth to water after well installation and well development was 896.7 ft bgs.

The well was completed in accordance with the NMED-approved well design. The well was developed and target water-quality parameters were met at both screened intervals. Aquifer testing indicates that both screened intervals at monitoring well R-57 are productive and will perform effectively to meet the planned objectives. A sampling system and transducers will be placed in the upper and lower screened intervals, and groundwater sampling at R-57 will be performed as part of the facility-wide groundwater monitoring program.

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Acronyms and Abbreviations

amsl	above mean sea level
ASTM	American Society for Testing and Materials
BETCO	Barometric and Earth Tide Correction (software)
bgs	below ground surface
Consent Order	Compliance Order on Consent
DO	dissolved oxygen
DOE	Department of Energy
DTW	depth to water
EES-14	Earth and Environmental Sciences Group (LANL)
EP	Environmental Programs
EPA	Environmental Protection Agency (U.S.)
gpd	gallons per day
gpm	gallons per minute
hp	horsepower
I.D.	inside diameter
LANL	Los Alamos National Laboratory
LH3	low-level tritium
µS/cm	microsiemens per centimeter
MDA	material disposal area
mV	millivolt
NAD	North American Datum
NMED	New Mexico Environment Department
NMSW	New Mexico Special Waste
NTU	nephelometric turbidity unit(s)
O.D.	outside diameter
ORP	oxidation-reduction potential
PVC	polyvinyl chloride
Qal	Quaternary alluvium
Qbo	Otowi Member of the Bandelier Tuff
Qbog	Guaje Pumice Bed of the Otowi Member of the Bandelier Tuff
Qbt	Tshirege Member of the Bandelier Tuff
Qct	Cerro Toledo interval
RPF	Records Processing Facility

SOP	standard operating procedure
TA	technical area
Tb 4	Cerros del Rio volcanic series
TD	total depth
TOC	total organic carbon
Tpft	Totavi Lentil of the Puye Formation
VOC	volatile organic compound
WCSF	waste characterization strategy form
WES-EDA	Waste and Environmental Services Division–Environmental Data and Analysis
WR	whole rock

1.0 INTRODUCTION

This completion report summarizes borehole drilling, well construction, well development, aquifer testing, and dedicated sampling system installation for regional aquifer well R-57. The report is written in accordance with the requirements in Section IV.A.3.e.iv of the March 1, 2005, (revised June 2008) Compliance Order on Consent (the Consent Order). The R-57 monitoring well borehole was drilled from March 28 to April 24, 2010, and completed from May 5 to June 8, 2010, at Los Alamos National Laboratory (LANL or the Laboratory) for the LANL Environmental Programs (EP) Directorate.

Well R-57 is located on the mesa top east of Material Disposal Area (MDA) G within the Laboratory's Technical Area 54 (TA-54) in Los Alamos County, New Mexico (Figure 1.0-1). R-57 was installed to provide supplemental monitoring near monitoring well R-22, downgradient of MDA G at the eastern end of TA-54.

The primary objective of the drilling activities at R-57 was to install a dual-screen monitoring well in the uppermost part of the regional aquifer. Secondary objectives were to establish water levels and flow characteristics in the regional aquifer in this area, to collect drill-cutting samples, and to conduct borehole geophysical logging.

The R-57 borehole was drilled to a total depth (TD) of 1081.6 ft below ground surface (bgs). During drilling, cuttings samples were collected at 5-ft intervals in the borehole from ground surface to TD. A monitoring well was installed with two screens. The upper 20-ft-long screened interval is between 910.0 and 930.5 ft bgs, and the lower 20-ft-long screened interval is between 971.5 and 992.1 ft bgs. The composite depth to water (DTW) after well installation and development was 896.7 ft bgs on June 21, 2010. A dedicated sampling system will be installed with an inflatable packer isolating the two well screens. The dedicated sampling system will allow discrete sampling and water-level monitoring of both screened intervals. Water-level transducers will be placed in the upper and lower well screened intervals to evaluate hydraulic relationships between this well and other nearby wells.

Postinstallation activities included well development, aquifer testing, surface completion, and conducting a geodetic survey. Future activities will include 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-57 project. Information on radioactive materials and radionuclides, including the results of sampling and analysis of radioactive constituents, is voluntarily provided to the New Mexico Environment Department (NMED) in accordance with U.S. Department of Energy (DOE) policy.

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 the R-57 project:

- “Drilling Work Plan for Regional Aquifer Well R-57,” (LANL 2010, 108861);
- “Drilling Plan for Regional Aquifer Well R-57,” (TerranearPMC 2010, 109125);
- “Integrated Work Document for Regional and Intermediate Aquifer Well Drilling” (LANL 2007, 100972);
- “Storm Water Pollution Prevention Plan for SWMUs and AOCs (Sites) and Storm Water Monitoring Plan” (LANL 2006, 092600); and
- “Waste Characterization Strategy Form for Regional Wells R-56 and R-57 at TA-54” (LANL 2010, 108753).

2.2 Site Preparation

Site preparation and access road construction were performed by Laboratory personnel before rig mobilization. The drill rig, air compressors, trailers, and support vehicles were mobilized to the drill site on March 26, 2010. The equipment and tooling were decontaminated before being mobilized to the site. Staging of alternative drilling tools and construction materials occurred at the Pajarito Road lay-down yard.

All potable water was obtained from a Pajarito Road fire hydrant at TA-18. 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 approach and provides a chronological summary of field activities conducted at monitoring well R-57.

3.1 Drilling Approach

The drilling methodology and selection of equipment and drill-casing sizes for the R-57 monitoring well were designed to retain the ability to investigate and case off any perched groundwater encountered above the regional aquifer. Further, the drilling approach ensured that a sufficiently sized drill casing was used to meet the required 2-in. minimum annular thickness of the filter pack around a 5.56-in. outside-diameter (O.D.) well casing.

Dual-rotary air-drilling methods using a Foremost DR-24HD drill rig were employed to drill the R-57 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, a deck-mounted air compressor, and general drilling equipment. Auxiliary equipment included two Ingersoll Rand trailer-mounted air compressors. Two sizes of A53 grade B flush-welded mild carbon-steel casing (16-in. and 12-in. inside diameter [I.D.]) were used for the R-57 project.

The dual-rotary technique at R-57 used filtered compressed air and fluid-assisted air to evacuate cuttings from the borehole during drilling. Drilling fluids, other than air, used in the borehole included potable water and a mixture of potable water with Baroid AQF-2 foaming agent. The fluids were used to cool the bit and help lift cuttings from the borehole. Use of the foaming agent was terminated at 786.0 ft bgs, roughly

100 ft above the expected top of the regional aquifer. No additives other than potable water were used for drilling below 786.0 ft bgs. Total amounts of drilling fluids introduced into the borehole are presented in Table 3.1-1.

3.2 Chronological Drilling Activities for the R-57 Well

On March 28, following on-site equipment inspections, the monitoring well borehole was initiated at 1130 h using dual-rotary methods with 16-in. drill casing and a 15.75-in. tricone bit.

Drilling and advancing 16-in. casing proceeded rapidly through alluvium, the Tshirege Member of the Bandelier Tuff, the Cerro Toledo interval, the Otowi Member of the Bandelier Tuff, the Guaje Pumice Bed, and upper stacked basaltic lava flows of the Cerros del Rio volcanic series. Drilling continued to 225.8 ft bgs where the 16-in. drill casing was landed on April 4. No indications of groundwater were observed while advancing the 16-in. casing.

On April 5, open-hole drilling commenced using a 15-in. hammer bit. Drilling proceeded through stacked basaltic lavas, basaltic cinders, and basaltic tephra to 426.0 ft bgs. Loose and unstable conditions in the basalt necessitated cementing in order to gain stability and help with circulation. Video and natural gamma logs were run in the open portion of the borehole on April 6. The borehole was cemented from 327.0 to 426.0 ft bgs using 6 yd^3 of sand grout (Portland cement with a minor amount of silica sand) on April 7. Open-hole drilling continued on April 8 in the basaltic tephra and dacitic lava flows of the Cerros del Rio volcanic series to 826.0 ft bgs. On April 10, video, natural gamma, and induction logs were run to document conditions in the open portion of the borehole.

On April 11, after the 16-in. casing shoe was cut off at 218.6 ft bgs, 12-in. drill casing was started into the borehole. From April 18 to 19, the 12-in. casing was advanced using an underreaming hammer bit from 826.0 to 886.0 ft bgs with no indications of groundwater. On April 20, water flow of 15 gallons per minute (gpm) was noted at 915.0 and 925.6 ft bgs. The 12-in. casing was landed at 925.6 ft bgs and DTW was measured at 888.1 ft bgs on the same day; the 12-in. casing was advanced to 964.6 ft bgs on April 21.

On April 23, the 12-in. casing was advanced using an 11.75-in. tricone bit from 964.6 to 1003.0 ft bgs. Water flow of 30 to 40 gpm was noted at 1003.0 ft bgs. The 12-in. casing was advanced to the borehole TD at 1081.6 ft bgs on April 24, with various water flow rates noted from 10 to 40 gpm. A natural gamma log was run on April 25 from surface to 1076 ft bgs (approximately 6 ft of slough was encountered at the bottom of the borehole). On May 1, the 12-in. casing shoe was cut off at 1060.0 ft bgs in preparation for well construction.

During drilling, field crews worked 12-h shifts, 7 d/wk. All associated activities proceeded normally without incident or delay.

4.0 SAMPLING ACTIVITIES

This section describes the cuttings and groundwater sampling activities for monitoring well R-57. All sampling activities were conducted in accordance with applicable quality procedures.

4.1 Cuttings Sampling

Cuttings samples were collected from the R-57 monitoring well borehole at 5-ft intervals from ground surface to the TD of 1081.6 ft bgs. At each interval, approximately 500 mL of bulk cuttings were collected by the site geologist from the drilling discharge cyclone, placed in resealable plastic bags, labeled, and archived in core boxes. Sieved fractions (>#10 and >#35 mesh) were also collected from ground surface to TD and placed in chip trays along with unsieved (whole rock) cuttings. Radiation control technicians screened the cuttings before removal from the site. All screening measurements were within the range of background values. The core boxes and chip trays were delivered to the Laboratory's archive at the conclusion of drilling activities.

R-57 stratigraphy is summarized in section 5.1 and a detailed lithologic log is presented in Appendix A.

4.2 Water Sampling

Two groundwater-screening samples were collected from the drilling discharge at 925.6 and 1081.0 ft bgs. These samples were collected after reaching the bottom of 20-ft runs of casing, where the driller stopped water circulation and circulated air. As the discharge cleared, the water samples were collected directly from the discharge cyclone. The water sample collected at 925.6 ft bgs was analyzed for anions, cations, metals, volatile organic compounds (VOCs), and low level tritium (LH3). The sample collected at 1081 ft bgs was not submitted for analysis because it contained a significant amount of sediment. Table 4.2-1 presents a summary of screening samples collected during the R-57 monitoring well installation project. Groundwater chemistry and field water quality parameters are discussed in Appendix B.

Three groundwater-screening samples were collected during well development from the development pump's discharge line, one from the upper screened interval and two from the lower screened interval. Development screening samples were analyzed only for total organic carbon (TOC). Additionally, ten groundwater-screening samples were collected during aquifer testing from the pump's discharge line and also analyzed for TOC only.

Groundwater characterization samples will be collected from the completed well in accordance with the Consent Order. For the first year, the samples will be analyzed for the full suite of constituents including radioactive elements; anions/cations; general inorganic chemicals; volatile and semi-volatile organic compounds; and stable isotopes of hydrogen, nitrogen, and oxygen. The analytical results will be included in the appropriate periodic monitoring report issued by the Laboratory. After the first year, the analytical suite and sample frequency at R-57 will be evaluated and presented in the annual "Interim Facility-Wide Groundwater Monitoring Plan."

5.0 GEOLOGY AND HYDROGEOLOGY

A brief description of the geologic and hydrogeologic features encountered at R-57 is presented below. The Laboratory's geology task leader and project 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-57.

5.1 Stratigraphy

Stratigraphic units for the R-57 borehole are presented below in order of youngest to oldest geologic occurrence. Lithologic descriptions are based on binocular microscope analysis of drill cuttings samples collected from the discharge hose. Cuttings and borehole geophysical logs were used to identify unit contacts. Figure 5.1-1 illustrates the stratigraphy at R-57. A detailed lithologic log is presented in Appendix A.

Quaternary Alluvium, Qal (0–2 ft bgs)

A thin layer of Quaternary alluvium, mixed with base-course gravel used to construct the drill pad, was indentified from 0 to 2 ft bgs. Alluvium consists of unconsolidated, poorly sorted sand, and gravelly sand composed of tuffaceous and volcanic detritus.

Unit 2, Tshirege Member of the Bandelier Tuff, Qbt 2 (2–40 ft bgs)

Unit 2 of the Tshirege Member of the Bandelier Tuff was intersected in R-57 from 2 to 40 ft bgs and has a minimum thickness of 38 ft. Unit 2 represents a single cooling unit of the Tshirege Member rhyolitic ash-flow tuff (ignimbrite). This unit is locally poorly welded, moderately indurated, pumiceous, crystal-rich, and lithic-poor. Pumices are typically devitrified and may show weak compression, or collapse, indicating a relatively limited degree of welding. Cuttings commonly contain abundant indurated tuff fragments, pumice lapilli, quartz and sanidine crystals, and minor small (up to 10 mm in diameter) dacite lithic fragments.

Unit 1v, Tshirege Member of the Bandelier Tuff, Qbt 1v (40–56 ft bgs)

Unit 1v of the Tshirege Member of the Bandelier Tuff was encountered from 40 to 56 ft bgs and is 16 ft thick. Unit 1v is a rhyolitic ash-flow tuff that is characterized by intense devitrification and recrystallization of pumice lapilli and fine glass within its volcanic ash matrix. This unit is poorly welded, generally poorly indurated, pumiceous, crystal-bearing, and lithic-bearing. Cuttings locally contain fragments of pumiceous crystal tuff, quartz and sanidine crystals, dacite lithic fragments (up to 18 mm in diameter), and abundant weathered volcanic ash. Pumice lapilli hosted by the tuff typically exhibit sugary crystalline textures, evidence of strong devitrification.

Unit 1g, Tshirege Member of the Bandelier Tuff, Qbt 1g (56–100 ft bgs)

Unit 1g of the Tshirege Member of the Bandelier Tuff occurs from 56 to 100 ft bgs and is locally 44 ft thick. As shown in cuttings, Unit 1g is a poorly welded rhyolitic ash-flow tuff that is strongly pumiceous, crystal-bearing, and lithic-bearing. Characteristic of Unit 1g are white to pale orange, lustrous, glassy pumice lapilli that are quartz- and sanidine-phyric. Cuttings contain minor fragments of moderately indurated pumiceous tuff, abundant free quartz and sanidine crystals, and minor small volcanic (predominantly dacitic) lithic inclusions.

Cerro Toledo Interval, Qct (100–106 ft bgs)

The Cerro Toledo interval is a layer of poorly consolidated tuffaceous and volcaniclastic sediments that regionally occurs between the Tshirege and Otowi members of the Bandelier Tuff. Cuttings suggest that a thin layer (possibly as much as 6 ft in thickness) of tuffaceous sediments is present in R-57 from 100 to 106 ft bgs. Evidence for the local presence of the Cerro Toledo interval is provided by minor fragments of white, tuffaceous, fine-grained sandstone and siltstone contained in drill cuttings in the interval from 100 to 110 ft bgs.

Otowi Member of the Bandelier Tuff, Qbo (106–170 ft bgs)

The Otowi Member of the Bandelier Tuff, estimated to be 64 ft thick, is present in R-57 from 106 to 170 ft bgs. The Otowi Member is a poorly welded rhyolitic ash-flow tuff (ignimbrite) that is pumiceous, crystal-bearing, and lithic-bearing to locally lithic rich. Abundant pumice lapilli are pale orange to white, glassy, lustrous, and quartz- and sanidine-phyric. Qbo drill cuttings typically contain white to pale orange (i.e., oxidized and weakly limonitic) glassy pumices, locally abundant volcanic lithic fragments, and quartz and sanidine crystals. Lithic fragments, representing tuff-hosted xenoliths, are commonly subangular to subrounded and generally of intermediate volcanic composition, including porphyritic dacites, rhyodacite, andesite, and obsidian.

Guaje Pumice Bed of the Otowi Member of the Bandelier Tuff, Qbog (170–175 ft bgs)

The Guaje Pumice Bed represents an ash- and pumice-fall deposit of rhyolitic tephra that forms the base of the Otowi Member. The Guaje deposit, recognized from 170 to 175 ft bgs, is estimated to be 5 ft thick. Drill cuttings in this interval contain abundant (up to 99% by volume) rounded, lustrous, vitric, phenocryst-poor pumice lapilli (up to 10 mm in diameter) with trace occurrences of small volcanic lithic fragments. The deposit is nonwelded and unconsolidated.

Cerros del Rio Volcanic Series, Tb 4 (175–950 ft bgs)

The Cerros del Rio volcanic series, encountered in R-57 from 175 to 950 ft bgs, locally forms a complex sequence of basaltic and dacitic lavas, pyroclastic deposits, and basaltic tephras interpreted to be of hydromagmatic origin. The sequence has a cumulative thickness of about 775 ft. The upper 2-ft layer, from 175 to 177 ft bgs, contains white siltstone and coarser clastic sediments interpreted to be gravels with soil development. Drill cuttings indicated at least three individual basalt lavas, each with a thin vesicular top and rubbly base, in a sequence of stacked flows from 177 to 378 ft bgs. Basalts in this sequence are generally porphyritic with phenocrysts (up to 5% by volume) of olivine and plagioclase enclosed in an aphanitic groundmass that is variably altered with local development of clays and possibly zeolite. Basaltic cinder deposits were indentified in the section from 378 to 408 ft bgs. A 172-ft-thick interval of basaltic tephra, containing abundant clasts of scoriaceous glassy lapilli cemented by yellowish palagonitic clay, was intersected from 408 to 580 ft bgs. These mafic volcanic sediments are interpreted to be maar-type hydromagmatic deposits. The basal part of the Cerros del Rio section, from 580 to 950 ft bgs, is formed of one, or possibly more, two-pyroxene dacitic lava flows. The dacitic portion of the section is estimated to be 370 ft thick. Lithologically, dacite throughout the interval is porphyritic with phenocrysts (up to 7% by volume) of black anhedral clinopyroxene, pale brown translucent orthopyroxene, rare euhedral hornblende, plagioclase, and frequent xenocrystic quartz set in an aphanitic groundmass that is locally altered. Plagioclase phenocrysts commonly exhibit glassy rinds. Quartz xenocrysts are invariably resorbed and exhibit distinctive orthopyroxene reaction rims. Alteration occurs in the form of clay and zeolite development.

Totavi Lentil of the Puye Formation, Tpft (950–1081.6 ft bgs)

Quartzo-feldspathic sediments representing the Totavi Lentil of the Puye Formation were encountered from 950 ft bgs to the R-57 borehole TD at 1081.6 ft bgs. The Totavi section has a minimum thickness of 131.6 ft. These silty fine-grained to gravel-rich sediments are moderately to well sorted and weakly to moderately indurated. Detrital materials are composed of mixed Precambrian crystalline and younger volcanic lithologies. The upper portion of the Totavi section contains abundant (up to 80% by volume) clasts composed of quartz, quartzite, microcline, granite, chert, and mica schist. The proportion of volcanic (dacite, andesite, and rhyolite) detritus relative to quartzo-feldspathic rocks increased with depth in the interval.

5.2 Groundwater

No indications of groundwater were noted while advancing 16-in. casing to 225.8 ft bgs. Open-hole drilling proceeded without any groundwater indications until 826.0 ft bgs in the middle dacitic lava flows of the Cerros del Rio volcanic series; drilling was stopped and a video log recorded a water level at 793.0 ft bgs. The standing water observed on the video log was attributed to drilling water. While advancing 12-in. casing, estimated water production of 15 gpm was noted in the dacitic lava flows of the lower Cerros del Rio volcanic series at 915.0 and 925.6 ft bgs and DTW was measured at 888.1 ft bgs. Drilling proceeded into the Puye Formation to 1003 ft bgs with estimated water production from 30 to 40 gpm. Drilling continued from 1003 to 1081.6 ft bgs (TD) with various water flow rates ranging from 10 to 40 gpm. The DTW stabilized at approximately 879.3 ft bgs on April 27, 2010, before well installation.

6.0 BOREHOLE LOGGING

Two video logs, an induction log, and three gamma logs were collected during the R-57 drilling project using Laboratory-owned equipment. A summary of video and geophysical logging runs is presented in Table 6.0-1.

6.1 Video Logging

A video log was made in the R-57 borehole on April 6, 2010, from ground surface to 385.0 ft bgs, with open borehole between 225.8 and 385.0 ft bgs. The video verified that no perched intermediate water was entering the 15-in. open borehole from 225.8 to 385.0 ft bgs.

The second video log was run in the R-57 borehole on April 10, 2010, from ground surface to 826.0 ft bgs, with open hole between 225.8 and 826.0 ft bgs. The video recorded a water level at 793.0 ft bgs. The video logs are presented on DVD as Appendix D included with this document.

6.2 Geophysical Logging

A natural gamma survey was made on April 6, 2010, between 0 and 385.0 ft bgs (open hole from 225.8 to 385.0 ft bgs), and natural gamma and induction logs were run on April 10, 2010, between 0 and 826.0 ft bgs (open hole between 225.8 and 826.0 ft bgs).

A final natural gamma survey was obtained on April 25, 2010, from 0 to1076.0 ft bgs inside the drill casing before well construction. Geophysical logging data are presented on CD as part of Appendix E included with this document.

7.0 WELL INSTALLATION

The R-57 well was installed between May 5 and June 8, 2010.

7.1 Well Design

The R-57 well was designed in accordance with the Consent Order. Appendix F contains the final well design report. NMED approved the final well design before installation. The well was designed with an upper screened interval between 910.0 and 930.5 ft bgs and a lower screened interval between 971.5 and 992.1 ft bgs. The R-57 well was designed with dual screens to monitor groundwater quality near the top of the regional aquifer within the lower Cerros del Rio volcanic series and deeper in the regional aquifer within the Puye Formation.

7.2 Well Construction

The R-57 monitoring well was constructed of 5.0-in. I.D./5.56-in. O.D., type A304 passivated stainless-steel threaded casing fabricated to American Society for Testing and Materials (ASTM) A312 standards. Screened sections used four 10-ft lengths of 5.0-in.-I.D. rod-based 0.020-in. wire-wrapped screens to make up the 20-ft-long upper and lower well screen intervals. Compatible external stainless-steel couplings (also type A304 stainless steel fabricated to ASTM A312 standards) were used to join all individual casing and screen sections. The coupled unions between threaded sections were approximately 0.7 ft long. All casing, couplings, and screens were steam- and pressure-washed on-site before installation. A 2-in. I.D. threaded/coupled steel tremie pipe (decontaminated before use) was used for delivery of backfill and annular fill materials downhole during well construction. Short lengths of 12-in. drill casing (21.6-ft casing and shoe, at a depth of 1060.0 to 1081.6 ft bgs) and 16-in. drill casing (7.2-ft casing and shoe, at a depth of 218.6 to 225.8 ft bgs) remain in the borehole. The 12-in. casing stub was encased in slough, while the 16-in. casing stub was encased in the upper bentonite seal.

A 21.7-ft-long stainless-steel sump was placed below the bottom of the lower well screen. Stainless-steel centralizers (two sets of four) were welded to the well casing approximately 2.0 ft above and below each screen. A Pulstar workover rig was used for all well construction activities. Figure 7.2-1 presents an as-built schematic showing construction details for the completed well.

Decontamination of the stainless-steel well casing, screens, and tremie pipe, along with mobilization of the Pulstar workover rig and initial well construction materials to the site, took place on May 4, 2010. On May 5 at 1045 h, the 5-in.-I.D. well casing was started into the borehole. The well casing was hung by wireline with the bottom at 1013.8 ft bgs.

The installation of annular materials began on May 7 after the bottom of the borehole was measured at 1053.2 ft bgs (approximately 28.4 ft of slough in borehole). From May 9 to May 13, the lower bentonite seal was installed from 997.3 to 1053.2 ft bgs using 26.1 ft^3 of 3/8-in. bentonite chips and ¼-in. bentonite pellets. The discrepancy between the calculated volume of 46.9 ft^3 versus the actual volume of 26.1 ft^3 for backfill within the lower seal interval was due to the formation sloughing after casing extraction and the inability to install bentonite inside the casing as it was extracted (as opposed to filter sand, which is routinely installed in this fashion).

From May 13 to May 15, the lower filter pack was installed from 965.0 to 997.3 ft bgs using 79.5 ft^3 of 10/20 silica sand. The filter pack was then surged to promote compaction. The filter pack volume exceeded the calculated filter pack volume of 23.0 ft^3 by approximately 246%. It is possible that the high air pressures used at the tricone bit during drilling (ahead of the casing) caused excessive formation loss in the unconsolidated silt, sand, and fine gravels of the Totavi Lentil. That effect, in combination with possible sloughing of the loose water-bearing sediments, may have resulted in a larger-diameter borehole. On May 15 the lower fine sand collar was installed above the lower filter pack from 960.9 to 965.0 ft bgs using 7.5 ft^3 of 20/40 silica sand. The actual volume of fine sand exceeded the calculated volume by 150% and was likely caused by the same reasons described for the filter pack sand discrepancy.

Installation of annular fill materials was temporarily suspended on May 16 to deploy an inflatable packer inside the well casing between the two screens. The inflatable packer was deployed before installing the middle bentonite seal in order to isolate the more productive lower screen zone from the relatively low-producing upper screen zone.

From May 16 to May 17, the middle bentonite seal was installed from 935.9 to 960.9 ft bgs using 23.8 ft^3 of 3/8-in. bentonite chips. The actual volume of bentonite exceeded the calculated volume by 34% and was likely due to an irregular and larger borehole diameter in the lowermost interval of the dacitic lavas. From May 17 to May 18, the upper filter pack was installed from 905.4 to 935.9 ft bgs using 30.0 ft^3 of 10/20 silica sand. Again, the actual filter pack volume exceeded the calculated volume of 21.8 ft^3 by 37%. On May 18, the upper fine sand collar was installed above the upper filter pack from 903.3 to 905.4 ft bgs using 4.0 ft^3 of 20/40 silica sand, which also exceeded the calculated volume of 1.5 ft^3. The filter pack and fine sand collar volume discrepancies were likely caused by the same factors described for the middle bentonite seal volume discrepancy.

From May 19 to June 7, the upper bentonite seal was installed from 59.9 to 903.3 ft bgs using 877.9 ft^3 of 3/8-in. bentonite chips. Installation of annular fill materials was temporarily suspended on June 6 to retrieve the packer. From June 7 to 8, the surface seal was installed from 3.0 to 59.9 ft bgs using 89.6 ft^3 of Portland Type I/II/V cement. Installation of the cement surface seal on June 8, 2010, at 1115 h marked the end of well construction. Table 7.2-1 lists the volumes of all materials used during well construction, and Figure 7.2-1 shows the completed well schematic.

Operationally, well construction proceeded smoothly, 12 h/d, 7 d/wk, from May 5 through June 8, 2010.

8.0 POSTINSTALLATION ACTIVITIES

Following well installation at R-57, the well was developed and aquifer tests were conducted. The wellhead and surface pad were constructed and a geodetic survey was performed. A dedicated Baski sampling system will be installed. Site restoration activities will be completed following the final disposition of contained drill cuttings and groundwater, per the NMED-approved waste disposal decision trees.

8.1 Well Development

Well development was conducted between June 9 and 14, 2010. Initially, both screened intervals were bailed and swabbed to remove formation fines in the filter pack and well sump. Bailing continued until water clarity visibly improved. Final development was then performed with a submersible pump.

The swabbing tool employed was a 4.5-in.-O.D., 1-in.-thick nylon disc attached to a weighted steel rod. The wireline-conveyed tool was drawn repeatedly across the screened interval, causing a surging action across the screen and filter pack. The bailing tool employed was a 4.0-in.-O.D. by 21.0-ft-long carbon-steel bailer with a total capacity of 12 gal. Using the bailer, water was repeatedly withdrawn from the well and dumped into the cuttings pit. Approximately 390 gal. of groundwater was removed during bailing activities. After bailing, a 5-horsepower (hp), 4-in. Berkeley submersible pump and inflatable packers located above and below the pump were installed in the well for the final pumping stage of well development of each screen.

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 were collected from each screen for TOC analysis. 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 (NTU), respectively.

Table B-1.2-1 in Appendix B presents a summary of volumes purged during each phase of development as well as measured and calculated water quality parameters.

Upper screen

On June 11 and 12, the 5-hp pump was used to purge the upper screen from bottom to top in 2-ft increments from 928 to 908 ft bgs. On June 12, the pump was set at 930 ft bgs with the packers inflated. The pump was observed to cavitate, but the water level remained 1.0 ft above the top of the well screen. Purged water from the upper screened interval displayed turbidity values less than 5 NTU. Approximately 4070 gal. of groundwater was purged during upper screen well development.

Lower screen

On June 13, the development pump was set at 971 ft bgs and the lower screen was purged from top to bottom in 2-ft increments from 971 to 992 ft bgs. After pumping throughout the lower screened interval, the pump was set at 965 ft bgs and the packers were inflated. Purged water from the lower screened interval immediately displayed turbidity values less than 5 NTU. Approximately 4780 gal. of groundwater was purged during lower screen well development.

Approximately 9240 gal. of groundwater was purged at R-57 during well-development activities. Another 49,082 gal. was purged during aquifer testing. Total groundwater purged during postinstallation activities from both screened intervals combined was 58,322 gal.

8.1.1 Well Development Field Parameters

Field parameters during well development were measured at well R-57 by collecting aliquots of groundwater from the discharge pipe with the use of a flow-through cell. A further discussion of well-development field parameters is presented in Appendix B; Table B-1.2-1 lists field parameters measured during development and aquifer testing.

During development of the upper screen, measurements of pH and temperature varied from 7.81 to 7.93 and from 22.41°C to 22.70°C, respectively. Concentrations of DO varied from 6.17 to 6.27 mg/L. Corrected oxidation-reduction potential (Eh) values ranged from 265.5 to 279.2 millivolts (mV). Specific conductance varied from 140 to 132 microsiemens per centimeter (µS/cm), and turbidity values varied from 2.0 to 2.7 NTU. The final parameters for the upper screen at the end of development were pH of 7.83, temperature of 22.57°C, specific conductance of 135 µS/cm, and turbidity of 2.1 NTU.

During development of the lower screen, measurements of pH and temperature varied from 7.87 to 8.13 and from 21.51°C to 22.59°C, respectively. Concentrations of DO varied from 6.43 to 3.95 mg/L. Eh values ranged from 235.4 to 255.3 mV. Specific conductance varied from 132 to 150 µS/cm, and turbidity values ranged between 5.0 and 2.2 NTU. The final parameters for the lower screen at the end of development were pH of 7.89, temperature of 22.26°C, specific conductance of 146 µS/cm, and turbidity of 3.2 NTU.

8.2 Aquifer Testing

Aquifer pumping tests were conducted at R-57 between June 22 and July 1, 2010. Several short-duration tests with short-duration recovery periods were performed on the first day of testing each of the two screened intervals.

A10-hp pump was used for the aquifer test on the lower screened interval. Initially, the pump’s flow rate was set to approximately 16.1 gpm. Approximately 25,588 gal. of groundwater was purged from the lower screened interval. Additionally, 12,681 gal. of groundwater was purged following the 24-h aquifer test. A 24-h recovery period completed the testing of the lower screened interval.

A 5-hp pump was used for the aquifer test on the upper screened interval. A 24-h test followed by a 24-h recovery period completed the testing of the upper screened interval. Approximately 10,813 gal. of groundwater was purged from the upper screened interval at a flow rate of approximately 7.1 gpm.

Turbidity, temperature, pH, DO, ORP, and specific conductance parameters were measured during the 24-h tests. In addition, water samples were collected for TOC analysis. Water quality parameters and TOC results are presented in Appendix B. The R-57 aquifer test results are presented in Appendix C. Approximately 49,082 gal. of groundwater was purged during aquifer testing.

8.3 Dedicated Sampling System Installation

The dedicated sampling system for R-57 will be installed in November 2010, shortly after the due date for this report. Figures 8.3-1a and 8.3-1b, included in this report, will be revised with the final sampling system specifications and submitted as a separate package to NMED following the sampling system installation.

The system will be a Baski, Inc.-manufactured system that uses a single 3-hp, 4-in.-O.D. environmentally retrofitted Grundfos submersible pump capable of purging each screened interval discretely via pneumatically actuated access port valves. The system will include a Viton-wrapped isolation packer between the screened intervals. The pump riser pipe will consist of threaded and coupled nonannealed 1-in.-diameter stainless steel. Two 1-in.-diameter, schedule 80 polyvinyl chloride (PVC) tubes for dedicated transducers will be banded to the pump riser. 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 extends from a threaded end cap at the bottom of the PVC tube through the isolation packer to measure water levels in the lower screened interval. Two In-Situ Level Troll 500 transducers will be installed in the PVC tubes to monitor water levels in each screened interval.

The planned sampling system components for R-57 are shown in Figure 8.3-1a. Figure 8.3-1b lists the technical notes and planned sampling system components for the well.

8.4 Wellhead Completion

A reinforced concrete surface pad, 10 ft × 10 ft × 6 in. thick, was installed at the R-57 wellhead. The concrete pad was slightly elevated above the ground surface and crowned to promote runoff. The pad will provide long-term structural integrity for the well. A brass survey pin was embedded in the northwest corner of the pad. A 16-in.-I.D. steel protective casing with a locking lid was installed around the stainless-steel well riser. A total of four bollards, painted yellow for visibility, are set at the outside edges of the pad to protect the well from traffic. All four bollards are designed for easy removal to allow access to the well. Details of the wellhead completion are shown in Figure 8.3-1a.

8.5 Geodetic Survey

A New Mexico licensed professional land surveyor conducted a geodetic survey on August 13, 2010 (Table 8.5-1). The survey data conform 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 relative to the New Mexico State Plane Coordinate System Central Zone (NAD 83); elevation is expressed in feet above mean sea level (amsl) 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 for the R-57 monitoring well.

8.6 Waste Management and Site Restoration

Waste generated from the R-57 project included drilling fluids, purged groundwater, drill cuttings, decontamination water, and contact waste. A summary of the waste characterization samples collected during drilling, well construction, and development of the R-57 well is presented in Table 8.6-1.

All waste streams produced during drilling and development activities were sampled in accordance with the “Waste Characterization Strategy Form for Regional Wells R-56 and R-57 at TA-54” (LANL 2010, 108753).

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 (WCSF) and the standard operating procedure (SOP) ENV-RCRA-SOP-010, Land Application of Groundwater. If it is determined the drilling fluids are nonhazardous but cannot meet the criteria for land application, they 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, Land Application of Drill Cuttings. If the drill cuttings do not meet the criterion for land application, they will be disposed of at an authorized facility. Decontamination fluid used for cleaning equipment is containerized. The fluid waste was sampled and will be 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, purge water, and decontamination fluid.

Site restoration activities will include removing drilling fluids and cuttings from the pit and managing the fluids and cuttings in accordance with applicable SOPs, 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-57 were performed as specified in the “Drilling Plan for Regional Aquifer Well R-57,” (TerranearPMC 2010, 109125).

10.0 ACKNOWLEDGMENTS

Boart Longyear drilled and installed the R-57 monitoring well.

David C. Schafer designed, implemented, and analyzed the aquifer tests.

LANL personnel ran downhole video equipment.

Terranear PMC provided oversight on all preparatory and field-related activities.

11.0 REFERENCES AND MAP DATA SOURCES

11.1 References

The following list includes all documents cited in this report. 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), 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), February 24, 2010. "Waste Characterization Strategy Form for Regional Wells R-56 and R-57 at TA-54, Regional Well Installation and Corehole Drilling," Los Alamos, New Mexico. (LANL 2010, 108753)

LANL (Los Alamos National Laboratory), March 2010. "Drilling Work Plan for Regional Aquifer Well R-57," Los Alamos National Laboratory document LA-UR-10-0992, Los Alamos, New Mexico. (LANL 2010, 108861)

TerranearPMC, March 2010. "Drilling Plan for Regional Aquifer Well R-57," plan prepared for Los Alamos National Laboratory, Los Alamos, New Mexico. (TerranearPMC 2010, 109125)

11.2 Map Data Sources

Point Feature Locations of the Environmental Restoration Project Database; Los Alamos National Laboratory, Waste and Environmental Services Division, EP2008-0109; 12 April 2010.

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 28 May 2009.

Dirt Road Arcs; Los Alamos National Laboratory, KSL Site Support Services, Planning, Locating and Mapping Section; 06 January 2004; as published 28 May 2009.

Structures; Los Alamos National Laboratory, KSL Site Support Services, Planning, Locating and Mapping Section; 06 January 2004; as published 28 May 2009.

Technical Area Boundaries; Los Alamos National Laboratory, Site Planning & Project Initiation Group, Infrastructure Planning Division; 4 December 2009.

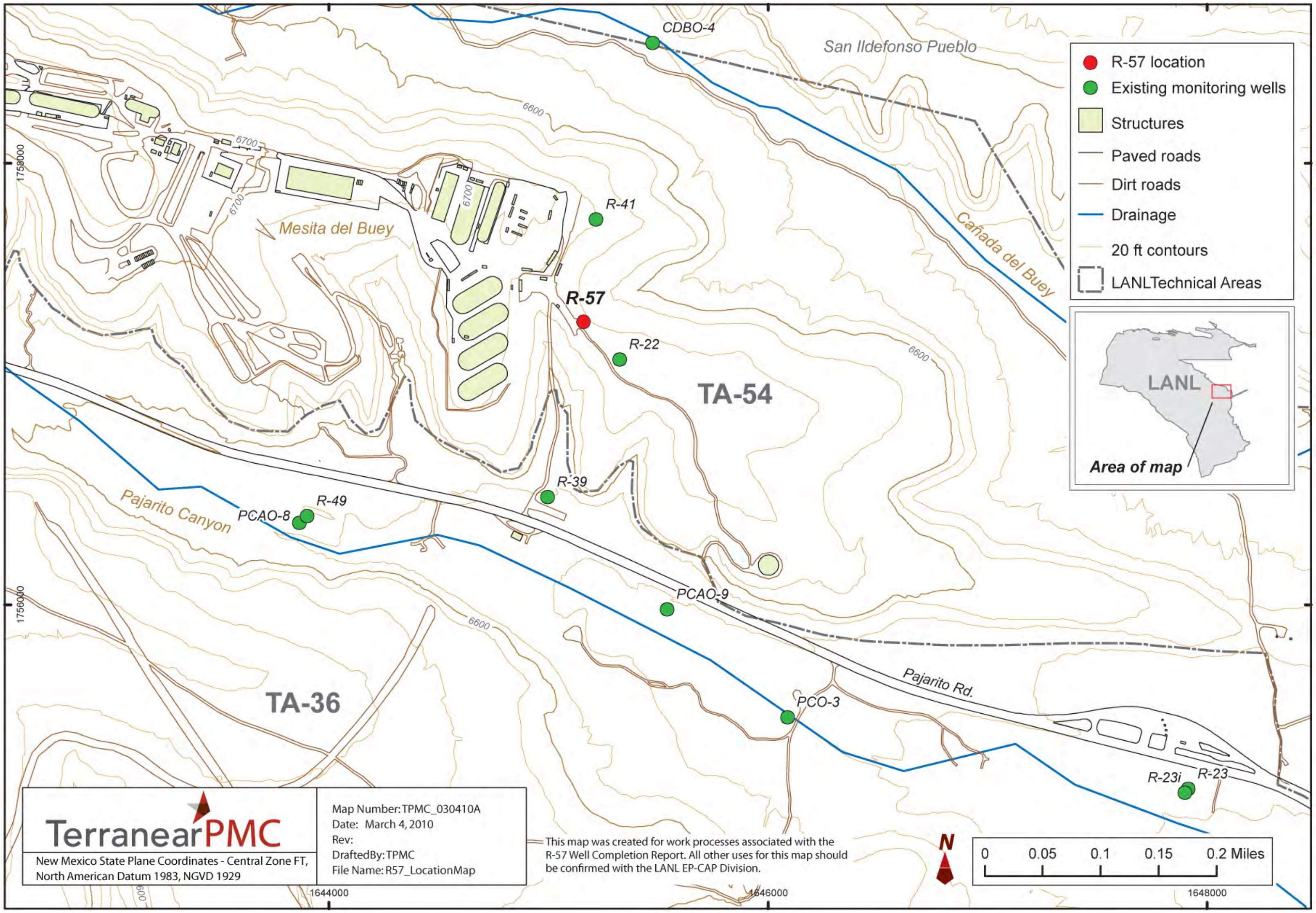

Figure 1.0-1 Location of monitoring well R-57

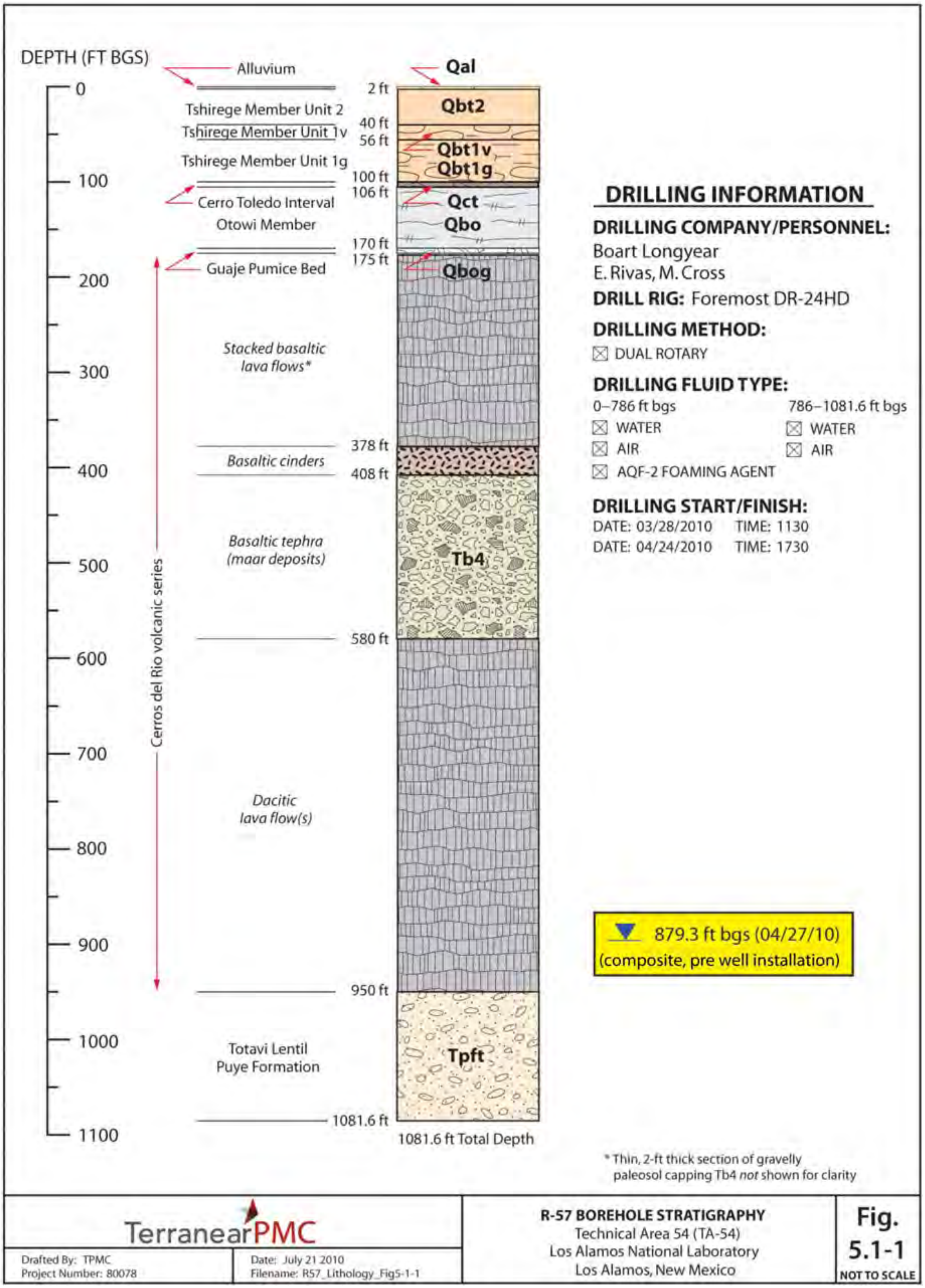

Figure 5.1-1 Monitoring well R-57 borehole stratigraphy

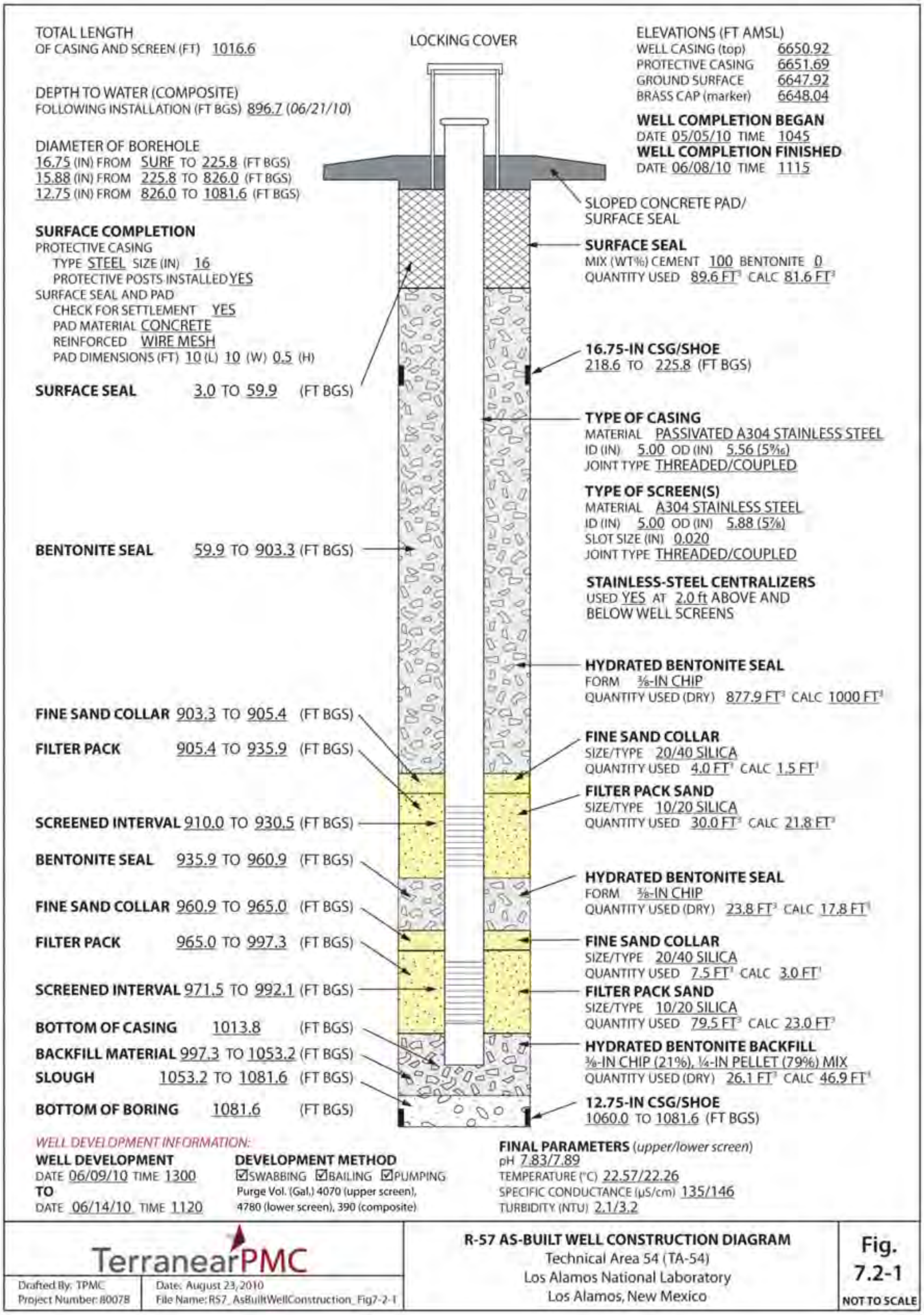

Figure 7.2-1 Monitoring well R-57 as-built well construction diagram

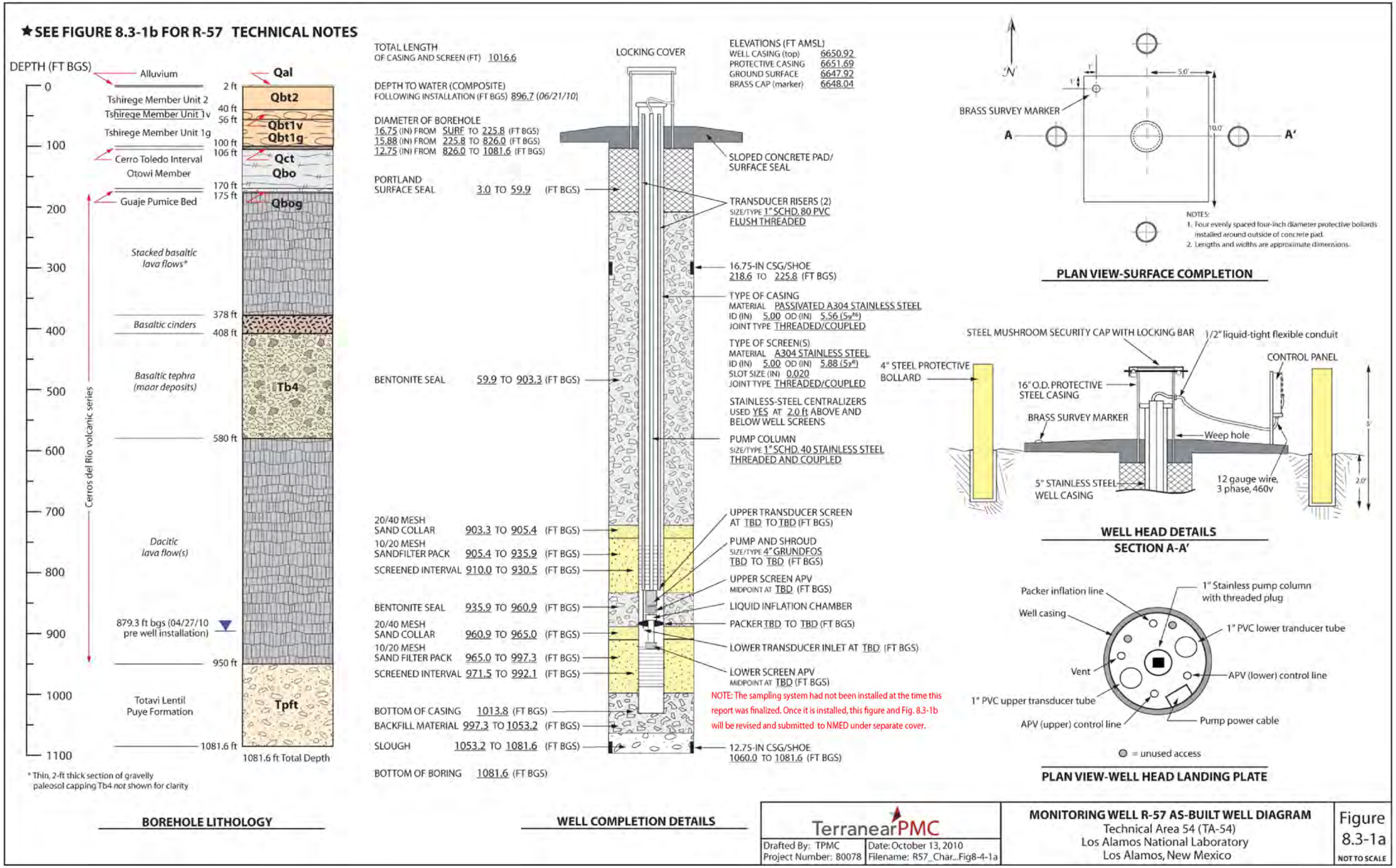

Figure 8.3-1a As-built schematic for regional aquifer monitoring well R-57

R-57 TECHNICAL NOTES:

SURVEY INFORMATION*

Brass Marker

Northing: 1757337.71 ft
Easting: 1645109.00 ft
Elevation: 6648.04 ft AMSL

Well Casing (top of stainless steel)

Northing: 1757332.04 ft
Easting: 1645108.88 ft
Elevation: 6650.92 ft AMSL

BOREHOLE GEOPHYSICAL LOGS

LANL: Video, Natural Gamma Ray, Induction

DRILLING INFORMATION

Drilling Company
Boart Longyear

Drill Rig
Foremost DR-24HD

Drilling Methods
Dual Rotary
Fluid-assisted air rotary, Foam-assisted air rotary

Drilling Fluids
Air, potable water, AQF-2 Foam (to 786 ft bgs)

MILESTONE DATES

Drilling
Start: 03/28/2010
Finished: 04/24/2010

Well Completion
Start: 05/05/2010
Finished: 06/08/2010

Well Development
Start: 06/09/2010
Finished: 06/14/2010

WELL DEVELOPMENT

Development Methods
Performed swabbing, bailing, and pumping
Total Volume Purged: 9240 gal. (4070 gal. upper screen, 4780 gal. lower screen, 390 gal. composite)

Parameter Measurments (Final, upper screen/lower screen)

pH: 7.83/7.89
Temperature: 22.57/22.26°C
Specific Conductance: 135/146 µS/cm
Turbidity: 2.1/3.2 NTU

AQUIFER TESTING

Constant Rate Pumping Test

Upper Screen
Water Produced: 10,813 gal.
Average Flow Rate: 7.1 gpm
Performed on: 06/28–07/01/2010

Lower Screen
Water Produced: 38,269 gal.
Average Flow Rate: 16.1 gpm
Performed on: 06/22–27/2010

DEDICATED SAMPLING SYSTEM

Pump
Make: Grundfos
Model: TBD
TBD U.S. gpm, APVs (Acccess Port Valves) midpoints at TBD (upper) and TBD (lower) ft bgs
Environmental retrofit

Motor
Make: Franklin Electric
Model: TBD
TBD hp, 3-phase

Pump Column
1-in. threaded/coupled schd. 40, ASTM pickled and passivated A312 stainless steel tubing

Transducer Tubes
2 × 1-in. flush threaded schd. 80 PVC tubing
Upper 0.01-in. slot screen at TBD–TBD ft bgs,
Lower flexible tube from transducer set at TBD ft bgs

Transducers
Make: In-Situ, Inc.
Model: Level TROLL 500
30 psig range (vented)
S/Ns: TBD, TBD

NOTE: The sampling system had not been installed at the time this report was finalized. Once it is installed, this figure and Fig. 8.3-1a will be revised and submitted to NMED under separate cover.

NOTES:
* Coordinates based on New Mexico State Plane Grid Coordinates, Central Zone (NAD83); Elevation expressed in feet amsl using the National Geodetic Vertical Datum of 1929.

TerranearPMC
Drafted By: TPMC
Project Number: 80078
Date: August 23, 2010
Filename: R57_TechnicalNotes_Fig8-3-1b

R-57 TECHNICAL NOTES
Technical Area 54 (TA-54)
Los Alamos National Laboratory
Los Alamos, New Mexico

Figure 8.3-1b
NOT TO SCALE

Figure 8.3-1b As-built technical notes for monitoring well R-57

Table 3.1-1
Fluid Quantities Used during R-57 Drilling and Well Construction

Date	Water (gal.)	Cumulative Water (gal.)	AQF-2 Foam (gal.)	Cumulative AQF-2 Foam (gal.)
Drilling				
03/28/10	650	650	0	0
03/29/10	800	1450	0	0
03/30/10	500	1950	0	0
04/03/10	100	2050	1	1
04/04/10	2500	4550	20	21
04/05/10	3500	8050	40	61
04/08/10	3000	11,050	40	101
04/09/10	2500	13,550	20	121
04/17/10	500	14,050	0	121
04/18/10	1000	15,050	0	121
04/19/10	1200	16,250	0	121
04/20/10	1500	17,750	0	121
04/21/10	1200	18,950	0	121
04/23/10	3000	21,950	0	121
04/24/10	3500	25,450	0	121
Well Construction				
05/07/10	4500	4500	n/a*	n/a
05/08/10	2000	6500	n/a	n/a
05/09/10	300	6800	n/a	n/a
05/10/10	5700	12,500	n/a	n/a
05/11/10	1500	14,000	n/a	n/a
05/12/10	4500	18,500	n/a	n/a
05/13/10	3500	22,000	n/a	n/a
05/14/10	3500	25,500	n/a	n/a
05/15/10	1800	27,300	n/a	n/a
05/16/10	1200	28,500	n/a	n/a
05/17/10	6500	35,000	n/a	n/a
05/18/10	3000	38,000	n/a	n/a
05/19/10	7000	45,000	n/a	n/a
05/21/10	12,000	57,000	n/a	n/a
05/23/10	9000	65,000	n/a	n/a
06/02/10	3000	68,000	n/a	n/a
06/03/10	3500	71,500	n/a	n/a
06/04/10	3000	74,500	n/a	n/a

Table 3.1-1, continued

Date	Water (gal.)	Cumulative Water (gal.)	AQF-2 Foam (gal.)	Cumulative AQF-2 Foam (gal.)
Well Construction				
06/05/10	1500	76,000	n/a	n/a
06/06/10	500	76,500	n/a	n/a
06/07/10	780	77,280	n/a	n/a
06/08/10	210	77,490	n/a	n/a
Total Water Volume (gal.)				
R-57	102,940			

Note: Foam use terminated at 786.0 ft bgs during drilling; none used during well construction.
* n/a = Not applicable.

Table 4.2-1
Summary of Groundwater Screening Samples Collected during Drilling, Well Development, and Aquifer Testing of Well R-57

Location ID	Sample ID	Date Collected	Collection Depth (ft bgs)	Sample Type	Analysis
Drilling					
R-57	GW57-10-15480	04/20/10	925.6	Groundwater; airlifted	Anions, metals, H3, VOC
R-57	Not submitted	04/25/10	1081.0	Groundwater; airlifted	Not submitted for analysis*
Well Development					
R-57	GW57-10-15520	06/12/10	910−930	Groundwater, pumped	TOC
R-57	GW57-10-15521	06/13/10	971−992	Groundwater, pumped	TOC
R-57	GW57-10-15522	06/14/10	971−992	Groundwater, pumped	TOC
Aquifer Testing					
R-57	GW57-10-15523	06/24/10	971.5−992.1	Groundwater, pumped	TOC
R-57	GW57-10-15524	06/24/10	971.5−992.1	Groundwater, pumped	TOC
R-57	GW57-10-15525	06/24/10	971.5−992.1	Groundwater, pumped	TOC
R-57	GW57-10-15526	06/24/10	971.5−992.1	Groundwater, pumped	TOC
R-57	GW57-10-15527	06/25/10	971.5−992.1	Groundwater, pumped	TOC
R-57	GW57-10-15528	06/25/10	971.5−992.1	Groundwater, pumped	TOC
R-57	GW57-10-15529	06/30/10	910.0−930.5	Groundwater, pumped	TOC
R-57	GW57-10-15530	06/30/10	910.0−930.5	Groundwater, pumped	TOC
R-57	GW57-10-15531	06/30/10	910.0−930.5	Groundwater, pumped	TOC
R-57	GW57-10-15532	070/1/10	910.0−930.5	Groundwater, pumped	TOC

*04/25/10 water sample was too sediment laden to decant enough water for analysis.

Table 6.0-1
R-57 Logging Runs

Date	Type	Depth (ft bgs)	Description
04/06/10	Video, natural gamma	Surface to 385 (open hole from 225.8 to 385 ft bgs).	LANL personnel ran video and natural gamma logs after the 15-in. open borehole was drilled to 426.0 ft bgs. Boulder at 385 ft bgs blocked geophysical tools from reaching 426.0 ft bgs.
04/10/10	Video, natural gamma, induction	Surface to 826.0 (open hole from 225.8 to 826.0 ft bgs).	LANL personnel ran video, natural gamma, and induction logs after the 15-in. open borehole was drilled to 826.0 ft bgs.
04/25/10	Natural gamma	Surface to 1076 ft bgs.	LANL personnel ran natural gamma log inside the 12-in. drill casing at TD.

Table 7.2-1
R-57 Monitoring Well Annular Fill Materials

Material	Volume
Upper surface seal: cement slurry	89.6 ft^3
Upper bentonite seal: bentonite chips	877.9 ft^3
Fine sand collar: 20/40 silica sand	4.0 ft^3
Filter pack: 10/20 silica sand	30.0 ft^3
Middle bentonite seal: bentonite chips	23.8 ft^3
Fine sand collar: 20/40 silica sand	7.5 ft^3
Filter pack: 10/20 silica sand	79.5 ft^3
Backfill: bentonite chips/pellets	26.1 ft^3

Table 8.5-1
R-57 Survey Coordinates

Identification	Northing	Easting	Elevation
R-57 brass cap embedded in pad	1757337.71	1645108.00	6648.04
R-57 ground surface near pad	1757329.59	1645103.66	6647.92
R-57 top of 16-in. protective casing	1757331.70	1645108.71	6651.69
R-57 top of stainless-steel well casing	1757332.04	1645108.88	6650.92

Note: All coordinates are expressed as New Mexico State Plane Coordinate System Central Zone (NAD 83); elevation is expressed in ft amsl using the National Geodetic Vertical Datum of 1929.

Table 8.6-1
Summary of Waste Samples Collected during Drilling and Development of R-57

Location ID	Sample ID	Date Collected	Description	Sample Type
R-57	WST57-10-15067	04/14/10	Decon fluid, replaced mechanical parts (unfiltered)	Liquid
R-57	WST57-10-15063	04/14/10	Decon fluid, replaced mechanical parts (filtered)	Liquid
R-57	WST57-10-15071	04/14/10	Decon fluid, replaced mechanical parts (duplicate)	Liquid
R-57	WST57-10-15075	04/14/10	Decon fluid, replaced mechanical parts	Liquid
R-57	WST57-10-15068	05/03/10	Decon fluid, well casing (unfiltered)	Liquid
R-57	WST57-10-15064	05/03/10	Decon fluid, well casing (filtered)	Liquid
R-57	WST57-10-15072	05/03/10	Decon fluid, well casing (duplicate)	Liquid
R-57	WST57-10-15076	05/03/10	Decon fluid, well casing	Liquid
R-57	WST57-10-16977	05/03/10	NMSW*	Liquid
R-57	WST57-10-16979	05/03/10	NMSW	Liquid
R-57	WST57-10-15080	06/15/10	Development water (unfiltered)	Liquid
R-57	WST57-10-15079	06/15/10	Development water (filtered)	Liquid
R-57	WST57-10-15081	06/15/10	Development water (duplicate)	Liquid
R-57	WST57-10-15082	06/15/10	Development water	Liquid
R-57	WST57-10-17030	06/16/10	Drilling fluids (unfiltered)	Liquid
R-57	WST57-10-17029	06/16/10	Drilling fluids (filtered)	Liquid
R-57	WST57-10-17031	06/16/10	Drilling fluids (duplicate)	Liquid
R-57	WST57-10-17032	06/16/10	Drilling fluids	Liquid
R-57	WST57-10-16978	07/16/10	NMSW	Liquid
R-57	WST57-10-16980	07/16/10	NMSW	Liquid
R-57	WST57-10-15065	07/27/10	Decon fluid, pump equipment	Liquid
R-57	WST57-10-15069	07/27/10	Decon fluid, pump equipment	Liquid
R-57	WST57-10-15073	07/27/10	Decon fluid, pump equipment (duplicate)	Liquid
R-57	WST57-10-15077	07/27/10	Decon fluid, pump equipment	Liquid

* NMSW = New Mexico Special Waste.

Appendix A

Borehole R-57 Lithologic Log

BOREHOLE IDENTIFICATION (ID): R-57	**TECHNICAL AREA (TA):** 54	**PAGE:** 1 of 21
DRILLING COMPANY: Boart Longyear Company	**START DATE/TIME:** 3/28/2010/ 1130	**END DATE/TIME:** 4/24/2010/1730
DRILLING METHOD: Dual Rotary	**MACHINE**: Foremost DR24 HD	**SAMPLING METHOD:** Grab
GROUND ELEVATION: 6647.92 ft AMSL		**TOTAL DEPTH:** 1081.6 ft
DRILLERS: E. Rivas, M. Cross	**SITE GEOLOGIST:** J. R. Lawrence	

DEPTH (ft bgs)	LITHOLOGY	LITHOLOGIC SYMBOL	NOTES
0–2	**ALLUVIUM:** Construction fill—light pinkish gray (5YR 8/1) mixed chips of indurated Qbt 2 tuff, quartz and sanidine crystals, and exotic subrounded to subangular clasts (dacite, quartzite) indicating imported base course gravels used in drill pad construction; silty ash matrix. Disturbed section no more than 2 ft thick.	**Qal**	Note: Drill cuttings for microscopic and descriptive analysis were collected at 5-ft intervals from 0 ft to borehole TD at 1081.6 ft bgs. Alluvial sediments, encountered from 0 ft to 2 ft, are approximately 2 ft thick.
2–10	**UNIT 2 OF THE TSHIREGE MEMBER OF THE BANDELIER TUFF:** Rhyolite Tuff—very light pinkish gray (5YR 8/1), poorly to moderately welded, weak to moderately indurated, crystal-rich, pumice-bearing, lithic-bearing, strongly weathered. 2'–10' WR: abundant silty fine volcanic ash. +10F: 90–95% fragments of indurated pumiceous, crystal-bearing ash flow tuff [i.e., ignimbrite); 5–10% exotic clasts of indurated white fine-grained volcanic/tuffaceous sandstone with ash matrix exhibiting angular sand grains (up to 1 mm) of quartz crystal, rocks of intermediate volcanic composition, and quartzite(?). +35F: 85–90% free quartz and sanidine crystals; 10–15% tuff fragments and rare volcanic lithic grains.	**Qbt 2**	Unit 2 of the Tshirege Member of the Bandelier Tuff (Qbt 2), encountered from 2 ft to 40 ft bgs, is estimated to be 38 ft thick.
10–30	Rhyolite Tuff—light pinkish gray (5YR 8/1), samples predominantly of tuff fragments, poorly welded, weak to moderately indurated, pumiceous (pumices devitrified), crystal-rich, lithic-poor, strongly weathered. 10'– 30' WR: variable abundances of glassy volcanic ash. +10F: 95–100% fragments of crystal-bearing ash flow tuff (i.e. ignimbrite); 5–10% dacitic and andesitic lithics (up to 10 mm). The ash-flow tuff is composed of 15–20% quartz and sanidine crystals, 10–15% small (up to 4 mm) pumice lapilli that are strongly devitirified and slightly deformed (i.e. slightly compressed, indicating poor degree of welding), rare dacitic lithic fragments set in a matrix of glassy to weathered volcanic ash. Note exotic fragments of volcanic sandstone in interval 15' –20'. +35F: 90–95% quartz and sanidine crystals; 5–10% tuff fragments and rare lithic grains.	**Qbt 2**	

BOREHOLE IDENTIFICATION (ID): R-57	**TECHNICAL AREA (TA):** 54	**PAGE:** 2 of 21
DRILLING COMPANY: Boart Longyear Company	**START DATE/TIME:** 3/28/2010/ 1130	**END DATE/TIME:** 4/24/2010/1730
DRILLING METHOD: Dual Rotary	**MACHINE**: Foremost DR24 HD	**SAMPLING METHOD:** Grab
GROUND ELEVATION: 6647.92 ft AMSL		**TOTAL DEPTH:** 1081.6 ft
DRILLERS: E. Rivas, M. Cross	**SITE GEOLOGIST:** J. R. Lawrence	

DEPTH (ft bgs)	LITHOLOGY	LITHOLOGIC SYMBOL	NOTES
30–40	Rhyolite Tuff—pinkish gray (5YR 8/1) poorly welded, pumiceous, crystal-rich, lithic–poor. Samples predominantly of indurated fragments of crystal-rich tuff. 30’–35’ WR: abundant fine ash, glassy to weathered. +10F: 100% fragments of indurated tuff. 35’–40’ +10F: 75–85% large (up to 4 mm) quartz and sanidine crystals; 20–25% tuff fragments; 2–5% volcanic fragments. +35F: 95% quartz and sanidine crystals; 5% tuff fragments; trace volcanic lithic fragments.	Qbt 2	The Qbt 2−Qbt 1v contact, estimated to be at 40 ft bgs, is based primarily on interpretation of natural gamma log.
40–56	**UNIT 1v OF THE TSHIREGE MEMBER OF THE BANDELIER TUFF:** RhyoliteTuff—very pale orange (10YR 8/2), poorly welded, weakly to moderately indurated, pumiceous, crystal-bearing, lithic-bearing. 40’–45’ WR: abundant weathered, silty volcanic ash. +10F: 80–85% fragments of indurated crystal tuff; 15–20% subangular to subrounded fragments of intermediate volcanic composition. 45’–55’ WR: abundant weathered, silty volcanic ash. +10F: 70–80% fragments of pale pinkish to locally orange (i.e., limonite-stained) ash-flow tuff [i.e., ignimbrite containing 15–20% quartz and sanidine crystals, 15–25% devitrified pumices that are compressed with sugary textures (i.e., recystallized glass), 1–2% volcanic lithics in a matrix of fine weathered volcanic ash]; 20–30% volcanic lithic fragments (up to 10 mm) predominantly of light gray dacite. +35F: 75–80% quartz and sanidine crystals, 15–20% ash-flow tuff fragments, 3–5% volcanic lithic fragments. 55’– 56’ +10F: 70–75% fragments of pumiceous crystal-tuff, light pink to orange, containing weakly compressed pumices that exhibit both devitrified and somewhat glassy textures; 20–25% angular to subrounded dacitic lithic fragments.	Qbt 1v	Unit 1v of the Tshirege Member of the Bandelier Tuff (Qbt 1v), encountered from 40 ft to 56 ft bgs, is estimated to be 16 ft thick. The Qbt 1v–Qbt 1g contact, estimated to be at 56 ft bgs, is based on cuttings examination and interpretation of the natural gamma log curve.

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DRILLING COMPANY: Boart Longyear Company	**START DATE/TIME:** 3/28/2010/ 1130	**END DATE/TIME:** 4/24/2010/1730
DRILLING METHOD: Dual Rotary	**MACHINE**: Foremost DR24 HD	**SAMPLING METHOD:** Grab
GROUND ELEVATION: 6647.92 ft AMSL		**TOTAL DEPTH:** 1081.6 ft
DRILLERS: E. Rivas, M. Cross	**SITE GEOLOGIST:** J. R. Lawrence	

DEPTH (ft bgs)	LITHOLOGY	LITHOLOGIC SYMBOL	NOTES
56–90	**UNIT 1g OF THE TSHIREGE MEMBER OF THE BANDELIER TUFF:** Rhyolite Tuff—pinkish orange gray (10YR 7/4), poorly welded, weakly indurated, strongly pumiceous, crystal-bearing, lithic-bearing. Samples contain predominantly fragments of glassy pumice. 56'– 85' WR/ +10F: 85–90% large fragments (up to 15 mm) of pinkish orange glassy, fibrous-textured, quartz- and sanidine-phyric pumices [pumices becoming more lustrous (vitreous) with depth]; 10–15% subangular volcanic lithics (dacite, obsidian). +35F: 30–40% glassy pumice fragments; 60–70% quartz and sanidine crystals; 2–3% volcanic lithics. 85'– 90' WR/ +10: 100% subrounded (milled during drilling) vitreous pumice fragments with somewhat paler color than above, quartz- and sanidine-phyric. +35F: 50–60% glassy pumice fragments; 40–50% quartz and sanidine crystals; 2–3% volcanic lithics.	**Qbt 1g**	Unit 1g of the Tshirege Member of the Bandelier Tuff (Qbt 1g), encountered from 56 ft to 100 ft bgs, is estimated to be 44 ft thick. Note: color change of pumices to light orange in interval 60'– 65' corresponds to change to glassy (vitric) pumiceous textures.
90–100	Rhyolite Tuff—very pale orange (10YR 8/2) poorly welded, weakly indurated, pumiceous, crystal-bearing; lithic-bearing. 90'– 100' +10F: 95–97% very pale orange to white angular, glassy pumice fragments, quartz-and sanidine-phyric; 3–5% angular lithic fragments (hornblende-dacite, andesite).	**Qbt 1g**	The basal Qbt 1g contact is estimated to be at 100 ft bgs based on cuttings examination and interpretation of the natural gamma log curve.
100–106	**CERRO TOLEDO INTERVAL:** Tuffaceous Sediments—very pale orange (10YR 8/2) non-welded, weakly indurated, pumiceous. 100'–106' WR: abundant pale orange volcanic ash. +10F: 95% very pale orange to white glassy pumice fragments; 5% fragments of indurated fine-grained tuffaceous sandstone. +35F: 65–70% quartz and sanidine crystals; 25–30% fragments of fine-grained sandstone and siltstone; 5–7% subangular to subrounded grains of dacite and andesite.	**Qct**	Note: Tuffaceous sediments are noted as a minor constituent in sample intervals 100'–105' and 105'–110'. A thin sedimentary layer, possibly representing Cerro Toledo (Qct) sediments, is interpreted to occur from 100 ft to 106 ft bgs

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DRILLING COMPANY: Boart Longyear Company	**START DATE/TIME:** 3/28/2010/ 1130	**END DATE/TIME:** 4/24/2010/1730
DRILLING METHOD: Dual Rotary	**MACHINE**: Foremost DR24 HD	**SAMPLING METHOD:** Grab
GROUND ELEVATION: 6647.92 ft AMSL		**TOTAL DEPTH:** 1081.6 ft
DRILLERS: E. Rivas, M. Cross	**SITE GEOLOGIST:** J. R. Lawrence	

DEPTH (ft bgs)	LITHOLOGY	LITHOLOGIC SYMBOL	NOTES
106–110	**OTOWI MEMBER OF THE BANDELIER TUFF:** Rhyolite Tuff—very pale orange (10YR 8/2) to light brown (5YR 6/4) poorly welded, weakly indurated, crystal-bearing, lithic-bearing. 106’– 110’ +10F: 90% white and pale orange fibrous, glassy, quartz- and sanidine-phyric pumice fragments; 1–2% fragments of fine-grained pumiceous sandstone; 3–5% volcanic lithic fragments (dacite). +35F: 30–40% quartz and sanidine crystals; 30–40% white glassy pumices; 15–20% fine-grained vitric tuff; 7–10% volcanic lithic fragments.	**Qbo**	Otowi Member ash flows of the Bandelier Tuff (Qbo), encountered from 106 ft to 170 ft bgs, are estimated to be 64 ft thick.
110–115	Rhyolite Tuff—grayish orange pink (5YR 7/2), poorly welded, pumiceous, crystal-bearing, lithic-bearing. 110’– 115’ WR: abundant earthy, weathered, fine-grained volcanic ash. +10F: 85% white to very pale tan, glassy, quartz- and sanidine-phyric pumice fragments; 15% angular to subangular volcanic lithic fragments (dacite, obsidian). +35F: contains 15–20% fine-grained vitric tuff fragments.	**Qbo**	
115–135	Rhyolite Tuff— varicolored, very pale pinkish gray (5YR 8/1), poorly welded, pumiceous, crystal-bearing, lithic-rich. 115’– 135’ +10F: 30–50% white fibrous, vitreous, quartz- and sanidine-phyric pumices; 50–70% large (up to 26 mm) angular volcanic lithic fragments (gray and pink dacites, rhyodacite, and andesite) and trace fragments of quarzite and quartzo-feldspathic sandstone xenoliths. +35F: sample contains fragments of white vitric pumice, quartz and sanidine crystals, and volcanic lithics in variable proportions.	**Qbo**	

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DRILLING COMPANY: Boart Longyear Company	**START DATE/TIME:** 3/28/2010/ 1130	**END DATE/TIME:** 4/24/2010/1730
DRILLING METHOD: Dual Rotary	**MACHINE**: Foremost DR24 HD	**SAMPLING METHOD:** Grab
GROUND ELEVATION: 6647.92 ft AMSL		**TOTAL DEPTH:** 1081.6 ft
DRILLERS: E. Rivas, M. Cross	**SITE GEOLOGIST:** J. R. Lawrence	

DEPTH (ft bgs)	LITHOLOGY	LITHOLOGIC SYMBOL	NOTES
135–145	Rhyolite Tuff—very pale orange (10YR 8/2), poorly welded, pumiceous, crystal-bearing, lithic-rich. 135'– 145' +10F: 50–60% angular volcanic lithic fragments (dacite, andesite); 40–50% fragments of white to very pale orange, vitric pumices (fibrous-textured, quartz- and sanidine-phyric). +35F: 10–20% quartz and sanidine crystals: 40–50% white glassy pumices grains, 30–40% volcanic lithic fragments.	**Qbo**	
145–155	Rhyolite Tuff—very pale orange (10YR 8/2) to white (N9), poorly welded, pumice-rich, crystal-bearing, and lithic-rich. 145'– 155' WR: variable percentages of volcanic ash. +10F: 50–60% angular volcanic lithic fragments (dacite, andesite); 40–50% fragments of white, vitric, quartz- and sanidine-phyric pumice. +35F: 10–20% quartz and sanidine crystals: 40–50% white glassy pumices grains, 30–40% volcanic lithic fragments.	**Qbo**	
155–170	Rhyolite Tuff—very pale orange (10YR 8/2), poorly welded, pumiceous, crystal-bearing, lithic-bearing to lithic-rich. 155'–170' WR: moderately abundant glassy, fine volcanic ash. +35F: fragments of white glassy pumice, quartz and sanidine crystals, and volcanic lithics in variable proportions. 155'–160' +10F: 60–70% angular volcanic lithic fragments (dacite, andesite); 30–40% fragments of white, vitric, quartz- and sanidine-phyric pumice. 160'–165' +10F: 70% white glassy pumice fragments; 30% volcanic lithic fragments; trace exotic subrounded pebble quartzite and quartzo-feldspathic sandstone xenoliths. 165'–170' +10F: 80% angular volcanic lithic fragments (dacite, rhyodacite, andesite); 20% fragments of white, vitric, quartz- and sanidine-phyric pumice. +35F: 25–30% volcanic lithic fragments; 30–35% quartz and sanidine crystals; 30–35% white glassy pumice fragments.	**Qbo**	The Qbo–Qbog contact, estimated to be at 170 ft bgs, is based on interpretation of the natural gamma log and microscopic analysis of drill cuttings.

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DRILLING COMPANY: Boart Longyear Company	**START DATE/TIME:** 3/28/2010/ 1130	**END DATE/TIME:** 4/24/2010/1730
DRILLING METHOD: Dual Rotary	**MACHINE**: Foremost DR24 HD	**SAMPLING METHOD:** Grab
GROUND ELEVATION: 6647.92 ft AMSL		**TOTAL DEPTH:** 1081.6 ft
DRILLERS: E. Rivas, M. Cross	**SITE GEOLOGIST:** J. R. Lawrence	

DEPTH (ft bgs)	LITHOLOGY	LITHOLOGIC SYMBOL	NOTES
170–175	**GUAJE PUMICE BED OF THE OTOWI MEMBER OF THE BANDELIER TUFF:** Rhyolite Tuff—white (N9), non-welded, unconsolidated, pumice-rich, lithic- and crystal-poor. Samples contain predominantly glassy pumice lapilli. 170'– 175' WR/+10F: 100% rounded lapilli of uniform size (up to 10 mm) composed of glassy, pristine-appearing, quartz and sanidine-phyric pumice. +35F: 95–97% white glassy pumice fragments; 3–5% volcanic lithic fragments.	**Qbog**	Note: pristine pumice lapilli making up the interval 170'– 175', suggest the occurrence of a fallout pumice deposit. The lower Qbog contact is estimated to be at 175 ft bgs based on interpretation of the natural gamma log curve. Unit Qbog is estimated to be 5 ft thick.
175–180	**CERROS DEL RIO VOLCANIC SERIES:** Volcaniclastic Sediments and Basalt Lava—varicolored, yellowish gray (5YR 8/1), white (N9), and medium dark gray (N4). Sample contains mixed fragments of vesicular basalt lava, tuffaceous ash/siltstone, and white tuffaceous sandstone. 175'–177' Supplemental sample of drill cuttings in this interval contained fragments of indurated white silty volcanic ash, white fine-grained volcanic sandstone, and pink carbonate-cemented very fine-grained siltstone. Also noted were rare well-rounded quartzite pebbles, chips of vesicular basalt with white amygdaloidal zeolite(?) and/or carbonate plus white glassy pumice fragments. 177'–180' WR/+10F: 20–40% angular/broken fragments of vesicular basalt; 60–80% subrounded (i.e., milled during drilling) fragments of white to light pink very fine-grained tuffaceous carbonate-cemented ash and white tuffaceous fine-grained sandstone. +35F: 60–70% chips of olivine basalt; 30–40% fragments of white to light pink siltstone (altered tuff/ash bed?).	**Tb 4**	The Cerros del Rio Volcanic Series (Tb 4), encountered from 175 ft to 950 ft bgs, is estimated to have a cumulative thickness of 775 ft. Note: a supplemental subsample was collected from the interval 175-177 ft bgs while drilling. Sample constituents suggest the presence of lacustrine(?) and fine-grained clastic sediments in a thin layer, from 175 ft to 177 ft bgs, between the Guaje Pumice Bed and basalt lava of the Cerros del Rio Volcanic Series. The sedimentary layer is assigned to the Cerros del Rio Volcanic Series.

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DRILLING COMPANY: Boart Longyear Company	**START DATE/TIME:** 3/28/2010/ 1130		**END DATE/TIME:** 4/24/2010/1730
DRILLING METHOD: Dual Rotary	**MACHINE**: Foremost DR24 HD		**SAMPLING METHOD:** Grab
GROUND ELEVATION: 6647.92 ft AMSL			**TOTAL DEPTH:** 1081.6 ft
DRILLERS: E. Rivas, M. Cross	**SITE GEOLOGIST:** J. R. Lawrence		

DEPTH (ft bgs)	LITHOLOGY	LITHOLOGIC SYMBOL	NOTES
180–185	Basalt Lava—varicolored, medium dark gray (N4) to very pale orange (10YR 8/2). Sample predominantly made up of chips of vesicular basalt and lesser fragments of white tuffaceous siltstone. 180'–185' WR/+10F+35F: 85–90% angular/broken chips of strongly vesicular olivine-phyric basalt with abundant amygdaloidal clay and/or calcite; 10–15% chips of white tuffaceous siltstone.	**Tb 4**	
185–200	Basaltic Gravels—varicolored, medium dark gray (N4) to gray orange (10YR 7/4). Sample made up of chips of strongly vesicular olivine basalt and plagioclase basalt. 185'–200' WR/+10F/+35F: 97–99% angular/broken chips of vesicular basalt, partly oxidized, with abundant amygdaloidal brown clay and white calcite (locally exhibiting botryoidal structure); 1–3% chips of white tuffaceous siltstone (ash).	**Tb 4**	Note: the interval 185'–220' is interpreted as basaltic cobble gravels on the basis of driller observations (i.e., formation "drilled like loose gravels" from 190 ft to 208 ft bgs). Well-rounded cobbles (up to 6 cm) observed in unsieved cuttings from 188 ft to 208 ft bgs. Note: white secondary mineral with botryoidal structure was determined to be calcite using the x-ray diffraction analytical method.
200–220	Basaltic Gravels—medium dark gray (N4) to gray orange (10YR 7/4) chips of vesicular basalt, porphyritic with aphanitic groundmass, phenocrysts (5–7% by volume) of plagioclase (euhedral to anhedral, up to 2 mm), anhedral olivine (up to 1.5 mm, commonly intergrown with plagioclase). 200'–210' WR/+10F: 100% angular/broken chips of vesicular basalt with abundant amygdaloidal brown clay and white zeolite (botryoidal structure noted). +35F: 97–99% basalt chips; 1–3% fragments of pumice, tuffaceous sandstone, trace quartz crystals. 210'–220' WR/+10F: 99–100% angular/broken, chips of vesicular, locally glassy, basalt with abundant amygdaloidal brown clay and white calcite (note botryoidal structure); trace occurrence of exotic rounded pumices. +35F: 97–99% basalt chips; 1–3% fragments of pumice, tuffaceous sandstone, trace quartz crystal.	**Tb 4**	

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DRILLING COMPANY: Boart Longyear Company	**START DATE/TIME:** 3/28/2010/ 1130	**END DATE/TIME:** 4/24/2010/1730
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GROUND ELEVATION: 6647.92 ft AMSL		**TOTAL DEPTH:** 1081.6 ft
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DEPTH (ft bgs)	LITHOLOGY	LITHOLOGIC SYMBOL	NOTES
220–240	Basalt Lava— medium (N5) to medium light gray (N6) broken chips of massive (nonvesicular) olivine-plagioclase basalt exhibiting weak hydrothermal alteration of groundmass that progresses with depth. 220'–225' WR/+10F: 100% angular chips of massive olivine-plagioclase basalt. 225'–230' +10F: 99–100% angular/broken chips of massive basalt becoming slightly altered (zeolitized?); trace chips of white fine-grained tuffaceous/ volcanic sandstone. 230'–240' +10F: 100% angular/broken chips of massive basalt exhibiting weak alteration and bleaching of groundmass.	**Tb 4**	Note: contact between upper and lower basalt flows indicated at about 238 ft bgs based on presence of vesicular basalt from 235'-240'.
240–255	Basalt Lava—medium gray (N5), predominantly broken chips of vesicular basalt indicating lava flow top. Basalt is porphyritic with aphanitic groundmass and contains phenocrysts (2 –3% by volume) of plagioclase (anhedral, up to 2 mm) and olivine (subhedral, commonly iddingsitized). 240'–255' WR/+10F: 99–100% angular chips of vesicular to scoriaceous basalt, partly oxidized, commonly with reddish brown clay lining vesicles; trace chips of white tuffaceous fine-grained sandstone.	**Tb 4**	
255–290	Basalt Lava—light gray (N7), predominantly broken chips of massive, nonvesicular basalt. Basalt is weakly porphyritic (phenocrysts 2 –3% by volume) with plagioclase (subhedral, up to 3 mm) and green olivine (anhedral, up to 1 mm) set in an aphanitic groundmass that is weakly altered (zeolitized). 255'–275' WR/+10F: 100% angular chips of massive basalt; unwashed chips coated with fine white powder/silt indicating hydrothermal alteration. +35F: fine basalt chips appear somewhat glassy.	**Tb 4**	Note: contact between upper and lower basalt flows indicated at about 288 ft bgs.

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DRILLING COMPANY: Boart Longyear Company	**START DATE/TIME:** 3/28/2010/ 1130	**END DATE/TIME:** 4/24/2010/1730
DRILLING METHOD: Dual Rotary	**MACHINE**: Foremost DR24 HD	**SAMPLING METHOD:** Grab
GROUND ELEVATION: 6647.92 ft AMSL		**TOTAL DEPTH:** 1081.6 ft
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DEPTH (ft bgs)	LITHOLOGY	LITHOLOGIC SYMBOL	NOTES
255–290 (continued)	275'–290' WR/+10F: Predominantly (>90%) angular chips of massive plagioclase- olivine-phyric basalt exhibiting weakly altered and bleached groundmass; olivines weakly iddingsitized; vesicular basalt chips more frequent with depth, suggesting possible flow boundary at approximately 288 ft bgs. +35F: fine basalt chips, somewhat glassy.		
290–305	Basalt Lava—medium gray (N5), predominantly broken chips of strongly vesicular basalt lava. Basalt is olivine-phyric with trace plagioclase as phenocrysts. 290'–305' WR/+10F: >90% angular chips of strongly vesicular olivine-phyric basalt; vesicles lined with yellowish brown clay. +35F: fine basalt chips appear glassy.	**Tb 4**	
305–325	Basalt Lava—medium gray (N5) to light gray (N7), predominantly broken chips of massive basalt lava. Basalt is porphyritic with phenocrysts (2–4% by volume) of olivine (anhedral to euhderal, up to 2 mm, commonly iddingsitized) and rare plagioclase; groundmass moderately altered and bleached but otherwise has glassy appearance. 305'–325' WR/+10F: >90% angular chips of massive olivine-phyric basalt with vuggy groundmass that is moderately hydrothermally altered (zeolitized?); unwashed (WR) chips coated with white fine silty powder; olivine phenocrysts altered to iddingsite.	**Tb 4**	
325–360	Basalt Lava—medium gray (N5) mixed chips of massive (>50% by volume) and vesicular olivine-basalt. Basalt is porphyritic with phenocrysts (2–4% by volume) of olivine (subhedral, up to 2 mm, commonly iddingsitized) and black anhedral clinopyroxene (up to 2 mm) and rare plagioclase in an aphanitic groundmass that is vuggy, altered and bleached; groundmass moderately altered and bleached but otherwise has glassy appearance.	**Tb 4**	

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DRILLING COMPANY: Boart Longyear Company	**START DATE/TIME:** 3/28/2010/ 1130	**END DATE/TIME:** 4/24/2010/1730
DRILLING METHOD: Dual Rotary	**MACHINE**: Foremost DR24 HD	**SAMPLING METHOD:** Grab
GROUND ELEVATION: 6647.92 ft AMSL		**TOTAL DEPTH:** 1081.6 ft
DRILLERS: E. Rivas, M. Cross	**SITE GEOLOGIST:** J. R. Lawrence	

DEPTH (ft bgs)	LITHOLOGY	LITHOLOGIC SYMBOL	NOTES
325–360 (continued)	325’–345’ WR/+10F: angular chips of medium to light gray, massive (60–80% by volume) and vesicular (20–40% by volume) olivine-phyric basalt with distinctly altered (zeolitized?) and bleached groundmass. Bladed crystals of white zeolite(?) noted as precipitate lining vugs, cavities, and vesicles in the interval 335’–340’. 345’–360’ WR/+10F: 40–50% vesicular basalt chips with reddish brown clay lining vesicles; 50–60% chips of olivine-basalt; groundmass continues to exhibit moderate zeolite(?) alteration and bleaching.		
360–380	Basalt Lava—medium gray (N5), predominantly (>90% by volume) of massive olivine-basalt, as described in the interval 325’–360’. 360’–375’ WR/+10F: 90–98% angular chips of massive olivine-basalt exhibiting groundmass that is moderately altered (zeolitized?); 2–10% gray vesicular basalt chips of similar composition. 375’–380’ WR/+10F: 60–70% angular chips of altered massive olivine-basalt; 30–40% chips of reddish (oxidized) strongly scoriaceous basalt that is plagioclase- and olivine-phyric.	**Tb 4**	Note: Gamma log shows contact between upper basalt flow and underlying basaltic cinder deposits at about 378 ft bgs.
380–410	Basaltic Cinder Deposits—moderate red (5R 4/6) to light gray (N7) angular to subangular oxidized scoriaceous cinders, locally glassy, composed of plagioclase-phyric basalt (or basaltic andesite?) with minor olivine present as phenocrysts; vesicles and entire cinder surfaces are strongly oxidized and hematite-stained. Vesicular basalt is weakly prophyritic with phenocrysts (3–5% by volume) of plagioclase (anhedral to euhedral, up to 2 mm) and minor green olivine (anhedral, up to 1 mm); groundmass is aphanitic to partly glassy. 380’–385’ WR/+10F: 50–60% angular chips of oxidized cinders composed of plagioclase-phyric basalt; 40–50% angular to subrounded (milled) chips of altered olivine-basalt lava.	**Tb 4**	Note: contact between upper basaltic cinders deposits and underlying basaltic maar deposits estimated at about 408 ft bgs.

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DRILLERS: E. Rivas, M. Cross	**SITE GEOLOGIST:** J. R. Lawrence	

DEPTH (ft bgs)	LITHOLOGY	LITHOLOGIC SYMBOL	NOTES
380–410 (continued)	385'–390' WR/+10F: 90% cinders, 10% chips of basalt lava. 390'–410' WR/+10F: 90–98% chips and lapilli of reddish scoriaceous basalt cinders (or basaltic andesite?). Minor black clinopyroxene also present as phenocrysts. +35F: contains up to 10% black vitrophyric basalt scoria and trace grains of granite, microcline, and quartz.		
425–445	Basaltic Maar-type Tephra Deposits—pale yellowish gray (5YR 8/1) fine pebble gravel with sand, poorly to moderately sorted, moderately consolidated; detritus of glassy basalt scoria, dacite, rhyolite, and quartzo-feldspathic rocks; locally abundant rounded (milled by drilling) fragments of clay-cemented, very fine-grained basaltic sandstone. 425'–435' WR: unwashed clasts coated with fine white silt or clay particles. +10F: 70–80% angular to well-rounded fragments and clasts (up to 10 mm) of various volcanic rocks (vesicular to scoriaceous basalt, rhyolite, dacites); 20–30% subrounded to well-rounded detrital grains of quartzite, granite, and microcline; rounded fragments of very fine-grained sandstone also present. +35F: commonly fine subrounded grains made up of 40–60% volcanic detritus (glassy basalt cinders, dacite); 40–60% quartzo-feldspathic and quartzite grains. 435'–445' WR/+10F predominantly rounded (i.e., milled during drilling) fragments of very fine-grained basaltic sandstone. +35F: 15–20% quartzo-feldspathic grains; 80–85% glassy basaltic scoria grains.	**Tb 4**	

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DEPTH (ft bgs)	LITHOLOGY	LITHOLOGIC SYMBOL	NOTES
445–500	Basaltic Maar-type Tephra Deposits—pale brown (5YR 5/2) to medium gray (N5) coarse- to fine-grained sandstones, moderately well sorted, weakly to moderately consolidated; detritus predominantly of glassy basalt cinders (reworked, commonly exhibiting rinds of amygdaloidal clay) and generally minor (<5% by volume) abundances of exotic volcanic and quartzo-feldspathic lithologies. 445'–455' WR/+10F/+35F: 93–95% glassy basaltic scoria and rounded fragments of very fine-grained basaltic sandstone angular to well rounded (i.e., milled during drilling) fragments of very fine-grained basaltic sandstone; 5–7% clasts/grains of quartz, microcline, and dacite. 455'–500' WR/+10F/+35F: 95–98% sand-sized grains and granules of glassy basalt scoria, commonly subrounded to rounded, and rounded (i.e., milled due to drilling) fragments of very fine-grained basaltic sandstone cemented by yellowish palagonitic clay; 2–5% grains and granules of quartzite, quartz, microcline, and dacite.	**Tb 4**	Note: distinct increase in sorting of sands in the interval 445'–450'.
500–580	Basaltic Maar-type Tephra Deposits—pale yellowish brown (10YR 8/6) coarse- to very fine-grained sandstones and sandstone with fine gravel, moderately well sorted, moderately consolidated; samples contain abundant well-rounded (i.e., milled during drilling) fragments of very fine-grained basaltic sandstone with white zeolite(?) and yellowish brown palagonitic clay. Also present as less frequent detrital constituents are glassy scoria/cinders, altered olivine-basalt, white hornblende-dacite, gray fine-grained dacite, white tuffaceous ash fragments, quartzite, olivine crystal grains, microcline, quartz crystals, vesicular basalt, and white glassy pumices 500'–510' WR/+10F/+35F: 97–98% rounded (milled) basaltic sandstone fragments and clasts composed of glassy scoriaceous basalt cinders; 2–3% exotic clasts/grains of dacite and quartzo-feldspathic lithologies.	**Tb 4**	

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DEPTH (ft bgs)	LITHOLOGY	LITHOLOGIC SYMBOL	NOTES
500–580 (continued)	510’–515’ +10F: 90% rounded (milled) sandstone fragments and glassy scoriaceous basalt cinders; 5–10% chips of zeolitized(?) basalt with distinctive white amygdaloidal zeolite(?) filling vesicles and vugs. 515’–535’ WR/+10F: 80–90% fragments of fine-grained basaltic sandstone; 10–20% clasts/fragments of altered olivine-basalt, dacite, and trace quartzo-feldspathic detritus. 535’–550’ WR/+10F: 50–60% fragments of fine-grained basaltic sandstone and glassy basaltic cinders; 40–50% exotic detrital clasts/grains of dacite, altered olivine-basalt lava, quartzite, vesicular basalt with white amygdaloidal zeolite(?), and free olivine crystals. 550’–570’ WR/+10F: 60–70% fragments of fine-grained basaltic sandstone and basaltic cinders; 30–40% exotic clasts/fragments as in the interval 535’–550’. 570’–580’ WR/+10F: 80–90% fragments of fine-grained basaltic sandstone and basaltic cinders; 10–20% exotic clasts/fragments as in the interval 535’–550’.		
580–600	Dacitic Lava and Basaltic Maar-type Sediments—light gray (N7) to grayish orange (10YR 7/4). Samples contain mixed chips of light gray massive, porphyritic lava of intermediate composition plus abundant rounded (milled during drilling) fragments of indurated fine-grained basaltic sandstone cemented with yellowish clay (palagonite) and minor white zeolite(?). Note: the ratio of gray lava chips to basaltic sandstone fragments increases with depth in the interval.	**Tb 4**	Note: first appearance of light gray plagioclase- and hornblende(?)-phyric lava of intermediate composition in the Interval 580’–585’ indicates the top of dacitic flows at estimated depth of 580 ft bgs. Dacite lava(s), encountered from 580 ft to 950 ft bgs, have a cumulative thickness of 370 ft.

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DEPTH (ft bgs)	LITHOLOGY	LITHOLOGIC SYMBOL	NOTES
580–600 (continued)	580’–590’ WR/+10F: 40–60% angular/broken chips of light gray dacite that are porphyritic with phenocrysts (5–7% by volume) of plagioclase (anhedral, up to 2 mm), subhedral to euhedral hornblende (up to 1 mm), and trace resorbed xenocrystic quartz (commonly with pyroxene reaction rims) set in a vuggy, aphanitic to glassy groundmass; 40–60% angular to rounded (i.e., milled) fragments of yellowish fine-grained basaltic sandstone. 590’–600’ WR/+10F: 60–70% angular chips of gray glassy dacite; 30–40% chips of fine-grained basaltic sandstone.		
600–670	Dacitic Lava—light (N7) to medium gray (N5). Samples contain almost exclusively angular chips of porphyritic plagioclase- and pyroxene-phyric (two pyroxene phases noted) dacite lava with aphanitic to glassy groundmass. 600’–615’ WR/+10F: 98–99% angular/broken chips of porphyritic dacite with distinctive assemblage of phenocrysts (5–7% by volume) including plagioclase (up to 2 mm), stubby black clinopyroxene (euhedral, up to 2 mm), translucent pale brown orthopyroxene (hypersthene?), minor acicular hornblende (euhedral, up to 3 mm), and trace resorbed xenocrystic quartz set in a vuggy, glassy groundmass; 1–2% basaltic sandstone fragments. 615’–630’ WR/+10F: 99–100% angular chips of gray glassy dacite (as described above). Note: black stubby clinopyroxene (Cpx) commonly partially replaced by translucent pale brown orthopyroxene (Opx) as reaction rims. Pale gray groundmass is glassy and vuggy. 630’–670’ WR/+10F: Monolithologic sample; 100% angular chips of light gray (N7) to light pinkish gray (10R 6/2) porphyritic, two-pyroxene dacite; phenocrysts (3–5% by volume) include equidimensional black Cpx (up to 2 mm), pale brown Opx, plagioclase (resorbed with glassy rims), and resorbed xenocrystic quartz	**Tb 4**	Note: slight color and textural change occurring in interval 630’–635’, possibly indicating a flow boundary at 630 ft bgs.

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DEPTH (ft bgs)	LITHOLOGY	LITHOLOGIC SYMBOL	NOTES
670–685	Dacitic Lava with Clay—pale reddish gray (10R 6/2). Predominantly chips of porphyritic dacite as described above. 670'–685' WR/+10F: 95–99% angular/broken chips of porphyritic (two-pyroxene plus plagioclase) dacite lava with local fracture surfaces coated with white to very pale tan clay; 1–5% chips/fragments of white clay inferred to have been deposited as fracture fillings.	**Tb 4**	
685–715	Dacitic Lava—pale reddish gray (10R 6/2) to light gray (N7). Monolithologic sample of porphyritic two-pyroxene dacite lava (as described in interval 600'–670'). 685'–715' WR/+10F: 99–100% angular/broken chips of porphyritic dacite containing phenocrysts (3–5% by volume) of plagioclase, black Cpx, and pale brown translucent Opx; trace white clay associated with fracture surfaces. Local bleaching and weak hydrothermal alteration of dacite groundmass noted.	**Tb 4**	
715–730	Dacitic Lava—medium light gray (N6), predominantly angular chips of porphyritic dacite lava containing phenocrysts of plagioclase, Cpx, and Opx in a light gray, vuggy, glassy to aphanitic groundmass. Also present are chips of very pale tan clay. 715'–730' WR/+10F: 95–97% chips of gray dacite with phenocrysts (2–4% by volume) of intergrown pale brown Opx and black Cpx, plagioclase, and trace quartz xenocrysts with pyroxene(?) overgrowths; groundmass very glassy and vuggy; minor occurrences of white to pale yellow clay on lava fracture surfaces; 3-5% chips of light-colored clay.	**Tb 4**	

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DEPTH (ft bgs)	LITHOLOGY	LITHOLOGIC SYMBOL	NOTES
730–750	Dacitic Lava—medium dark gray (N4), predominantly angular chips of dark gray porphyritic dacite lava containing phenocrysts of plagioclase, both Cpx and Opx, and xenocrystic quartz grains. Also present are chips of white clay. 730'–750' WR/+10F: 93–95% chips of gray dacite with phenocrysts (3–5% by volume) of anhedral plagioclase commonly in cumulophyric clusters with black Cpx and pale brown Opx; grains of xenocrystic quartz occur with apparent Opx overgrowths; groundmass varies from glassy to fine-grained crystalline (aphanitic); local fracture surfaces are clay coated; 5–7% chips of white to pale pink clay.	**Tb 4**	
750–805	Dacitic Lava—medium (N5) to dark gray (N3), predominantly angular chips of two-pyroxene porphyritic dacite lava with dark gray glassy groundmass; abundant evidence of fractured lava and associated white clay. 750'–780' WR/+10F: 93–95% angular to subrounded (i.e., milled during drilling) chips of gray dacite; 5–7% chips/fragments of white clay. Locally abundant light tan to white clay fragments are evidence that this clay occurs as fracture fillings; clay also observed as coatings of fracture surfaces (noted in intervals 760'–765' and 775'–780'). 780'–805' WR/+10F: 95–97% chips of medium gray to light gray (altered) dacite containing phenocrysts (3–5% by volume) of anhedral plagioclase (up to 2 mm) that is commonly intergrown with black Cpx and light brown Opx; frequent quartz xenocrysts with Opx reaction rims and trace acicular hornblendes set in a vuggy, predominantly glassy groundmass; 3–5% chips/fragments of white clay.	**Tb 4**	

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DEPTH (ft bgs)	LITHOLOGY	LITHOLOGIC SYMBOL	NOTES
805–825	Dacitic Lava—medium (N5) to light gray (N7). Samples contain commonly rounded (milled) fragments of glassy two-pyroxene dacite; locally abundant pinkish to white clay fragments; trace occurrence of detrital dacite and quartzo-feldspathic sedimentary grains in +35F. 805'–825' WR/+10F: 85–95% coarse, commonly rounded (milled) chips of light gray glassy dacite with phenocrysts of pyroxene (Cpx and Opx present) and minor plagioclase; 5–15% chips of white clay (likely from fracture fillings). Noted also in dacite, the presence of anhedral quartz xenocrysts (up to 2 mm) with pale brown pyroxene(?) reaction rims. Dacite groundmass is glassy and partly altered (zeolitized?); locally abundant zeolite?, and/or clay, filling vugs.	**Tb 4**	
825–850	Dacitic Lava—medium gray (N5) to brownish gray (10YR 7/4). Commonly rounded (milled) fragments of glassy two-pyroxene dacite; locally abundant pinkish to white clay fragments; trace occurrences of detrital dacite and quartzo-feldspathic sedimentary grains in +35F. 825'–850' WR/+10F: 95–98% chips of massive gray glassy dacite lava containing phenocrysts (3–5% by volume) of black Cpx and pale brown Opx, anhedral plagioclase (up to 2 mm), and frequent resorbed quartz xenocrysts hosting pale brown translucent Opx reaction rims; groundmass glassy and partly altered (zeolite and/or clay); variable (2–5% by volume) abundances of white clay chips. +35F: interval 825'–850' contains trace exotic angular grains of quartz and rhyolite.	**Tb 4**	Note: unwashed (WR) cuttings in the interval 825'–835' are coated with fine brown silt, suggesting possible thin volcaniclastic sedimentary interbed.
850–900	Dacitic Lava—medium light gray (N6) to medium dark gray (N4) nearly monolithologic samples containing chips of two-pyroxene glassy dacite lava; locally minor fragments of white clay. 850'–900' WR/+10F: 90–98% coarse angular to partly subrounded (milled) chips of gray massive two-pyroxene dacite lava (as described in interval 825'–850'); 2–10% angular chips of white clay; trace occurrences of quartz and volcanic grains.	**Tb 4**	

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DEPTH (ft bgs)	LITHOLOGY	LITHOLOGIC SYMBOL	NOTES
900–940	Dacitic Lava—medium light gray (N6) to medium dark gray (N4) nearly monolithologic samples containing chips of two-pyroxene glassy dacite lava; locally trace fragments of white clay. 900'–940' WR/+10F: 98–100% chips of gray massive two-pyroxene dacite lava (as described in interval 825'–850'); phenocrysts (5–7% by volume) include locally abundant rounded/resorbed quartz xenocrysts with yellowish brown Opx rims; groundmass glassy to weakly altered; up to 2% angular chips of white clay.	**Tb 4**	
940–950	Dacitic Lava—medium (N5) to medium dark gray (N4), predominantly chips of two-pyroxene glassy dacite lava with minor fragments of clay, zeolite(?) and fine-grained quartzo-feldspathic sandstone. 940'–950' WR/+10F: 90–95% chips of glassy two-pyroxene dacite lava (as described in interval 900'–940'); 5–10% fragments of indurated fine-grained quartzo-feldspathic sandstone, pinkish clay and/or siltstone, and white vitreous mineral (calcite?) +35F: 945'–950' sample contains 90–95% chips of glassy dacite lava; 5–10% angular grains of quartz and microcline plus sandstone fragments.	**Tb 4**	The contact between Tb 4 volcanic rocks and underlying Totavi Lentil riverine sediments is estimated to be at 950 ft bgs based on microscopic analysis of drill cuttings and interpretation of the natural gamma log.
950–960	**TOTAVI LENTIL OF THE PUYE FORMATION** Quartzo-feldspathic Sediments—varicolored, medium light gray (N6) to very pale orange (10YR 8/2) silty fine-grained sandstone, well sorted, weakly to moderately indurated. Samples contain grains/clasts and sandstone fragments composed predominantly of quartz, microcline feldspar, and Precambrian granitic rocks with less frequent Tschicoma-like dacites. Mixed chips of glassy two-pyroxene dacitic lava are also present.	**Tpft**	Totavi Lentil quartzo-feldspathic sediments, interpreted as ancestral Rio Grande deposits, were encountered from 950 ft to the bottom of the R-57 borehole at 1081.6 ft bgs TD. These sediments are a minimum of 131.6 ft thick.

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DEPTH (ft bgs)	LITHOLOGY	LITHOLOGIC SYMBOL	NOTES
950–960 (continued)	950’–960’ WR/+10F: 60–80% fragments of indurated silty fine-grained quartzo-felsdpathic sandstone and subrounded granule-size clasts composed of light gray hornblende-dacite, microcline, quartz, and granite plus chips of white siltstone; 20–40% angular chips of glassy two-pyroxene dacite lava typical of that described in the interval 940’–950’. +35F: 950’–955’ sample contains 70–80% chips of glassy two-pyroxene dacite lava; 20–30% quartzo-feldspathic sandstone fragments plus grains of quartz, microcline, and minor dacite. +35F: 955’–960’ sample contains 15–25% chips of glassy dacite lava, 75–85% quartzo-feldspathic detritus, and sandstone fragments.		
960–965	Quartzo-feldspathic Sediments—very pale orange (10YR 8/2) silty fine- to medium-grained sandstone and sandstone with fine gravel, well sorted, weakly to moderately indurated. Detritus predominantly of quartz, microcline feldspar, and Precambrian granitic rocks, and lesser volcanic rocks of diverse composition. 960’–965’ WR: abundant silt matrix. +10F: 15–20% fragments of silty fine-grained quartzo-feldspathic sandstone; 50–60% subrounded to angular clasts/fragments of quartz, microcline, granite; 20–30% subrounded volcanic clasts (dacite, andesite, rhyolite); 2–3% chips of two-pyroxene glassy dacitic lava.	**Tpft**	
965–980	Quartzo-feldspathic Sediments—varicolored, medium light gray ((N6) to very pale orange (10YR 8/2) silty fine to medium gravels with medium- to coarse-grained sandstone, moderately sorted, weakly to moderately cemented. Detritus of mixed quartzo-feldspathic and various volcanic lithologies. 965’–980’ WR/+10F: subrounded to angular/broken clasts composed of 50–60% Precambrian quartzo-feldpathic rocks (quartz, quartzite, microcline, mica-schist, granite); 40–50% clasts of various volcanic rocks (hornblende- and biotite-dacites, black vitrophyre, andesite). +35F: 70–80% grains of quartz, feldspar, and granite; 20–30% grains of various volcanic rocks.	**Tpft**	

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DEPTH (ft bgs)	LITHOLOGY	LITHOLOGIC SYMBOL	NOTES
980–985	Quartzo-feldspathic Sediments—very pale orange (10YR 8/2) silty fine (pebble) gravels with fine- to coarse-grained sandstone, moderately to poorly sorted, weakly to moderately cemented; mixed quartzo-feldspathic and volcanic detritus. 980’–985’ WR: moderately abundant silt matrix. +10F: subrounded pebbles composed of 50–60% volcanic lithologies (rhyolite, dacite, andesite); 40–50% quartz, quartzite, microcline feldspar, granite; +35F: 70% quartzo-feldspathic grains/fragments; 30% various volcanic grains.	**Tpft**	
985–1005	Quartzo-feldspathic Sediments—varicolored, medium gray (N5) to very pale orange (10YR 8/2) silty fine to medium gravels with fine- to coarse-grained sandstone, moderately to poorly sorted, weakly cemented; mixed quartzo-feldspathic and less abundant volcanic detritus. 985’–1005’ WR/+10F: clasts subrounded to well rounded composed of 40–60% Precambrian rocks (quartz, quartzite, microcline, granite); 40–60% clasts of diverse volcanic rocks (hornblende-dacite, andesite, flow-banded rhyolite). +35F: 60–70% quartzo-feldspathic grains; 30–40% various volcanic grains.	**Tpft**	
1005–1040	Quartzo-feldspathic Sediments—varicolored, medium gray (N5) to very pale orange (10YR 8/2) medium to fine gravels with fine- to coarse-grained sandstone, moderately sorted, weakly to moderately cemented; mixed volcanic and quartzo-feldspathic detritus. 1005’–1040’ WR/+10F: pebble and larger size clasts subrounded to well rounded, composed of 40–60% diverse volcanic rocks (andesite, dacite, rhyolite); 40–50% quartzo-feldspathic lithologies (quartzite, microcline, granite, mica schist, trace chert). +35F: 50–60% quartzo-feldspathic grains/fragments; 40–50% grains primarily of intermediate volcanic composition.	**Tpft**	

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DRILLERS: E. Rivas, M. Cross	**SITE GEOLOGIST:** J. R. Lawrence	

DEPTH (ft bgs)	LITHOLOGY	LITHOLOGIC SYMBOL	NOTES
1040–1060	Quartzo-feldspathic Sediments—varicolored, medium gray (N5) to very pale orange (10YR 8/2) medium to fine gravels with fine- to coarse-grained sandstone, moderately to poorly sorted, moderately cemented; mixed volcanic and quartzo-feldspathic detritus that is moderately to well rounded. 1040'–1060' WR/+10F: pebble (up to 20 mm) and larger size clasts composed of 40–50% diverse volcanic rocks (andesite, hornblende-dacite, rhyolite); 40–50% Precambrian quartzo-feldspathic lithologies (quartzite, granite, trace chert); 10–15% fragments of quartzo-feldspathic sandstone and siltstone. +35F: mixed grains/fragments of both quartzo-feldspathic and volcanic materials in proportions as above.	**Tpft**	
1060–1081.6	Quartzo-feldspathic Sediments—varicolored, medium gray (N5) to very pale orange (10YR 8/2) pebbly fine to medium sandstone grading downward in the interval to silty fine-grained sandstone with minor fine gravel, moderately to well sorted, moderately cemented. Samples contain mixed volcanic and quartzo-feldspathic detritus grading downward to clasts/grains of predominantly volcanic composition. 1060'–1065' +10F: subrounded pebbles (up to 10 mm) and granules composed of 50–60% volcanic rocks (andesite, light gray hornblende-dacite); 40–50% Precambrian quartzo-feldspathic lithologies (quartzite, granite). +35F: 70–75% quartzo-feldspathic grains; 25–30% volcanic grains. 1065'–1070' WR: silty fine- to medium-grained sandstone with minor pebble gravel. +10F: 80–90% subrounded volcanic pebbles and granules (light gray hornblende-dacite, rhyolite, andesite); 10–20% quartzo-feldspathic clasts (quartzite, granite, mica schist, chert); 10–15% fragments of silty fine-grained sandstone. 1070'–1081.6' WR: silty fine-grained sandstone with minor pebble gravel. +10F: 80–90% volcanic clasts (dacite, rhyolite, andesite); 2–5% quartzo-feldspathic clasts; 5–7% fragments of silty fine-grained sandstone. +35F: 60–70% volcanic grains; 30–40% quartzo-feldspathic grains.	**Tpft**	Note: the increase in natural gamma activity shown in the log at 1065 ft bgs corresponds to increased proportion of volcanic versus quartzo-feldspathic constituents observed in Tpft riverine sediments. Drilling at R-57 was completed at a depth of 1081.6 ft (TD) bgs.

Abbreviations

5YR 8/4 = Munsell rock color notation where hue (e.g., 5YR), value (e.g., 8), and chroma (e.g., 4) 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

AMSL = above mean sea level

bgs = below ground surface

Cpx = clinopyroxene

ft = feet.

GM = groundmass

Opx = orthopyroxene

Qal = Quaternary alluvium

Qbo = Otowi Member of Bandelier Tuff

Qbog = Guaje Pumice Bed

Qbt = Tshirege Member of the BandelierTuff

Qct = Cerro Toledo interval

Tb 4 = Cerros del Rio volcanic series

Tpft = Totavi-like riverine deposits of the Puye Formation

+10F = plus No. 10 sieve sample fraction

+35F = plus No. 35 sieve sample fraction

WR = whole rock (unsieved sample)

1 mm = 0.039 in

1 in = 25.4 mm

Appendix B

Groundwater Analytical Results

B-1.0 SAMPLING AND ANALYSIS OF GROUNDWATER AT R-57

One groundwater sample was collected from the open borehole during drilling from 925.6 ft below ground surface (bgs) at well R-57 from the regional aquifer in the Cerros del Rio volcanic series. This sample was analyzed by an off-site laboratory for volatile organic compounds (VOCs) and low-level tritium (LH3). Aliquots of the sample were also analyzed for cations and anions, including perchlorate, by Los Alamos National Laboratory's (LANL's or the Laboratory's) Earth and Environmental Sciences Group 14 (EES-14).

Thirteen groundwater samples were collected from both screens at well R-57 during development and aquifer testing and analyzed for total organic carbon (TOC) by EES-14.

B-1.1 EES-14 Analytical Techniques

Groundwater samples were filtered (0.45-µm 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 by the U.S. Environmental Protection Agency (EPA) methods for water analyses. Ion chromatography (EPA Method 300, rev. 2.1) was the analytical method for bromide, chloride, fluoride, nitrate, nitrite, oxalate, perchlorate, phosphate, and sulfate. The instrument detection limit for perchlorate was 0.005 ppm using EPA Method 314.0, rev. 1. Total carbonate alkalinity (EPA Method 310.1) was measured using standard titration techniques. The precision limits (analytical error) for major ions and trace elements were generally less than ±7%.

Inductively coupled (argon) plasma optical emission spectroscopy (EPA Method 200.7, rev. 4.4) 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 (EPA Method 200.8, rev. 5.4). For metals analyzed by both techniques, EES-14 reports the analytical result with the lower concentration.

For the groundwater samples collected during well development and aquifer testing, TOC analysis was performed per EPA Method 415.1. The borehole groundwater sample was not analyzed for TOC because of potential sample matrix interference from drilling foam.

B-1.2 Field Parameters

B-1.2.1 Well Development

Water samples were drawn from the pump discharge line into sealed containers, and field parameters were measured using a YSI multimeter. Results of field parameters, consisting of pH, temperature, dissolved oxygen (DO), oxidation-reduction potential (ORP), specific conductance, and turbidity measured during development at well R-57, are provided in Table B-1.2-1.

Upper Screen

During development of the upper screen, pH and temperature varied from 7.81 to 7.93 and from 22.41°C to 22.70°C, respectively. Concentrations of DO ranged from 6.17 to 6.27 ppm. Corrected Eh values determined from field ORP measurements varied from 265.5 to 279.2 millivolts (mV). Two temperature-dependent correction factors based on an Ag/AgCl, KCl-saturated filling solution contained in the ORP electrode were used to calculate Eh values from field ORP measurements. The correction factors were 203.9 mV and 198.5 mV at 20ºC and 25ºC, respectively. Corrected Eh values, in combination with

203.9 mV and 198.5 mV at 20ºC and 25ºC, respectively. Corrected Eh values, in combination with measured DO concentrations, are considered to be consistent with known relatively oxidizing conditions characteristic of the regional aquifer beneath the Pajarito Plateau. Specific conductance varied from 132 to 140 microsiemens per centimeter (μS/cm), and turbidity ranged from 2.0 to 2.7 nephelometric turbidity units (NTU) (Table B-1.2-1).

Lower Screen

During development of the lower screen, pH and temperature varied from 7.87 to 8.13 and from 21.51°C to 22.59°C, respectively. Concentrations of DO varied from 3.95 to 6.43 ppm. Corrected Eh values calculated from field ORP measurements varied from 235.4 to 255.3 mV. Specific conductance values varied from 132 to 150 μS/cm, and turbidity varied from 2.2 to 5.0 NTU (Table B-1.2-1).

B-1.2.2 Aquifer Testing

Upper Screen

During aquifer testing of the upper screen, pH and temperature varied from 6.16 to 8.04 and from 21.50°C to 23.85°C, respectively. Concentrations of DO varied from 5.88 to 6.87 ppm. Corrected Eh values determined from field ORP measurements varied from 260.9 to 353.6 mV. Specific conductance varied from 123 to 264 μS/cm, and turbidity values varied from 5.9 to 0.4 NTU (Table B-1.2-1).

Lower Screen

During aquifer testing of the lower screen, pH and temperature varied from 6.58 to 7.75 and from 22.23°C to 24.43°C, respectively. Concentrations of DO varied from 5.54 to 6.66 ppm. Corrected Eh values determined from field ORP measurements varied from 252.5 to 293.3 mV. Specific conductance varied from 149 to 257 μS/cm, and turbidity varied from 1.2 to 10.2 NTU (Table B-1.2-1).

B-1.3 Analytical Results

One borehole groundwater sample (GW57-10-15480 from approximately 925.6 ft bgs) was analyzed by an off-site laboratory, GEL, for VOCs and LH3, and by LANL EES-14 for anions, cations, metals, and TOC. The filtered borehole water sample consisted of colloidal aquifer material, drilling material, water used during drilling, and native groundwater. The analytical results are presented below. Selected analytical results are screened against background concentrations for the Laboratory as a whole (LANL 2007, 095817). It should be noted that, because of localized variations in geochemistry, background concentrations for the area upgradient of well R-57 may vary.

B-1.3.1 Off-site Laboratory Analytical Results for VOCs and LH3

VOCs and LH3 were not detected in the borehole water sample (Table B-1.3-1).

B-1.3.2 EES-14 Analytical Results for Cations, Anions, Perchlorate, and Metals

Analytical results for cations, anions (including perchlorate), and metals in the borehole sample are provided in Table B-1.3-2.

Analytical results for select cations are as follows:

- Dissolved molybdenum was reported at 0.010 ppm, above the maximum background value of 0.0044 ppm for regional groundwater (LANL 2007, 095817). This result is likely attributable to the pipe lubricant used during drilling.

- Total dissolved chromium was 0.003 ppm, below the median and maximum background concentrations of 0.00305 and 0.0072 ppm, respectively, for the regional aquifer (LANL 2007, 095817).

Analytical results for select anions are as follows:

- Dissolved fluoride was 0.32 ppm, less than the median background concentration of 0.35 ppm for developed wells in the regional aquifer (LANL 2007, 095817).
- Dissolved nitrate(N) was 0.59 ppm, slightly above the maximum background concentration of 0.53 ppm (LANL 2007, 095817).
- Dissolved sulfate was 7.14 ppm, less than the maximum background concentration in the regional aquifer of 8.63 ppm (LANL 2007, 095817).
- Perchlorate was not detected in the borehole water sample.
- The charge balance error for total cations and anions for the borehole water sample was −12%. The negative cation-anion charge balance value indicates excess anions for the filtered sample.

B-1.3.2.3 EES-14 Analytical Results for Total Organic Carbon

TOC was not detected in any of the samples collected from the completed well during development and aquifer testing (Table B-1.3-3).

B-1.4 Summary

In summary, perchlorate, VOCs, and LH3 were not detected in the borehole water sample, and TOC was not detected in any of the samples collected from both screens during well during development and aquifer testing. Groundwater at well R-57 is relatively oxidizing, based on corrected positive Eh values and DO measured during well development and aquifer testing. Redox conditions based on corrected field ORP measurements at well R-57 are similar to other previously drilled wells in the Pajarito watershed.

B-2.0 REFERENCE

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
Purge Volumes and Water Quality Parameters during Well Development and Aquifer Testing at R-57

Date	pH	Temp (°C)	DO (ppm)	ORP, Eh[a] (mV)	Specific Conductivity (µS/cm)	Turbidity (NTU)	Purge Volume between Samples (gal.)	Cumulative Purge Volume (gal.)
Well Development Composite Water from Both Screens								
06/09/10	n/r[b]; bailing						120	120
06/10/10	n/r, bailing						270	390
Well Development Upper Screen								
06/11/10	n/r, pumping while swabbing screen						1250	1640
06/12/10	n/r, pumping while swabbing screen						890	2530
	7.89	22.41	6.20	61.9, 265.8	140	2.7	276	2806
	7.88	22.44	6.21	66.5, 270.4	140	2.7	138	2944
	7.93	22.51	6.22	67.5, 266.0	135	2.2	138	3082
	7.89	22.53	6.17	67.0, 265.5	132	2.7	138	3220
	7.85	22.54	6.27	74.3, 272.8	132	2.0	138	3358
	7.86	22.70	6.27	75.7, 274.2	133	2.2	138	3496
	7.81	22.54	6.26	80.7, 279.2	133	2.0	138	3634
	7.82	22.53	6.26	77.0, 275.5	134	2.0	138	3772
	7.83	22.57	6.27	78.9, 277.4	135	2.1	138	3910
	n/r, packer deflated, screens 1 and 2 not isolated						550	4460
Well Development Lower Screen								
06/13/10	n/r, pumping while swabbing screen						2260	6720
	7.87	22.11	6.43	46.2, 250.1	141	2.2	264	6984
	7.95	22.59	6.02	52.7, 251.2	132	2.7	262	7246
	7.88	22.55	5.98	56.8, 255.3	134	2.5	264	7510
06/14/10	8.13	21.51	3.95	44.5, 248.4	146	5.0	264	7774
	8.01	22.09	4.51	43.5, 247.4	150	4.2	264	8038
	7.94	22.17	4.79	33.0, 236.9	148	3.5	264	8302
	7.89	22.26	5.13	31.5, 235.4	146	3.2	258	8560
	n/r, pumping sump						680	9240

Table B-1.2-1, continued

Date	pH	Temp (°C)	DO (ppm)	ORP, Eh[a] (mV)	Specific Conductivity (μS/cm)	Turbidity (NTU)	Purge Volume between Samples (gal.)	Cumulative Purge Volume (gal.)
Aquifer Test Lower Screen								
06/22/10	n/r, pumping, mini-test preparation						1940	11,180
06/24/10 to 06/25/10	6.58	22.76	5.54	94.8, 293.3	257	10.2	984	12,164
	7.59	23.14	5.80	83.7, 282.2	255	8.0	984	13,148
	7.49	23.44	5.92	78.7, 277.2	249	5.3	981	14,129
	7.57	24.43	5.87	60.8, 259.3	249	5.0	984	15,113
	7.72	23.45	6.32	54.0, 252.5	241	3.2	984	16,097
	7.67	23.44	6.23	64.7, 263.2	240	3.3	984	17,081
	7.62	24.34	5.97	66.9, 265.4	242	2.4	984	18,065
	7.55	23.52	6.20	77.3, 275.8	205	4.7	984	19,049
	7.52	23.01	6.46	75.8, 274.3	243	4.5	984	20,033
	7.64	23.12	6.28	73.6, 272.1	238	4.6	984	21,017
	7.71	23.08	6.20	72.5, 271.0	241	1.2	984	22,001
	7.62	23.03	6.93	76.0, 274.5	242	2.7	984	22,985
	7.51	22.72	6.11	75.7, 274.2	243	2.3	984	23,969
	7.48	22.51	6.17	79.4, 277.9	149	4.3	984	24,953
	7.65	22.47	6.22	72.4, 276.3	243	4.1	978	25,931
	7.58	22.44	6.10	71.3, 275.2	246	5.1	984	26,915
	7.65	22.42	5.91	73.0, 276.9	246	2.8	984	27,899
	7.73	22.37	6.07	69.9, 273.8	246	2.7	990	28,889
	7.65	22.36	6.04	69.9, 273.8	244	3.0	990	29,879
	7.67	22.32	6.10	69.9, 273.8	248	2.4	1014	30,893
	7.61	22.23	5.86	78.2, 282.1	248	5.0	990	31,883
	7.75	22.48	6.24	70.5, 274.4	251	4.7	990	32,873
	7.57	22.53	6.66	73.0, 271.5	247	2.2	990	33,863
	7.69	22.91	6.22	71.8, 270.3	249	3.2	965	34,828
06/27/10	n/r pumping, aquifer purge						12,681	47,509

Table B-1.2-1, continued

Date	pH	Temp (°C)	DO (ppm)	ORP, Eh[a] (mV)	Specific Conductivity (µS/cm)	Turbidity (NTU)	Purge Volume between Samples (gal.)	Cumulative Purge Volume (gal.)
Aquifer Test Upper Screen								
06/28/10	n/r, pumping, mini-test preparation						58	47,567
06/29/10	n/r, pumping, mini-test						546	48,113
06/30/10 to 07/01/10	6.16	23.85	5.93	155.1, 353.6	264	4.3	426	48,539
	7.06	23.37	5.88	84.1, 282.6	199	5.9	426	48,965
	7.65	23.22	6.11	71.9, 270.4	192	0.4	426	49,391
	7.67	23.73	5.95	63.3, 261.8	194	0.9	426	49,817
	7.65	23.50	6.38	65.1, 263.6	191	1.9	426	50,243
	7.56	23.16	6.51	81.1, 279.6	189	0.8	426	50,669
	7.55	23.29	6.24	77.1, 275.6	190	1.1	426	51,095
	7.66	23.41	6.62	62.4, 260.9	189	0.9	426	51,521
	7.64	23.58	6.35	63.2, 261.7	192	0.9	426	51,947
	7.77	23.59	6.77	62.8, 261.3	123	0.7	426	52,373
	7.72	22.99	6.79	80.3, 278.8	176	0.6	420	52,793
	7.79	22.72	6.60	69.9, 268.4	183	0.5	426	53,219
	7.72	22.63	6.82	81.8, 280.3	125	2.1	426	53,645
	7.74	22.59	6.61	78.1, 276.6	149	1.6	426	54,071
	7.74	22.55	6.30	84.2, 282.7	187	2.0	426	54,497
	7.70	21.75	6.77	95.4, 299.3	188	0.6	426	54,923
	7.60	22.38	6.43	97.3, 301.2	137	2.0	426	55,349
	7.68	22.32	6.47	88.3, 292.2	145	0.8	426	55,775
	7.72	22.25	6.70	92.1, 296.0	184	1.0	426	56,201
	8.02	21.75	6.24	106.4, 310.3	187	1.7	426	56,627
	8.04	21.50	6.79	94.6, 298.5	187	2.0	426	57,053
	7.87	22.24	6.78	99.3, 303.2	193	0.6	426	57,479
	7.92	22.59	6.81	96.1, 294.6	194	0.4	426	57,905
	7.75	22.59	6.87	99.7, 298.2	193	0.5	417	58,322

[a] Eh (mV) is calculated from a Ag/AgCl saturated KCl electrode filling solution at 20ºC and 25ºC by adding temperature-sensitive correction factors of 203.9 mV and 198.5 mV, respectively.

[b] n/r = Not recorded.

Table B-1.3-1
Off-site Analytical Results

Lab Request Number	Sample Name	Analytical Suite Code	Analytical Method Code	Analyte Description	Lab Result	Unit	Validation Qualifier Code
10-2860	GW57-10-15480	VOC	SW-846:8260B	Ethylbenzene	1	µg/L	U[a]
10-2860	GW57-10-15480	VOC	SW-846:8260B	Styrene	1	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Dichloropropene[cis-1,3-]	1	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Dichloropropene[trans-1,3-]	1	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Propylbenzene[1-]	1	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Butylbenzene[n-]	1	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Chlorotoluene[4-]	1	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Dichlorobenzene[1,4-]	1	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Dibromoethane[1,2-]	1	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Acrolein	5	µg/L	R[b]
10-2860	GW57-10-15480	VOC	SW-846:8260B	Chloro-1-propene[3-]	5	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Dichloroethane[1,2-]	1	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Propionitrile	5	µg/L	R
10-2860	GW57-10-15480	VOC	SW-846:8260B	Acrylonitrile	5	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Vinyl acetate	5	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Methyl-2-pentanone[4-]	5	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Trimethylbenzene[1,3,5-]	1	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Bromobenzene	1	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Toluene	1	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Chlorobenzene	1	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Trichlorobenzene[1,2,4-]	1	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Chlorodibromomethane	1	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Methacrylonitrile	5	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Chloro-1,3-butadiene[2-]	1	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Tetrachloroethene	1	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Butylbenzene[sec-]	1	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Dichloropropane[1,3-]	1	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Dichloroethene[cis-1,2-]	1	µg/L	U

Table B-1.3-1 (continued)

Lab Request Number	Sample Name	Analytical Suite Code	Analytical Method Code	Analyte Description	Lab Result	Unit	Validation Qualifier Code
10-2860	GW57-10-15480	VOC	SW-846:8260B	Dichloroethene[trans-1,2-]	1	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Methyl tert-Butyl Ether	1	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Dichlorobenzene[1,3-]	1	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Carbon Tetrachloride	1	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Dichloropropene[1,1-]	1	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Hexanone[2-]	5	µg/L	UJ[c]
10-2860	GW57-10-15480	VOC	SW-846:8260B	Dichloropropane[2,2-]	1	µg/L	UJ
10-2860	GW57-10-15480	VOC	SW-846:8260B	Diethyl Ether	1	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Tetrachloroethane[1,1,1,2-]	1	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Acetone	10	µg/L	UJ
10-2860	GW57-10-15480	VOC	SW-846:8260B	Chloroform	1	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Butanol[1-]	50	µg/L	UJ
10-2860	GW57-10-15480	VOC	SW-846:8260B	Benzene	1	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Trichloroethane[1,1,1-]	1	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Bromomethane	1	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Chloromethane	1	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Iodomethane	5	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Dibromomethane	1	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Bromochloromethane	1	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Chloroethane	1	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Vinyl Chloride	1	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Acetonitrile	25	µg/L	R
10-2860	GW57-10-15480	VOC	SW-846:8260B	Methylene Chloride	10	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Carbon Disulfide	5	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Bromoform	1	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Bromodichloromethane	1	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Dichloroethane[1,1-]	1	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Dichloroethene[1,1-]	1	µg/L	U

Table B-1.3-1 (continued)

Lab Request Number	Sample Name	Analytical Suite Code	Analytical Method Code	Analyte Description	Lab Result	Unit	Validation Qualifier Code
10-2860	GW57-10-15480	VOC	SW-846:8260B	Trichlorofluoromethane	1	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Dichlorodifluoromethane	1	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Trichloro-1,2,2-trifluoroethane[1,1,2-]	5	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Isobutyl alcohol	50	µg/L	R
10-2860	GW57-10-15480	VOC	SW-846:8260B	Dichloropropane[1,2-]	1	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Butanone[2-]	5	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Trichloroethane[1,1,2-]	1	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Trichloroethene	1	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Tetrachloroethane[1,1,2,2-]	1	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Methyl Methacrylate	5	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Trichlorobenzene[1,2,3-]	1	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Hexachlorobutadiene	1	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Naphthalene	1	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Xylene[1,2-]	1	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Chlorotoluene[2-]	1	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Dichlorobenzene[1,2-]	1	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Trimethylbenzene[1,2,4-]	1	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Dibromo-3-Chloropropane[1,2-]	1	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Trichloropropane[1,2,3-]	1	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Ethyl Methacrylate	5	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Butylbenzene[tert-]	1	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Isopropylbenzene	1	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Isopropyltoluene[4-]	1	µg/L	U
10-2860	GW57-10-15480	VOC	SW-846:8260B	Xylene[1,3-]+Xylene[1,4-]	2	µg/L	U
10-2951	GW57-10-15480	LH3	Low_Level_Tritium	Tritium	0.6945	TU[d]	U

[a] U = The analyte was analyzed for but not detected.

[b] R = The data are rejected as a result of major problems with quality assurance/quality control parameters.

[c] UJ = The analyte was not identified in the sample, and the associated value is an estimate of the sample-specific detection or quantitation limit.

[d] TU = Tritium unit.

Table B-1.3-2
EES-14 Analytical Results

Sample ID	Sample Type	ER/RRES-WQH	Depth (ft)	Ag rslt (ppm)	stdev (Ag)	Al rslt (ppm)	stdev (Al)	As rslt (ppm)	stdev (As)	B rslt (ppm)	stdev (B)	Ba rslt (ppm)	stdev (Ba)	Be rslt (ppm)	stdev (Be)	Br(-) ppm	Ca rslt (ppm)	stdev (Ca)	Cd rslt (ppm)	stdev (Cd)	Cl(-) ppm	ClO4(-) ppm	Co rslt (ppm)	stdev (Co)	Alk-CO3 rslt (ppm)	ALK-CO3 (U)
GW57-10-15480	Borehole	10-2859	925	0.001	U	0.048	0.001	0.0003	0.0000	0.087	0.000	0.595	0.004	0.001	U	0.03	12.26	0.08	0.001	U	4.56	0.005, U	0.001	U*	0.8	U

Table B-1.3-2 (continued)

Sample ID	Sample Type	ER/RRES-WQH	Cr rslt (ppm)	stdev (Cr)	Cs rslt (ppm)	stdev (Cs)	Cu rslt (ppm)	stdev (Cu)	F(-) ppm	Fe rslt (ppm)	stdev (Fe)	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)	Na rslt (ppm)	stdev (Na)
GW57-10-15480	Borehole	10-2859	0.003	0.000	0.001	U	0.001	U	0.32	2.75	0.01	77.7	0.00005	U	1.10	0.00	0.025	0.000	3.26	0.01	0.086	0.000	0.010	0.000	11.64	0.08

Table B-1.3-2 (continued)

Sample ID	Sample Type	ER/RRES-WQH	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)	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)
GW57-10-15480	Borehole	10-2859	0.002	0.000	0.01	0.003, U	2.62	0.59	0.01, U	0.0002	U	7.56	0.10	0.001	U	0.001	U	0.001	U	23.7	0.2	50.8	0.5	0.001	U

Table B-1.3-2 (continued)

Sample ID	Sample Type	ER/RRES-WQH	SO4(-2) rslt (ppm)	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)	stdev (Zn)	TDS (ppm)	Cations	Anions	Balance
GW57-10-15480	Borehole	10-2859	7.14	0.039	0.000	0.001	U	0.002	U	0.001	U	0.0002	U	0.001	0.000	0.064	0.000	189	1.43	1.83	-0.12

* U = not detected.

Table B-1.3-3
Total Organic Carbon Results

Sample ID	Sample Type	Sample Depth (ft)	TOC (ppm)	Validation Code
GW57-10-15520	Development, Screen 1	910.0−930.5	0.2	U*
GW57-10-15521	Development, Screen 2	971.5−992.1	0.2	U
GW57-10-15522	Development, Screen 2	971.5−992.1	0.2	U
GW57-10-15523	Aquifer testing, Screen 2	971.5−992.1	0.2	U
GW57-10-15524	Aquifer testing, Screen 2	971.5−992.1	0.2	U
GW57-10-15525	Aquifer testing, Screen 2	971.5−992.1	0.2	U
GW57-10-15526	Aquifer testing, Screen 2	971.5−992.1	0.2	U
GW57-10-15527	Aquifer testing, Screen 2	971.5−992.1	0.2	U
GW57-10-15528	Aquifer testing, Screen 2	971.5−992.1	0.2	U
GW57-10-15529	Aquifer testing, Screen 1	910.0−930.5	0.2	U
GW57-10-15530	Aquifer testing, Screen 1	910.0−930.5	0.2	U
GW57-10-15531	Aquifer testing, Screen 1	910.0−930.5	0.2	U
GW57-10-15532	Aquifer testing, Screen 1	910.0−930.5	0.2	U

*U = Not detected.

Appendix C

Aquifer Testing Report

C-1.0 INTRODUCTION

This appendix describes the hydraulic analysis of pumping tests conducted during June and July 2010 at R-57, a dual-screen regional aquifer well located on Mesita del Buey about 300 ft east of Material Disposal Area G. The tests on R-57 were conducted to quantify the hydraulic properties of the two zones in which the well is screened, evaluate the hydraulic interconnection of the zones, and check for interference effects at regional wells R-39, R-41, and R-49 located at estimated distances of 760, 540, and 1530 ft, respectively.

Testing planned for each screen interval consisted of brief trial pumping, background water-level data collection, and a 24-h constant-rate pumping test. Water levels were monitored in both zones during each of the pumping tests in each screen.

As in most of the R-well pumping tests conducted on the Pajarito Plateau, an inflatable packer system was used in R-57, both to hydraulically isolate the screen zones and to minimize casing-storage effects on the test data. Based on the test results, storage effects appear to have been successfully eliminated.

Conceptual Hydrogeology

R-57 screen 1 lies within dacitic lavas of the Cerros del Rio basalt. Screen 1 is 20.5 ft long, extending from 910 to 930.5 ft below ground surface (bgs). Screen 2, on the other hand, is completed within the sands and gravels of the Puye Formation, presumably in the Totavi Lentil interval. Screen 2 is 20.6 ft long, placed from 971.5 to 992.1 ft bgs.

The composite static water level measured on June 20, 2010 before testing was 896.67 ft bgs. The ground surface elevation at the well was estimated to be about 6647 ft above mean sea level (amsl), making the approximate composite water-level elevation 5750.33 ft amsl.

When the screen zones were isolated using an inflatable packer, the water level in screen 1 rose 7.16 ft, to a depth of 889.51 ft bgs and an estimated elevation of 5757.49 ft amsl. At the same time, the water level in screen 2 declined 1.11 ft, making its depth to water 897.78 ft bgs at an approximate elevation of 5749.22 ft amsl. Thus, the water levels showed a head difference of 8.27 ft and a strong downward hydraulic gradient, implying a hydraulically resistive zone between the two screens—possibly the contact between the Cerros del Rio basalt and Puye formation.

No specific aquitards were identified in the saturated interval penetrated by R-57. Thus, the effective aquifer thickness of the hydraulically contiguous zone associated with each screen interval was not known. As an approximation, the hydraulically contiguous upper zone was estimated to extend from the static water level of 889.51 ft bgs to the contact between the Cerros del Rio basalt and Puye Formation at 950 ft—a saturated thickness of a little over 60 ft. The original borehole was advanced to 1081.6 ft bgs and still showed sand and gravel with no identifiable aquitards through that depth. Thus, the hydraulically contiguous screen-2 zone may have been more than 100 ft thick.

R-57 Screen 1 Testing

The two screens were tested in reverse order, with screen 1 testing occurring after screen 2 testing. Screen 1 was tested from June 28 to July 2, 2010. After the drop pipe was filled and the discharge rate was set on June 28, testing began with brief trial pumping on June 29 followed by a 24-h constant-rate pumping test that was started on June 30. Following shutdown of the 24-h test on July 1, recovery data were recorded for 1 d until July 2.

Trial testing of screen 1 was attempted initially at 7:00 a.m. on June 29. However, the pump appeared to malfunction and did not produce water initially. Similar pump performance had been observed the previous day during the process of filling the drop pipe and setting the discharge rate. At that time, multiple starts and restarts were needed to finally get the pump running. When the pump failed again on the morning of June 29, the packer was deflated temporarily (as a precaution to release any trapped air that might be in the system), and the pump was started at 7:13 a.m., this time producing water immediately at a discharge rate of 7.1 gallons per minute (gpm). The packer was reinflated shortly after water was produced. Pumping continued for 17 min until 7:30 a.m. Recovery data were recorded for 30 min until 8:00 a.m., when trial 2 pumping began at a discharge rate of 7.1 gpm. Following shutdown at 9:00 a.m., trial 2 recovery data were collected for 1382 min until 8:02 a.m. on June 30.

At 8:00 a.m. on June 30, start of the 24-h pumping test was attempted. Again, the pump did not produce water. Electrical power to the pump was cut at 8:01 a.m. and a restart was attempted at 8:02 a.m. This time, the pump produced water immediately at a discharge rate of 7.1 gpm. Pumping continued for 1438 min until 8:00 a.m. on July 1. Following shutdown, recovery data were recorded for 1440 min until 8:00 a.m. on July 2, when the pump was pulled from the well.

The cause of the pump malfunction was not determined. Air entrainment seemed unlikely to be the cause, as the water produced from screen 1 had only minimal gas content—substantially less than most of the recently tested R-wells.

R-57 Screen 2 Testing

Well R-57 screen 2 was tested from June 22 to 28, 2010. After the pump was installed, testing began with brief trial pumping on June 22, background data collection, and a 24-h constant-rate pumping test that began on June 24. Following shutdown on June 25, recovery/background data were collected for 2 d until June 27. At that time, additional purging of screen 2 was performed to achieve the water volume withdrawal requirements of the well-development protocol. This additional purging provided the opportunity to conduct a supplemental pumping and recovery test.

Two trial tests were conducted on June 22. Trial 1 was conducted at a discharge rate of 16.2 gpm for 60 min from 1:00 to 2:00 p.m. and was followed by 60 min of recovery until 3:00 p.m. Trial 2 was conducted for 60 min from 3:00 to 4:00 p.m. at a rate of 16.3 gpm. Following shutdown, recovery/background data were recorded for 2400 min until 8:00 a.m. on June 24.

At 8:00 a.m. on June 24, the 24-h pumping test began at a rate of 16.5 gpm. Pumping continued for 1440 min until 8:00 a.m. on June 25. Following shutdown, recovery/background measurements were recorded for 2896 min until 8:16 a.m. on June 27.

The final purging event began at 8:16 a.m. on June 27 at a discharge rate of 23.5 gpm and continued for 538 min until 5:14 p.m. Following shutdown, recovery data were recorded for 824 min until 6:58 a.m. on June 28, when the pump was pulled from the well.

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 Pajarito 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-57, 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, 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 at about 6647 ft amsl. The static water level in R-57 was 896.67 ft bgs, making the estimated water-table elevation 5750.33 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-57.

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

$$P_{WT} = P_{TA54} \exp\left[-\frac{g}{3.281R}\left(\frac{E_{R-57} - E_{TA54}}{T_{TA54}} + \frac{E_{WT} - E_{R-57}}{T_{WELL}}\right)\right]$$

Equation C-1

where P_{WT} = barometric pressure at the water table inside R-57

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

g = acceleration of gravity, in meters per square second (9.80665 m/s^2)

R = gas constant, in joule/kilogram/kelvin (287.04 J/kg/K)

$E_{R\text{-}57}$ = land surface elevation at R-57 site, in feet (approximately 6647 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-57, in feet (approximately 5750.33 ft)

T_{TA54} = air temperature near TA-54, in kelvins (assigned a value of 70.1ºF, or 294.3 K)

T_{WELL} = air temperature inside R-57, in kelvins (assigned a value of 67.6 ºF, or 292.9 K)

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 hydrograph to discern the correlation between the two and determine whether water-level corrections would be needed before data analysis.

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 Pajarito Plateau, the early pumping period is the only time that the effective height of the cone of depression is known with certainty because, soon after startup, the cone of depression expands vertically through permeable materials above and/or below the screened interval. 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, potentially 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).

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

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

The calculated casing-storage time is quite conservative. Often, the data show that significant effects of casing storage have dissipated after about half the computed time.

For wells screened across the water table, there can be an additional storage contribution from the filter pack around the screen. The following equation provides an estimate of the storage duration accounting for both casing and filter pack storage.

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

Equation C-3

where S_y = short-term specific yield of filter media (typically 0.2)

D_B = diameter of borehole, in inches

D_C = outside diameter of well casing, in inches

This equation was derived from Equation C-2 on a proportional basis by increasing the computed time in direct proportion to the additional volume of water expected to drain from the filter pack. (As proof, note that the left-hand term within the brackets is directly proportional to the annular area [and volume] between the casing and drop pipe, while the right-hand term is proportional to the area [and volume] between the borehole and the casing, corrected for the drainable porosity of the filter pack. Thus, the summed term within the brackets accounts for all of the volume [casing water and drained filter pack water] appropriately.)

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. This approach was successful in the R-57 pumping test effort.

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-4

where

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

Equation C-5

and

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

Equation C-6

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-7

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

Equation C-8

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:

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

Equation C-9

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. An exception occurs when the transmissivity of the aquifer is very low. In that case, some of the early pumped well drawdown data may not be well approximated by the Cooper-Jacob 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 the following:

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

Equation C-10

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 many of the test wells completed on the Pajarito Plateau 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-11

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

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

b = aquifer thickness

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

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

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

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

K_z = vertical hydraulic conductivity

K_r = horizontal hydraulic conductivity

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

$$\beta = \sqrt{\frac{K_z}{K_r}}\frac{n\pi r}{b}$$

Equation C-12

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

C-4.1 Fractured Rock Methods

In fractured rock settings, there are two primary approaches to analyzing water-level data from constant-rate pumping tests. In one approach, porous media assumptions are applied and the fractured aquifer is analyzed as though it were a homogeneous, equivalent porous medium. This is often called the *radial* conceptual model, because groundwater is assumed to move radially toward the pumped well. If there are a large number of interconnected fractures, this conceptual model may be reasonable and the response to pumping may be similar to what would be observed in typical unconsolidated sediments. At sufficiently large scales (time or distance), many fractured rock environments show response consistent with the radial flow model.

In another approach, the pumped well is assumed to intersect a fully penetrating fracture, which has infinite conductivity and is imbedded in an otherwise homogeneous aquifer. This is referred to as the *linear* conceptual model because for a very long fracture, groundwater flows along straight lines that are approximately perpendicular to the orientation of the fracture. If there is one dominant fracture in the vicinity of the pumped well (actually penetrated by the well), this conceptual model may describe the flow regime more accurately than the radial model. At late time, as the cone of depression expands to a sufficiently large size compared to the fracture length, the transient flow response gradually transitions to radial flow. Thus, linear flow systems often exhibit radial flow response at large pumping times.

It is important to note that sometimes in fractured rock aquifers, neither conceptual model adequately describes the response to pumping. This is because there are often several dominant fractures, rather than just one, and numerous other fractures of various sizes. The resulting heterogeneous flow system may be too complex to be described accurately by either the radial model or the linear model. In these cases careful review of the data is required and the limitations of the available analytical methods must be considered in the analysis.

Another common conceptual description of fractured systems is the *fracture and block* model (or dual porosity model), in which the aquifer is assumed to be composed of a large number of uniform, permeable fractures with blocks of tighter materials between the fractures. However, this is nothing more than a radial flow model with special features. During pumping, the fractures draw down rapidly and then are gradually recharged by water contained in the low-permeability blocks. This dual porosity representation of the aquifer produces a bimodal drawdown curve analogous to the delayed yield response seen in typical unconfined aquifers. Except for the bimodal character of the drawdown curve, the analysis is similar to that applicable to standard radial flow systems.

Most radial flow systems are described adequately by the Theis and Cooper-Jacob equations described above. Linear flow to a single primary fracture, on the other hand, is generally described by the Gringarten-Witherspoon solution (Gringarten and Witherspoon 1972, 111048). For a well drilled into a fracture of length $2x_f$ oriented along the *x*-axis and centered at the origin of an *x*-*y* coordinate system, the following equation applies:

$$s = \frac{Q}{8\sqrt{\pi}T}\int_0^{t_D}\left[erf\,\frac{1-x_D}{2\sqrt{\tau}} + erf\,\frac{1+x_D}{2\sqrt{\tau}}\right]\exp\left(\frac{-y_D^2}{4\tau}\right)\frac{d\tau}{\sqrt{\tau}}$$

Equation C-13

where, in consistent units, the following definitions apply:

$$t_D = \frac{Tt}{Sx_f^2}$$

Equation C-14

$$x_D = \frac{x}{x_f}$$

Equation C-15

$$y_D = \frac{y}{x_f}$$

Equation C-16

The term erf is the error function, defined as follows:

$$erf(z) = \frac{2}{\sqrt{\pi}} \int_0^z \exp\left(-\tau^2\right) d\tau$$

Equation C-17

One of the drawbacks of interpreting pumping tests using the linear model is that the parameter x_f, the half-length of the fracture, is not known. Introduction of this additional unknown parameter often makes it impossible to determine a unique solution for the hydraulic aquifer parameters. Nevertheless, application of the linear analysis provides insight into the system response and can provide an explanation for multiple slopes that may be observed in conventional plots of the drawdown data. This, in turn, can aid subsequent interpretation of the data using the Theis method by clarifying those instances when the Theis analysis must be restricted to the late-time data.

Another drawback of the linear model is that curve-matching methods based on log-log plots often fail. This can occur because well losses or head loss within the fracture (assumed in the theory to be infinitely permeable) alter both the position and shape of the data plot, resulting in poor curve matches and calculation of erroneous aquifer coefficients.

For drawdown data in the pumped well (and any observation wells located within the same fracture as the pumped well), the Gringarten-Witherspoon equation (Gringarten and Witherspoon 1972, 111048) can be simplified for early pumping times as follows:

$$s = \frac{Q}{2x_f \sqrt{\pi TS}} \sqrt{t}$$

Equation C-18

This shows that the initial drawdown response is related to the square root of the pumping time. Thus, a linear plot of *s* versus the square root of *t* yields a straight line. Further, because of this relationship, a log-log plot of *s* versus *t* yields a straight line having a slope of one-half. Again, these simplified responses occur only in the pumped well and observation wells installed in the same fracture as the pumped well and only at early time. At late time, as the flow transitions from linear to radial, the response is more similar to the Theis type curve.

Part of the analyst's job in reviewing and interpreting pumping test data is choosing which model—radial, linear, dual porosity, etc.—does the best job of describing the flow system. This decision cannot be deduced from the geologic setting alone but must consider the drawdown response as well. As stated above, radial flow data generally exhibit a Theis type curve shape on log-log plots and a straight-line trend on semilog plots. In contrast, early-time linear flow data from wells completed within the same fracture as the pumped well typically show a straight-line trend on both log-log plots (with a slope of one-half) and linear plots of *s* versus the square root of *t*. These combinations of plotting trends are the strongest indicators of which flow regime is prevalent in a given pumping test.

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:

$$T = \frac{264Q}{\Delta s}$$ **Equation C-19**

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

Recovery data also can be analyzed using the Hantush equation for partial penetration (Hantush 1961, 098237; Hantush 1961, 106003). This approach is generally applied to the early data in a plot of recovery versus recovery time.

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:

$$s_P = \frac{1-\frac{L}{b}}{\frac{L}{b}}\left[\ln\frac{b}{r_w} - 2.948 + 7.363\frac{L}{b} - 11.447\left(\frac{L}{b}\right)^2 + 4.675\left(\frac{L}{b}\right)^3\right]$$ **Equation C-20**

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:

$$K = \frac{264Q}{sb}\left(\log\frac{0.3Tt}{r_w^2 S} + \frac{2s_P}{\ln 10}\right)$$ **Equation C-21**

The Brons and Marting procedure can be applied to both partially penetrating and fully penetrating wells.

To apply this procedure, a storage coefficient value must be assigned. Storage coefficient values generally range from 10^{-5} to 10^{-3} for confined aquifers and 0.01 to 0.25 for unconfined granular aquifers (Driscoll 1986, 104226). The screen 1 zone was treated as unconfined in this analysis but, because it included fractured lavas, it was assigned a relatively low storage coefficient of 0.01. The screen 2 zone was considered confined and assigned an arbitrary storage coefficient value of 5×10^{-4}. The calculation result is not particularly sensitive to the choice of storage coefficient value, so a rough estimate is generally adequate to support the calculations.

The analysis also requires assigning a value for the saturated aquifer thickness, b. Because locations of aquitards were not identified, an estimated thickness value of 60 ft was assigned to the upper zone and an arbitrary thickness of 100 ft was assigned to the lower zone for the purpose of these calculations. For partially penetrating conditions, the calculations are not particularly sensitive to the choice of aquifer thickness because sediments far above or below the screen typically contribute little flow.

C-7.0 BACKGROUND DATA ANALYSIS

Background aquifer pressure data collected during the R-57 tests were plotted along with barometric pressure to determine the barometric effect on water levels.

Figure C-7.0-1 shows aquifer pressure data from R-57 screen 1 during the screen 1 pumping test 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-57 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 pumping times for the R-57 screen 1 pumping tests are included on the figure for reference. R-57 screen 1 showed only slight pressure change in response to barometric pressure fluctuations, suggesting a high barometric efficiency. Close examination of the apparent hydrograph showed a slight “ripple” effect that appeared to be a delayed response to dips in barometric pressure on June 29 and again on July 1.

Figure C-7.0-2 shows aquifer pressure data collected from R-57 screen 2 during the screen 1 pumping test. Portions of the hydrograph had a strikingly similar shape to the barometric pressure curve. The apparent hydrograph data were replotted on the expanded scale shown in Figure C-7.0-3 to align the data more closely with the barometric pressure curve. Although the shapes of the curves were similar, changes in the hydrograph preceded those in the barometric pressure record by as much as several hours—ostensibly an impossibility. Also, as described below, subsequent monitoring of screen 2 (during the screen 2 testing period) showed the hydrograph and barometric pressure curves to be even more out of phase. It was possible that the sinusoidal fluctuations in the apparent hydrograph were Earth-tide effects rather than barometric pressure effects. The magnitude of the perturbations in the hydrograph (a few hundredths of a foot) were consistent with Earth-tide effects observed at Los Alamos. Because both Earth tides and barometric pressure fluctuations are diurnal, the similar appearance of the two curves on Figure C-7.0-3 may have been coincidental.

Figures C-7.0-2 and C-7.0-3 show that pumping screen 1 had no discernable effect on water levels in screen 2.

Figure C-7.0-4 shows aquifer pressure data from R-57 screen 1 during the screen 2 pumping test along with barometric pressure data from TA-54 that have been corrected to equivalent barometric pressure in feet of water at the water table. As observed during the screen 1 test period, fluctuations in barometric pressure appeared to induce subtle ripples in the total aquifer pressure curve, indicating a fairly high barometric efficiency. The timing of the ripples lagged the fluctuations in barometric pressure, showing a significantly delayed response.

The data from Figure C-7.0-4 were replotted in Figure C-7.0-5 with a tenfold increase in the hydrograph scale to show more of the water-level data. A curious effect observed during each pumping event was a slight immediate rise in screen 1 water level at the onset of pumping screen 2. This may have been an indication of reverse water-level response associated with elastic deformation of the subsurface strata, also called the Noordbergum effect (Wolff 1970, 098242; Rodrigues 1983, 098239; Heish 1996, 098238). It also may have been nothing more than an elastic response in the pumping string caused by stretching or thermal expansion of the drop pipe when the pump was run.

Figures C-7.0-4 and C-7.0-5 showed a steady rise in the screen 1 water level during the monitoring period once the inflatable packer was expanded to isolate the two screen zones for testing at screen 2. At the end of the monitoring period, the screen 1 head was still rising. Thus, the maximum head difference of 8.27 observed between the screen 1 and 2 water levels at the end of the screen 2 test period may underestimate the actual head difference between the two zones. It appears likely that a longer equilibration period would have shown a greater head difference.

Aside from the reverse water-level response and steady overall rise in level, the screen 1 zone showed no discernable drawdown response to pumping screen 2.

Figure C-7.0-6 shows aquifer pressure data collected from R-57 screen 2 during the screen 2 pumping tests. As before, the apparent hydrograph showed diurnal perturbations of a few hundredths of a foot magnitude.

The data on Figure C-7.0-6 were replotted on the expanded-scale graph shown in Figure C-7.0-7 in an effort to match the hydrograph to the barometric pressure curve. The two curves did not match well in position or magnitude and exhibited a significant phase difference. This was particularly evident in the data from late June 26, when the illustrated rise in aquifer pressure nearly coincided with a decline in barometric pressure. As suggested previously, the diurnal sinusoidal fluctuations in aquifer pressure may have been caused by Earth tides rather than barometric pressure fluctuations. This conclusion implies the possibility of a relatively high barometric efficiency for the screen 2 aquifer. Alternatively, there may be a large delay (multiple days, as observed at nearby R-22) between barometric pressure changes and aquifer pressure response rather than the typical immediate response.

Hydrograph data from nearby wells R-39 (about 760 ft away), R-41 screen 2 (540 ft away—screen 1 is dry), and R-49 (1530 ft away) were obtained to check for a possible pumping response to the R-57 tests. Because these wells were monitored using vented pressure transducers and the barometric-pressure-induced fluctuations in the hydrographs were large, it was necessary to correct the water-level data by removing the barometric effect. This was done using the Barometric and Earth Tide Correction (BETCO) 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 it can also remove Earth tide effects.

Figure C-7.0-8 shows the hydrograph data obtained from R-39, located about 760 ft from R-57. The data show a clear response to pumping R-57 screen 2 but no response to pumping screen 1. On the BETCO correction curve, the hydrograph data show an abrupt rise in level around midday on June 21. This corresponded to removal of the development pump and temporary isolation packer that had been installed in the well before testing. Once the temporary packer was deflated, water from screen 1 flowed downward to screen 2, raising the screen 2 water level as well as that of R-39. The rise in the R-39 water level associated with this injection event was about 0.1 ft. The times during which the packer was deflated so that cross-flow could occur are identified on the graph.

The test pump and accompanying packer assembly were installed and the packer inflated about midday on June 22. When the packer was inflated, cross-flow from screen 1 to screen 2 ceased and the water level in R-39 declined back to the static level. Subsequent trial pumping of R-57 screen 2 produced only miniscule drawdown in R-39 because of the short duration of the trial tests. The 24-h test conducted at 16.5 gpm from June 24 to 25, on the other hand, appeared to induce a drawdown of around 0.13 ft in

R-39. When the pump was shut off at the conclusion of the 24-h pumping period, the water level in R-39 rebounded to static conditions.

On the morning of June 27, purging R-57 screen 2 at 23.5 gpm caused around 0.2 ft of drawdown at R-39. The following morning, the packer was deflated so the pump and packer string could be removed and reconfigured for testing screen 1. The new assembly was installed later that afternoon. As shown on the figure, temporary removal of the inflatable packer allowed cross-flow from screen 1 to screen 2, which raised the R-39 water level about 0.1 ft.

During the screen 1 pumping tests, there was no discernable drawdown in R-39. However, on July 2 the R-39 water level rose about 0.1 ft, again during cross-flow when the test pump was removed and replaced with a temporary isolation packer following the screen 1 testing effort.

Figure C-7.0-9 shows the hydrograph data obtained from R-41 screen 2, located about 540 ft from R-57. The BETCO-corrected hydrograph shows no discernable response to pumping either screen in R-57.

Figure C-7.0-10 shows the hydrograph data obtained from R-49 screen 1, located about 1530 ft from R-57. The BETCO-corrected hydrograph shows no discernable response to pumping either screen in R-57.

Figure C-7.0-11 shows the hydrograph data obtained from R-49 screen 2, located about 1530 ft from R-57. The BETCO-corrected hydrograph shows no discernable response to pumping R-57 screen 1 but shows response similar to that observed in R-39 to pumping and injecting R-57 screen 2. During cross-flow on June 21 to 22, June 28, and July 2, there was a water-level rise of about 0.08 ft in R-49 screen 2. When R-57 screen 2 was pumped at 16.5 gpm for 24 h from June 24 to 25, R-49 screen 2 showed a drawdown of about 0.08 ft early on and 0.1 ft by the end of the test. When purging was performed in R-57 screen 2 at 23.5 gpm on June 27, R-49 screen 2 showed about 0.012 ft of drawdown.

The data indicate that R-57 screen 2, R-39, and R-49 screen 2 appear to be located in the same hydrologic zone, while R-57 screen 1, R-41 screen 2, and R-49 screen 1 do not fall within that unit.

C-8.0 WELL R-57 SCREEN 1 DATA ANALYSIS

This section presents the data obtained from the R-57 screen 1 pumping tests and the results of the analytical interpretations. Data are presented for drawdown and/or recovery from trial 1, trial 2, and the 24-h constant-rate test.

C-8.1 Well R-57 Screen 1, Trial 1

As described previously, because of intermittent pump failure, the trial 1 test on R-57 screen 1 began with the packer deflated. After the pump was started, the packer was inflated to isolate the two screen zones. This chaotic startup precluded analysis of the trial 1 drawdown data.

Figure C-8.1-1 shows the recovery data collected following shutdown of the trial 1 pumping test. The early data suggested a transmissivity of 1150 gallons per day per foot (gpd/ft). The subsequent data showed severe flattening of the recovery curve. As described below, this flattening was believed to reflect either a dual-porosity effect or possibly refilling of voids in the lava formation that had drained during pumping. It appeared unlikely that the flat slope shown on the figure was indicative of formation transmissivity.

C-8.2 Well R-57 Screen 1, Trial 2

Figure C-8.2-1 shows a semilog plot of the drawdown data collected from the 60-min trial 2 test on screen 1 at a discharge rate of 7.1 gpm. The transmissivity estimated from the plot was 1330 gpd/ft. The subsequent flat slope likely reflected dewatering of a prominent fractured bedrock void or possibly a dual-porosity response. It also could have indicated leakage from above, from a void that subsequently drained.

Figure C-8.2-2 shows the recovery data collected following shutdown of the trial 2 pumping test. The early data suggested a transmissivity of 1590 gpd/ft. The subsequent data showed the flattening observed on previous plots. At late time, this was followed by a severe increase in slope with the data trace going nearly vertical.

As stated above, the flat portion of the drawdown/recovery curves may have reflected dewatering/refilling of a prominent fractured bedrock void or possibly a dual-porosity response. It also could have indicated leakage from above the screened interval, from a void that drained during pumping and subsequently refilled.

As suggested by the hydrograph in Figure C-7.0-1, the trial tests were superimposed on a general water-level rebound trend where the average rate of rebound was about 0.28 ft/d. This background trend may have biased the apparent recovery rate shown in Figure C-8.2-2. Therefore, the late recovery data were adjusted by subtracting out 0.28 ft/d from the measured recovery. The corrected data plot is shown on the graph. The transmissivity value determined from the resulting slope was 3900 gpd/ft. The accuracy of this value was considered somewhat questionable, however, because the mathematical drawdown correction was large in comparison with the observed water-level change.

C-8.3 Well R-57 Screen 1, 24-Hour Constant-Rate Test

Figure C-8.3-1 shows a semilog plot of the drawdown data collected from the 24-h constant-rate pumping test conducted at 7.1 gpm. The longer test clearly showed the early steep slope, the flat transition, and the final steep slope. The analysis shown on the graph yielded an early-time transmissivity of 2340 gpd/ft and a late-time transmissivity of 2110 gpd/ft.

The general shape of the curve in Figure C-8.3-1 was consistent with typical dual-porosity response. There were two anomalies in the plot, however. First, it was expected that the early-time transmissivity would reflect just the screened interval and that the late-time value would reflect a greater thickness of Cerros del Rio basalt (for example, the 60 ft between the static water level and the contact between the Cerros del Rio basalt and underlying Puye Formation). Thus, it was expected that the second slope would have been flatter, yielding a greater transmissivity value corresponding to the full saturated thickness of the Cerros del Rio basalt. Second, the storage coefficient computed from the second slope (calculation omitted) was unusually large, i.e., greater than theoretically possible based on the geology (unless massive voids were present). These two observations were consistent with the possibility of a negative boundary near the pumped well. A local boundary would have had the effect of altering the second slope, making it steeper than it otherwise would have been, resulting in both an erroneously low transmissivity value and erroneously high storage coefficient value. The idea of a local boundary is speculative but would explain the observed drawdown response.

It should be pointed out that the general shape of the drawdown curve is also consistent with presence of a large void, such as a lava tube, that may have been dewatered during the pumping test. Such a void near the water table would have the observed effect of attenuating the rate of drawdown until the void was dewatered and, likewise, would retard the recovery rate until the void was refilled.

Figure C-8.3-2 shows the recovery data recorded following the 24-h pumping test. The general form of the curve was similar to the drawdown plot, showing steep early and late slopes and a flat transition in between. The transmissivity computed from the early data was 1550 gpd/ft─presumably representative of just the screened interval. The late-time slope produced a computed transmissivity value of 1870 gpd/ft─presumably too low for the full saturated thickness of the Cerros del Rio basalt and possibly indicative of a local boundary as mentioned above.

C-8.4 Well R-57 Screen 1 Specific Capacity Data

Specific capacity data were used along with well geometry to estimate a lower-bound transmissivity value for the permeable zone penetrated by R-57 screen 1. This was done to provide a frame of reference for evaluating the foregoing analyses. The method used (Brons and Marting, 1961, 098235) is valid for granular aquifers. In fractured rock, such as lavas, the pumped well usually penetrates a void or large fracture, which increases its effective hydraulic radius and consequently its specific capacity. This usually has the effect of overestimating the lower-bound hydraulic conductivity.

During the 24-h pumping test, the discharge rate was 7.1 gpm after 1438 min of pumping, with a resulting drawdown of 3.27 ft for a specific capacity of 2.17 gpm/ft. In addition to specific capacity and pumping time, other input values used in the calculations included an assigned storage coefficient value of 0.01, a borehole radius of 0.62 ft (inferred from the volume of filter pack required to backfill the screen zone), a screen length of 20.5 ft, and an estimated saturated aquifer thickness of 60 ft.

Applying the Brons and Marting method to these inputs yielded a lower-bound hydraulic conductivity value of 88 gpd/ft^2, or 11.8 ft/d. The early-time data from the drawdown and recovery plots discussed above produced an average transmissivity of 1590 gpd/ft, suggesting an average hydraulic conductivity for the screened interval of 78 gpd/ft, or 10.4 ft/d. Thus, the “lower-bound” value was similar to, but greater than, the pumping test value. This is the expected result when applying the specific capacity method to a fractured aquifer. As stated above, any large, permeable fracture or void penetrated by the pumped well increases the effective radius of the well and increases the specific capacity correspondingly. The increased specific capacity leads to an overestimate of the “lower-bound” hydraulic conductivity. Taking this into account, the specific capacity data were not inconsistent with the pumping test analysis results.

C-9.0 WELL R-57 SCREEN 2 DATA ANALYSIS

This section presents the data obtained from the R-57 screen 2 pumping tests and the results of the analytical interpretations. Data are presented for drawdown and/or recovery from trial 1, trial 2, the 24-h constant-rate test, and the final purge event.

C-9.1 Well R-57 Screen 2, Trial 1

The trial 1 pumping period was used to adjust the discharge rate for subsequent pumping. The resulting chaotic pumping rate variation precluded analysis of the trial 1 drawdown data.

Figure C-9.1-1 shows the recovery data collected following shutdown of the trial 1 pumping test. The transmissivity estimated from the graph was 20,300 gpd/ft. If this value represented just the screened interval, the corresponding hydraulic conductivity would be 985 gpd/ft^2, or 132 ft/d. It was also possible that some vertical expansion of the cone of depression had occurred, meaning that this transmissivity represented a somewhat greater interval than just the screen length, with a correspondingly lower hydraulic conductivity. The lack of identifiable aquitards made it impossible to know the exact thickness of the hydraulically contiguous unit corresponding to the computed transmissivity.

C-9.2 Well R-57 Screen 2, Trial 2

Figure C-9.2-1 shows a semilog plot of the drawdown data collected from the trial 2 test at a discharge rate of 16.3 gpm. The transmissivity value computed from the line of fit shown on the graph was 21,500 gpd/ft, making the average hydraulic conductivity of the screened interval 1040 gpd/ft^2, or 140 ft/d, or possibly less, depending on the effective aquifer thickness.

Figure C-9.2-2 shows the recovery data collected following shutdown of the trial 2 pumping test. The transmissivity estimated from the graph was 20,300 gpd/ft, making the computed hydraulic conductivity 985 gpd/ft^2, or 132 ft/d.

C-9.3 Well R-57 Screen 2, 24-Hour Constant-Rate Test

Figure C-9.3-1 shows a semilog plot of the drawdown data collected from the 24-h constant-rate pumping test conducted at 16.5 gpm. Analysis of the data showed a screen interval transmissivity of 20,600 gpd/ft and a hydraulic conductivity of 1000 gpd/ft^2, or 134 ft/d.

Late data from the pumping test showed an apparent flattening of the drawdown curve, presumably a result of vertical growth of the cone of depression into a greater thickness of sediment. This portion of the curve also could have been affected by lateral heterogeneity and/or leakage from above or below. The flatter slope shown on the graph implies an overall transmissivity for the aquifer penetrated by screen 2 far in excess of 20,000 gpd/ft. The exact value could not be determined because the scatter in the recorded data was large in comparison with the drawdown change over time.

Figure C-9.3-2 shows the recovery data collected following shutdown of the 24-h constant-rate pumping test. As indicated on the plot, the transmissivity computed from the graph was 18,600 gpd/ft with a corresponding hydraulic conductivity of 903 gpd/ft^2, or 121 ft/d. The late-time trend was apparently obscured by background fluctuations, perhaps Earth-tide effects.

C-9.4 Well R-57 Screen 2 Purge Event

Figure C-9.4-1 shows a semilog plot of the drawdown data collected from the 9-h purge event conducted at 23.5 gpm. As indicated on the plot, the transmissivity computed from the graph was 17,000 gpd/ft with a corresponding hydraulic conductivity of 825 gpd/ft2, or 110 ft/d. After a few h of pumping, the curve appeared to flatten, presumably in response to vertical growth of the cone of depression, indicating an overall transmissivity well in excess of 20,000 gpd/ft.

Figure C-9.4-2 shows the recovery data collected following shutdown of the supplemental pumping period. As indicated on the plot, the transmissivity computed from the graph was 15,900 gpd/ft with a corresponding hydraulic conductivity of 772 gpd/ft^2, or 103 ft/d.

C-9.5 Well R-57 Screen 2 Specific Capacity Data

Specific capacity data were used along with well geometry to estimate a lower-bound hydraulic conductivity value for the permeable zone penetrated by R-57 screen 2. This was done to provide a frame of reference for evaluating the foregoing analyses.

During the 24-h constant-rate pumping test, the discharge rate was 16.5 gpm after 1440 min of pumping, with a resulting drawdown of 1.67 ft for a specific capacity of 9.9 gpm/ft. In addition to specific capacity and pumping time, other input values used in the calculations included a storage coefficient value of 5×10^{-4}, a borehole radius of 0.90 ft (inferred from the volume of filter pack required to backfill the screen zone), a screen length of 20.6 ft, and an arbitrary assigned saturated thickness of 100 ft.

Applying the Brons and Marting method (1961, 098235) to these inputs yielded a lower-bound hydraulic conductivity value of 440 gpd/ft^2, or 59 ft/d. The foregoing pumping test analyses yielded transmissivity values averaging about 19,200 gpd/ft immediately adjacent to the well with an average hydraulic conductivity of 930 gpd/ft^2, or 125 ft/d. The lower-bound value was consistent with these results and implied a well efficiency of about 50%. It is also possible that the measured transmissivity values represented an effective thickness somewhat greater than the screen length. This would have the effect of reducing the hydraulic conductivity values computed from the pumping tests and implying a well efficiency greater than 50%.

C-10.0 R-39 AND R-49 SCREEN 2 DISTANCE-DRAWDOWN ANALYSIS

Distance-drawdown analysis was used to evaluate the interference drawdown effects observed at wells R-39 and R-49 screen 2 when pumping R-57 screen 2. Recall that operating R-57 screen 2 at 23.5 gpm for 0.37 d produced drawdown values of approximately 0.2 and 0.12 ft in R-39 and R-49 screen 2, respectively. After a similar duration of pumping, partway through the 24-h pumping test at 16.5 gpm, the corresponding observed drawdown values were about 0.13 and 0.08 ft, respectively. These drawdown values were converted to specific drawdown by dividing each value by the respective discharge rate. The resulting specific drawdown values were analyzed using distance-drawdown methods and Theis curve matching (1934-1935, 098241). In the approach, specific drawdown is plotted versus the square of the reciprocal of the distance to the observation well, and standard Theis curve matching is used to obtain aquifer parameters.

Figure C-10.0-1 shows the resulting distance-drawdown graph and computed aquifer coefficients. The calculations yielded an aquifer transmissivity of 46,000 gpd/ft and a storage coefficient of 3.3×10^{-4}. The computed transmissivity was reasonable, being consistent with the flat slopes observed at late time on the drawdown and recovery plots, which had implied a transmissivity far in excess of 20,000 gpd/ft. Likewise, the storage coefficient was typical of what is expected in a confined granular aquifer. These parameters probably provide a reasonable characterization of the portion of the Puye Formation aquifer spanned by R-39 and R-49 screen 2.

C-11.0 SUMMARY

Constant-rate pumping tests were conducted on R-57 screens 1 and 2. The tests were performed to gain an understanding of the hydraulic characteristics of the screen zones and the degree of interconnection between them. Numerous observations and conclusions were drawn from the tests as summarized below.

The static water level observed in screen 1 was 8.27 ft higher than that in screen 2, showing a strong downward hydraulic gradient and implying resistive strata separating the screen zones. The water level in screen 1 was still rising at the end of the monitoring period, and thus the true head difference between the screen zones was likely greater than 8.27 ft.

A comparison of barometric pressure and R-57 water-level data showed a fairly high barometric efficiency for both screen zones.

Pumping either screen had no observable effect on the other.

Pumping R-57 screen 1 at 7.1 gpm had no discernable effect on water levels at R-39, R-41 screen 2, or R-49 screens 1 and 2. Pumping screen 2 at 16.5 to 23.5 gpm had no effect on water levels at R-41 screen 2 and R-49 screen 1 but induced 0.1 to 0.2 ft of drawdown in R-39 and R-49 screen 2.

Analysis of the screen 1 pumping tests showed an average hydraulic conductivity value of 78 gpd/ft^2, or 10.4 ft/d. The data showed dual-porosity characteristics, suggesting prominent bedrock fracture effects–either classical dual-porosity effects or a major void that was dewatered during testing. Late drawdown and recovery data provided indirect evidence of the possibility of a nearby boundary.

Screen 1 produced 7.1 gpm for 1438 min with 3.27 ft of drawdown for a specific capacity of 2.17 gpm/ft. The lower-bound hydraulic conductivity computed from this information using porous media assumptions was 88 gpd/ft^2 or 11.8 ft/d, somewhat greater than the pumping test values. This was the expected result, as fractured media produce higher specific capacities than comparable porous media. In that light, the observed specific capacity was consistent with the pumping test analysis.

Analysis of the screen 2 pumping tests suggested a transmissivity of 19,200 gpd/ft for the screened interval of perhaps a somewhat greater thickness. This corresponded to an average hydraulic conductivity of about 930 gpd/ft^2 (125 ft/d) or possibly less, depending on the sediment thickness represented by the computed transmissivity. Late drawdown and recovery water levels showed significant flattening of the data curve, implying an overall transmissivity for the aquifer penetrated by screen 2 well in excess of 20,000 gpd/ft.

Screen 2 produced 16.5 gpm for 1440 min with 1.67 ft of drawdown for a specific capacity of 9.9 gpm/ft. The lower-bound hydraulic conductivity computed from this information was 440 gpd/ft^2 or 59 ft/d, consistent with the pumping test values and suggesting a screen-zone efficiency on the order of 50% or greater.

Distance-drawdown analysis of the response to pumping R-57 screen 2 observed at R-39 and R-49 screen 2 suggested an area-wide aquifer transmissivity of 46,000 gpd/ft and an estimated storage coefficient of 3.3×10^{-4}.

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)

Gringarten, A.C., and P.A. Witherspoon, 1972. “A Method of Analyzing Pump Test Data from Fractured Aquifers,” Proceedings from the Symposium on Percolation through Fissured Rock, International Society for Rock Mechanics and International Association of Engineering Geology, September 18-19, 1971, Stuttgart, Germany, pp. T3-B1 to T3-B8. (Gringarten and Witherspoon 1972, 111048)

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)

Heish, P.A., November-December 1996. “Deformation-Induced Changes in Hydraulic Head During Ground-Water Withdrawal,” *Ground Water,* Vol. 34, No. 6, pp. 1082-1089. (Hsieh 1996, 098238)

Rodrigues, J.D., 1983. “The Noordbergum Effect and Characterization of Aquitards at the Rio Maior Mining Project,” *Ground Water,* Vol. 21, No. 2, pp. 200-207. (Rodrigues 1983, 098239)

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)

Wolff, R.G., December 1970. “Relationship Between Horizontal Strain Near a Well and Reverse Water Level Fluctuation,” *Water Resources Research,* Vol. 6, No. 6, pp. 1721-1728. (Wolff 1970, 098242)

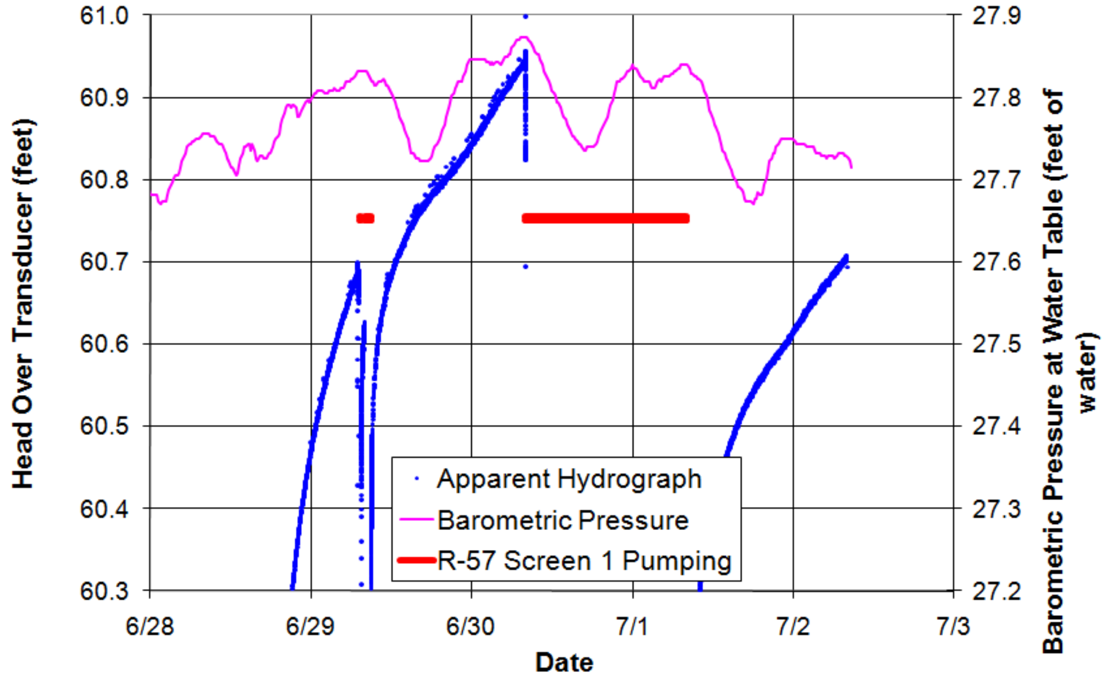

Figure C-7.0-1 Well R-57 screen 1 apparent hydrograph during screen 1 test

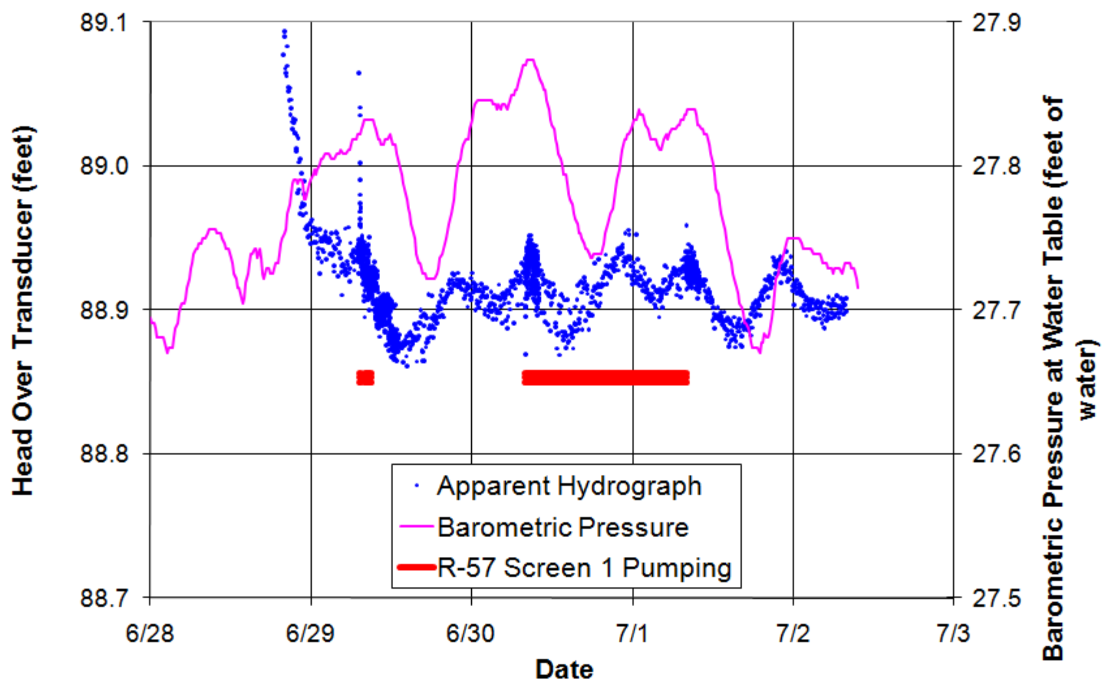

Figure C-7.0-2 Well R-57 screen 2 apparent hydrograph during screen 1 test

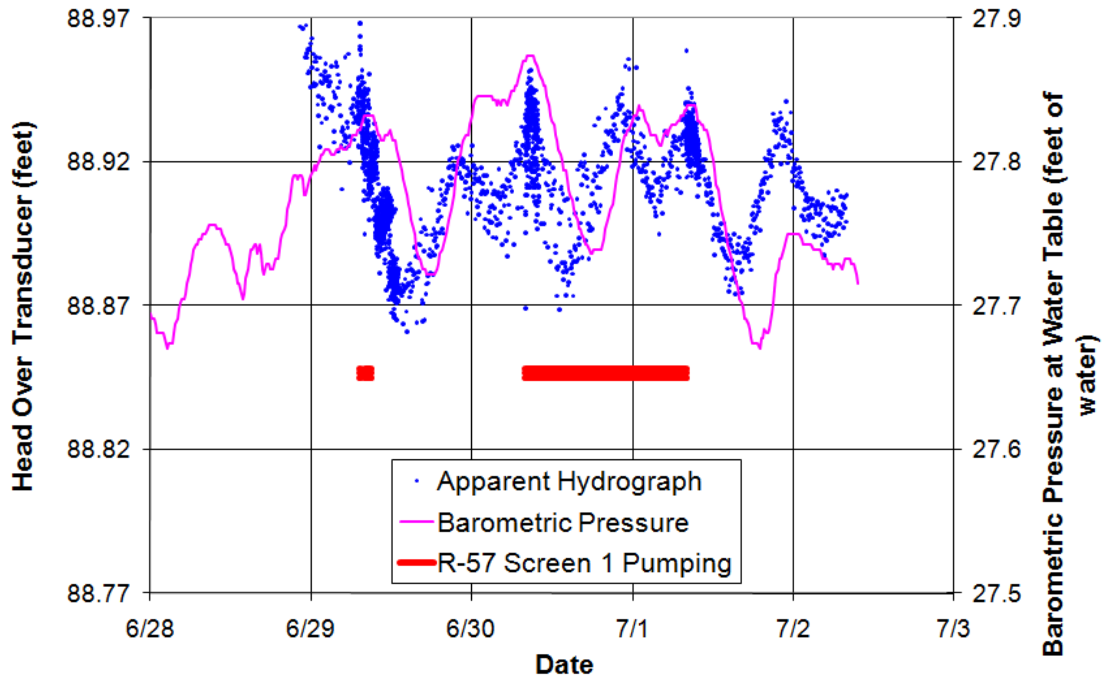

Figure C-7.0-3 Well R-57 screen 2 apparent hydrograph during screen 1 test – expanded scale

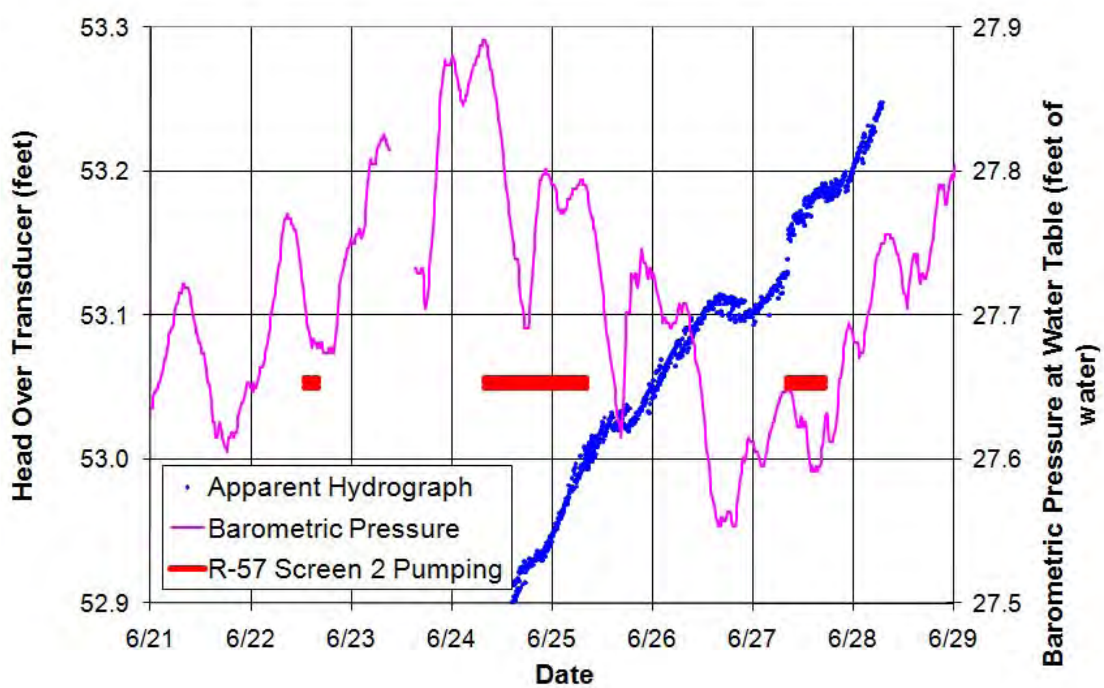

Figure C-7.0-4 Well R-57 screen 1 apparent hydrograph during screen 2 test

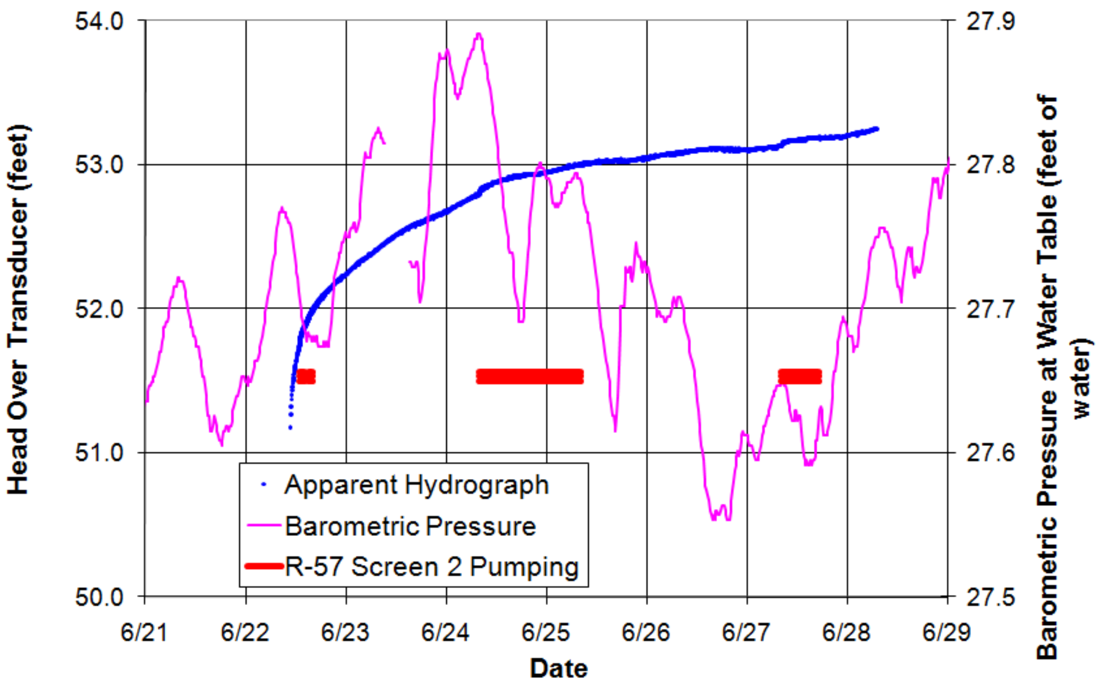

Figure C-7.0-5 Well R-57 screen 1 apparent hydrograph during screen 2 test – full scale

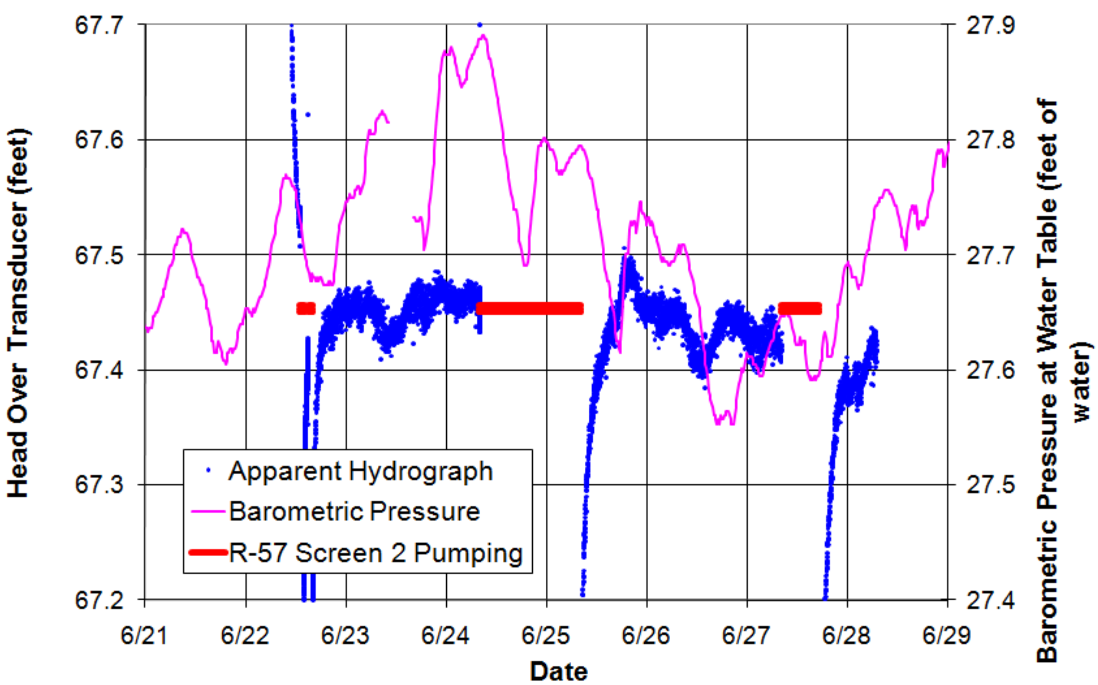

Figure C-7.0-6 Well R-57 screen 2 apparent hydrograph during screen 2 test

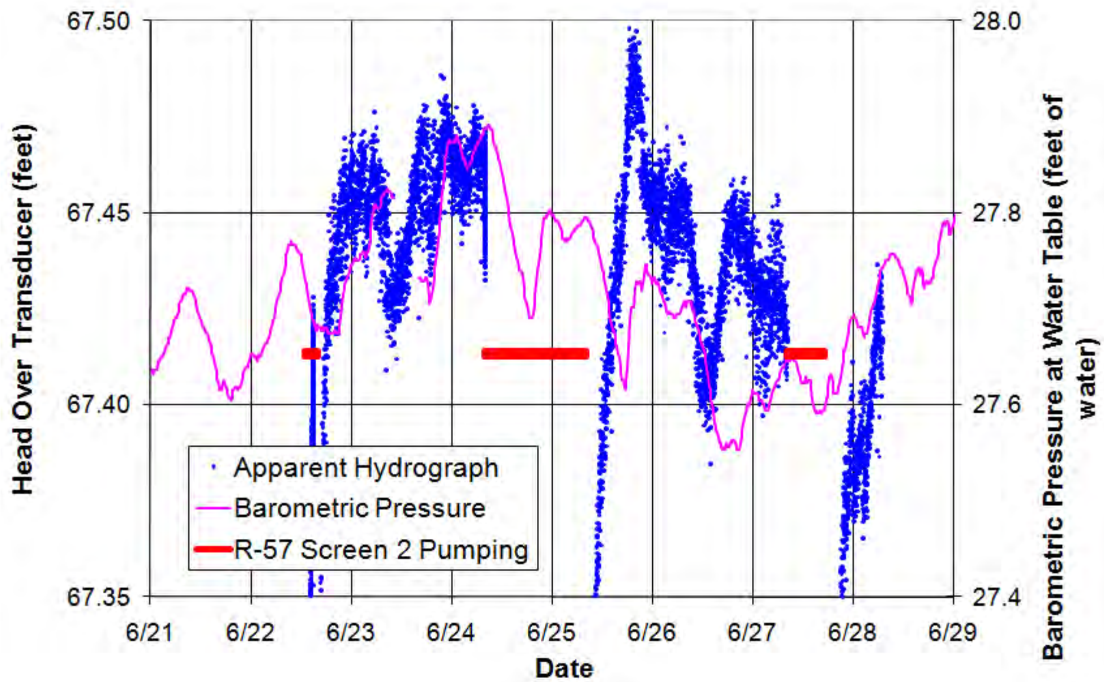

Figure C-7.0-7 Well R-57 screen 2 apparent hydrograph during screen 2 test – expanded scale

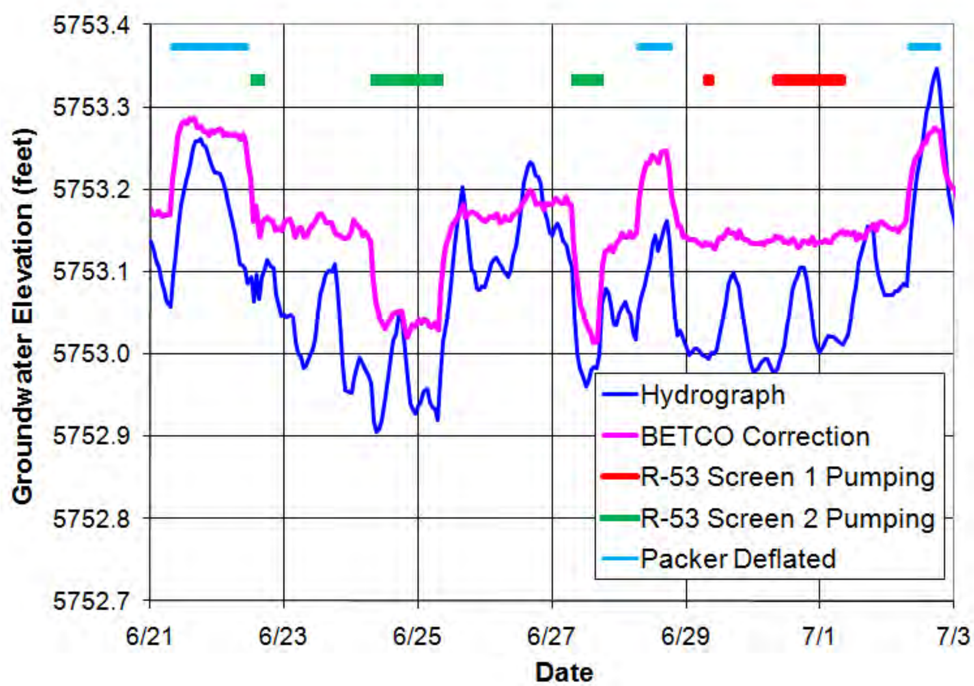

Figure C-7.0-8 Well R-39 hydrograph

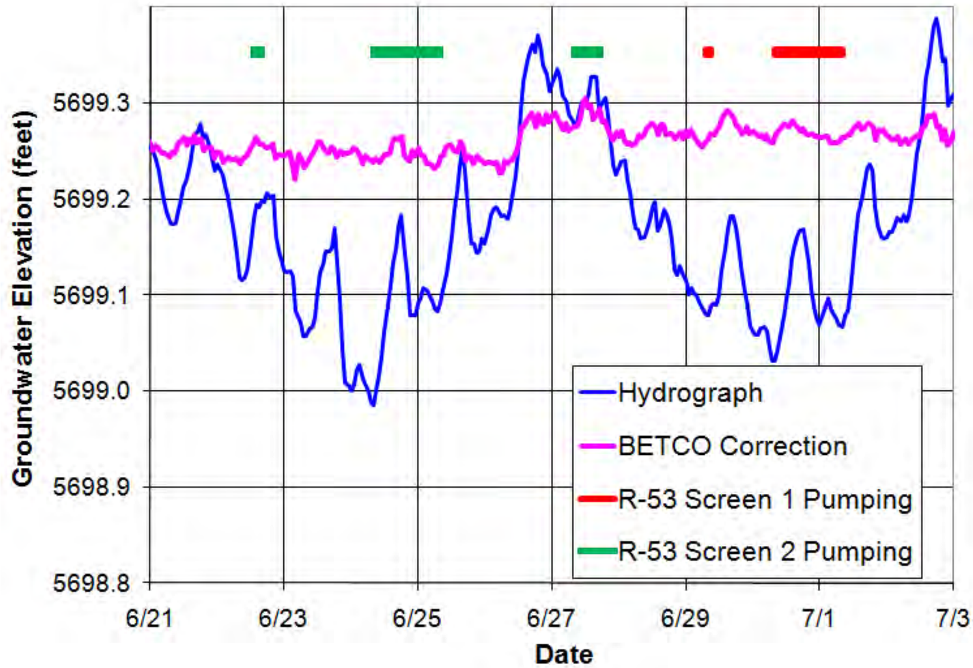

Figure C-7.0-9 Well R-41 hydrograph

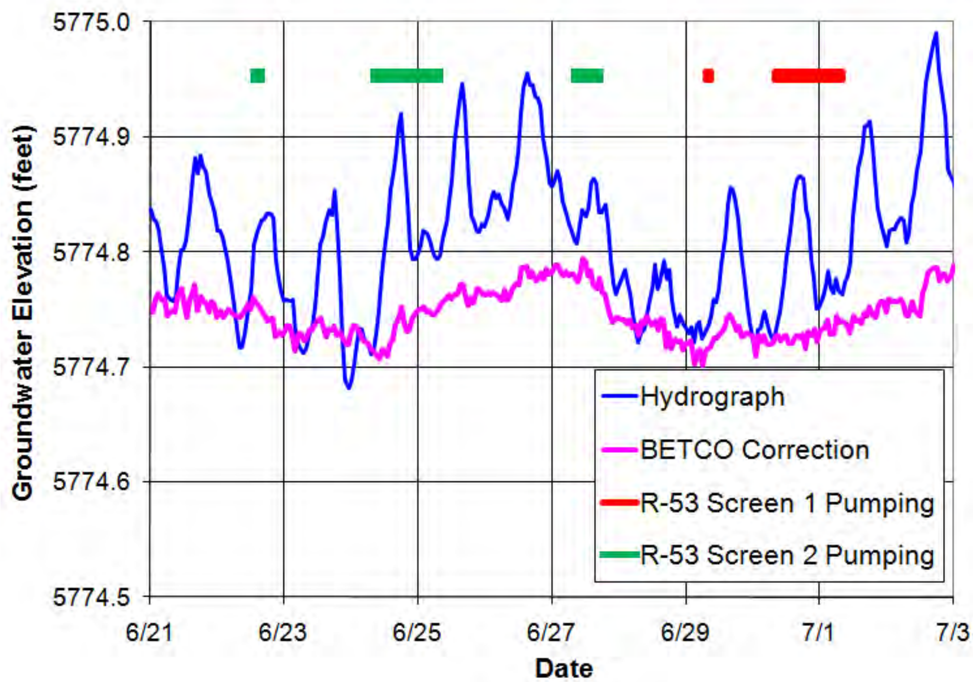

Figure C-7.0-10 Well R-49 screen 1 hydrograph

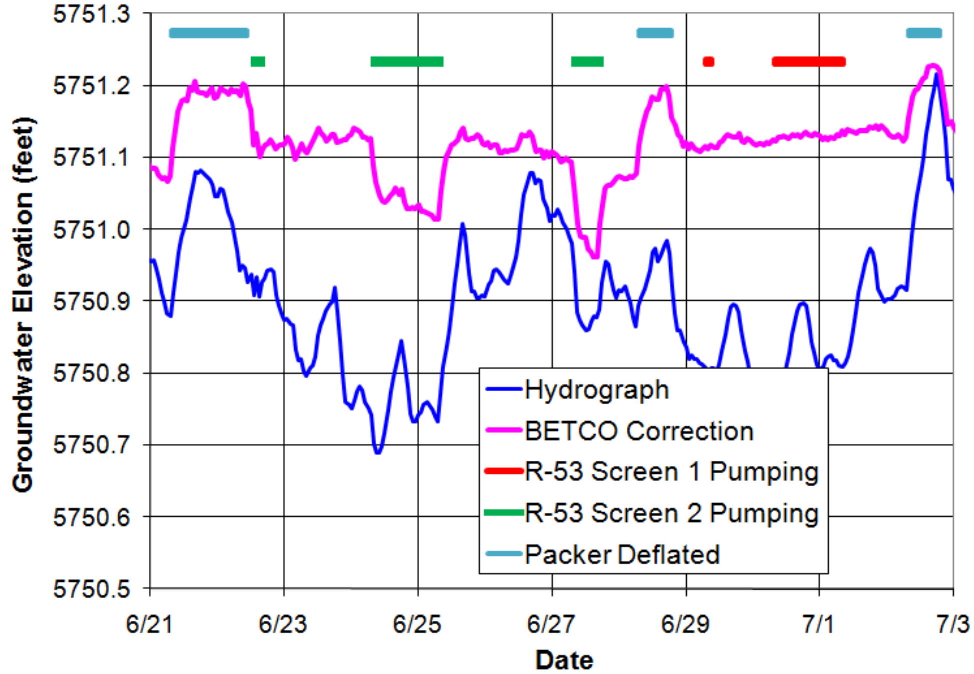

Figure C-7.0-11 Well R-49 screen 2 hydrograph

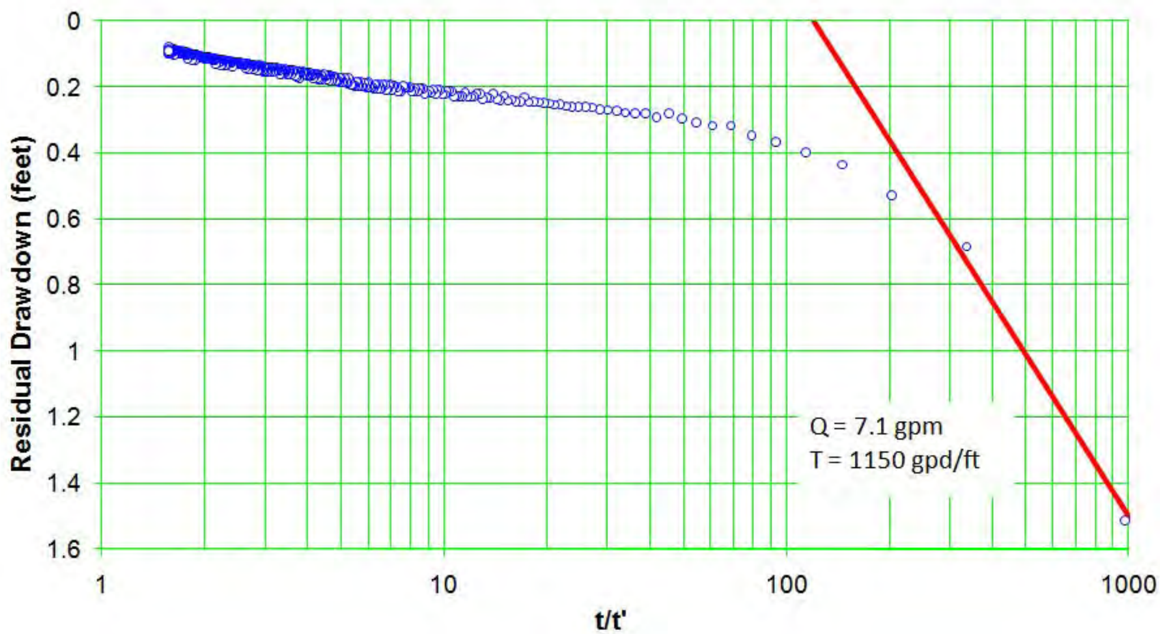

Figure C-8.1-1 Well R-57 screen 1, trial 1 recovery

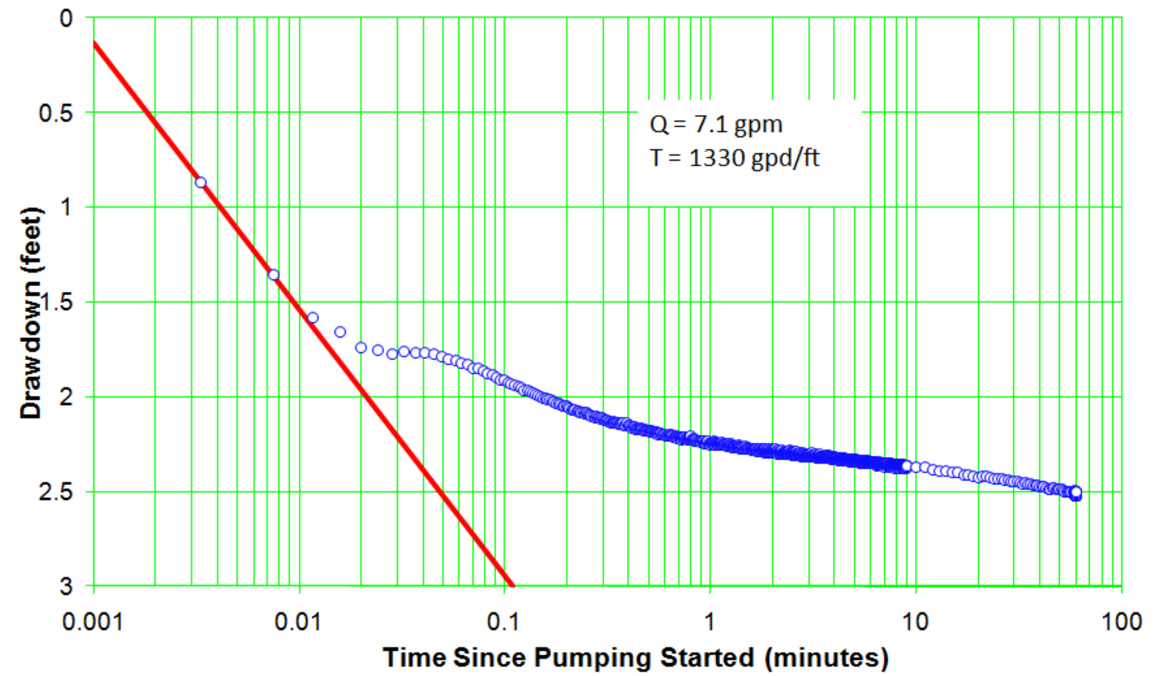

Figure C-8.2-1 Well R-57 screen 1, trial 2 drawdown

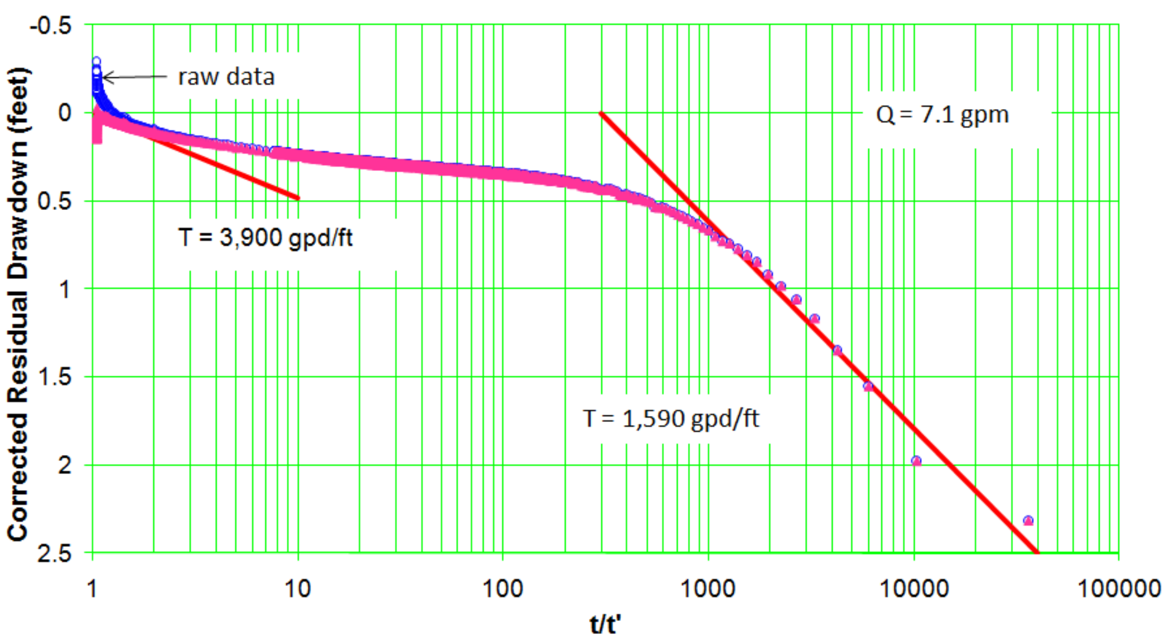

Figure C-8.2-2 Well R-57 screen 1, trial 2 recovery

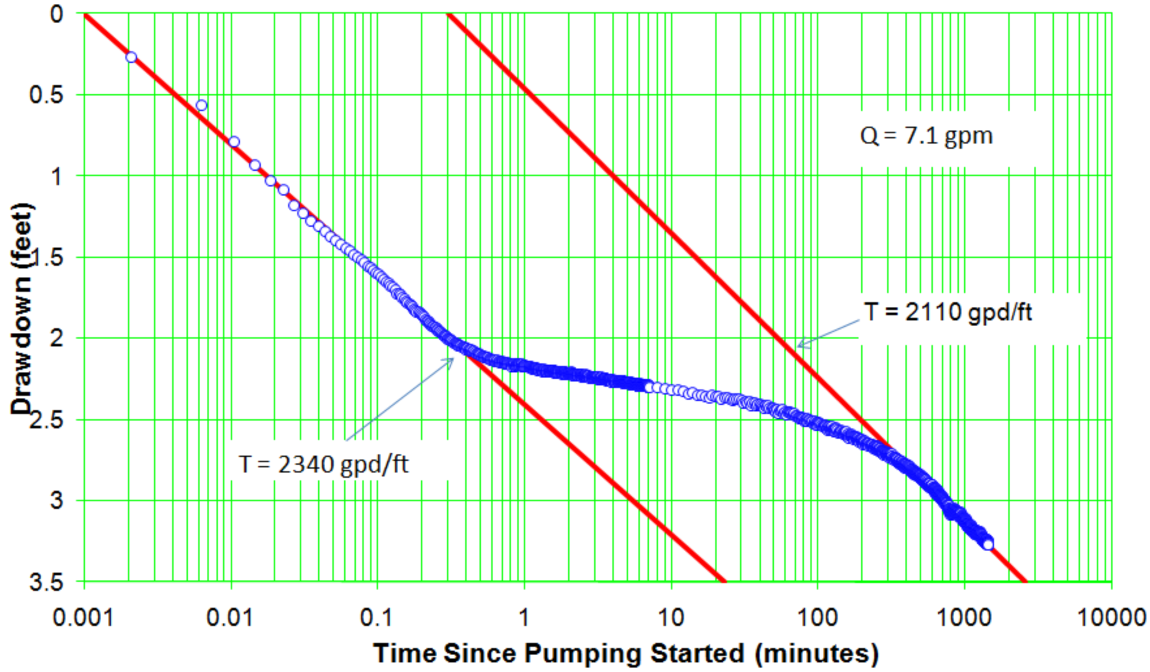

Figure C-8.3-1 Well R-57 screen 1 drawdown

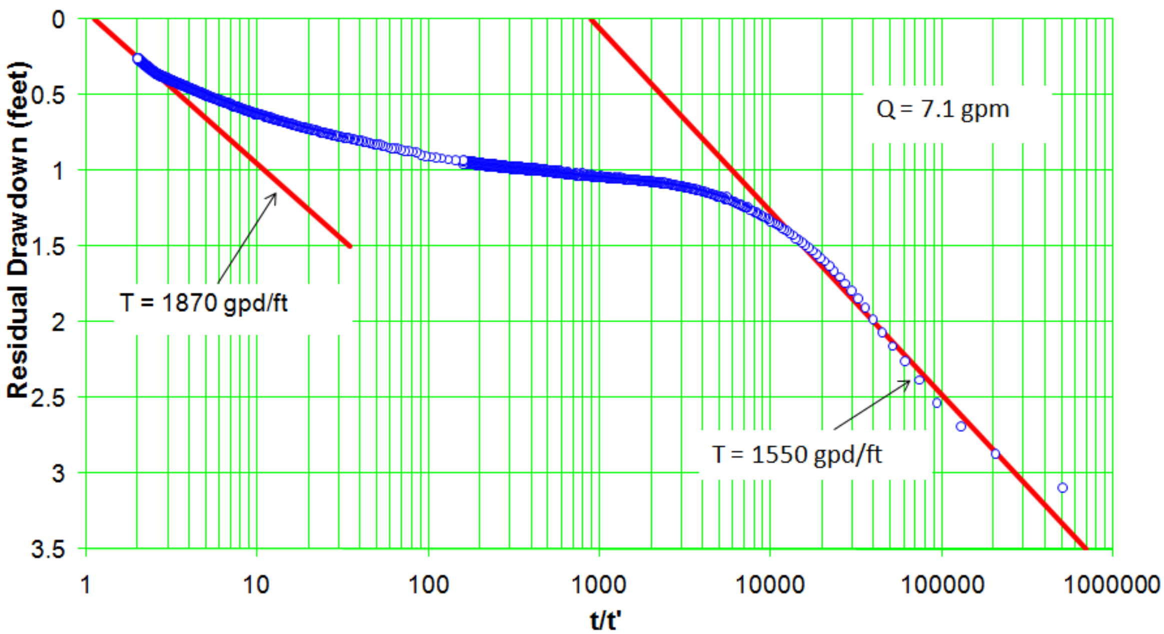

Figure C-8.3-2 Well R-57 screen 1 recovery

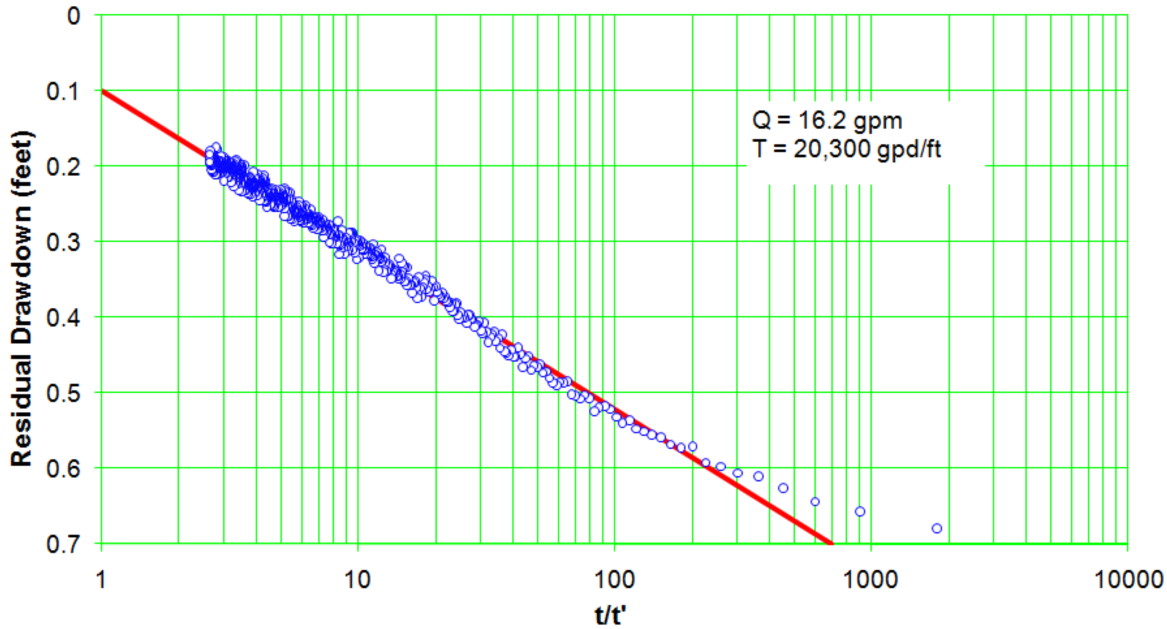

Figure C-9.1-1 Well R-57 screen 2, trial 1 recovery

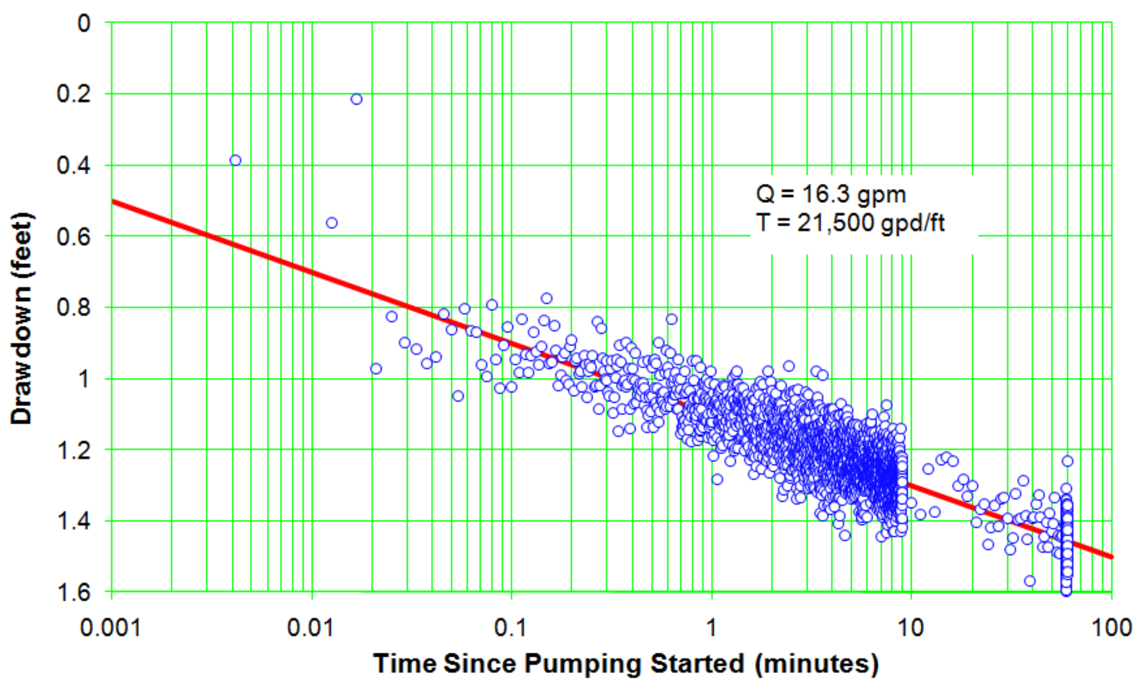

Figure C-9.2-1 Well R-57 screen 2, trial 2 drawdown

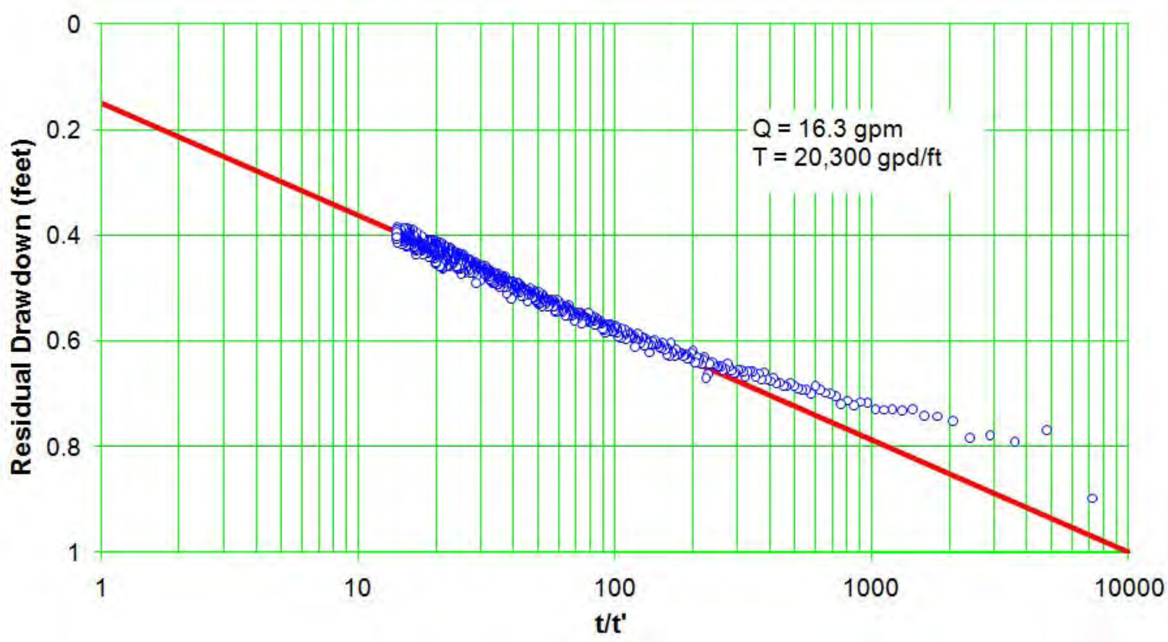

Figure C-9.2-2 Well R-57 screen 2, trial 2 recovery

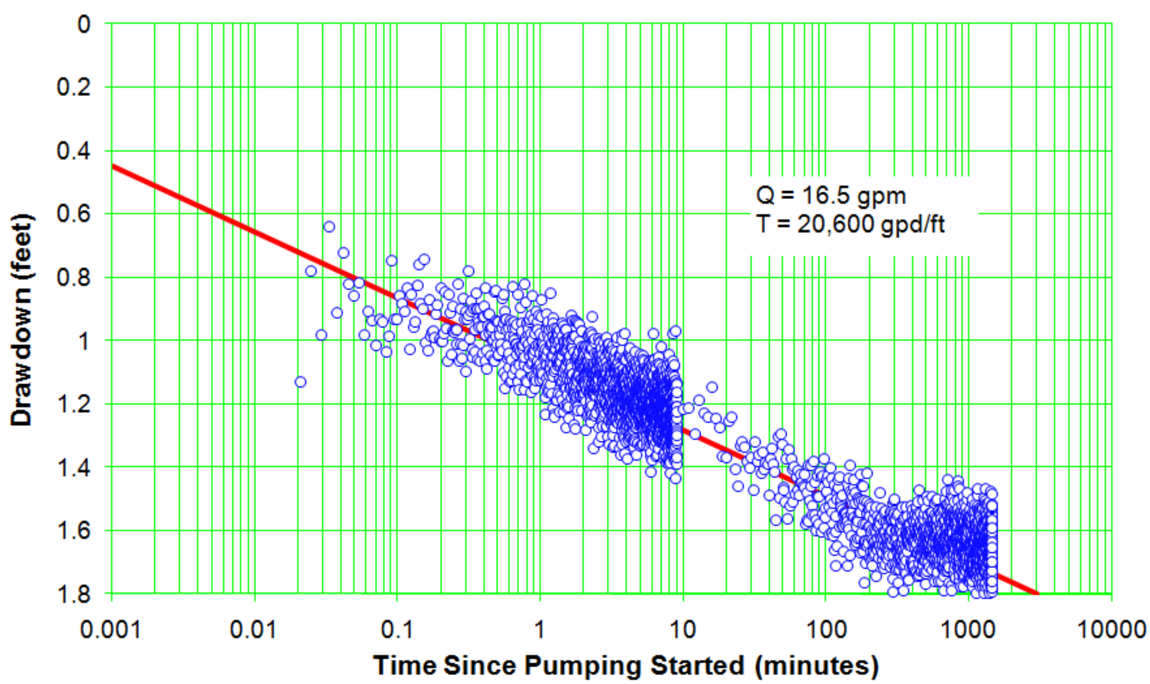

Figure C-9.3-1 Well R-57 screen 2 drawdown

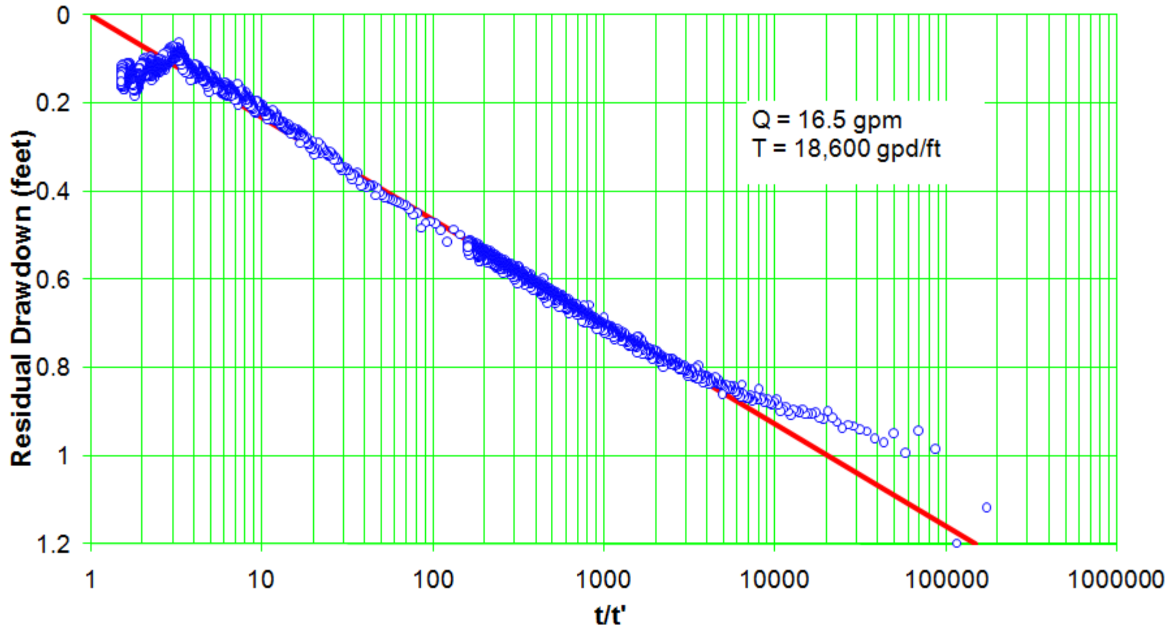

Figure C-9.3-2 Well R-57 screen 2 recovery

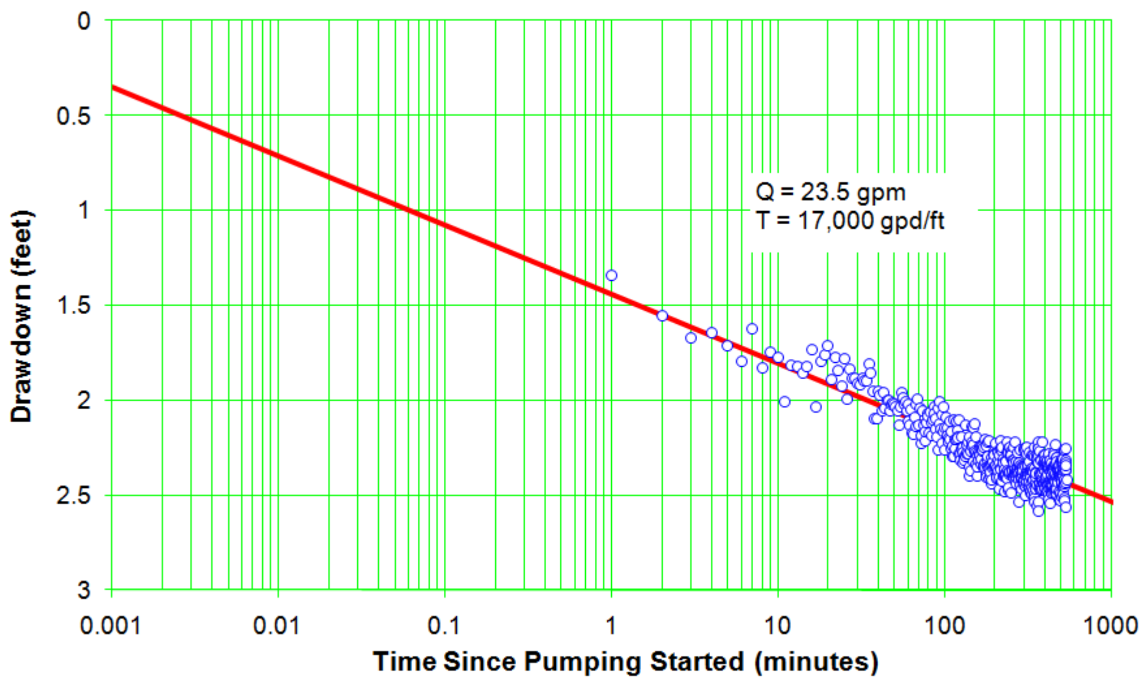

Figure C-9.4-1 Well R-57 screen 2 purge event drawdown

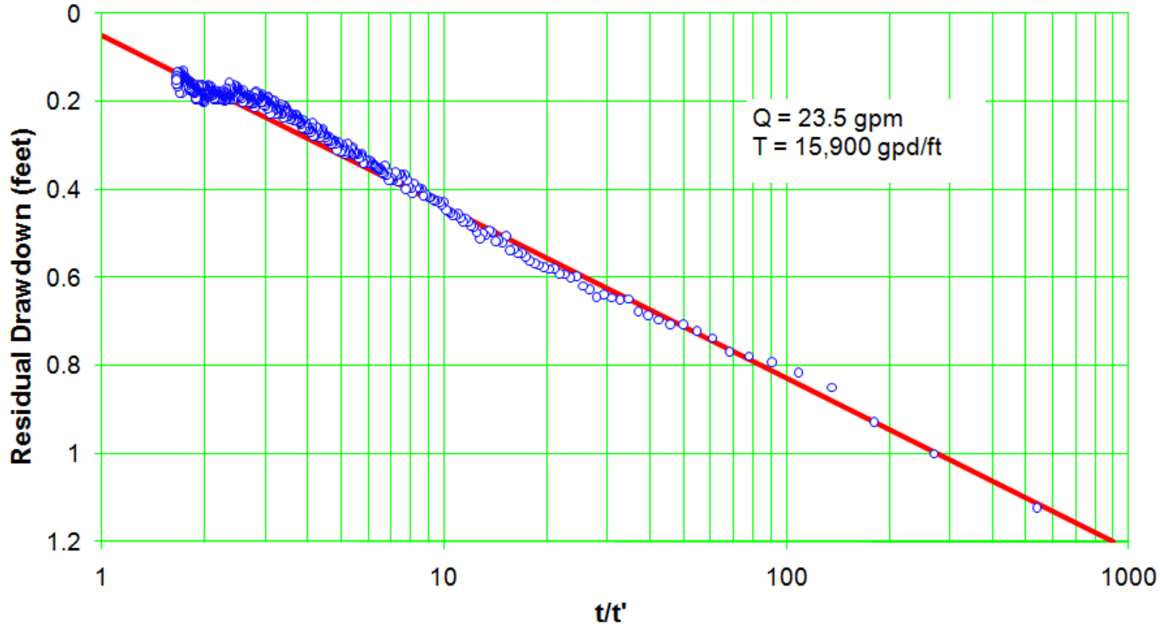

Figure C-9.4-2 Well R-57 screen 2 purge event recovery

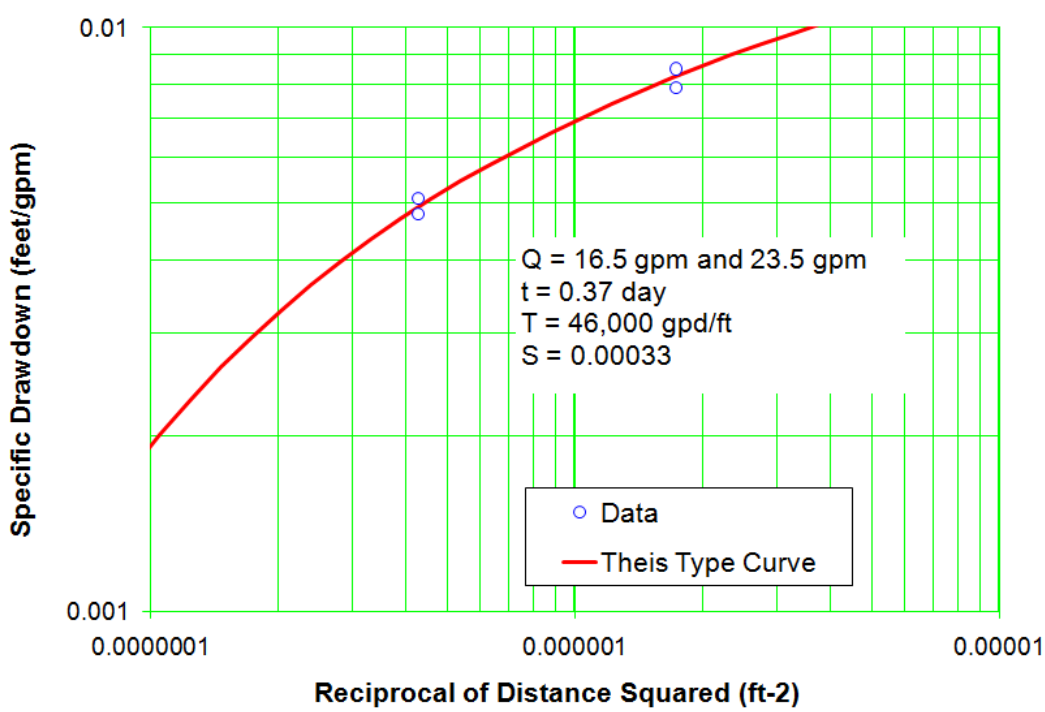

Figure C-10.1-1 Well R-57 screen 2 distance-drawdown analysis

Appendix D

Borehole Video Logging
(on DVD included with this document)

Appendix E

Geophysical Logging
(on CD included with this document)

Appendix F

R-57 Final Well Design

F-1.0 R-57 WELL OBJECTIVES

R-57 is a regional groundwater monitoring well located on Mesita del Buey about 300 ft east of Material Disposal Area (MDA) G and 200 ft northwest of well R-22 (Figure F-1.0-1). The primary purpose of R-57 is to monitor regional groundwater downgradient of MDA G at the eastern end of Technical Area 54. Well R-57 will supplement groundwater monitoring for MDA G provided by wells R-22, R-23, R-39, R-41, and R-49. Secondary objectives for well R-57 include establishing water levels for the regional aquifer in this area, determining if perched intermediate groundwater occurs in the vicinity of MDA G, and characterizing rock units that can impact contaminant pathways in the vadose zone and regional aquifer.

Transport of potential contaminants reaching the regional aquifer is expected to occur primarily by lateral groundwater flow within the upper part of the regional aquifer. At R-57, the upper 62 ft of the regional aquifer is located within fractured dacite lava and a possible flow breccia, and deeper parts of the aquifer consist of porous sands and gravels. The projected groundwater flow direction is towards the east-southeast, based on water-table maps using water levels from existing wells in the area. Water-level data collected from R-57 will improve the water-level map in the vicinity of MDA G.

The R-57 well objectives are best met by installing a two-screen well to monitor water quality and water levels in the lavas and sedimentary deposits that make up the upper part of the regional aquifer downgradient of MDA G.

F-2.0 R-57 RECOMMENDED WELL DESIGN

It is recommended that R-57 be completed as a two-screen well with a 20-ft-long stainless-steel, 20-slot (0.020-in.), wire-wrapped well screen in the lavas extending from 910 to 930 ft below ground surface (bgs) (screen 1) and a 20-ft-long stainless-steel, 20-slot, wire-wrapped well screen in the sedimentary deposits extending from 970 to 990 ft bgs (screen 2). The primary filter pack will consist of 10/20 sand extending 5 ft above and 5 ft below both well screens. A 2-ft secondary filter pack consisting of 20/40 sand will be placed above the primary filter pack of both well screens. A Baski sampling system with a submersible pump and isolating packers will be installed to sample the two well screens. The proposed well design is shown in Figure F-2.0-1.

This well design is based on the objectives stated above and on the information summarized below.

F-3.0 R-57 WELL DESIGN CONSIDERATIONS

Preliminary lithological logs from R-57 indicate that the geologic contacts are, in descending stratigraphic order, Tshirege Member of the Bandelier Tuff (0–95 ft); Otowi Member of the Bandelier Tuff (95–177 ft); basaltic and dacitic lavas of the Cerros del Rio volcanic series and associated scoria, cinder, maar, and sedimentary deposits (177–950 ft); and quartzo-feldspathic riverine deposits (950–1081.5 ft total depth). The preliminary logs identify the quartzo-feldspathic riverine deposits as part of the Totavi Lentil of the Puye Formation. Note that these contacts may be modified in the final R-57 well completion report following more detailed lithologic analysis.

No potential perched intermediate groundwater was identified in the R-57 borehole. Open borehole video logs collected from 226 to 385 ft bgs and from 226 to 793 ft bgs show no evidence for saturation in the vadose zone.

Regional groundwater was predicted to occur at a depth of approximately 888 ft bgs based on water-table maps for the area, with particular emphasis on water levels measured in screen 1 at nearby well R-22. At R-57, a stable water level of 888.1 ft bgs was measured in dacitic lava and possible flow breccia when the cased borehole reached a depth of 926 ft bgs. The measured water level of 888.1 ft bgs is consistent with the predicted water level of 888 ft bgs, and it was used to constrain the placement of the well screen near the water table.

Screen 1, at 910 to 930 ft bgs, targets the dacite lava of the Cerros del Rio volcanic series to monitor the uppermost part of the regional aquifer downgradient of MDA G. Small amounts of pink clay and discoloration of some lava clasts suggest that the target interval includes fractured lava and possible flow breccia. The interval from 888 to 926 ft bgs produced an estimated 15 gallons per minute (gpm) after airlifting groundwater for 40 min with the drill casing set at 926 ft. A 20-ft-long well screen is recommended for this interval to increase the likelihood that water production from fractures or breccia is intercepted by the well screen. The top of the well screen is 22 ft below the water table to ensure that the well screen remains submerged during pumping development and aquifer testing, particularly if this zone has poor transmissivity. In comparison to well-screen elevations at nearby wells, screen 1 at R-57 overlaps the uppermost well screens at R-22 and R-41, and is slightly higher than the single well screen at R-39. Screen 1 at R-22 straddles the water table, and screen 1 at R-41 was dry. The anomalously low water level at R-41 may be due to placement of screen 1 in a section of the regional aquifer that is not hydraulically well connected with the rest of the aquifer.

Screen 2, at 970 to 990 ft bgs, targets a riverine sequence of coarse sands and gravel deposits that are tentatively identified as the Totavi Lentil of the Puye Formation. The sand fraction contains abundant frosted quartz and/or quartzite, pink microcline, and subordinate mafic to intermediate lava. The gravels are up 4 cm in diameter and consist of well-rounded clasts of quartzite, granite, chert, and mafic to intermediate lava. Although these deposits are stratified, no aquicludes such as clays or strongly cemented sediments were identified. Screen 2 is proposed to be 20-ft long to ensure that the well screen includes a number of productive beds in these heterogeneous deposits. The top of the well screen is placed 50 ft below the bottom of screen 1, the minimum separation needed for installation of the Baski sampling system. Thus screen 2 is placed as high as possible within the porous sedimentary deposits in the area immediately downgradient of MDA G to monitor groundwater exiting the overlying fractured lavas and entering the regime of porous flow. In comparison to well-screen elevations at nearby wells, screen 2 at R-57 overlaps the lower part of screen 2 at R-22 and is deeper than screen 2 at R-41.

F-4.0 OTHER ZONES AND SCREEN PLACEMENTS CONSIDERED FOR R-57 WELL DESIGN

Screen 1 is placed as close to the water table as possible, consistent with observations made during drilling, and development and aquifer testing considerations. Placement of a well screen in dacite lava could result in poor water production or a dry (nonproductive) screen. Consideration was given to placing screen 1 in the riverine deposits below the lava, but the top of the well screen would be submerged at least 62 ft. This was considered too deep, given that a primary goal of R-57 is to monitor groundwater in the uppermost part of the regional aquifer downgradient of MDA G.

Screen 2 is placed as high as possible within the riverine deposits of the regional groundwater system, consistent with constraints imposed by the Baski sampling system and sampling goals described above. Borehole cuttings indicate that deeper horizons in the riverine deposits are similar in lithology to the selected well-screen interval and probably have similar hydraulic characteristics. Flowing fine- to medium-grained sands that occur below 1065 ft bgs are probably very transmissive, but proper installation of the annular filter pack and bentonite seals during well construction could be compromised in these unstable deposits.

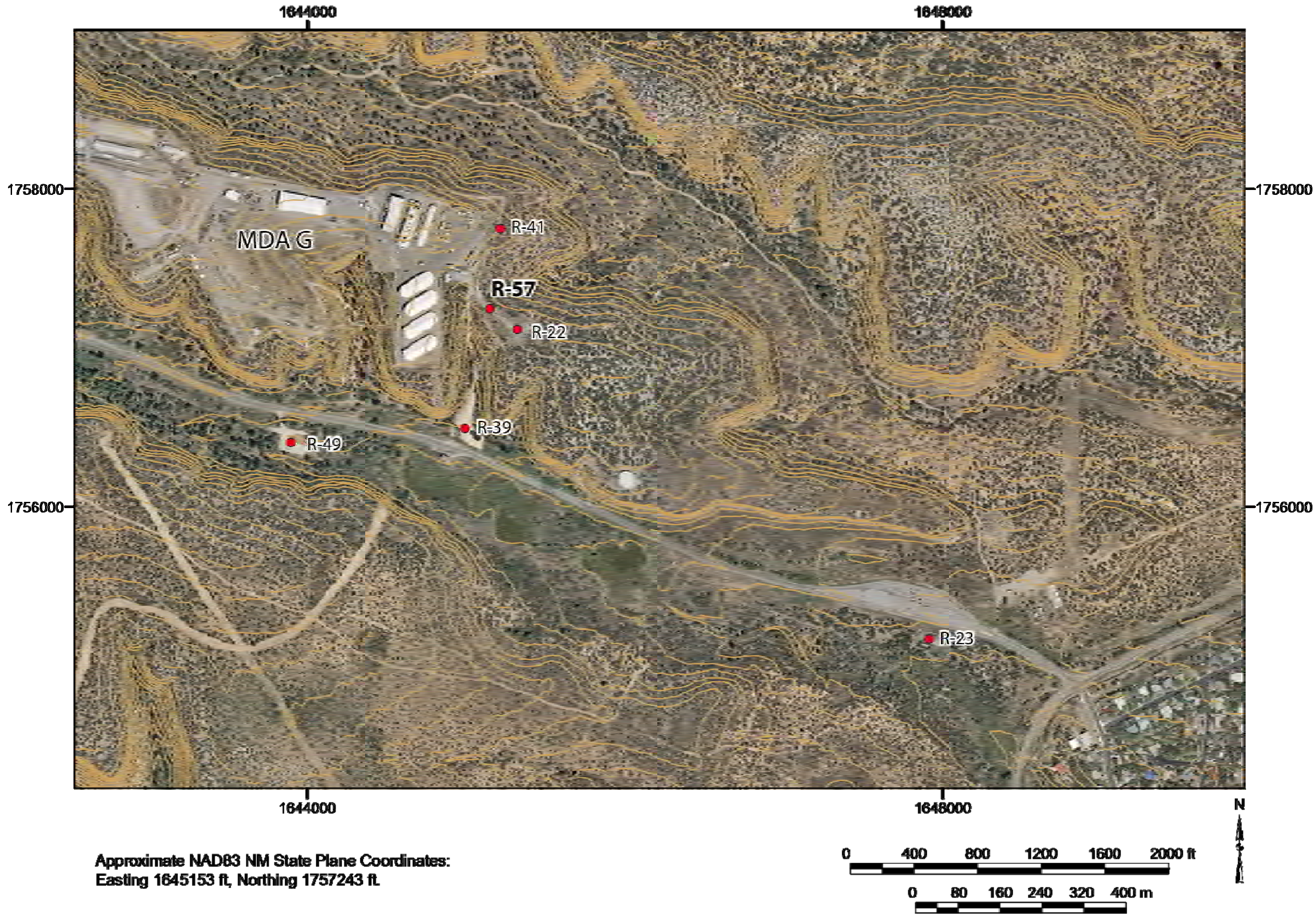

Figure F-1.0-1 Location map for R-57 and nearby monitoring wells

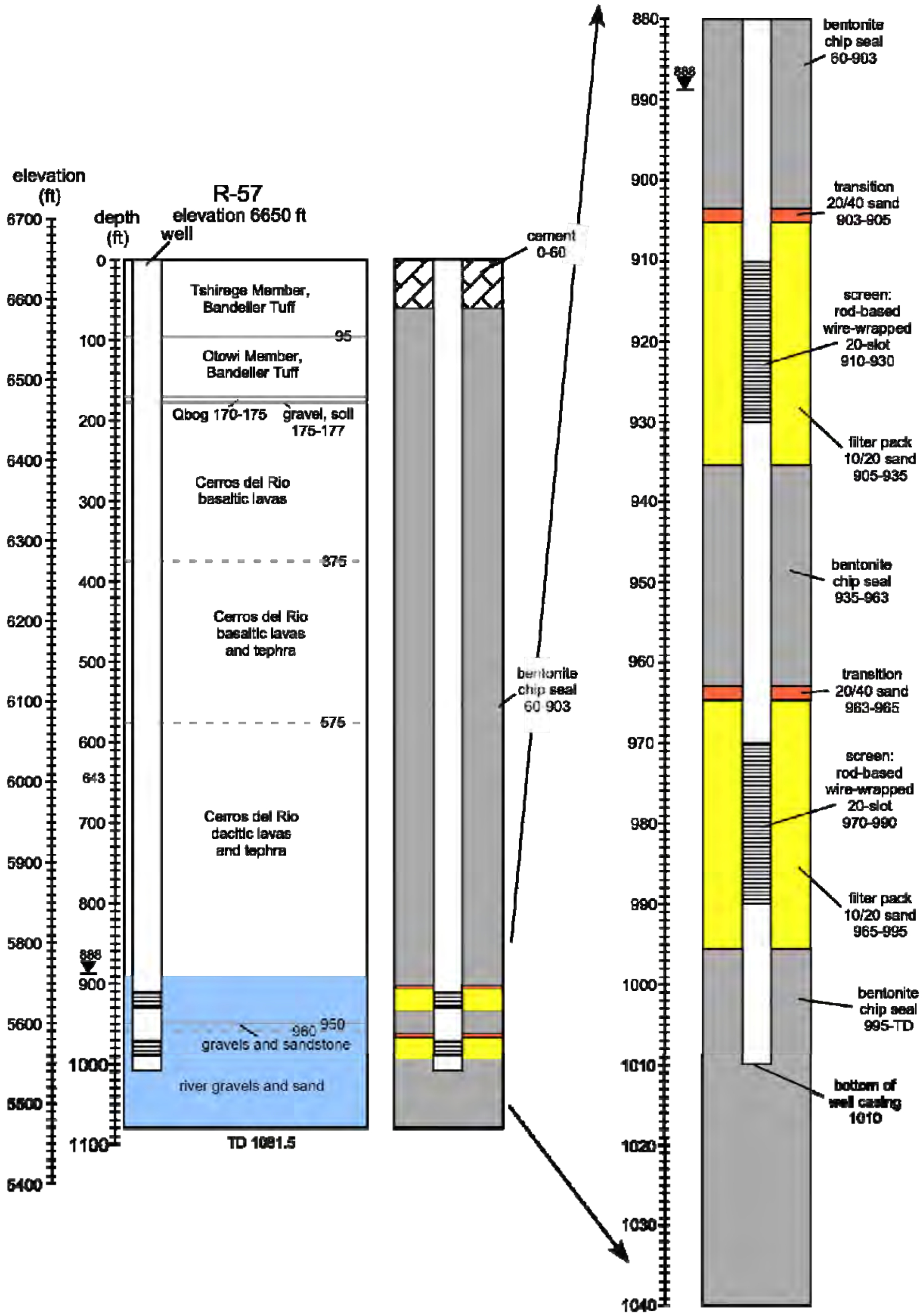

Figure F-2.0-1 Proposed well design for R-57