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Completion Report for Regional Aquifer Well R-56

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EXECUTIVE SUMMARY

This well completion report describes the drilling, well construction, development, and aquifer testing for regional aquifer well R-56, located between Material Disposal Area (MDA) L and MDA G within Los Alamos National Laboratory (LANL or the Laboratory) Technical Area-54 in Los Alamos County, New Mexico.

The R-56 monitoring well borehole was drilled using dual-rotary air-drilling methods. Fluid additives used included potable water and foam. Foam-assisted drilling was used only above the regional aquifer; potable water was used below 819 ft below ground surface (bgs), approximately 100 ft above the expected top of the regional aquifer.

During drilling, the following formations were encountered: the Tshirege Member of the Bandelier Tuff, the Cerro Toledo interval, the Otowi Member of the Bandelier Tuff, the Guaje Pumice Bed, the Cerros del Rio volcanic series, and the Puye Formation. The total depth of R-56 was 1087 ft bgs.

Well R-56 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 945 and 965.6 ft bgs, immediately beneath the lava flows of the Cerros del Rio volcanic series, while the lower 20-ft-long screened interval is set between 1046.6 and 1067.1 ft bgs within the Puye Formation. The composite depth-to-water after well installation and well development was 923.9 ft bgs. The well screens are separated by a packer to ensure isolation of groundwater from each screened interval.

The well was completed in accordance with a New Mexico Environment Department-approved well design. The well was thoroughly developed and target water-quality parameters were met at both screened intervals. Aquifer testing indicates that both screened zones at monitoring well R-56 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 will be performed at R-56 as part of the facility-wide groundwater monitoring program.

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Acronyms and Abbreviations

amsl	above mean sea level
APV	access port valve
ASTM	American Society for Testing and Materials
bgs	below ground surface
Consent Order	Compliance Order on Consent
DO	dissolved oxygen
DOE	Department of Energy (U.S.)
DTW	depth to water
EES-14	Earth and Environmental Sciences 14 (Group)
Eh	oxidation reduction potential
EP	Environmental Programs
EPA	Environmental Protection Agency (U.S.)
gpm	gallons per minute
hp	horsepower
I.D.	inside diameter
LANL	Los Alamos National Laboratory
LH3	low-level tritium
µmS/cm	millisiemens 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
O.D.	outside diameter
ORP	oxidation-reduction potential
PVC	polyvinyl chloride
Qal	alluvium
Qbo	Otowi Member of the Bandelier Tuff
Qbog	Guaje Pumice Bed of 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
Tpf	Puye Formation
TU	tritium unit
VOC	volatile organic compound
WCSF	waste characterization strategy form
WES-EDA	Waste and Environmental Services Division Environmental Data and Analysis
WR	whole rock
wt%	weight percent

1.0 INTRODUCTION

This completion report summarizes borehole drilling, well construction, well development, and aquifer testing for regional aquifer monitoring well R-56. The report is written in accordance with the requirements in section IV.A.3.e.iv of the March 1, 2005 (revised 2008), Compliance Order on Consent (the Consent Order). The R-56 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-56 is located between Material Disposal Area (MDA) L and MDA G within the Laboratory's Technical Area (TA) 54 in Los Alamos County, New Mexico (Figure 1.0-1). R-56 was installed to satisfy a New Mexico Environment Department (NMED) requirement for a monitoring well between MDAs L and G. The primary purpose of R-56 is to monitor regional groundwater east of MDA L and to provide baseline data for groundwater flowing eastward toward MDA G. 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-56 borehole was drilled to a total depth (TD) of 1087 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 945.0 and 965.6 ft bgs and the lower 20-ft-long screened interval is between 1046.6 and 1067.1 ft bgs. The composite depth to water (DTW) after well installation and well development was recorded on July 26, 2010, at 923.9 ft bgs. 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 screened intervals to evaluate hydraulic relationships between this well and other nearby wells.

Post-installation activities included well development, aquifer testing, surface completion, and geodetic surveying. Future activities will include sampling system installation, site restoration, and waste disposal.

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 associated with the R-56 project. Information on radioactive materials and radionuclides, including the results of sampling and analysis of radioactive constituents, is voluntarily provided to the 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-56 project:

- "Drilling Work Plan for Regional Aquifer Well R-56," (LANL 2010, 108543);
- "Drilling Plan for Regional Aquifer Well R-56," (TerranearPMC 2009, 106320);

- "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 from April 17 to 22, 2010. Decontamination of the equipment and tooling was performed before mobilization 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 fire hydrant within TA-54 approximately 200 yd northwest of the R-56 drill site. 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-56.

3.1 Drilling Approach

The drilling methodology and selection of equipment and drill-casing sizes for the R-56 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-56 borehole. Dual-rotary drilling has the advantage of simultaneously advancing and casing the borehole. The 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 three Ingersoll Rand trailer-mounted air compressors. Three sizes of A53 grade B flush-welded mild carbon-steel casing (18-in., 16-in., and 12-in.-inside-diameter [I.D.]) were used for the R-56 project.

The dual-rotary technique at R-56 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 (all within the vadose zone) 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 819 ft bgs, roughly 100 ft above the expected top of the regional aquifer. No additives other than potable water were used for drilling below 819 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-56 Well

On April 23, following on-site equipment inspections, the monitoring well borehole was initiated at 1325 h using dual-rotary methods with 18-in. drill casing and a 17.5-in. tricone bit.

Drilling and advancing 18-in. casing proceeded rapidly through the Tshirege Member of the Bandelier Tuff. Drilling continued to 196.1 ft bgs where the 18-in. drill casing was landed on May 2, 2010. No indications of groundwater were observed while advancing the 18-in. casing.

On May 3, 2010, a string of 16-in. drill casing was started into the borehole. Drilling using dual-rotary methods with the 16-in. casing string and a 14.75-in. tricone bit started on May 5, 2010 at 198 ft bgs. Drilling progressed through the remaining portion of the Tshirege Member of the Bandelier Tuff, the Cerro Toledo interval, the Otowi Member ash flows, and the Guaje Pumice Bed. The 16-in. casing was landed at a depth of 395.0 ft bgs at the base of the Guaje Pumice Bed on May 7. No indications of groundwater were observed while advancing the 16-in. casing.

On May 9, open-hole drilling commenced using a 15-in. hammer bit. Drilling proceeded through the Cerros del Rio volcanic series to 545 ft bgs. The borehole was cemented on May 11 from 401 to 545 ft bgs due to unstable borehole conditions and poor circulation. Open-hole drilling continued on May 12 through the basaltic tephra and intermediate composition (possibly dacitic) lava flows of the Cerros del Rio volcanic series to 625 ft bgs. On May 14, another unstable borehole interval from 570 to 623.5 ft bgs was cemented. Open-hole drilling continued on May 15 through the Cerros del Rio volcanic series to 665 ft bgs. On May 17, another unstable borehole interval from 631.5 to 662.8 ft bgs was cemented and open-hole drilling continued in the Cerros del Rio volcanic series to 705 ft bgs. Because the Cerros del Rio volcanic series was not particularly massive or consolidated at the R-56 location and was requiring multiple cementing intervals, the decision was made to discontinue open-hole drilling methods and switch to casing advance methods.

On May 20, the 16-in. casing shoe was cut off at 384.1 ft bgs and 12-in. drill casing was started into the borehole. From June 5 to 11, the 12-in. casing was advanced using an under-reaming hammer bit from 717 to 955 ft bgs, approximately 10 ft into the Puye Formation, with no indications of groundwater over that interval. However, water production of approximately 7 gallons per minute (gpm) was noted at 955 ft bgs. The 12-in. casing was temporarily landed at 995 ft bgs and the under-reaming hammer bit was removed due to softer drilling conditions in the Puye Formation.

On June 13, the 12-in. casing was advanced using an 11 7/8-in. tricone bit from 995 to 1087 ft bgs. Water production of approximately 35 to 40 gpm was noted at 1087 ft bgs. A natural gamma log was run on June 14 from the surface to 1085 ft bgs inside the drill casing. On June 15, the 12-in. casing shoe was cut off at 1080.4 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-56. All sampling activities were conducted in accordance with applicable quality procedures.

4.1 Cuttings Sampling

Cuttings samples were collected from the R-56 monitoring well borehole at 5-ft intervals from ground surface to 70 ft bgs and from 160 ft bgs to the TD of 1087 ft bgs. Drill cuttings were not collected from 70 to 160 ft bgs because tritium was believed to have been detected in the breathing zone at the borehole over this interval and geologists were directed to stand away from the cyclone. (Note that liquid scintillation counting on all smear samples collected during drilling were negative for tritium, and therefore the breathing zone readings were determined to be false positives by Laboratory radiological control technicians.)

At each sampled 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 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-56 stratigraphy is summarized in section 5.1 and a detailed lithologic log is presented in Appendix A.

4.2 Water Sampling

Two borehole groundwater-screening samples were collected from the drilling discharge at 955 and 1087 ft bgs. These samples were collected after reaching the bottom of 20-ft runs of casing when the driller stopped water circulation and circulated air. As the discharge cleared, the water samples were collected directly from the discharge cyclone. The borehole water samples collected at 955 and 1087 ft bgs were analyzed for anions (including perchlorate), cations, metals, volatile organic compounds (VOCs), and low level tritium (LH3). Table 4.2-1 presents a summary of screening samples collected during the R-56 monitoring well installation project. Groundwater chemistry and field water-quality parameters are discussed in Appendix B.

One groundwater-screening sample was collected from each screened interval during well development from the development pump's discharge line. Development screening samples were analyzed only for total organic carbon (TOC). Additionally, 12 groundwater-screening samples were collected during aquifer testing from the pump's discharge line. These samples were also analyzed only for TOC.

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 semivolatile 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-56 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-56 is presented below. The Laboratory's geology task leader and project site geologist 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 at R-56.

5.1 Stratigraphy

Rock units for the R-56 borehole are presented below in order of younger to older in stratigraphic 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-56. A detailed lithologic log is presented in Appendix A.

Alluvium, Qal (0–2 ft bgs)

Thin Quaternary alluvium mixed with base-course gravel used to construct the drill pad was encountered from 0 to 2 ft bgs. Alluvium consists of unconsolidated, poorly sorted sand and silt with Bandelier Tuff detritus. No evidence of alluvial groundwater was observed.

Unit 2, Tshirege Member of the Bandelier Tuff, Qbt 2 (2–57 ft bgs)

Unit 2 of the Tshirege Member of the Bandelier Tuff was intersected in R-56 from 2 to 57 ft bgs and locally has a minimum thickness of 55 ft. Unit 2 represents a single cooling unit of the Tshirege Member rhyolitic ash-flow tuff (ignimbrite). This unit is generally poorly welded, moderately indurated, pumiceous, crystal-bearing to 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 (57–135 ft bgs)

Unit 1v of the Tshirege Member of the Bandelier Tuff was encountered from 57 to 135 ft bgs and is 78-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 to nonwelded, generally poorly to moderately indurated, pumiceous, crystal-bearing, and lithic-bearing. Samples from 57 to 70 ft bgs contain fragments of pumiceous crystal tuff, quartz and sanidine crystals, dacite lithic fragments (up to 15 mm in diameter), and abundant weathered volcanic ash. Pumice lapilli hosted by the tuff typically exhibit sugary crystalline textures, evidence of intense devitrification shortly after deposition. The basal Qbt 1v contact was estimated from the natural gamma log profile.

Unit 1g, Tshirege Member of the Bandelier Tuff, Qbt 1g (135–265 ft bgs)

Unit 1g of the Tshirege Member of the Bandelier Tuff occurred from 135 to 265 ft bgs and is locally 130-ft thick. The remainder of Unit 1g is a poorly welded rhyolitic ash-flow tuff that is poorly to moderately indurated, 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 (up to 15 mm) volcanic (predominantly dacitic) lithic inclusions.

Cerro Toledo Interval, Qct (265–320 ft bgs)

The Cerro Toledo interval occurred from 265 to 320 ft bgs and is 55 ft thick. It consists of a sequence of poorly consolidated tuffaceous and volcaniclastic sediments that regionally occur between the Tshirege and Otowi Members of the Bandelier Tuff. The Cerro Toledo interval is locally made up of poorly to moderately sorted pebble gravels with fine to coarse sand composed of detrital pumice, lithics (predominantly dacite), quartz and sanidine crystals, and abundant silt.

Otowi Member of the Bandelier Tuff, Qbo (320–375 ft bgs)

The Otowi Member of the Bandelier Tuff, estimated to be 55 ft thick, was present from 320 to 375 ft bgs. The Otowi Member ash flows consist of poorly welded rhyolitic ash-flow tuff (ignimbrite) that is pumiceous, crystal- and lithic-bearing to locally lithic-rich. It contains abundant pumice lapilli that are pale orange to white, glassy, lustrous, and quartz- and sanidine-phyric as well as 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, rhyolite, and andesite.

Guaje Pumice Bed of the Otowi Member of the Bandelier Tuff, Qbog (375–395 ft bgs)

The Guaje Pumice Bed, encountered from 375 to 395 ft bgs, is estimated to be 20 ft thick. The Guaje Pumice Bed represents a rhyolite ash- and pumice-fall tephra deposit that forms the base of the Otowi Member. Drill cuttings in this interval contain abundant (up to 95% by volume) rounded, lustrous vitric pumice lapilli (up to 12 mm in diameter) with trace occurrences of small, volcanic lithic fragments. The deposit is nonwelded and unconsolidated.

Cerros del Rio Volcanic Series, Tb 4 (395–945 ft bgs)

The Cerros del Rio volcanic series was present from 395 to 945 ft bgs and is estimated to be 550 ft thick. The series locally forms a complex sequence that includes reworked volcanic sediments, basaltic and intermediate-composition (possibly dacite) lavas, pyroclastic fall deposits, and basaltic tephras interpreted to be of hydromagmatic origin. The sequence has a cumulative thickness of approximately 550 ft. The upper 30 ft, from 395 to 425 ft bgs, consists of volcanic sediments containing detrital basalt, intermediate-composition volcanics, pumice, and reworked cinders. The Tb 4 section from 425 to 545 ft bgs forms a series of two or more stacked, strongly vesicular olivine-basalt lava flows. Basalts in this sequence are generally porphyritic with phenocrysts (up to 5% by volume) of olivine and plagioclase enclosed in an aphanitic to glassy groundmass that is variably altered with local development of secondary calcite, clay, and possibly zeolite. Basaltic cinders and air-fall pyroclastic deposits occur in the section from 545 to 685 ft bgs. The interval from 685 to 775 ft bgs contains at least two olivine+clinopyroxene basalt flows separated by a 20-ft thick sedimentary interbed containing scoriaceous basalt cinders and white tuffaceous sandstone from 695 to 715 ft bgs. Maar-type basaltic tephra deposits, with abundant clasts of glassy scoriaceous lapilli cemented by yellowish palagonitic clay, are present from 775 to 795 ft bgs.

The lower part of the Cerros del Rio section, from 795 to 945 ft bgs, is composed of two lava flows of intermediate composition (possibly dacite) separated by 20 ft of interbedded volcanic sediments. The intermediate composition (possibly dacitic) portion of the Tb 4 section is estimated to be 150 ft thick. The intermediate-composition volcanic rocks present throughout the interval are glassy to aphanitic and phenocryst-poor to aphyric. Rare, pale brown translucent phenocrysts, possibly orthopyroxene, are noted. Volcaniclastic sediments and siltstone occur as interflow deposits from 890 to 910 ft bgs.

Puye Formation, Tpf (945–1087 ft bgs)

Puye Formation volcaniclastic sediments were encountered from 945 ft bgs to the bottom of the R-56 borehole at 1087 ft bgs. These poorly sorted, heterogeneous deposits are fine to coarse gravels with silty fine- to coarse-grained volcanic sandstones. Typically subrounded to well-rounded detrital materials are composed of abundant Tschicoma-like coarsely porphyritic dacites, basalt, pumice, and variable occurrences of Precambrian quartz, quartzite, microcline, granite, and gneissic lithologies. A Totavi-like interval of riverine gravels, containing up to 20% quartzo-feldspathic detritus, occurs in the interval from 990 to 1005 ft bgs.

5.2 Groundwater

No indications of groundwater were noted during drilling or casing advance to a depth of 955 ft bgs. An estimated water production of 7 gpm was noted in the silty gravels of the upper Puye Formation at 955 ft bgs where the DTW was measured at 930.3 ft bgs. Drilling proceeded into the Puye Formation to the TD of 1087 ft bgs with estimated water production of 35 to 40 gpm. The DTW stabilized at approximately 924.6 ft bgs on June 15, 2010, before well installation.

6.0 BOREHOLE LOGGING

A video log, induction log, and two natural gamma logs were collected during the R-56 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 run in the R-56 borehole on May 20, 2010, from ground surface to 705.0 ft bgs with open hole between 395 and 705 ft bgs. The video log is presented on a DVD as Appendix D included with this document.

6.2 Geophysical Logging

Natural gamma and induction logs were also run on May 20 from surface to 705 ft bgs with open borehole between 395 and 705 ft bgs. A final, natural gamma survey was obtained on June 14, from surface to 1085 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 R-56 MONITORING WELL

The R-56 well was installed between June 23 and July 19, 2010.

7.1 Well Design

The R-56 well was designed in accordance with the NMED Consent Order. NMED approved the final well design before installation. The final well design for R-56 is included in Appendix F. The well was designed with an upper screened interval between 945 and 965 ft bgs in the uppermost Puye Formation immediately below the Cerros del Rio volcanic series, and a lower screened interval between 1045 and 1065 ft bgs deeper within the Puye Formation.

7.2 Well Construction

The R-56 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 (6.6-ft casing and shoe at a depth of 1080.4 to 1087 ft bgs) and 16-in. drill casing (10.5-ft casing and shoe at a depth of 384.1 to 394.6 ft bgs) remain in the borehole. The 12-in. casing stub was encased in slough and bentonite backfill, while the 16-in. casing stub was encased in the upper bentonite seal.

An 11.7-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 ft above and below each screen. A Pulstar work-over 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 work-over rig and initial well construction materials to the site took place from June 18 to 22, 2010. On June 23 at 1121 h, the 5.0-in.-I.D. well casing was started into the borehole. The well casing was hung by wireline with the bottom at 1078.8 ft bgs.

The installation of annular materials began on June 27 after the bottom of the borehole was measured at 1085.0 ft bgs (approximately 2 ft of slough in the borehole). On June 27, the lower bentonite seal was installed from 1072.1 to 1085 ft bgs using 6.7 ft^3 of 3/8-in. bentonite chips. This volume was approximately 34% more than the calculated volume of 10.2 ft^3 and was due to formational sloughing across that interval.

From June 27 to June 29, the lower filter pack was installed from 1041.4 to 1072.1 ft bgs using 30.2 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 22 ft^3 by approximately 37%. On June 29, the lower fine sand collar was installed above the lower filter pack from 1039 to 1041.4 ft bgs using 2.5 ft^3 of 20/40 silica sand. The actual volume of fine sand exceeded the calculated volume by 47%. The volume exceedances for the filter pack and fine sand collar are likely attributable to a slightly wider borehole in the poorly consolidated silty gravels of the Puye Formation.

Installation of annular fill materials was temporarily suspended on June 29 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 June 30 to July 1, the middle bentonite seal was installed from 970.6 to 1039.0 ft bgs using 41.5 ft^3 of 3/8-in. bentonite chips. From July 1 to July 6, the upper filter pack was installed from 940.1to 970.6 ft bgs using 32.5 ft^3 of 10/20 silica sand. Again, the actual filter pack volume slightly exceeded the calculated volume of 21.8 ft^3 and is likely due to a slightly wider borehole in the poorly consolidated silty gravels of the Puye Formation. Installation of annular fill materials was temporarily suspended on July 6, 2010, to retrieve and remove the packer from the well casing. On July 6, the upper fine sand collar was installed above the upper filter pack from 938 to 940.1 ft bgs using 1.5 ft^3 of 20/40 silica sand.

From July 7 to July18, the upper bentonite seal was installed from 59.8 to 938.0 ft bgs using 816.1 ft^3 of 3/8-in. bentonite chips. From July 18 to July 19, the surface seal was installed from 3.0 to 59.8 ft bgs using 137.6 ft^3 of Portland Type I/II/V cement. The volume of cement required for this zone exceeded the calculated volume of 98.8 ft^3 and likely represents cement losses to the dry upper formation. Installation of the cement surface seal on July 19, 2010, at 0930 marked the end of well construction per NMED Consent Order guidelines. Table 7.2-1 itemizes 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 June 23 through July 19, 2010.

8.0 POST-INSTALLATION ACTIVITIES

Following well installation at R-56, the well was developed and aquifer tests were conducted. The wellhead and surface pad were constructed, and a geodetic survey was performed. Site restoration 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 July 27 and August 2, 2010. Initially, both screen 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 intervals causing a surging action across the screens/filter packs. The bailing tool employed was a 4.0-in.-O.D. by 21-ft-long carbon steel bailer with a total capacity of 12 gal. The tool was lowered to the bottom of the well by wireline and repeatedly filled, withdrawn from the well, and dumped into the cuttings pit. Approximately 390 gal. of groundwater were removed during bailing activities. After bailing, a 5-horsepower (hp), 4-in. diameter Berkeley submersible pump and inflatable packers were installed in the well for the final 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 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.

Lower screened Interval

On July 29 and 30, a 10-hp pump was used to purge the lower screen from top to bottom in 2 ft increments from 1046 to 1066 ft bgs. On August 2, the pump was set at 1044.1 ft bgs and the packer was inflated to ensure discrete water quality parameter samples. Approximately 4626 gal. of groundwater were purged during lower screen well development.

Upper screened Interval

On July 29, the 10-hp pump was used to purge the upper screen in 2 ft increments from 945 to 967 ft bgs. Additional pumping was conducted on August 2 using a 5-hp pump. The pump was set at 970.2 ft bgs with the packer inflated. Approximately 4935 gal. of groundwater were purged during development of the upper well screen.

Approximately 9951 gal. of groundwater were purged at R-56 during well development activities: 4935 gal. from the upper screened interval, 4626 gal. from the lower screened interval, and 390 gal. from both screens. Another 31,197 gal. were purged during aquifer testing. Total groundwater purged during post-installation activities from both screened intervals combined was 41,148 gal.

8.1.1 Well Development Field Parameters

Field parameters during well development were measured at well R-56 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 final development of the upper screen, measurements of pH and temperature varied from 6.84 to 7.94°C and from 24.04 to 26.28°C, respectively. Concentrations of DO varied from 7.12 to 7.73 mg/L. Corrected oxidation-reduction values potential (Eh) ranged from 308.5 to 326.8 millivolts (mV). Specific conductance varied from 147 to 195 microSiemens per centimeter (µS/cm), and turbidity values varied from 0.9 to 11.5 NTU. The final parameters for the upper screen at the end of development were pH of 7.93, temperature of 24.21°C, specific conductance of 147 µS/cm, and turbidity of 0.9 NTU.

During development of the lower screen, measurements of pH and temperature varied from 6.85 to 7.93°C and from 21.33 to 23.98°C, respectively. Concentrations of DO varied from 5.42 to 6.82 mg/L. Eh values decreased from 362.6 to 307.9 mV. Specific conductance varied from 145 to 212 µS/cm, and turbidity values decreased from 0.1 to 3.9 NTU. The final parameters for the lower screen at the end of development were pH of 7.93, temperature of 23.98°C, specific conductance of 146 µS/cm, and turbidity of 1.0 NTU.

8.2 Aquifer Testing

Aquifer pumping tests were conducted at R-56 between August 12 and August 18, 2010. Several short-duration tests with short-duration recovery periods were performed on the first day of testing each of the two screened intervals.

A 10-hp pump was used for the aquifer test on the lower screened interval. Initially, the pump's flow rate was set to approximately 15 gpm. Approximately 22,548 gal. of groundwater were purged from the lower screened interval. 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 8649 gal. of groundwater were purged from the upper screened interval at a flow rate of approximately 5.6 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. TOC results and water quality parameters are presented in Appendix B. The R-56 aquifer test results are presented in Appendix C.

Approximately 31,197 gal. of groundwater were purged during aquifer testing activities.

8.3 Dedicated Sampling System Installation

The dedicated sampling system for R-56 will be installed in either late December 2010 or early January 2011. The system will be a Baski, Inc.-manufactured system with a single 3-hp, 4-in.-O.D. environmentally retrofitted Grundfos submersible pump capable of purging each screened interval discretely by means of pneumatically-actuated access port valves (APVs). 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 and will measure water levels in the lower screened interval. Two In-Situ, Inc., Level Troll 500 transducers will be installed in the PVC tubes to monitor water levels in each screened interval.

Sampling system components that are planned for R-56 are presented in Figure 8.3-1a. Figure 8.3-1b presents technical notes for the well. These figures will be updated with the final sampling system specifications and submitted to NMED under separate cover.

8.4 Wellhead Completion

A reinforced concrete surface pad, 10-ft-long× 10-ft–wide × 6-in.-thick, was installed at the R-56 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 presented in Figure 8.3-1a.

8.5 Geodetic Survey

A New Mexico licensed professional land surveyor conducted a geodetic survey on September 2, 2010 (Table 8.5-1). The survey data collected 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-56 monitoring well.

8.6 Waste Management and Site Restoration

Waste generated from the R-56 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-56 well is presented in Table 8.6-1.

All waste streams produced during drilling and development activities were sampled in accordance with “Waste Characterization Strategy Form for 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 EP-Directorate Standard Operating Procedure (SOP) 010.0, 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-QA-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 from the pit, 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-56 were performed as specified in “Drilling Plan for Regional Aquifer Well R-56,” (TerranearPMC 2009, 106320).

10.0 ACKNOWLEDGMENTS

Boart Longyear drilled and installed the R-56 monitoring well.

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

LANL personnel ran downhole video and logging 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), January 2010. "Drilling Work Plan for Regional Aquifer Well R-56," Los Alamos National Laboratory document LA-UR-10-0426, Los Alamos, New Mexico. (LANL 2010, 108543)

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)

TerranearPMC, March 2009. "Drilling Plan for Intermediate Well PCI-2 and PCI-2 Corehole," plan prepared for Los Alamos National Laboratory, Los Alamos, New Mexico. (TerranearPMC 2009, 106320)

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.

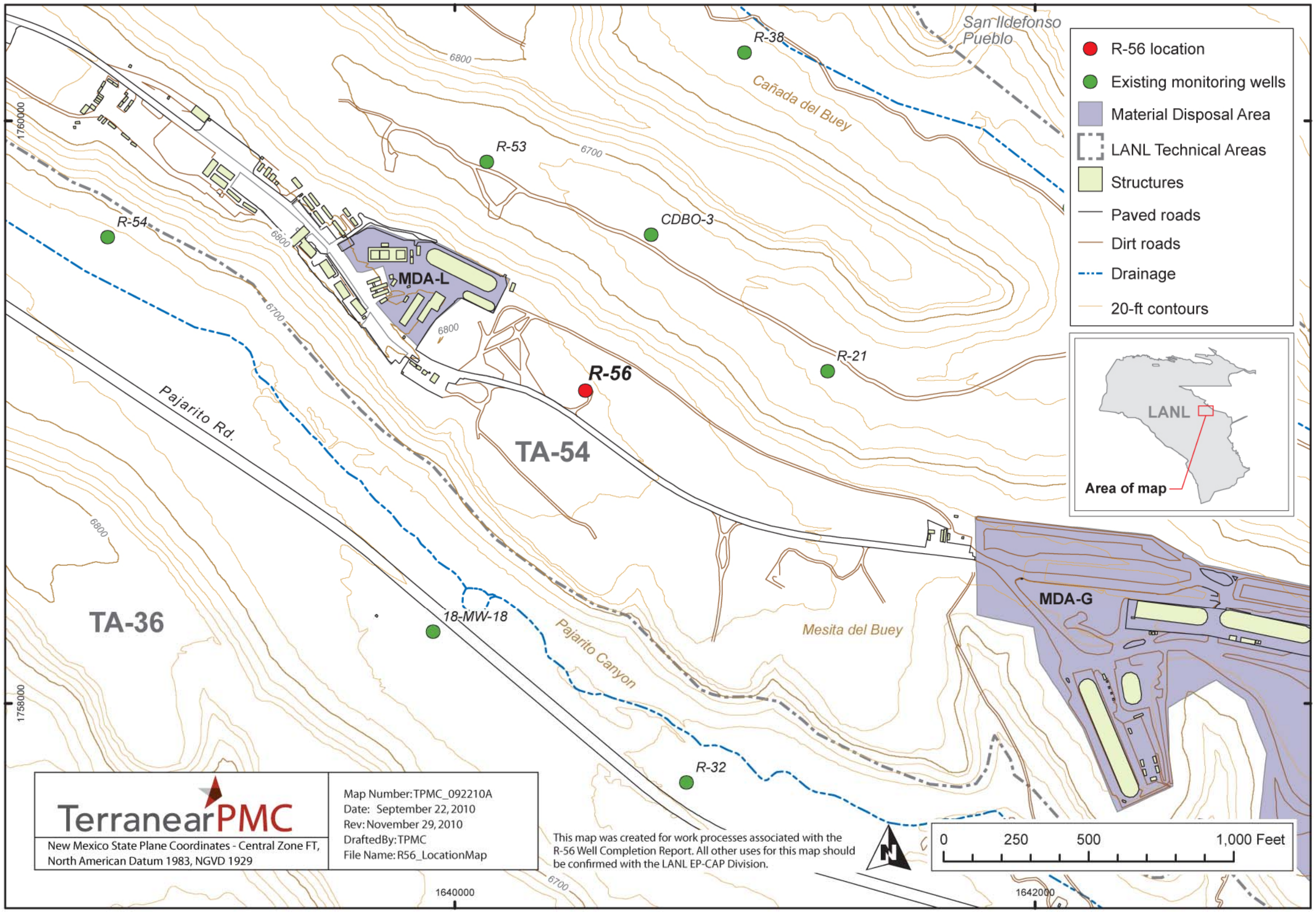

Figure 1.0-1 Location of monitoring well R-56

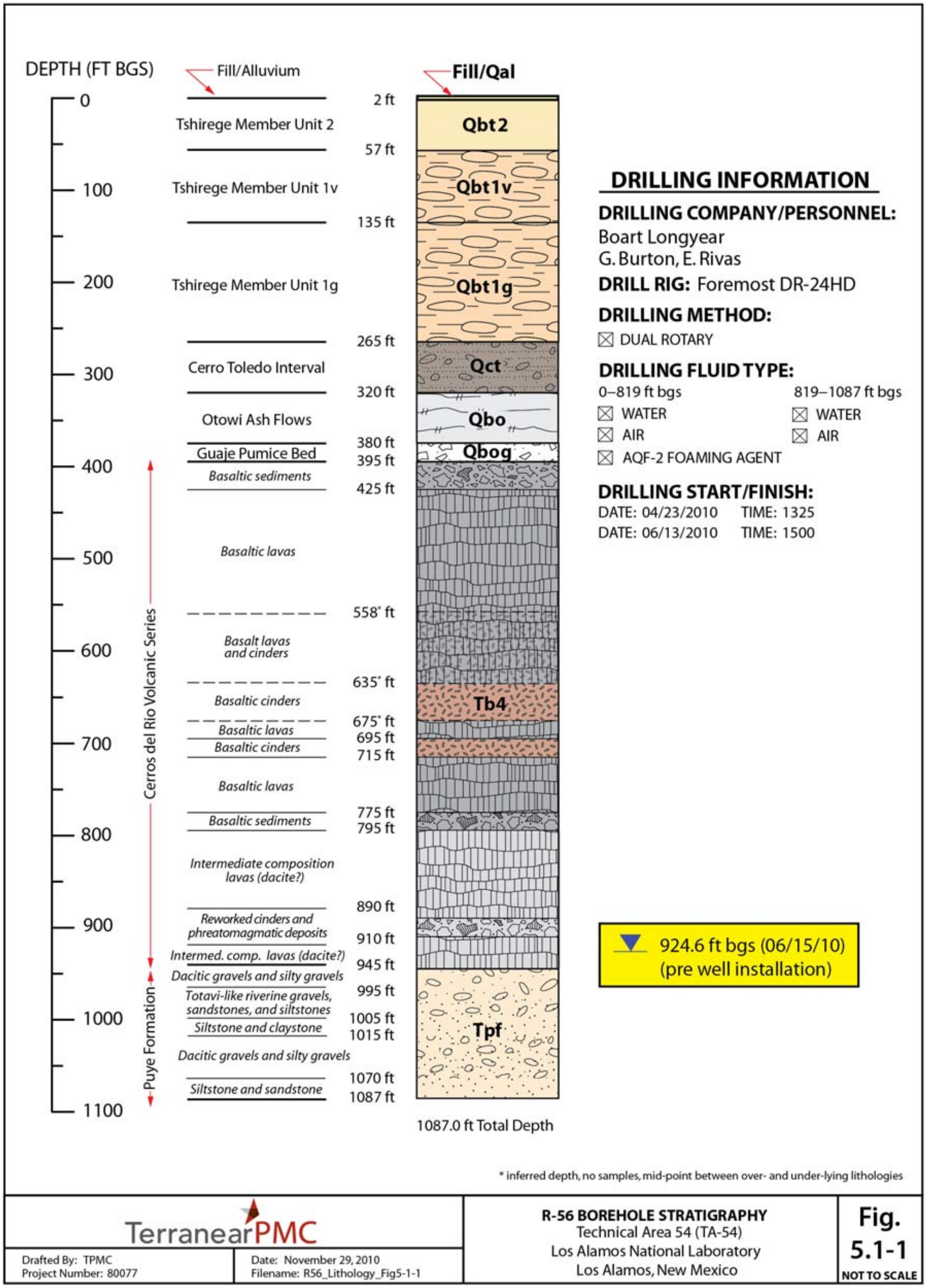

Figure 5.1-1 Monitoring well R-56 borehole stratigraphy

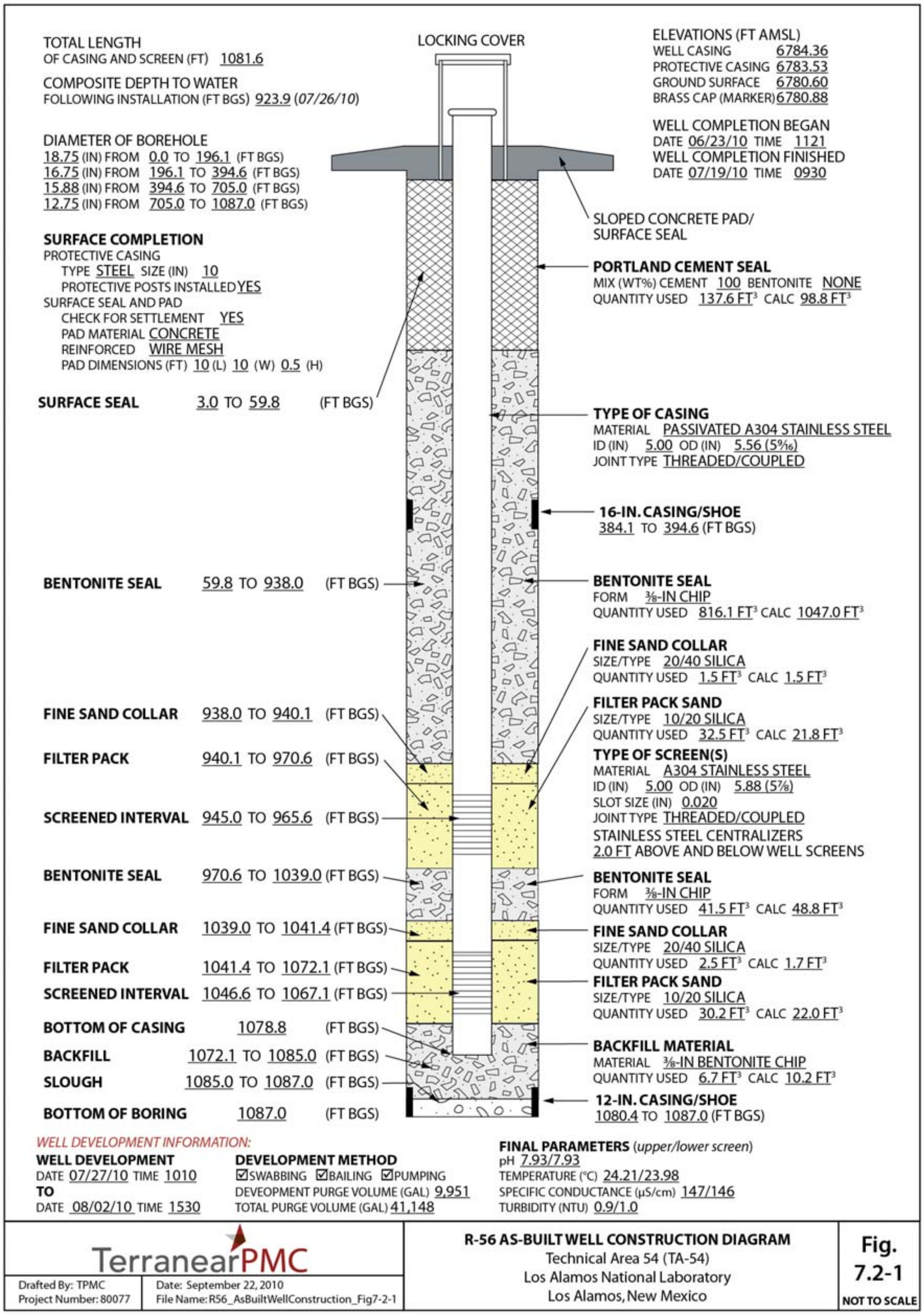

Figure 7.2-1 Monitoring well R-56 as-built well construction diagram

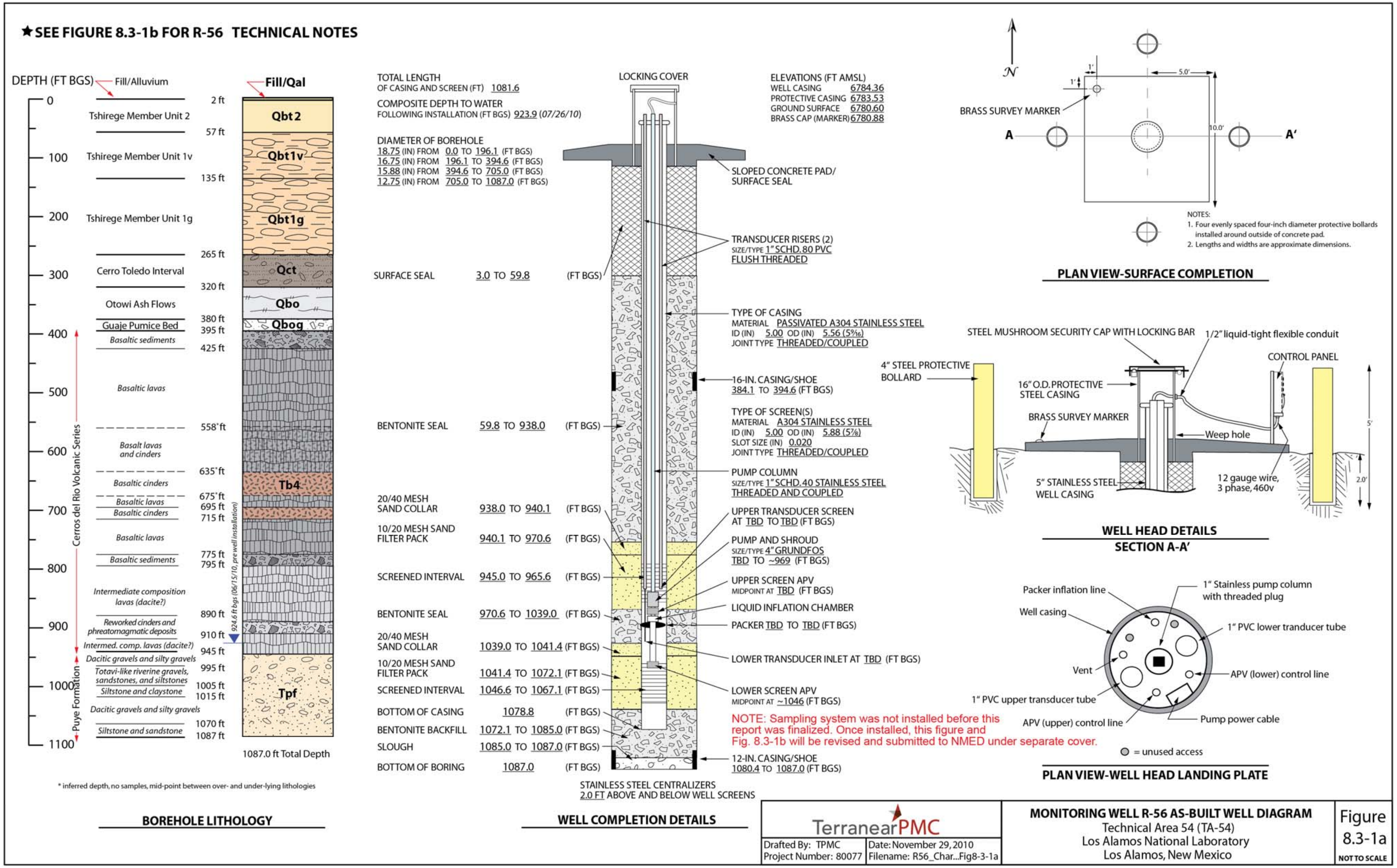

Figure 8.3-1a As-built schematic for regional water monitoring well R-56

R-56 TECHNICAL NOTES:

SURVEY INFORMATION*

Brass Marker

Northing:	1759044.73 ft
Easting:	1640507.31 ft
Elevation:	6780.88 ft AMSL

Well Casing (top of stainless steel)

Northing:	1759039.61 ft
Easting:	1640509.20 ft
Elevation:	6784.36 ft AMSL

BOREHOLE GEOPHYSICAL LOGS

LANL: Natural gamma ray (×2), induction, video

DRILLING INFORMATION

Drilling Company
Boart Longyear

Drill Rig
Foremost DR-24HD

Drilling Methods
Dual Rotary
Fluid-assisted air rotary

Drilling Fluids
Air, potable water, AQF-2 Foam (to 819 ft bgs)

MILESTONE DATES

Drilling

Start:	04/23/2010
Finished:	06/13/2010

Well Completion

Start:	06/23/2010
Finished:	07/19/2010

Well Development

Start:	07/27/2010
Finished:	08/02/2010

WELL DEVELOPMENT

Development Methods
Performed swabbing, bailing, and pumping
Total Volume Purged: 9,951 gal (4,935 gal upper screen, 4626 gal lower screen, and 390 gal combined screens)

Parameter Measurements (Final, upper screen/lower screen)

pH:	7.93/7.93
Temperature:	24.21/23.98°C
Specific Conductance:	147/146 µS/cm
Turbidity:	0.9/1.0 NTU

AQUIFER TESTING

Constant Rate Pumping Test

Upper Screen

Water Produced:	22,548 gal
Average Flow Rate:	14.1 gpm
Performed on:	08/10–13/2010

Lower Screen

Water Produced:	8,649 gal
Average Flow Rate:	5.6 gpm
Performed on:	08/17–19/2010

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: Sampling system had not been installed by the time this report was submitted. Once 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 above mean sea level using the National Geodetic Vertical Datum of 1929.

TerranearPMC

Drafted By: TPMC
Project Number: 80077

Date: November 29, 2010
Filename: R56_TechnicalNotes_Fig8-3-1b

R-56 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-56

Table 3.1-1
Fluid Quantities Used during R-56 Drilling and Well Construction

Date	Water (gal.)	Cumulative Water (gal.)	AQF-2 Foam (gal.)	Cumulative AQF-2 Foam (gal.)
Drilling				
04/23/10	400	400	0	0
04/24/10	300	700	1	1
04/30/10	500	1200	2	3
05/01/10	800	2000	10	13
05/02/10	300	2300	1.5	14.5
05/05/10	100	2400	2	16.5
05/06/10	1500	3900	8	24.5
05/07/10	1500	5400	10	34.5
05/09/10	2100	7500	40	74.5
05/10/10	1000	8500	10	84.5
05/12/10	150	8650	2	86.5
05/13/10	1800	10,450	50	136.5
05/15/10	1000	11,450	15	151.5
05/16/10	1000	12,450	15	166.5
05/17/10	250	12,700	5	171.5
05/18/10	800	13,500	10	181.5
05/19/10	100	13,600	0	181.5
06/03/10	100	13,700	3	184.5
06/04/10	300	14,000	5	189.5
06/05/10	900	14,900	5	194.5
06/06/10	2000	16,900	20	214.5
06/07/10	1200	18,100	60	274.5
06/08/10	2800	20,900	2	276.5
06/09/10	2100	23,000	0	276.5
06/10/10	3300	26,300	0	276.5
06/11/10	1200	27,500	0	276.5
06/12/10	1200	28,700	0	276.5
06/13/10	1200	29,900	0	276.5

Table 3.1-1 (continued)

Date	Water (gal.)	Cumulative Water (gal.)	AQF-2 Foam (gal.)	Cumulative AQF-2 Foam (gal.)
Well Construction				
06/27/10	2700	2700	n/a*	n/a
06/28/10	1600	4300	n/a	n/a
06/29/10	700	5000	n/a	n/a
06/30/10	2200	7200	n/a	n/a
07/01/10	2000	9200	n/a	n/a
07/02/10	1400	10,600	n/a	n/a
07/06/10	100	10,700	n/a	n/a
07/07/10	2400	13,100	n/a	n/a
07/08/10	1700	14,800	n/a	n/a
07/09/10	1800	16,600	n/a	n/a
07/10/10	500	17,100	n/a	n/a
07/11/10	1500	18,600	n/a	n/a
07/14/10	800	19,400	n/a	n/a
07/15/10	550	19,950	n/a	n/a
07/16/10	650	20,600	n/a	n/a
07/17/10	1300	21,900	n/a	n/a
07/18/10	700	22,600	n/a	n/a
07/19/10	81	22,681	n/a	n/a
Total Water Volume (gal.)				
R-56	52,581			

Note: Foam use terminated at 819 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-56

Location ID	Sample ID	Date Collected	Collection Depth (ft bgs)	Sample Type	Analysis
Drilling					
R-56	GW56-10-15470	06/11/10	955.0	Groundwater; airlifted	Anions, metals, LH3, VOCs
R-56	GW56-10-15471	06/13/10	1087.0	Groundwater; airlifted	Anions, metals, LH3, VOCs
Well Development					
R-56	GW56-10-15490	08/02/10	1044.10	Groundwater, pumped	TOC
R-56	GW56-10-15491	08/03/10	970.15	Groundwater, pumped	TOC
Aquifer Testing					
R-56	GW56-10-15492	08/12/10	1001.57	Groundwater, pumped	TOC
R-56	GW56-10-15493	08/12/10	1001.57	Groundwater, pumped	TOC
R-56	GW56-10-15494	08/12/10	1001.57	Groundwater, pumped	TOC
R-56	GW56-10-15495	08/13/10	1001.57	Groundwater, pumped	TOC
R-56	GW56-10-15496	08/13/10	1001.57	Groundwater, pumped	TOC
R-56	GW56-10-15497	08/13/10	1001.57	Groundwater, pumped	TOC
R-56	GW56-10-15498	08/18/10	940.3	Groundwater, pumped	TOC
R-56	GW56-10-15499	08/18/10	940.3	Groundwater, pumped	TOC
R-56	GW56-10-15500	08/18/10	940.3	Groundwater, pumped	TOC
R-56	GW56-10-15501	08/19/10	940.3	Groundwater, pumped	TOC
R-56	GW56-10-15502	08/19/10	940.3	Groundwater, pumped	TOC
R-56	GW56-10-15503	08/19/10	940.3	Groundwater, pumped	TOC

Table 6.0-1
R-56 Logging Runs

Date	Type	Depth (ft bgs)	Description
05/20/10	Video, gamma, induction	Surface to 705 (open hole from 395 to 705).	LANL personnel ran video, gamma, and induction logs after the 16-in. casing was cut at 384.1 ft bgs.
06/14/10	Gamma	Surface to 1085	LANL personnel ran a gamma log inside the 12-in. casing at TD.

Table 7.2-1
R-56 Monitoring Well Annular Fill Materials

Material	Volume (ft^3)
Upper surface seal: cement slurry	137.6
Upper bentonite seal: bentonite chips	816.1
Fine sand collar: 20/40 silica sand	1.5
Filter pack: 10/20 silica sand	32.5
Middle bentonite seal: bentonite chips	41.5
Fine sand collar: 20/40 silica sand	2.5
Filter pack: 10/20 silica sand	30.2
Backfill: bentonite chips/pellets	6.7

Table 8.5-1
R-56 Survey Coordinates

Identification	Northing	Easting	Elevation
R-56 brass cap embedded in pad	1759044.73	1640507.31	6780.88
R-56 ground surface near pad	1759045.97	1640508.97	6780.60
R-56 top of 16-in. protective casing	1759039.37	1640508.59	6783.53
R-56 top of stainless-steel well casing	1759039.61	1640509.20	6784.36

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-56

Location ID	Sample ID	Date Collected	Description	Sample Type
R-56	WST56-10-19362	06/08/2010	NMSW*	Liquid
R-56	WST56-10-19364	06/08/2010	NMSW	Liquid
R-56	WST56-10-18997	06/23/2010	Decontamination fluid (unfiltered)	Liquid
R-56	WST56-10-18996	06/23/2010	Decontamination fluid (filtered)	Liquid
R-56	WST56-10-18998	06/23/2010	Decontamination fluid (duplicate)	Liquid
R-56	WST56-10-18999	06/23/2010	Decontamination fluid	Liquid
R-56	WST56-10-18984	08/06/2010	Development water (unfiltered)	Liquid
R-56	WST56-10-18983	08/06/2010	Development water (filtered)	Liquid
R-56	WST56-10-18985	08/06/2010	Development water (duplicate)	Liquid
R-56	WST56-10-18986	08/06/2010	Development water	Liquid
R-56	WST56-10-18992	08/24/2010	Drill fluid (unfiltered)	Liquid
R-56	WST56-10-18991	08/24/2010	Drill fluid (filtered)	Liquid
R-56	WST56-10-18993	08/24/2010	Drill fluid (duplicate)	Liquid
R-56	WST56-10-18994	08/24/2010	Drill fluid	Liquid

*NMSW = New Mexico Special Waste.

Appendix A

Borehole R-56 Lithologic Log

BOREHOLE IDENTIFICATION (ID): R-56		TECHNICAL AREA (TA): 54	PAGE: 1 of 19
DRILLING COMPANY: Boart Longyear Company		START DATE/TIME: 04-23-10/1325	END DATE/TIME: 06-13-10/1455
DRILLING METHOD: Dual Rotary		MACHINE: Foremost DR24 HD	SAMPLING METHOD: Grab
GROUND Elevation: 6780.60 ft amsl			TOTAL DEPTH: 1087 ft
DRILLERS: G. Burton, E. Rivas		SITE GEOLOGISTS: J. R. Lawrence	

DEPTH (ft bgs)	LITHOLOGY	LITHOLOGIC SYMBOL	NOTES
0–2	**CONSTRUCTION FILL/ALLUVIUM:** Construction fill—light pinkish gray (5YR 8/1), mixed constituents include, silt, tuff fragments, quartz and sanidine crystals, and exotic subrounded to subangular volcanic and quartzo-feldspathic pebbles indicative of imported base-course gravels used in drill pad construction. 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 1087 ft bgs. Fill and disturbed alluvial sediments, encountered from 0 to 2 ft bgs, are approximately 2-ft thick.
2–15	**UNIT 2 OF THE TSHIREGE MEMBER OF THE BANDELIER TUFF:** Rhyolite Tuff—pale pinkish gray (5YR 8/1) to moderate orange pink (5YR 8/4), poorly to moderately welded, moderately indurated, pumiceous, crystal-rich, lithic-bearing. Cuttings predominantly of ash-flow tuff fragments plus minor quartz and sanidine crystals and ash. 2–15 ft whole rock (WR): moderate white fine volcanic ash. +10F: 99% fragments of indurated crystal-bearing ash-flow tuff [i.e., ignimbrite) exhibiting moderately compressed devitrified pumices; 1% exotic quartzite fragments (fill debris). +35F: 75–80% free quartz and sanidine crystals; 20–25% tuff fragments; rare volcanic lithic grains.	Qbt 2	Unit 2 of the Tshirege Member of the Bandelier Tuff (Qbt 2), encountered from 2 to 57 ft bgs, is estimated to be 55-ft thick
15–35	Rhyolite Tuff—pale pinkish gray (5YR 8/1), poorly to moderately welded, moderately indurated, pumiceous, crystal-rich, lithic-bearing. Cuttings predominantly of ash-flow tuff fragments, quartz and sanidine crystals, and minor ash. 15–35 ft +10F: 99–100% fragments of indurated crystal-bearing ash flow tuff; trace large (up to 3 mm) quartz and sanidine crystals and intermediate-composition volcanic (ICV) (dacite?) lithic fragments (up to 8 mm). Note: ash flow tuff exhibits quartz and sanidine crystals (20–30% by volume), slightly compressed/collapsed pumice lapilli (5–15% by volume, devitrifed) and volcanic lithics (up to 6 mm) in a matrix of fine weathered ash. +35F: 65–75% free quartz and sanidine crystals; 25–35% tuff fragments.	Qbt 2	

Borehole Lithologic Log (continued)

Borehole ID: R-56		**TA:** 54	**Page:** 2 of 19
DEPTH (ft bgs)	LITHOLOGY	LITHOLOGIC SYMBOL	NOTES
35–45	Rhyolite Tuff—pale pinkish gray (5YR 8/1), poorly to moderately welded, moderately indurated, pumiceous, crystal-rich, lithic-bearing. Cuttings predominantly of ash-flow tuff fragments plus quartz and sanidine crystals and volcanic ash. 35–45ft WR: abundant fine, weathered to glassy volcanic ash. +10F: 99–100% fragments of indurated crystal-bearing ash flow tuff; up to 1% chips/fragments of devitrified, compressed pumices (up to 3 mm). +35F: 80–90% free quartz and sanidine crystals; 10–20% tuff fragments.	Qbt 2	
45–57	Rhyolite Tuff—pale pinkish gray (5YR 8/1), poorly to moderately welded, moderately indurated, pumiceous, crystal-rich, lithic-bearing. Cuttings predominantly of ash-flow tuff fragments plus quartz and sanidine crystals and volcanic ash. 45–50 ft WR: minor fine, weathered to glassy volcanic ash. +10F: 90–95% fragments of crystal-rich ash-flow tuff exhibiting moderately collapsed/compressed devitrifed pumice lapilli (up to 6 mm); 5–10% ICV lithic fragments (up to 10 mm). +35F: 5–10% free quartz and sanidine crystals; 10–20% tuff fragments and minor volcanic lithics. 50–57 ft WR: moderately abundant weathered volcanic ash. +10F: 95% fragments of crystal-rich ash-flow tuff; 5% ICV lithic fragments (up to 10 mm). +35F:95–97% free quartz and sanidine crystals; 3–5% tuff fragments and minor volcanic lithics.	Qbt 2	The Qbt 2–Qbt 1v contact, estimated to be at 57 ft bgs, is based primarily on interpretation of natural gamma log curve.
57–70	**UNIT 1v OF THE TSHIREGE MEMBER OF THE BANDELIER TUFF:** Rhyolite Tuff—very pale pinkish gray (5YR 8/1), poorly welded, weakly to moderately indurated, pumiceous, crystal-bearing, lithic-bearing. Samples/cuttings predominantly composed of tuff fragments and quartz and sanidine crystals with moderate amounts of weathered volcanic ash. 57–70 ft WR: moderately abundant weathered, silty volcanic ash. +10F: 95–98% fragments of indurated crystal tuff; 2–5% volcanic lithic fragments. Note: ash-flow tuff (ignimbrite) composed of 10–15% quartz and sanidine crystals, strongly devitrifed and moderately compressed pumice lapilli (up to 3 mm), and up to 5% ICV (dacite?, flow-banded rhyodacite?) lithic fragments set in a matrix of weathered (devitrified) volcanic ash. +35F: 95% quartz and sanidine crystals; 5% fragments of volcanic tuff and minor volcanic lithics.	Qbt 1v	Unit 1v of the Tshirege Member of the Bandelier Tuff (Qbt 1v), encountered from 57 to 135 ft bgs, is estimated to be 78-ft thick.

Borehole Lithologic Log (continued)

Borehole ID: R-56	**TA:** 54		**Page:** 3 of 19
DEPTH (ft bgs)	LITHOLOGY	LITHOLOGIC SYMBOL	NOTES
70–160	Rhyolite Tuff—No samples collected in this interval.	Qbt 1v	The Qbt 1v–Qbt 1g contact, estimated to be at 135 ft bgs, is based on interpretation of the natural gamma log curve.
160–165	**UNIT 1g OF THE TSHIREGE MEMBER OF THE BANDELIER TUFF:** Rhyolite Tuff—varicolored, very pale orange (10YR 8/2) to light gray (N7), poorly welded, weakly indurated, strongly pumiceous, crystal- and lithic-bearing. 160–165 ft WR/ +10F: 40–50% fragments/lapilli of glassy, quartz- and sanidine-phyric pumice; 30–40% volcanic lithic fragments; 5–10% fragments of pumiceous crystal-bearing ash-flow tuff (ignimbrite). +35F: 85–95% quartz and sanidine crystals; 5–15% pumice and obsidian fragments.	Qbt 1g	Unit 1g of the Tshirege Member of the Bandelier Tuff (Qbt 1g), encountered from 135 to 265 ft bgs, is estimated to be 130-ft thick.
165–185	Rhyolite Tuff—varicolored, very pale orange (10YR 8/2) to light gray (N7), poorly welded, weakly indurated, pumiceous, crystal- and lithic-bearing. 165–185 ft WR/ +10F: 90–98% fragments/lapilli of very pale orange glassy, fibrous-textured, quartz- and sanidine-phyric pumice; 2–10% ICV (possibly dacite, andesite, rhyodacite) lithic fragments (up to 10 mm). 165–175 ft +35F: 10–20% quartz and sanidine crystals (Note: obsidian rinds and apparent remelting of crystal faces); 80–90% glassy pumice fragments. 175–180 ft +35F: 50–60% quartz and sanidine crystals (obsidian grains also noted); 40–55% glassy pumice fragments. 180–185 ft +35F: 10–20% quartz and sanidine crystals, 80–90% glassy pumice fragments and minor volcanic lithics.	Qbt 1g	
185–200	Rhyolite Tuff—white (N9) to very pale orange (10YR 8/2), poorly welded, weakly indurated, strongly pumiceous, crystal-bearing, lithic-bearing. Samples contain fragments of glassy pumice and lesser volcanic lithic fragments. 95–200 ft WR/+10F: 75–80% generally white glassy (vitric), quartz- and sanidine-phyric pumice lapilli (up to 23 mm) and fragments 10–15% angular ICV lithics (dacite, andesite) fragments (up to 15 mm). +35F: 50–60% glassy white pumice fragments; 40–50% quartz and sanidine crystals; 3–5% volcanic lithics.	Qbt 1g	Note: color change of pumices to predominantly white, glassy.

Borehole Lithologic Log (continued)

Borehole ID: R-56	**TA:** 54		**Page:** 4 of 19
DEPTH (ft bgs)	LITHOLOGY	LITHOLOGIC SYMBOL	NOTES
185–200	Rhyolite Tuff—white (N9) to very pale orange (10YR 8/2), poorly welded, weakly indurated, strongly pumiceous, crystal-bearing, lithic-bearing. Samples contain fragments of glassy pumice and lesser volcanic lithic fragments. 95–200 ft WR/ +10F: 75–80% generally white glassy (vitric), quartz- and sanidine-phyric pumice lapilli (up to 23 mm) and fragments 10–15% angular ICV lithics (dacite, andesite) fragments (up to 15 mm). +35F: 50–60% glassy white pumice fragments; 40–50% quartz and sanidine crystals; 3–5% volcanic lithics.	Qbt 1g	Note: color change of pumices to predominantly white, glassy.
200–230	Rhyolite Tuff—white (N9) to very pale orange (10YR 8/2), poorly welded, weakly indurated, strongly pumiceous, crystal-bearing, lithic-bearing. Samples contain predominantly fragments of glassy pumice and lesser volcanic lithic fragments. 200–210 ft WR: moderate amounts of fine white, glassy volcanic ash. 210–220 ft WR: minor volcanic ash 200–230 ft +10F: 90–100% lapilli/fragments (up to 12 mm) of white glassy, fibrous, quartz- and sanidine-phyric pumice; up to 2% ICV lithics (dacite?, up to 5 mm). +35F: variable proportions of glassy white pumice fragments and quartz and sanidine crystals; trace volcanic lithics.	Qbt 1g	
230–255	Rhyolite Tuff—white (N9), poorly welded, weakly indurated, strongly pumiceous, crystal-bearing, lithic-bearing to lithic-poor. Samples contain fragments of glassy pumice and lesser volcanic lithic fragments. 230–235 ft WR: minor amounts of fine white, glassy volcanic ash. 235–240 ft WR moderate amounts of volcanic ash. 240–255 ft WR: minor amounts of fine white, glassy volcanic ash 230–240 ft +10F: 97–98% lapilli/fragments (up to 15 mm) of white glassy, fibrous, quartz- and sanidine-phyric pumice; 2–3% ICV lithics (up to 8 mm). +35F: glassy white pumice fragments, quartz and sanidine crystals and volcanic lithics in variable proportions. 240–255 ft +10F: 98–100% lapilli/fragments (up to 15 mm) of white glassy, fibrous, quartz-and sanidine-phyric pumice; up to 2% volcanic lithics. Note presence of hb- and cp-phyric pumices at 245–250 ft and hb-phyric ICV lithic fragments at 250–255 ft. +35F: glassy white pumice fragments, quartz and sanidine crystals, and volcanic lithics in variable proportions.	Qbt 1g	

Borehole Lithologic Log (continued)

Borehole ID: R-56	**TA:** 54	**Page:** 5 of 19	
DEPTH (ft bgs)	LITHOLOGY	LITHOLOGIC SYMBOL	NOTES
230–255	Rhyolite Tuff—white (N9), poorly welded, weakly indurated, strongly pumiceous, crystal-bearing, lithic-bearing to lithic-poor. Samples contain fragments of glassy pumice and lesser volcanic lithic fragments. 230–235 ft WR: minor amounts of fine white, glassy volcanic ash. 235–240 ft WR moderate amounts of volcanic ash. 240–255 ft WR: minor amounts of fine white, glassy volcanic ash 230–240 ft +10F: 97–98% lapilli/fragments (up to 15 mm) of white glassy, fibrous, quartz-and sanidine-phyric pumice; 2–3% ICV lithics (up to 8 mm). +35F: glassy white pumice fragments, quartz and sanidine crystals, and volcanic lithics in variable proportions. 240–255 ft +10F: 98–100% lapilli/fragments (up to 15 mm) of white glassy, fibrous, quartz- and sanidine-phyric pumice; up to 2% volcanic lithics. Note presence of hb- and cp-phyric pumices at 245–250 ft and hb-phyric ICV lithic fragments at 250–255 ft. +35F: glassy white pumice fragments, quartz and sanidine crystals, and volcanic lithics in variable proportions.	Qbt 1g	
255–265	Rhyolite Tuff—white (N9), poorly welded, weakly indurated, strongly pumiceous, crystal-bearing, lithic-bearing to lithic-poor. Samples contain fragments of glassy pumice and lesser volcanic lithic fragments. 255–265 ft WR/+10F: 98–99% white fibrous, vitric, quartz-and sanidine-phyric pumice fragments and/or lapilli (up to 14 mm); 1–2% ICV lithic fragments. 260–265 ft +35F: composed of quartz and sanidine crystals, pumice fragments and minor volcanic lithics. Note: occurrences of both white glassy and pale tan earthy (weathered appearing) pumices, the latter suggesting detrital pumice as a first occurrence of Qct components.	Qbt 1g	The basal Qbt 1g contact is estimated to be at 265 ft bgs based on cuttings examination and interpretation of the natural gamma log curve.

Borehole Lithologic Log (continued)

Borehole ID: R-56	**TA:** 54		**Page:** 6 of 19
DEPTH (ft bgs)	LITHOLOGY	LITHOLOGIC SYMBOL	NOTES
265–270	**CERRO TOLEDO INTERVAL:** Tuffaceous and volcaniclastic sediments—varicolored, light gray (N7) to pale yellowish gray (5YR 8/1) pebble gravels with fine to coarse sand, moderately sorted, unconsolidated. Detrital pebbles and grains are noticeably subrounded to rounded. 265–270 ft WR/+10F: 50–60% glassy white to weathered tan pumice granules and pebbles (up to 12 mm); 30–40% ICV pebbles (up to 15 mm). +35F: 40–50% quartz and sanidine crystal grains; 30–40% pumice fragments (predominantly weathered appearing); 20–30% volcanic grains. Note: change in nature of +35F pumices to predominantly strongly weathered in appearance at 265 ft bgs.	Qct	The Cerro Toledo interval (Qct), encountered from 265 to 320 ft bgs, is estimated to be 55-ft thick.
270–290	Tuffaceous and volcaniclastic sediments—varicolored, light gray (N7) to pale yellowish gray (5YR 8/1) pebble gravels with fine to coarse sand, moderately sorted, unconsolidated. Samples composed of volcaniclastic (predominantly ICV) and tuffaceous (abundant pumice and quartz and sanidine crystals) detrital pebbles and grains that are subrounded to rounded. 270–280 ft WR: predominantly subrounded detrital pumices, glassy to weathered; lesser subrounded ICV clasts. +10F: 60–70% glassy white pumice granules and pebbles (up to 10 mm); 30–40% subangular to subrounded volcanic pebbles (up to 17 mm), predominantly composed of Tschicoma-like hb-phyric ICV. 280–290 ft +10F: 70–80% subangular to subrounded volcanic granule and pebbles (up to 16 mm), predominantly ICV; 20–30% subrounded detrital pumices. +35F: subrounded weathered detrital pumices, subangular to subrounded volcanic grains, and quartz and sanidine crystal grains in variable proportions.	Qct	
290–295	Tuffaceous and volcaniclastic sediments—varicolored, white (N9) to pale yellowish gray (5YR 8/1) silty fine to coarse sand with pebbles, weakly to moderately cemented. 290–295 ft WR: abundant white, silty volcanic ash. +10F: 80–90% subangular to subrounded detrital ICV granules and pebbles (up to 14 mm); 10–20% subrounded detrital pumices; 1–3% fragments of silty sandstone.	Qct	

Borehole Lithologic Log (continued)

Borehole ID: R-56		**TA:** 54	**Page:** 7 of 19
DEPTH (ft bgs)	LITHOLOGY	LITHOLOGIC SYMBOL	NOTES
295–305	Tuffaceous and volcaniclastic sediments—varicolored, light gray (N7) to pale yellowish gray (5YR 8/1) pebble gravels with fine to coarse sand, poorly to moderately sorted, weakly consolidated. Samples of volcanic and tuffaceous detritus. 295–305 ft WR/ +10F: 70–80% subrounded ICV (dacite, andesite) granules and pebbles (up to 14 mm); 20–30% subrounded to rounded detrital pumices. +35F: 10–15% quartz and sanidine crystals; 20–30% detrital pumice grains; 50–60% subangular to subrounded volcanic grains.	Qct	
305–310	Tuffaceous and volcaniclastic sediments—white (N9) to very pale orange (10YR 8/6). Samples of volcanic and tuffaceous materials. 305–310 ft WR/+10F: 70–80% yellowish (oxidized) vitric pumices; 20–30% angular volcanic fragments. Note diminished rounding of volcanic materials. +35F: 10–15% pale orange glassy pumice fragments, 5–10% quartz and sanidine crystals; 70–80% volcanic grains.	Qct	
310–315	Tuffaceous and volcaniclastic sediments—varicolored very pale orange (10YR 8/6) to light gray (N7). Samples of volcanic and tuffaceous materials. 310–315 ft WR: abundant amounts of white volcanic ash. +10F: 70–80% angular volcanic lithics (up to 13 mm) including ICV (dacite, rhyodacite, andesite); 20–30% pale orange glassy, quartz- and sanidine-phyric pumices (up to 12 mm) +35F: 40–50% white to pale orange glassy pumice fragments, 10–15% quartz and sanidine crystals; 30–40% volcanic lithic grains.	Qct	
315–320	Tuffaceous and volcaniclastic sediments—varicolored very pale orange (10YR 8/6) to light gray (N7). Samples of volcanic and tuffaceous materials. 315–320 ft WR: minor amounts of white ash. +10F: 10–15% pumice fragments; 85–90% angular volcanic lithic fragments.	Qct	The Qct–Qbo contact is estimated to be at 320 ft bgs based on interpretation of the natural gamma log curve.

Borehole Lithologic Log (continued)

Borehole ID: R-56	**TA:** 54		**Page:** 8 of 19
DEPTH (ft bgs)	LITHOLOGY	LITHOLOGIC SYMBOL	NOTES
320–325	**OTOWI MEMBER OF THE BANDELIER TUFF:** Rhyolite Tuff—varicolored, very pale orange (10YR 8/6) to light gray (N7)5YR 6/4) poorly welded, weakly indurated, pumiceous, crystal-poor, lithic-rich. 320–325 ft WR/ +10F: 60–70% fragments of white to pale orange glassy, quartz- and sanidine-phyric pumice; 30–40% subangular to subrounded ICV lithic fragments (dacite, andesite). +35F: glassy pumice fragments, volcanic lithic fragments and quartz and sanidine crystals in variable proportions.	Qbo	
325–340	Rhyolite Tuff—varicolored, very pale orange (10YR 8/6) to light gray (N7)5YR 6/4) poorly welded, weakly indurated, pumiceous, crystal-poor, lithic-rich. 325–340 ft WR/ +10F: 60–70% fragments of white to pale orange glassy, quartz- and sanidine-phyric pumice; 30–40% subangular to subrounded ICV lithic fragments (dacite, andesite). +35F: glassy pumice fragments, volcanic lithic fragments, and quartz and sanidine crystals in variable proportions.	Qbo	.
340–350	Rhyolite Tuff—white (N9), poorly welded, weakly indurated, pumiceous, crystal- and lithic-bearing. 340–350 ft WR/ +10F: 70–80% fragments of white to pale orange glassy, fibrous, quartz- and sanidine-phyric pumice; 20–30% small (up to 6 mm) volcanic lithic fragments. +35F: 50–60% white glassy pumice fragments, 40–50% volcanic lithic fragments; 10–15% quartz and sanidine crystals.	Qbo	
350–370	Rhyolite Tuff—white (N9), poorly welded, weakly indurated, pumiceous crystal-poor, lithic-bearing. 350–360 ft +10F: 95–97% fragments (up to 15 mm) of white glassy, fibrous-textured, quartz- and sanidine-phyric pumice; 3–5% ICV (dacite, andesite) lithic fragments. 360–370 ft +10F: 85–90% fragments and/or lapilli (up to 23 mm) of white glassy, fibrous-textured, quartz- and sanidine-phyric pumice; 10–15% volcanic lithics. +35F: white glassy pumice fragments. Volcanic lithics and quartz and sanidine crystals in variable proportions.	Qbo	

Borehole Lithologic Log (continued)

Borehole ID: R-56		**TA:** 54	**Page:** 9 of 19
DEPTH (ft bgs)	LITHOLOGY	LITHOLOGIC SYMBOL	NOTES
370–375	Rhyolite Tuff—varicolored, white (N9) to medium gray (N5), poorly welded, weakly indurated, pumiceous, crystal-poor, lithic-bearing. 370–375 ft +10F: 40–50% fragments and/or lapilli of white glassy, quartz- and sanidine-phyric pumice; 40–50% volcanic lithic fragments (up to 8 mm).	Qbo	The Qbo–Qbog contact is estimated to be at 375 ft bgs based on interpretation of the natural gamma log.
375–390	**GUAJE PUMICE BED OF THE OTOWI MEMBER OF THE BANDELIER TUFF:** Rhyolite Tuff—varicolored, white (N9) to medium gray (N5), poorly welded to non-welded, weakly indurated, strongly pumiceous, crystal-poor, lithic-poor. 375–380 ft +10F: 40–50% fragments and/or lapilli of white glassy, quartz- and sanidine-phyric pumice; 40–50% volcanic lithic fragments (up to 8 mm). 380–385 ft +10F: 80–85% fragments and/or lapilli of white glassy, quartz- and sanidine-phyric pumice; 15–20% volcanic (ICV) lithic fragments. 385–390 ft +10F: 60–70% fragments and/or lapilli of white glassy, quartz- and sanidine-phyric pumice; 10–15% ICV (dacite?) lithic fragments; 10–15% fragments of fine-grained volcaniclastic sediment, well cemented, siliceous/tuffaceous matrix. +35F: white glassy pumice fragments. Volcanic lithics and quartz and sanidine crystals in variable proportions.	Qbog	The Guaje Pumice Bed (Qbog), encountered from 375 to 395 ft bgs, is estimated to be 20-ft thick.
390–395	Rhyolite Tuff—white (N9), non-welded, unconsolidated, pumice-rich, crystal-poor, lithic-poor. 390–395 ft WR/+10F: 90–95% subrounded pumice lapilli (up to 12 mm), lustrous, glassy with pristine appearance, quartz- and sanidine-phyric; 5–10% fragments of tuffaceous sandstone, white, calcareous cementation; trace-free volcanic lithics. +35F: 25% volcanic lithics, 20% quartz and sanidine crystals, 60% white glassy pumice fragments.	Qbog	Note: pristine pumice lapilli making up the interval 390–395 ft, suggest the occurrence of an air-fall pumice deposit. The base of Qbog, in contact with Cerros del Rio volcanic rocks, is estimated to be at 395 ft bgs based on cuttings examination and interpretation of the natural gamma log curve.

Borehole Lithologic Log (continued)

Borehole ID: R-56	**TA:** 54		**Page:** 10 of 19
DEPTH (ft bgs)	LITHOLOGY	LITHOLOGIC SYMBOL	NOTES
395–400	**CERROS DEL RIO VOLCANIC SERIES:** Basaltic sediments—varicolored, white (N9) to medium gray (N5) fine gravels with medium to coarse sand, moderately to well sorted, weakly cemented. Samples contain reworked volcanic materials: mixed rounded basaltic, ICV and pumiceous detritus 395–400 ft WR/+10F/+35F: rounded (i.e., by fluvial processes) granules and grains composed of vesicular basalt, hornblende (hb)-ICV (dacite?), reddish brown (oxidized) scoria, and white weathered pumices; also minor unidentified fine-grained intermediate volcanic rock.	Tb 4	The Cerros del Rio volcanic rocks (Tb 4), encountered from 395 to 945 ft bgs, are estimated to have a cumulative thickness of 550-ft thick.
400–410	Basaltic sediments and reworked cinders—varicolored, medium gray (N5) to dark yellowish orange (10YR 6/6) fine gravels with medium to coarse sand, moderately to well sorted, weakly cemented. Samples contain detritus of basalt and strongly oxidized basaltic cinders (?). 400–410 ft WR/+10F/+35F: 90–93% rounded granules and grains of reworked basalt and yellowish (oxidized) basalt; 7–10% pumice grains.	Tb 4	
410–425	Basaltic sediments and reworked cinders—subrounded detritus predominantly of basalt and strongly oxidized basaltic cinders (?). Varicolored, medium gray (N5) to dark yellowish orange (10YR 6/6) fine gravels with medium to coarse sand, moderately to well sorted, weakly cemented. Samples contain subrounded detritus predominantly of basalt and strongly oxidized basaltic cinders (?). 410–425 ft WR/+10F/+35F: moderately to well rounded granules and pebble clasts (typically in the range of 3 to 10 mm in diameter). Clasts composed of vesicular basalt, oxidized yellowish basalt, basalt scoria (cinders) plus pink and gray ICV (dacite?). Noted also, trace occurrences of white fine-grained tuffaceous/volcanic sandstone, calcite-cemented. Samples contain up to 15% white pumices interpreted to be exotic (e.g., an artifact of drilling in open-hole mode).	Tb 4	

Borehole Lithologic Log (continued)

Borehole ID: R-56	**TA:** 54		**Page:** 11 of 19
DEPTH (ft bgs)	LITHOLOGY	LITHOLOGIC SYMBOL	NOTES
425–450	Basalt lava(s)—medium (N5) to medium dark gray (N3), basalt, lava, vesicular to massive, olivine- and plagioclase-phyric. 425–440 ft +10F: chips predominantly of vesicular basalt lava that is weakly porphyritic with aphanitic groundmass; phenocrysts (2–4% by volume) of olivine (commonly iddingsitized) and plagioclase. Note: samples contain 2–5% exotic detrital reworked basalt and pumice grains. 440'– 450 ft +10F: chips predominantly of massive olivine-basalt lava and lesser vesicular basalt lava. Note: samples contain 2–3% exotic detrital basalt and pumice grains.	Tb 4	
450–465	Basalt lava(s)—medium dark gray (N3), chips predominantly of massive, olivine- and plagioclase-phyric basalt. 450–465 ft +10F: 98-–99% chips of massive basalt with minor vesicular basalt exhibiting some amygdaloidal calcite. Note: samples contain 1–2% exotic detrital basalt and pumice grains.	Tb 4	
465–495	Basalt lava(s)—medium (N5) to medium dark gray (N3), chips predominantly of vesicular olivine-basalt lava. 465–475 ft +10F: 99–100% chips of vesicular basalt (i.e., olivine- and plagioclase-phyric as described at 425–440); minor hematite coating vesicles; iddingsite after olivine is common. Note: samples contain trace exotic detrital basalt. 475–495 ft +10F: 100% chips of strongly vesicular basalt with hematite and white clay and/or calcite) lining vesicles. Amygdaloidal white clay especially abundant at 490–495 ft.	Tb 4	
495–515	Basalt lava(s)—medium (N5) to light gray (N7), chips predominantly of strongly vesicular olivine-basalt lava. 495–510 ft +10F: 100% chips of vesicular basalt that is weakly porphyritic with aphanitic groundmass; penocrysts (1–3% by volume) of anhedral pale green olivine and anhedral plagioclase (phenocrysts commonly occur as cumulophyric clusters). Amygdaloidal white clay occurs locally. Groundmass weakly altered with depth. 510–515 ft +10F: amygdaloidal white clay more frequent; chips coated with white silty powder (zeolite?).	Tb 4	

Borehole Lithologic Log (continued)

Borehole ID: R-56		**TA:** 54	**Page:** 12 of 19
DEPTH (ft bgs)	LITHOLOGY	LITHOLOGIC SYMBOL	NOTES
515–545	Basalt lava(s)—medium (N5) to light dark (N6), chips predominantly of vesicular olivine-basalt lava; local white amygdaloidal clay. 515–535 ft +10F: 100% chips of vesicular basalt with locally moderate amounts of white clay filling vesicles. Olivine-basalt is locally glassy. Note: glassy basalt with white clay and unidentified yellow secondary mineral filling vesicles 520–525 ft. 535–545 ft +10F: 100% chips of strongly vesicular olivine-basalt with local amygdaloidal white clay.	Tb 4	
545–570	545–570 ft Cemented borehole interval. Samples contain silt-coated chips of mixed basalt and exotic quartzo-feldspathic materials from cement used to stabilize the borehole. Samples do not reflect true nature of the formation; therefore, no formation sample description was attempted.	Tb 4	
570–605	Basalt lavas and cinders—moderate reddish gray (5R 5/4) to medium gray (N5), chips of mixed vesicular basalt and scoriaceous cinders. 570–590 ft +10F: 60–70% chips of gray vesicular basalt lava with local amygdaloidal white clay and/or calcite (?); clay also noted on fracture surfaces; 30–40’% red scoriaceous cinders. Basalt is phenocryst-poor with rare olivines; groundmass weakly altered. 590–605 ft +10F: 80–90’% chips of vesicular to massive basalt lava (basalt becoming clinopyroxene- (cp) and olivine-phyric); 10–20’% red basalt cinders.	Tb 4	
605–625	Basaltic cinder deposits and basalt lava(s)—moderate reddish gray (5R 5/4) to medium gray (N5), chips predominantly of reddish strongly vesicular to scoriaceous basaltic cinders and less frequent chips of cp- and olivine-phyric basalt lava. 605–620 ft WR/ +10F: 60–90’% coarse chips of scoricaeous basalt cinders exhibiting locally abundant amygdaloidal clay; 10–40’% chips of massive cp-phyric basalt lava. 620–625 ft +10F: 60’% reddish scoriaceous basalt cinders; 40% chips of basalt lava that is weakly porphyritic with aphanitic groundmass; phenocrysts (3–5’% by volume) of opaque black cp, subhedral plagioclase and minor olivine. Note: cp frequently occurs as replacement rims on olivines.	Tb 4	

Borehole Lithologic Log (continued)

Borehole ID: R-56		**TA:** 54	**Page:** 13 of 19
DEPTH (ft bgs)	LITHOLOGY	LITHOLOGIC SYMBOL	NOTES
625–645	625–645 ft Cemented borehole interval. No formation description.	Tb 4	
645–665	Basaltic cinder deposits—medium dark gray (N6) to pale reddish gray (10R 6/2), chips predominantly of reddish scoriaceous basaltic cinders. 645–665 ft WR/ +10F: 80–90% strongly oxidized (hematite-stained) scoriaceous cinders; 10–20'% chips of massive cp-phyric basalt lava.	Tb 4	
665–685	665–685 ft Cemented interval. No formation sample description.	Tb 4	
685–695	Basaltic lava—medium dark gray (N6), chips predominantly of olivine-basalt lava. 685–695 ft WR/ +10F: 70–80% chips of vesicular and massive basalt lava that is porphyritic with aphanitic groundmass; phenocrysts (2–4 % by volume) of olivine, plagioclase and minor cp; 20–30% chips of scoriaceous cinders.	Tb 4	
695–705	Basaltic cinder deposits—pale reddish gray (10R 6/2), chips predominantly of reddish strongly vesicular to scoriaceous basaltic cinders. 695–705 ft WR/ +10F: mixed chips of cp- and ol-phyric basalt plus red scoriaceous cinders. Note: black cp forming rims on olivine phenocrysts.	Tb 4	
705–715	Basaltic cinder and tuffaceous sandstone—white (N9) to medium light gray (N6), mixed chips/fragments of vesicular to scoriaceous basalt and white tuffaceous sandstone fragments. 705–715' ft WR/ +10F: 50–60% subrounded fragments of white carbonate-cemented silty tuffaceous sandstone composed of fine quartz and sanidine crystals, pumices, and ICV (dacite?) grains enclosed in a white silty matrix; 40–50% subangular chips of vesicular cp-phyric basalt and lesser reddish scoria (cinders).	Tb 4	Note: Possible white sandstone interval from approximately 707 to 712 ft bgs.

Borehole Lithologic Log (continued)

Borehole ID: R-56		**TA:** 54	**Page:** 14 of 19
DEPTH (ft bgs)	LITHOLOGY	LITHOLOGIC SYMBOL	NOTES
715–740	Basalt lava—medium (N5) to medium light gray (N6), angular chips of olivine- and cp-phyric basalt lava, vesicular grading downward to more massive in structure; groundmass weakly altered. 715–720 ft WR/ +10F: 100% angular chips of strongly vesicular olivine-bearing basalt; olivines partly replaced by, or intergrown with, opaque black cp; groundmass glassy to weakly altered. 720–740 ft WR/ +10F: 100% angular chips of olivine- and cp-phyric basalt lava that is porphyritic with aphanitic groundmass; phenocrysts (3–5 % by volume) of subhedral to euhedral greenish brown olivines (up to 2 mm) that are commonly intergrown with opaque black cp; groundmass is glassy to weakly altered; olivines partly iddingsitized	Tb 4	
740–755	Basalt lava with abundant clay—varicolored, medium gray (N5) to white (N9), angular chips of strongly vesicular cp-phyric basalt lava exhibiting abundant to intense amygdaloidal clay. 740–750 ft WR/ +10F: 100% angular chips of strongly vesicular cp-bearing basalt with locally reddish (oxidized) hematite staining and abundant white clay filling vesicles. Possible top of aa-type basalt flow associated with textural and commotional changes at 740 ft bgs. 750–755 ft WR/ +10F: 100% angular chips of vesicular cp-phyric basalt lava with weak to moderate hematite staining and minor white clay.	Tb 4	

Borehole Lithologic Log (continued)

Borehole ID: R-56	TA: 54		Page: 15 of 19
DEPTH (ft bgs)	LITHOLOGY	LITHOLOGIC SYMBOL	NOTES
755–775	Basalt lava—medium light gray (N6), angular chips of strongly vesicular to massive cp+olivine basalt lava. 755–760 ft WR/ +10F: 99% angular chips of vesicular clinopyroxene-phyric basalt with minor olivine phenocrysts; up to 1% hematite-stained basalt and white clay fragments. 760–765 ft WR/ +10F: apparent compositional changes noted. Basalt in this interval is porphyritic with aphanitic groundmass; phenocrysts (4–6 % by volume) of opaque black cp and locally euhedral olivines (up to 3 mm) that are iddingsitized and/or replaced by opaque cp. Note: olivine becomes more predominant phenocryst over cp with depth; cp is anhedral to resorbed. 765–770 ft WR/ +10F:100% angular chips olivine-phyric basalt with minor cp phenoocrysts; olivines pale greenish to reddish due to iddingsite alteration; rare black cp as phenocrysts; groundmass glassy to weakly altered. Trace white clay as fracture fillings.	Tb 4	
775–795	Basaltic sediments and hydromagmatic deposits—varicolored, orange red (10YR 6/6) to medium gray (N5), silty fine-grained volcaniclastic sandstone with pebble gravel. Samples contain rounded (milled during drilling) fragments of orange brown fine grained volcaniclastic sandstone and fluvially rounded scoriaceous lapilli plus detritus of basaltic and intermediate volcanic composition. 775–785 ft WR/+10F: 50–70% rounded fragments of silty fine-grained sandstone; 30–50% subangular to subrounded detrital clasts (up to 15 mm) composed of vesicular basalt, minor hb-ICV(dacite?), and glassy basaltic scoria. +35F: abundant orange silty fine-grained sandstone fragments; abundant subrounded grains of glassy basaltic scoria; minor detrital grains of basalt and other volcanic rocks; trace detrital quartz grains. 785–795 ft WR/+10F: 70–80% rounded (fluvial processes) to subrounded detrital clasts of basalt, ICV lithics (up to 18 mm), glassy basaltic scoria, quartz, quartzite, granite, microcline; 20–30% rounded (milled during drilling) fragments of fine-grained volcanic sandstone. +35F: rounded grains of similar composition to above.	Tb 4	Note: Maar-type hydromagmatic deposits from 775 to 795 ft bgs.

Borehole Lithologic Log (continued)

Borehole ID: R-56	**TA:** 54		**Page:** 16 of 19
DEPTH (ft bgs)	LITHOLOGY	LITHOLOGIC SYMBOL	NOTES
795–860	ICV (dacite?) lava—medium light gray (N6), angular chips of strongly vesicular to massive cp+olivine ICV (dacite?) lava. 795–805 ft WR/ +10F: 95–98% angular chips of strongly vesicular ICV (dacite?) lava exhibiting abundant pale tan clay as fracture and vesicle fillings; 2–5% rounded (milled) fragments of siltstone and silty very fine-grained sandstone. Note ICV (dacite?) lava is phenocryst-poor to aphyric, strongly vesicular, and contains trace xenocrystic quartz. +35F: 80–95% grains of vesicular lava; 5–20% grains of indurated sandstone, glassy lava, scoria, granite, and quartz. 805–810 ft WR/ +10F: 100% angular chips of strongly vesicular, aphyric lava; local limonite staining, and pale tan clay on fracture surfaces and lining vesicles. 810–860 ft WR/ +10F:100% chips of moderately vesicular basalt lava, phenocryst-poor to aphyric; rare orthopyroxene (?) (op) as phenocrysts; glassy to aphanitic texture.	Tb 4	
860–890	ICV (?) lava—medium (N5) to medium light gray (N6), monolithic samples containing chips of weakly vesicular to massive, phenocryst-poor ICV lava. 860–890 ft WR/ +10F/+35F: 100% subangular to subrounded (milled during drilling) chips of phenocryst-poor to aphyric, glassy ICV (dacite?) lava; rare pale greenish brown op (?) as phenocrysts.	Tb 4	
890–910	Volcanic sediments and siltstone—varicolored, medium light gray (N6) to very pale pinkish tan (10YR 8/2). Volcanic pebble gravels with fine to coarse sand and abundant siltstone, poorly sorted, weakly to moderately cemented. 890–900 ft WR/ +10F: 60–70% subrounded to rounded (e.g., by fluvial abrasion) pebbles (up to 17 mm) composed of vesicular to scoriaceous basalt, ICV (dacite?), and reworked cinders; 30–40% angular chips/fragments of pale pinkish sandstone. 900–910 ft WR/ +10F: 70–80% angular chips and rounded reworked detrital clasts composed of massive to vesicular basalt with amygdaloidal clay; 20–30% chips of pale tan siltstone and/or clay.	Tb 4	

Borehole Lithologic Log (continued)

Borehole ID: R-56		**TA:** 54	**Page:** 17 of 19
DEPTH (ft bgs)	LITHOLOGY	LITHOLOGIC SYMBOL	NOTES
910–945	ICV (dacite?) lava with clay-filled fractures—medium (N5), monolithic samples containing chips of weakly vesicular to massive, phenocryst-poor ICV (dacite?) lava; variable abundances of pale tan clay. 910–925 ft WR/ +10F: 100% angular chips of massive to very weakly vesicular ICV (dacite?) lava that is phenocryst-poor to aphyric; trace local amygdaloidal clay. 925–940 ft WR/ +10F: 85–90% angular chips of massive to weakly vesicular ICV (dacite?) lava, apparently aphyric, aphanitic to slightly glassy; 10–15% chips of pale tan clay that occur as amygdaloidal fillings and coatings on fracture surfaces; also as free particles. 940–945 ft WR/ +10F: 80–85% angular chips of aphyric ICV (dacite?) lava, 15–20% chips of pale tan clay that occur as amygdaloidal fillings and coatings; up to 5% exotic fragments and detrital particles of ICV (dacite?), and reworked basalt scoria.	Tb 4	The contact between Cerros del Rio volcanic rocks and underlying Puye Formation with Totavi Lentil riverine volcanic sediments is estimated to be at 945 ft bgs based on binocular microscope analysis of drill cuttings and interpretation of the natural gamma log curve.
945–975	**PUYE FORMATION:** Volcaniclastic sediments—varicolored, pale tan (10YR 8/2) to medium dark gray (N4), silty fine to medium sand with pebble gravel, moderate to poorly sorted, weakly to moderately cemented. Detrital volcanic pebbles and granules subrounded to well-rounded. Samples contain abundant fragments of silty volcanic sandstone and detrital pumices plus minor grains of quartzo-feldspathic rocks. 945–960 ft WR/ +10F: subrounded to well rounded (e.g., by fluvial abrasion) volcanic detritus (pebbles up to 12 mm) and fragments of fine-grained sandstone. 70–90% pebbles and granules composed of various volcanic rocks, including vesicular and scoriaceous basalt, biotite- and/or hb-phyric dacite plus locally abundant pale gray hb-phyric pumices; trace quartzo-feldspathic granules; 10–30% rounded (milled) fragments of pale tan silty sandstone. 960–975 ft WR/ +10F: samples contain abundant well rounded vesicular basalt pebbles (up to 15 mm) and light gray detrital dacite clasts, pumices, and trace quartz.	Tpf	The Puye Formation (Tpf)), encountered from 945 ft bgs to the bottom of the R-56 borehole at 1087 ft bgs, is a minimum of 142-ft thick.

Borehole Lithologic Log (continued)

Borehole ID: R-56		**TA:** 54	**Page:** 18 of 21
DEPTH (ft bgs)	LITHOLOGY	LITHOLOGIC SYMBOL	NOTES
975–990	Volcaniclastic sediments—pale brown (5YR 7/2) to medium gray (N5), silty pebble gravel with fine to coarse sand, moderate to poorly sorted, weakly indurated. Samples contain abundant silt and pebbles/granules of dacite and basalt. 945–960 ft WR: abundant silt matrix. +10F: 20–40% fragments of siltstone and very fine-grained sandstone; 60–80% subrounded granules and pebbles composed of gray hb-phyric dacite and vesicular basalt. Note: light gray porphyritic Tschicoma-like dacite (?) detritus becomes more abundant with depth.	Tpf	
990–1005	Volcaniclastic sediments with abundant quartzo-feldspathic detritus—pale tan (10YR 7/2) to medium gray (N5), siltstone and silty pebble gravel with fine to coarse sand, poorly sorted, weakly to moderately indurated. Samples contain abundant siltstone fragments and rounded detritus composed of mixed volcanic and quartzo-feldspathic (Precambrian) lithologies. 990–1005 ft WR: abundant silt matrix. +10F: 20–40% rounded (milled) fragments of siltstone and very fine grained sandstone; 10–20% detritus composed of Precambrian rocks (quartzite, biotite-gneiss, microcline, granite); 30–40% subrounded detritus of various volcanic rocks, including fine-grained and porphyritic dacite and vesicular basalt.	Tpf	Totavi Lentil-like quartzo-feldspathic sediments, interpreted as ancestral Rio Grande riverine deposits, were encountered from 990 to 1005 ft bgs. These sediments are estimated to be 15-ft thick.
1005–1020	Volcaniclastic sediments—light pinkish tan (5YR 7/2), siltstone with local grain-size to pebble-size detritus composed predominantly of volcanic rocks and less abundant quartzo-feldspathic rocks. Sediments are moderately to well sorted and moderately to weakly cemented. 1005–1020 ft WR: samples composed predominantly of silt and fragments of siltstone. +10F: 85–90% rounded (milled) fragments of light tan siltstone 10–15% subrounded clasts composed of quartzite, dacite, and basalt. +35F: 60–70% siltstone fragments, 15–15% subrounded grains of dacite and minor basalt; 10–15% quartzo-feldspathic grains.	Tpf	

Borehole Lithologic Log (continued)

Borehole ID: R-56		**TA:** 54	**Page:** 19 of 19
DEPTH (ft bgs)	LITHOLOGY	LITHOLOGIC SYMBOL	NOTES
1020–1035	Volcaniclastic sediments—grayish orange pink (5YR 7/2), pebble gravels with fine to coarse sand, moderately to poorly sorted. Volcanic detritus composed predominantly of light gray Tschicoma-like dacite. 1020–1035 ft WR/+10F: 100% subrounded granules and pebbles (up to 16 mm) composed almost uniquely of biotite- and/or hb-phyric dacite; minor basalt +35F:grains of similar composition to above; trace detrital pumice.	Tpf	
1035–1045	Volcaniclastic sediments—light tan (5YR 7/2) to medium light gray (N6) silty fine to coarse sandstone with fine gravels. Detritus composed primarily of Tschicoma-like porphyritic dacite. 1035–1045 ft WR/+10F: 10–30% fragments of siltstone and very fine-grained sandstone 70–90% subangular to subrounded detrital granules and small pebbles (up to 10 mm) composed primarily of gray porphyritic dacite with minor basalt.	Tpf	
1045–1070	Volcaniclastic sediments—varicolored light tan (5YR 7/2) to medium light gray (N6) fine to medium gravels with fine to coarse sand, poorly sorted, weakly cemented. Detritus composed primarily of porphyritic dacite with lesser black porphyritic vitrophyre and locally abundant detrital pumices. 1045–1070 ft WR/+10F/35F: samples contain broken fragments and subrounded to subangular detritus composed of light gray porphyritic dacite, glassy porphyritic dacite, weathered to glassy pumices (locally present). Note: clasts commonly occur with rinds of adhered siltstone.	Tpf	
1070–1087	Volcaniclastic sediments with abundant detrital pumice—light pinkish tan (5YR 7/2) silty fine to coarse sandstone with very fine gravel, moderately sorted, weakly to moderately cemented. Detritus composed of dacite and abundant pumice. 1070–1080 ft WR/+10F: 50–60% rounded (milled) fragments of siltstone and silty very fine-grained volcanic sandstone; 30–40% detritus composed of light gray porphyritic dacite and black glassy porphyritic dacite; 10–20% , weathered detrital hb-phyric dacite pumices. 1080–1087 ft WR/+10F: 50–60% rounded (milled) siltstone fragments; 30–50% weathered hb-phyric pumices (note: pristine euhedral hornblende phenocrysts); 10–15% granules of detrital dacite.	Tpf	Bottom of borehole at 1087 ft 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

cp = clinopyroxene

ft = feet

GM = groundmass

hb = hornblende

ICV = intermediate-composition volcanic(s)

op = orthopyroxene

ol = olivine

Qal = alluvium

Qbo = Otowi Member of Bandelier Tuff

Qbog = Guaje Pumice Bed of the Otowi Member of the Bandelier Tuff

Qbt = Tshirege Member of the BandelierTuff

Qct = Cerro Toledo Interval

Tb 4 = Cerros del Rio Volcanic Series

Tpf = Puye Formation

+10F = plus No. 10 sieve sample fraction

+35F = plus No. 35 sieve sample fraction

WR = whole rock (unsieved sample)

1mm = 0.039 in.

1 in. = 25.4 mm

Appendix B

Groundwater Analytical Results

B-1.0 SAMPLING AND ANALYSIS OF GROUNDWATER AT R-56

Two borehole water samples were collected during drilling at well R-56 at depths of 955 and 1087 ft below ground surface (bgs) from the regional aquifer in the Puye Formation. These two samples were analyzed for anions, metals, low-level tritium (LH3), and volatile organic compounds (VOCs). The anion and metal analyses were conducted by Los Alamos National Laboratory's (LANL's or the Laboratory's) Earth and Environmental Sciences 14 (EES-14) Group, and the LH3 and VOC analyses were conducted by an off-site laboratory.

Additionally, 14 samples were collected during development and aquifer testing at well R-56 and analyzed only 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 detection limit.

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 analyses due to potential sample matrix interference from drilling foam.

The charge balance error for total cations and anions for the two borehole water samples were –10% and +4% collected during drilling of R-56. The negative cation–anion charge balance value indicates excess anions for the filtered sample.

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-56, are provided in Table B-1.2-1.

Upper Screen

During development of the upper screen, pH and temperature varied from 6.84 to 7.93 and from 24.04°C to 26.28°C, respectively. Concentrations of DO varied from 7.12 to 7.73 mg/L. Corrected oxidation reduction potential (Eh) values determined from field ORP measurements varied from 308.5 to 326.8 millivolts (mV) (Table B-1.2-1). The temperature-dependent correction factor used to calculate Eh values from field ORP measurements, based on an Ag/AgCl, KCl-saturated filling solution contained in the ORP electrode, was 198.5 mV at 25ºC. Corrected Eh values and DO concentrations are consistent with the known relatively oxidizing conditions of the regional aquifer beneath the Pajarito Plateau. Specific conductance decreased from 195 to 147 microsiemens per centimeter (μS/cm), and turbidity decreased from 11.5 to 0.9 nephelometric turbidity units (NTU) during development of the upper screen (Table B-1.2-1).

Lower Screen

During development of the lower screen, pH and temperature varied from 6.85 to 7.93 and from 21.33°C to 23.98°C, respectively. Concentrations of DO varied from 5.42 to 6.82 mg/L. Corrected Eh values determined from field ORP measurements decreased from 362.6 to 307.9 mV during development of the lower screen (Table B-1.2-1). The temperature-dependent correction factors used to calculate Eh values from field ORP measurements, based on an Ag/AgCl, KCl-saturated filling solution contained in the ORP electrode, were 203.9 and 198.5 mV at 20ºC and 25ºC, respectively. Specific conductance varied from 212 to 145 μS/cm, and turbidity values generally decreased from 3.9 to 0.1 NTU during development of the lower screen (Table B-1.2-1).

B-1.3 Analytical Results

Analytical results from LANL's EES-14 and external analytical laboratories are presented below. Where available, analytical results for well R-56 collected only during drilling are screened against background concentrations developed for the Laboratory as a whole (LANL 2007, 095817). It should be noted that, due to localized variations in geochemistry, background concentrations for the area upgradient of well R-56 may vary.

B-1.3.1 Offsite Laboratory Analytical Results for VOCs and LH3

Two borehole water samples, GW56-10-15470 and GW56-10-15471, were analyzed for VOCs and LH3 during drilling of R-56 (Table B-1.3-1). Two VOCs, 1-butanol and 2-butanone, were reported at estimated concentrations of 28.1 μg/L and 4.14 μg/L, respectively, in sample GW56-10-15470 collected at a depth of 955 ft. bgs. VOCs were not detected in sample GW56-10-15471 from 1087 ft bgs. Tritium was not detected in either sample.

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

Analytical results for the two borehole samples collected at well R-56 during drilling and 14 groundwater-screening samples collected during well development and aquifer testing are provided in Table B-1.3-2. The filtered-borehole samples (GW56-10-15470 and GW56-10-15471) consist of disaggregated colloidal aquifer material, drilling material, water used during drilling, and native groundwater.

Results for selected analytes are as follows.

- Dissolved concentrations of fluoride were 0.65 and 0.71 ppm in the two borehole water samples, slightly above the maximum dissolved fluoride concentration of 0.57 ppm for developed wells in the regional aquifer (LANL 2007, 095817).

- Dissolved concentrations of nitrate(N) were 0.04 and 0.50 ppm in the samples (Table B-1.3-2). Median background concentration for dissolved nitrate(N) in the regional aquifer is 0.31 ppm (LANL 2007, 095817).
- Dissolved sulfate was detected at concentrations of 6.54 and 2.71 ppm in the two borehole water samples (Table B-1.3-2). Median background concentration for dissolved sulfate in the regional aquifer is 2.83 ppm (LANL 2007, 095817).
- Perchlorate was not detected (<0.005 ppm) in the two borehole water samples.
- The total dissolved chromium concentrations were 0.004 and 0.002 ppm in the borehole water samples (Table B.1-3-2). Maximum background concentration of total dissolved chromium is 0.0072 ppm for the regional aquifer (LANL 2007, 095817).
- Analytical results for the borehole water samples show elevated concentrations of dissolved molybdenum (0.029 and 0.037 ppm), suggesting that the samples contain a component of drilling lubricant used during drilling.

B-1.3.3 Total Organic Carbon

TOC was measured at 0.3 mgC/L in each sample collected from the upper and lower screens during development (Table B.1-3-3). However, TOC was not detected in any of the six samples from each screened interval during aquifer testing.

B-1.4 Summary

In summary, two VOCs, 1-butanol and 2-butanone, were reported in the borehole water sample collected at 955 ft bgs, at concentrations of 28.1 μg/L and 4.14 μg/L, respectively. VOCs were not reported from the borehole sample from 1087 ft bgs. Tritium and perchlorate were not detected in either borehole water sample. TOC was not detected in the groundwater samples collected during aquifer testing.

Groundwater at well R-56 is relatively oxidizing, based on corrected positive Eh values and measurable concentrations of DO during well development and aquifer testing. Redox conditions, based on corrected field ORP measurements at well R-56, are similar to other previously drilled wells in the Pajarito watershed, including R-21 and R-23.

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 New Mexico Environment Department 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-56

Date	pH	Temp (°C)	DO (mg/L)	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								
07/27/10	n/r[b]; Swabbing and bailing						390	390
Well Development Upper Screen								
07/29/10	n/r, Pumping while swabbing screen						4453	4843
08/03/10	6.84	26.28	7.73	120.8, 319.3	195	11.5	126	4969
	7.77	24.04	7.48	128.3, 326.8	147	3.0	132	5101
	7.91	25.37	7.17	110.0, 308.5	147	2.1	84	5185
	7.94	25.30	7.12	115.6, 314.1	147	1.9	70	5255
	7.93	24.21	7.50	122.6, 321.1	147	0.9	70	5325
Well Development Lower Screen								
07/30/10	n/r, Pumping while swabbing screen						3165	8490
08/02/10	6.85	21.33	5.42	158.7, 362.6	212	3.9	292	8782
	7.75	23.13	6.37	129.8, 328.3	153	2.0	292	9074
	7.88	23.59	6.69	121.3, 319.8	145	2.0	292	9366
	7.92	23.78	6.75	120.3, 318.8	146	0.1	291	9657
	7.93	23.98	6.82	109.4, 307.9	146	1.0	294	9951
Aquifer Pumping Test Lower Screen								
08/10/10	n/r, Pumping, mini-test preparation						454	10,405
08/11/10	n/r, Pumping, mini-test preparation						1783	12,188
08/12/10 to 08/13/10	6.20	22.56	6.49	175.0, 373.5	243	18.0	449	12,637
	7.34	22.64	6.19	129.1, 327.6	147	1.8	901	13,538
	7.75	23.59	6.05	111.9, 310.4	146	1.2	903	14,441
	7.79	23.98	6.11	107.3, 305.8	146	1.3	901	15,342
	7.71	23.25	6.70	129.6, 328.1	145	1.2	6308	21,650
	7.72	22.39	6.50	136.6, 340.5	145	0.0	901	22,551
	6.20	22.56	6.49	175.0, 373.5	243	18.0	449	12,637
	7.72	22.40	6.55	136.9, 340.8	145	0.0	901	23,452
	7.83	21.55	6.59	151.7, 355.6	142	0.0	908	24,360
	7.82	21.40	6.85	156.2, 360.1	142	0.0	904	25,264
	7.82	21.68	6.95	163.1, 367.0	142	0.0	905	26,169
	7.83	21.65	6.87	164.2, 368.1	142	0.0	914	27,083
	7.83	21.71	6.86	163.9, 367.8	142	0.0	901	27,984
	7.81	21.45	6.82	167.2, 371.1	142	0.0	903	28,887
	7.83	21.64	6.95	166.8, 370.7	142	0.0	904	29,791
	7.83	21.73	7.02	167.7, 371.6	142	0.0	901	30,692
	7.82	21.21	7.00	170.5, 374.4	140	0.0	903	31,595
	7.83	21.56	6.76	170.5, 374.4	142	0.0	904	32,499

Table B-1.2-1 (continued)

Date	pH	Temp (°C)	DO (mg/L)	ORP, Eh[a] (mV)	Specific Conductivity (µS/cm)	Turbidity (NTU)	Purge Volume between Samples (gal.)	Cumulative Purge Volume (gal.)
Aquifer Pumping Test Upper Screen								
08/17/10	n/r, Pumping, mini-test						584	33,083
08/18/10 to 08/19/10	7.39	20.69	6.20	48.2, 252.1	157	0.0	168	33,251
	7.82	22.66	6.82	43.9, 242.4	146	6.6	335	33,586
	7.87	23.12	6.49	28.8, 227.3	147	0.0	335	33,921
	7.85	23.11	6.97	138.1, 336.6	147	0.0	334	34,255
	7.86	23.07	7.20	178.0, 376.5	147	0.0	2344	36,599
	7.88	22.81	7.23	178.1, 376.6	144	0.0	336	36,935
	7.90	22.34	7.07	185.1, 389.0	137	0.0	335	37,270
	7.89	22.36	6.95	188.9, 392.8	142	0.0	335	37,605
	7.89	22.32	7.13	192.0, 395.9	142	0.0	335	37,940
	7.89	22.20	7.25	194.0,397.9	140	0.0	335	38,275
	7.89	22.11	7.31	195.3, 399.2	138	0.0	338	38,613
	7.92	21.92	7.09	197.2, 401.1	146	0.0	337	38,950
	7.93	21.91	7.28	196.4, 400.0	146	0.0	337	39,287
	7.94	21.80	7.47	192.1, 396.0	144	0.0	339	39,626
	7.95	21.75	7.22	189.3, 393.2	145	0.0	338	39,964
	7.93	21.87	8.04	202.0, 405.9	143	0.0	338	40,302
	7.93	22.01	8.02	204.1, 408.0	134	0.0	846	41,148

[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 Laboratory Analytical Results

Lab Request Number	Sample Name	Analytical Suite Code	Analyte Description	Lab Result	Unit	Qualifier Code
10-3431	GW56-10-15470	LH3	Low-level tritium	0.61	TU[a]	U[b]
10-3379	GW56-10-15470	VOC	Acetone	10	µg/L	U
10-3379	GW56-10-15470	VOC	Acetonitrile	25	µg/L	U
10-3379	GW56-10-15470	VOC	Acrolein	5	µg/L	U
10-3379	GW56-10-15470	VOC	Acrylonitrile	5	µg/L	U
10-3379	GW56-10-15470	VOC	Benzene	1	µg/L	U
10-3379	GW56-10-15470	VOC	Bromobenzene	1	µg/L	U
10-3379	GW56-10-15470	VOC	Bromochloromethane	1	µg/L	U
10-3379	GW56-10-15470	VOC	Bromodichloromethane	1	µg/L	U
10-3379	GW56-10-15470	VOC	Bromoform	1	µg/L	U
10-3379	GW56-10-15470	VOC	Bromomethane	1	µg/L	U
10-3379	GW56-10-15470	VOC	Butanol[1-]	28.1	µg/L	J[c]
10-3379	GW56-10-15470	VOC	Butanone[2-]	4.14	µg/L	J
10-3379	GW56-10-15470	VOC	Butylbenzene[n-]	1	µg/L	U
10-3379	GW56-10-15470	VOC	Butylbenzene[sec-]	1	µg/L	U
10-3379	GW56-10-15470	VOC	Butylbenzene[tert-]	1	µg/L	U
10-3379	GW56-10-15470	VOC	Carbon disulfide	5	µg/L	U
10-3379	GW56-10-15470	VOC	Carbon tetrachloride	1	µg/L	U
10-3379	GW56-10-15470	VOC	Chloro-1,3-butadiene[2-]	1	µg/L	UJ[d]
10-3379	GW56-10-15470	VOC	Chloro-1-propene[3-]	5	µg/L	U
10-3379	GW56-10-15470	VOC	Chlorobenzene	1	µg/L	U
10-3379	GW56-10-15470	VOC	Chlorodibromomethane	1	µg/L	U
10-3379	GW56-10-15470	VOC	Chloroethane	1	µg/L	U
10-3379	GW56-10-15470	VOC	Chloroform	1	µg/L	U
10-3379	GW56-10-15470	VOC	Chloromethane	1	µg/L	U
10-3379	GW56-10-15470	VOC	Chlorotoluene[2-]	1	µg/L	U
10-3379	GW56-10-15470	VOC	Chlorotoluene[4-]	1	µg/L	U
10-3379	GW56-10-15470	VOC	Dibromo-3-chloropropane[1,2-]	1	µg/L	U
10-3379	GW56-10-15470	VOC	Dibromoethane[1,2-]	1	µg/L	U
10-3379	GW56-10-15470	VOC	Dibromomethane	1	µg/L	U
10-3379	GW56-10-15470	VOC	Dichlorobenzene[1,2-]	1	µg/L	U
10-3379	GW56-10-15470	VOC	Dichlorobenzene[1,3-]	1	µg/L	U
10-3379	GW56-10-15470	VOC	Dichlorobenzene[1,4-]	1	µg/L	U
10-3379	GW56-10-15470	VOC	Dichlorodifluoromethane	1	µg/L	UJ
10-3379	GW56-10-15470	VOC	Dichloroethane[1,1-]	1	µg/L	U
10-3379	GW56-10-15470	VOC	Dichloroethane[1,2-]	1	µg/L	U
10-3379	GW56-10-15470	VOC	Dichloroethene[1,1-]	1	µg/L	U
10-3379	GW56-10-15470	VOC	Dichloroethene[cis-1,2-]	1	µg/L	U

Table B-1.3-1 (continued)

Lab Request Number	Sample Name	Analytical Suite Code	Analyte Description	Lab Result	Unit	Qualifier Code
10-3379	GW56-10-15470	VOC	Dichloroethene[trans-1,2-]	1	µg/L	U
10-3379	GW56-10-15470	VOC	Dichloropropane[1,2-]	1	µg/L	U
10-3379	GW56-10-15470	VOC	Dichloropropane[1,3-]	1	µg/L	U
10-3379	GW56-10-15470	VOC	Dichloropropane[2,2-]	1	µg/L	U
10-3379	GW56-10-15470	VOC	Dichloropropene[1,1-]	1	µg/L	U
10-3379	GW56-10-15470	VOC	Dichloropropene[cis-1,3-]	1	µg/L	U
10-3379	GW56-10-15470	VOC	Dichloropropene[trans-1,3-]	1	µg/L	U
10-3379	GW56-10-15470	VOC	Diethyl ether	1	µg/L	U
10-3379	GW56-10-15470	VOC	Ethyl methacrylate	5	µg/L	UJ
10-3379	GW56-10-15470	VOC	Ethylbenzene	1	µg/L	U
10-3379	GW56-10-15470	VOC	Hexachlorobutadiene	1	µg/L	U
10-3379	GW56-10-15470	VOC	Hexanone[2-]	5	µg/L	U
10-3379	GW56-10-15470	VOC	Iodomethane	5	µg/L	U
10-3379	GW56-10-15470	VOC	Isobutyl alcohol	50	µg/L	R[e]
10-3379	GW56-10-15470	VOC	Isopropylbenzene	1	µg/L	U
10-3379	GW56-10-15470	VOC	Isopropyltoluene[4-]	1	µg/L	U
10-3379	GW56-10-15470	VOC	Methacrylonitrile	5	µg/L	U
10-3379	GW56-10-15470	VOC	Methyl Methacrylate	5	µg/L	UJ
10-3379	GW56-10-15470	VOC	Methyl tert-butyl ether	1	µg/L	U
10-3379	GW56-10-15470	VOC	Methyl-2-pentanone[4-]	5	µg/L	U
10-3379	GW56-10-15470	VOC	Methylene chloride	10	µg/L	U
10-3379	GW56-10-15470	VOC	Naphthalene	1	µg/L	U
10-3379	GW56-10-15470	VOC	Propionitrile	5	µg/L	U
10-3379	GW56-10-15470	VOC	Propylbenzene[1-]	1	µg/L	U
10-3379	GW56-10-15470	VOC	Styrene	1	µg/L	U
10-3379	GW56-10-15470	VOC	Tetrachloroethane[1,1,1,2-]	1	µg/L	U
10-3379	GW56-10-15470	VOC	Tetrachloroethane[1,1,2,2-]	1	µg/L	U
10-3379	GW56-10-15470	VOC	Tetrachloroethene	1	µg/L	U
10-3379	GW56-10-15470	VOC	Toluene	1	µg/L	U
10-3379	GW56-10-15470	VOC	Trichloro-1,2,2-trifluoroethane[1,1,2-]	5	µg/L	U
10-3379	GW56-10-15470	VOC	Trichlorobenzene[1,2,3-]	1	µg/L	U
10-3379	GW56-10-15470	VOC	Trichlorobenzene[1,2,4-]	1	µg/L	U
10-3379	GW56-10-15470	VOC	Trichloroethane[1,1,1-]	1	µg/L	U
10-3379	GW56-10-15470	VOC	Trichloroethane[1,1,2-]	1	µg/L	U
10-3379	GW56-10-15470	VOC	Trichloroethene	1	µg/L	U
10-3379	GW56-10-15470	VOC	Trichlorofluoromethane	1	µg/L	U
10-3379	GW56-10-15470	VOC	Trichloropropane[1,2,3-]	1	µg/L	U

Table B-1.3-1 (continued)

Lab Request Number	Sample Name	Analytical Suite Code	Analyte Description	Lab Result	Unit	Qualifier Code
10-3379	GW56-10-15470	VOC	Trimethylbenzene[1,2,4-]	1	µg/L	U
10-3379	GW56-10-15470	VOC	Trimethylbenzene[1,3,5-]	1	µg/L	U
10-3379	GW56-10-15470	VOC	Vinyl acetate	5	µg/L	U
10-3379	GW56-10-15470	VOC	Vinyl chloride	1	µg/L	U
10-3379	GW56-10-15470	VOC	Xylene[1,2-]	1	µg/L	U
10-3379	GW56-10-15470	VOC	Xylene[1,3-]+xylene[1,4-]	2	µg/L	U
10-3431	GW56-10-15471	LH3	Low-level tritium	0.71	TU	U
10-3388	GW56-10-15471	VOC	Acetone	10	µg/L	U
10-3388	GW56-10-15471	VOC	Acetonitrile	25	µg/L	R
10-3388	GW56-10-15471	VOC	Acrolein	5	µg/L	U
10-3388	GW56-10-15471	VOC	Acrylonitrile	5	µg/L	U
10-3388	GW56-10-15471	VOC	Benzene	1	µg/L	U
10-3388	GW56-10-15471	VOC	Bromobenzene	1	µg/L	U
10-3388	GW56-10-15471	VOC	Bromochloromethane	1	µg/L	U
10-3388	GW56-10-15471	VOC	Bromodichloromethane	1	µg/L	U
10-3388	GW56-10-15471	VOC	Bromoform	1	µg/L	U
10-3388	GW56-10-15471	VOC	Bromomethane	1	µg/L	U
10-3388	GW56-10-15471	VOC	Butanol[1-]	50	µg/L	R
10-3388	GW56-10-15471	VOC	Butanone[2-]	5	µg/L	U
10-3388	GW56-10-15471	VOC	Butylbenzene[n-]	1	µg/L	U
10-3388	GW56-10-15471	VOC	Butylbenzene[sec-]	1	µg/L	U
10-3388	GW56-10-15471	VOC	Butylbenzene[tert-]	1	µg/L	U
10-3388	GW56-10-15471	VOC	Carbon disulfide	5	µg/L	U
10-3388	GW56-10-15471	VOC	Carbon tetrachloride	1	µg/L	U
10-3388	GW56-10-15471	VOC	Chloro-1,3-butadiene[2-]	1	µg/L	U
10-3388	GW56-10-15471	VOC	Chloro-1-propene[3-]	5	µg/L	U
10-3388	GW56-10-15471	VOC	Chlorobenzene	1	µg/L	U
10-3388	GW56-10-15471	VOC	Chlorodibromomethane	1	µg/L	U
10-3388	GW56-10-15471	VOC	Chloroethane	1	µg/L	U
10-3388	GW56-10-15471	VOC	Chloroform	1	µg/L	U
10-3388	GW56-10-15471	VOC	Chloromethane	1	µg/L	U
10-3388	GW56-10-15471	VOC	Chlorotoluene[2-]	1	µg/L	U
10-3388	GW56-10-15471	VOC	Chlorotoluene[4-]	1	µg/L	U
10-3388	GW56-10-15471	VOC	Dibromo-3-chloropropane[1,2-]	1	µg/L	U
10-3388	GW56-10-15471	VOC	Dibromoethane[1,2-]	1	µg/L	U
10-3388	GW56-10-15471	VOC	Dibromomethane	1	µg/L	U
10-3388	GW56-10-15471	VOC	Dichlorobenzene[1,2-]	1	µg/L	U
10-3388	GW56-10-15471	VOC	Dichlorobenzene[1,3-]	1	µg/L	U

Table B-1.3-1 (continued)

Lab Request Number	Sample Name	Analytical Suite Code	Analyte Description	Lab Result	Unit	Qualifier Code
10-3388	GW56-10-15471	VOC	Dichlorobenzene[1,4-]	1	µg/L	U
10-3388	GW56-10-15471	VOC	Dichlorodifluoromethane	1	µg/L	U
10-3388	GW56-10-15471	VOC	Dichloroethane[1,1-]	1	µg/L	U
10-3388	GW56-10-15471	VOC	Dichloroethane[1,2-]	1	µg/L	U
10-3388	GW56-10-15471	VOC	Dichloroethene[1,1-]	1	µg/L	U
10-3388	GW56-10-15471	VOC	Dichloroethene[cis-1,2-]	1	µg/L	U
10-3388	GW56-10-15471	VOC	Dichloroethene[trans-1,2-]	1	µg/L	U
10-3388	GW56-10-15471	VOC	Dichloropropane[1,2-]	1	µg/L	U
10-3388	GW56-10-15471	VOC	Dichloropropane[1,3-]	1	µg/L	U
10-3388	GW56-10-15471	VOC	Dichloropropane[2,2-]	1	µg/L	U
10-3388	GW56-10-15471	VOC	Dichloropropene[1,1-]	1	µg/L	U
10-3388	GW56-10-15471	VOC	Dichloropropene[cis-1,3-]	1	µg/L	U
10-3388	GW56-10-15471	VOC	Dichloropropene[trans-1,3-]	1	µg/L	U
10-3388	GW56-10-15471	VOC	Diethyl ether	1	µg/L	U
10-3388	GW56-10-15471	VOC	Ethyl methacrylate	5	µg/L	U
10-3388	GW56-10-15471	VOC	Ethylbenzene	1	µg/L	U
10-3388	GW56-10-15471	VOC	Hexachlorobutadiene	1	µg/L	U
10-3388	GW56-10-15471	VOC	Hexanone[2-]	5	µg/L	UJ
10-3388	GW56-10-15471	VOC	Iodomethane	5	µg/L	U
10-3388	GW56-10-15471	VOC	Isobutyl alcohol	50	µg/L	R
10-3388	GW56-10-15471	VOC	Isopropylbenzene	1	µg/L	U
10-3388	GW56-10-15471	VOC	Isopropyltoluene[4-]	1	µg/L	U
10-3388	GW56-10-15471	VOC	Methacrylonitrile	5	µg/L	U
10-3388	GW56-10-15471	VOC	Methyl methacrylate	5	µg/L	U
10-3388	GW56-10-15471	VOC	Methyl tert-butyl ether	1	µg/L	U
10-3388	GW56-10-15471	VOC	Methyl-2-pentanone[4-]	5	µg/L	U
10-3388	GW56-10-15471	VOC	Methylene chloride	10	µg/L	U
10-3388	GW56-10-15471	VOC	Naphthalene	1	µg/L	U
10-3388	GW56-10-15471	VOC	Propionitrile	5	µg/L	U
10-3388	GW56-10-15471	VOC	Propylbenzene[1-]	1	µg/L	U
10-3388	GW56-10-15471	VOC	Styrene	1	µg/L	U
10-3388	GW56-10-15471	VOC	Tetrachloroethane[1,1,1,2-]	1	µg/L	U
10-3388	GW56-10-15471	VOC	Tetrachloroethane[1,1,2,2-]	1	µg/L	U
10-3388	GW56-10-15471	VOC	Tetrachloroethene	1	µg/L	U
10-3388	GW56-10-15471	VOC	Toluene	1	µg/L	U
10-3388	GW56-10-15471	VOC	Trichloro-1,2,2-trifluoroethane[1,1,2-]	5	µg/L	U
10-3388	GW56-10-15471	VOC	Trichlorobenzene[1,2,3-]	1	µg/L	U
10-3388	GW56-10-15471	VOC	Trichlorobenzene[1,2,4-]	1	µg/L	U

Table B-1.3-1 (continued)

Lab Request Number	Sample Name	Analytical Suite Code	Analyte Description	Lab Result	Unit	Qualifier Code
10-3388	GW56-10-15471	VOC	Trichloroethane[1,1,1-]	1	µg/L	U
10-3388	GW56-10-15471	VOC	Trichloroethane[1,1,2-]	1	µg/L	U
10-3388	GW56-10-15471	VOC	Trichloroethene	1	µg/L	U
10-3388	GW56-10-15471	VOC	Trichlorofluoromethane	1	µg/L	U
10-3388	GW56-10-15471	VOC	Trichloropropane[1,2,3-]	1	µg/L	U
10-3388	GW56-10-15471	VOC	Trimethylbenzene[1,2,4-]	1	µg/L	U
10-3388	GW56-10-15471	VOC	Trimethylbenzene[1,3,5-]	1	µg/L	U
10-3388	GW56-10-15471	VOC	Vinyl acetate	5	µg/L	U
10-3388	GW56-10-15471	VOC	Vinyl chloride	1	µg/L	U
10-3388	GW56-10-15471	VOC	Xylene[1,2-]	1	µg/L	U
10-3388	GW56-10-15471	VOC	Xylene[1,3-]+Xylene[1,4-]	2	µg/L	U

[a] TU = Tritium unit.

[b] U = Analyte was undetected.

[c] J = Estimated concentration.

[d] UJ = Analyte was undetected; reported value is the estimated detection limit.

[e] R = Rejected value.

Table B-1.3-2
EES-14 Analytical Results

Sample ID	Sample Type	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)
GW56-10-15470	Borehole	955	0.001	U	0.164	0.001	0.0002	0.0000	0.181	0.000	1.700	0.019	0.001	U	0.05	15.90	0.08	0.001	U	10.38	0.005, U	0.001	U	0.8	U
GW56-10-15471	Borehole	1087	0.001	U	0.240	0.001	0.0008	0.0000	0.066	0.001	0.805	0.005	0.001	U	0.04	12.85	0.02	0.001	U	4.92	0.005, U	0.001	U	0.8	U

Sample ID	Sample Type	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)
GW56-10-15470	Borehole	0.004	0.000	0.001	U	0.003	0.000	0.65	0.04	0.00	102	0.00008	0.00001	2.30	0.01	0.027	0.000	4.43	0.01	0.073	0.001	0.029	0.000	25.27	0.09
GW56-10-15471	Borehole	0.002	0.000	0.001	U	0.001	U	0.71	0.35	0.00	111	0.00049	0.00002	3.06	0.01	0.027	0.001	4.15	0.03	0.045	0.000	0.037	0.001	15.08	0.07

Sample ID	Sample Type	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)	SO4(-2) Rslt (ppm)
GW56-10-15470	Borehole	0.003	0.000	0.01	0.003, U	0.18	0.04	0.37	0.0002	U	7.50	0.01	0.001	U	0.001	U	0.001	U	11.70	0.03	25.03	0.07	0.001	U	6.54
GW56-10-15471	Borehole	0.002	0.000	0.01	0.003, U	2.22	0.50	0.03	0.0008	0.0000	7.32	0.04	0.002	0.000	0.001	U	0.001	U	24.31	0.04	52.03	0.08	0.001	U	2.71

Sample ID	Sample Type	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**
GW56-10-15470	Borehole	0.060	0.000	0.001	U	0.003	0.000	0.001	U	0.0002	U	0.002	0.000	0.025	0.000	196	2.35	2.17	0.04
GW56-10-15471	Borehole	0.057	0.001	0.001	U	0.033	0.000	0.001	U	0.0012	0.0000	0.003	0.000	0.031	0.002	211	1.74	2.12	-0.10

Table B-1.3-3
TOC Results

Sample ID	Sample Type	Depth (ft bgs)	TOC (ppm)	Qualifier
GW56-10-15490	Well development	1046.6-1067.1	0.3	NQ[a]
GW56-10-15491	Well development	945.0-965.6	0.3	NQ
GW56-10-15492	Aquifer testing	1046.6-1067.1	0.2	U[b]
GW56-10-15493	Aquifer testing	1046.6-1067.1	0.2	U
GW56-10-15494	Aquifer testing	1046.6-1067.1	0.2	U
GW56-10-15495	Aquifer testing	1046.6-1067.1	0.2	U
GW56-10-15496	Aquifer testing	1046.6-1067.1	0.2	U
GW56-10-15497	Aquifer testing	1046.6-1067.1	0.2	U
GW56-10-15498	Aquifer testing	945.0-965.6	0.2	U
GW56-10-15499	Aquifer testing	945.0-965.6	0.2	U
GW56-10-15500	Aquifer testing	945.0-965.6	0.2	U
GW56-10-15501	Aquifer testing	945.0-965.6	0.2	U
GW56-10-15502	Aquifer testing	945.0-965.6	0.2	U
GW56-10-15503	Aquifer testing	945.0-965.6	0.2	U

[a] NQ = Not qualified; data are valid.
[b] U = Analyte was undetected.

Appendix C

Aquifer Testing Report

C-1.0 INTRODUCTION

This appendix describes the hydraulic analysis of pumping tests conducted during August 2010 at well R-56, a dual-screen regional aquifer well located on Mesita del Buey just east of Material Disposal Area L (MDA-L). The tests on R-56 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 among neighboring wells.

Tests planned for each screened 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-56 to both hydraulically isolate the screen zones and to try to eliminate casing storage effects on the test data. The implementation of the inflatable packer system was successful in eliminating storage effects.

Conceptual Hydrogeology

Both screens in R-56 are within the sands and gravels of the Puye Formation. Screen 1 is 20.6-ft long, extending from 945.0 ft below ground surface (bgs) to 965.6 ft bgs. Screen 2 is 20.5-ft-long and is positioned approximately 81 ft beneath screen 1, extending from 1046.4 ft bgs to 1067.1 ft bgs.

The composite static water level, measured on August 10, 2010, prior to testing was 924.04 ft bgs. The brass cap elevation at the well is 6780.88 ft above mean sea level (amsl), making the composite water-level elevation 5856.84 ft amsl.

When the screen zones were isolated using an inflatable packer, the water level in screen 1 rose 2.19 ft, to a depth of 921.85 ft bgs and an elevation of 5859.03 ft amsl. At the same time, the water level in screen 2 declined 1.81 ft to 925.85 ft bgs at an elevation of 5855.03 ft amsl. Thus, the water levels showed a large head difference of 4.0 ft and a strong downward hydraulic gradient, implying highly resistive sediments separating the two screen zones.

At R-56, the Puye Formation is overlain by lava flows of the Cerros del Rio basalt at a depth of 945 ft—the location of the top of screen 1. It was suspected that this unit might act as an aquitard, confining the screen 1 aquifer zone.

R-56 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 August 17 to 20, 2010. Testing began with brief trial pumping on August 17, followed by a 24-h constant-rate pumping test that was started on August 18. Following shutdown of the 24-h test on August 19, recovery/background data were recorded for 24 h until August 20.

Trial testing of screen 1 began at 12:30 p.m. on August 17 at a discharge rate of 5.5 gpm and continued for 30 min until 1:00 p.m. Recovery data were recorded for 60 min until 2:00 p.m. when trial 2 pumping began at a discharge rate of 5.5 gallons per minute (gpm). Following shutdown at 3:00 p.m. trial 2 recovery data were collected for 1020 min until 8:00 a.m. on August 18.

At 8:00 a.m. on August 18, the 24-h pumping test was initiated at a discharge rate of 5.6 gpm. Pumping continued for 1440 min until 8:00 a.m. on August 19. Following shutdown, recovery/background data were recorded for 1440 min until 8:00 a.m. on August 20 when the pump was pulled from the well.

R-56 Screen 2 Testing

Well R-56 screen 2 was tested from August 11 to 16, 2010. Testing began with brief trial pumping on August 11. A 24-h constant-rate pumping test began August 12, and recovery/background data were collected until August 16.

Two trial tests were conducted on August 11. Trial 1 was conducted at a discharge rate of 14.8 gpm for 60 min, from 8:00 to 9:00 a.m., and was followed by 60 min of recovery until 10:00 a.m. Trial 2 was conducted for 60 min, from 10:00 to 11:00 a.m., at a rate of 14.9 gpm. Following shutdown, recovery/background data were recorded for 1260 min until 8:00 a.m. on August 12.

At 8:00 a.m. on August 12, the 24-h pumping test began at a rate of 15.0 gpm. Pumping continued for 1440 min until 8:00 a.m. on August 13. Following shutdown, recovery/background measurements were recorded for 4265 min, until 7:05 a.m. on August 16 when the pump was tripped out of 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 to barometric pressure data from the area to determine if a correlation existed.

Previous pumping tests on the plateau have demonstrated a barometric efficiency for most wells of between 90% and 100%. Barometric efficiency is defined as the ratio of water-level change divided by barometric pressure change, expressed as a percentage. In the initial pumping tests conducted on the early R-wells, downhole pressure was monitored using a vented pressure transducer. This equipment measures the difference between the total pressure applied to the transducer and the barometric pressure; this difference is the true height of water above the transducer.

Subsequent pumping tests, including R-56, 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. For example, when a 90% barometrically efficient well is monitored using a vented transducer, an increase in barometric pressure of 1 unit causes a decrease in recorded downhole pressure of 0.9 unit because the water level is forced downward 0.9 unit by the barometric pressure change. However, using a nonvented transducer, the total measured pressure increases by 0.1 unit (the combination of the barometric pressure increase and the water-level decrease). Thus, the resulting apparent hydrograph changes by a factor of 100 minus the barometric efficiency and in the same direction as the barometric pressure change rather than in the opposite direction.

Barometric pressure data were obtained from 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 estimated at 6782 ft amsl. The static water level in R-56 was 924.04 ft below land surface, making the water-table elevation 5856.84 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-56.

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

$$P_{WT} = P_{TA54} \exp\left[-\frac{g}{3.281R}\left(\frac{E_{R-56} - E_{TA54}}{T_{TA54}} + \frac{E_{WT} - E_{R-56}}{T_{WELL}}\right)\right]$$

Equation C-1

Where, P_{WT} = barometric pressure at the water table inside R-56

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

g = acceleration of gravity, in m/s^2 (9.80665 m/s^2)

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

E_{R-56} = land surface elevation at R-56 site in feet (estimated at 6782 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-56 in feet (5856.84 ft)

T_{TA54} = air temperature near TA-54 in degrees Kelvin (assigned a value of 69.8 degrees Fahrenheit, or 294.2 degrees Kelvin)

T_{WELL} = air temperature inside R-56 in degrees Kelvin (assigned a value of 66.2 degrees Fahrenheit, or 292.2 degrees Kelvin)

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

The corrected barometric pressure data reflecting pressure conditions at the water table were compared to 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 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 length of the well screen.

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 approximately 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. To prove this, note that the leftmost term within the brackets is directly proportional to the annular area (and volume) between the casing and drop pipe while the right-most 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 appropriately accounts for all of the volume (casing water and drained filter pack water).

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-56 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, thereby 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 approximately 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:

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

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 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:

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

Equation C-12

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

C-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-13

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. 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 Rothschild (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-14

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-15

The Brons and Marting procedure (1961, 098235) 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 (Driscoll 1986, 104226). The pumping test data and geologic log suggested that both screen 1 and 2 zones were confined. An arbitrary storage coefficient value of 5×10^{-4} was used for the calculations for both screen 1 and screen 2. 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. For screen 1, the aquifer was considered to extend from the overlying lava at 945 ft to the midpoint between the screen zones at approximately 1004 ft—a distance of roughly 59 ft. 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. For screen 2, an arbitrary thickness of 100 ft was assigned.

C-7.0 BACKGROUND DATA ANALYSIS

To determine the barometric effect on water levels, background aquifer pressure data collected during the R-56 tests were plotted along with barometric pressure.

Figure C-7.0-1 shows aquifer pressure data from R-56 screen 1 during the test period 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-56 data are referred to in the figure as the “apparent hydrograph” because the measurements reflect the sum of water pressure and barometric pressure that were recorded with a non-vented pressure transducer. The times of the pumping periods for the R-56 pumping tests are included on the figure for reference.

R-56 screen 1 showed no significant pressure change in response to barometric pressure fluctuations, suggesting a high barometric efficiency. The data did show a slight diurnal perturbation of a few hundredths of a foot that likely resulted from Earth-tide effects.

The data on Figure C-7.0-1 showed no drawdown response in screen 1 to pumping screen 2. This was consistent with the substantial observed head difference between screens 1 and 2, confirming the belief that tight sediments separate the two screen zones. The apparent hydrograph signal did become noisier, however, when screen 2 was pumped, possibly because of electrical interference from the pump cable or vibrations from operating the pump affecting the screen 1 transducer. Despite the noise in the signal, it appeared that screen 1 water levels actually rose slightly during the screen 2 testing. 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, or possibly a small leak in a drop pipe joint during pumping screen 2.

Figure C-7.0-2 shows aquifer pressure data collected from R-56 screen 2 during the pumping test effort. As with screen 1, screen 2 aquifer pressure did not show a distinct correlation with barometric pressure changes, suggesting a high barometric efficiency. The data did show a sinusoidal diurnal effect with a magnitude of several hundredths of a foot, possibly an Earth-tide effect.

The data did not show a response in screen 2 to pumping screen 1.

Hydrograph data from additional nearby R-wells were downloaded to check for a possible pumping response to the R-56 tests. Screen zones examined included R-21 (783 ft away), R-32 screen 1 (1341 ft), R-38 (1275 ft), R-53 screens 1 and 2 (906 ft), and R-54 screens 1 and 2 (1793 ft). Figures C-7.0-3 through C-7.0-9 show data retrieved from R-21, R-32 screen 1, R-38, R-53 screens 1 and 2, and R-54 screens 1 and 2, respectively.

Because the barometric pressure fluctuations in the hydrographs were large, it was necessary to correct the water-level data by removing the barometric effect. This was done using BETCO (barometric and earth tide correction) software—a mathematically complex correction algorithm that uses regression deconvolution (Toll and Rasmussen 2007, 104799) to modify the data. The BETCO correction not only removes barometric pressure effects, but can remove Earth-tide effects as well. The BETCO barometric corrected data for each of the nearby monitoring wells are included in the data plots on Figures C-7.0-3 through C-7.0-9.

Figure C-7.0-3 shows the hydrograph data obtained from R-21 located 783 ft from R-56. Pumping R-56 screen 1 had no effect on R-21 water levels, but pumping screen 2 had a clear effect during both the trial tests and the 24-h test. After 24 h of pumping screen 2 at 15.0 gpm, the drawdown in R-21 was approximately 1.1 ft. The R-21 hydrograph also showed episodes of water-level rise corresponding to the times when the packer separating the two screens in R-56 was deflated– on August 10 when the temporary packer installed in R-56 was removed and the test pumping system was installed and again on August 16 and 17 when the test pump and packers were removed following the screen 2 test and reconfigured for testing screen 1. Whenever the packer separating screens 1 and 2 was deflated, water from screen 1 flowed downward into screen 2, raising the head at R-21 approximately 0.1 ft. The times when the packer separating the screens was deflated are depicted on the graph for reference.

Figure C-7.0-4 shows the hydrograph data obtained from R-32 screen 1 located 1341 ft from R-56. There did not appear to be any response in R-32 to pumping either screen 1 or screen 2 in R-56.

Figure C-7.0-5 shows the hydrograph data obtained from R-38 located 1275 ft from R-56. There did not appear to be any response in R-38 to pumping either screen 1 or screen 2 in R-56.

Figure C-7.0-6 shows the hydrograph data obtained from R-53 screen 1 located 906 ft from R-56. While there did not appear to be a response to pumping R-56 screen 2, pumping screen 1 at 5.6 gpm for 24 h caused nearly 0.1 ft of drawdown in R-53 screen 1. There also was a water level decline of a few hundredths of a foot on August 10 and again on August 16 and 17 when the packer separating the screens in R-56 was deflated. When this occurred, water from screen 1 flowed downward to screen 2, essentially mimicking pumping of R-56 screen 1. The fairly quick response to pumping 906 ft away (rapid expansion of the cone of depression) helped confirm the idea of confined conditions for R-56 screen 1 and, potentially, for R-53 screen 1.

Figure C-7.0-7 shows the hydrograph data obtained from R-53 screen 2. Pumping R-56 screen 2 caused significant drawdown effects in R-53 screen 2 during both the trial tests and the 24-h test, reaching a maximum of approximately 0.5 ft after pumping 15.0 gpm for 24 h. Pumping R-56 screen 1, on the other hand, may have had little or no effect on R-53 screen 1, although any possible effect may have been masked by the residual noise in the corrected hydrograph. Note that R-53 is located at a similar distance from the pumped well as R-21 (906 ft versus 783 ft), yet the observed drawdown was less than half that observed in R-21. This suggests that R-53 screen 2 is more hydraulically separated from R-56 screen 2 than is R-21, perhaps displaced vertically across stratigraphic layers. It also could be an artifact of lateral inhomogeneity in the aquifer system.

Figure C-7.0-8 shows the hydrograph data obtained from R-54 screen 1 located 1793 ft from R-56. There did not appear to be any response in R-54 screen 1 to pumping either screen 1 or screen 2 in R-56.

Figure C-7.0-9 shows the hydrograph data obtained from R-54 screen 2. Pumping R-56 screen 1 had no effect on R-54 screen 2 water levels, but pumping screen 2 had a clear effect during both the trial tests and the 24-h test. The maximum drawdown observed in R-54 screen 2 after pumping R-56 screen 2 at 15.0 gpm for 24 h was approximately 0.08 ft.

C-8.0 WELL R-56 SCREEN 1 DATA ANALYSIS

This section presents the data obtained from the R-56 screen 1 pumping tests and the results of the analytical interpretations. Data are presented for drawdown and recovery from trial 1, trial 2, and the 24-h constant-rate test.

C-8.1 Well R-56 Screen 1 Trial Test

Figure C-8.1-1 shows a semilog plot of the drawdown data collected from the 30-min trial 1 test on screen 1 at a discharge rate of 5.5 gpm. The transmissivity estimated from the first few minutes of data was 1030 gpd/ft. Based on the screen length of 20.6 ft, the computed hydraulic conductivity was 50 gpd/ft^2 or 6.7 ft/day.

The first several seconds of drawdown data showed a flatter slope than the subsequent few minutes. Subsequent testing showed a similar flat, early slope but of shorter duration (approximately 1 second). It was possible that minor antecedent drainage of a small portion of the pump drop pipe contributed somewhat to the longer-duration early slope during trial 1.

After a few minutes of pumping, the slope of the drawdown curve flattened steadily. This "recharge" effect likely corresponded to gradual vertical growth of the cone of depression (partial penetration effects) or leakage from above or below the screened interval.

Figure C-8.1-2 shows the recovery data collected following shutdown of the trial 1 pumping test. The bulk of the data suggested a transmissivity of 980 gpd/ft and a hydraulic conductivity of 48 gpd/ft^2 or 6.4 ft/d. The early data showed a slightly flatter slope, likely indicating that the sediments in the immediate vicinity of the wellbore were somewhat more permeable than the aquifer average. However, because the data density collection scheme was not as great as subsequent tests, the plot did not reveal an even flatter slope occurring at earlier time that was detected in later tests described below.

The late recovery data showed the same flattening effect seen in the drawdown data, consistent with leakage or general vertical growth of the cone of depression.

C-8.2 Well R-56 Screen 1 Trial 2 Test

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 5.5 gpm. The transmissivity estimated from the data plot was 1000 gpd/ft, making the computed hydraulic conductivity 49 gpd/ft^2 or 6.5 ft/day.

The early data showed exaggerated drawdown for several seconds. This was an indication that a minor amount of water had drained from the drop pipe between tests, allowing the pump to operate at a greater rate (against reduced head) momentarily on startup.

The late data showed the gradual flattening observed previously.

Figure C-8.2-2 shows the recovery data collected following shutdown of the trial 2 pumping test. The very early data suggested a transmissivity of 2020 gpd/ft, roughly double that observed subsequently. This brief hydraulic response suggested that the sediments near the wellbore were approximately twice as permeable as the aquifer average. The bulk of the data suggested an average transmissivity of 1020 gpd/ft and a hydraulic conductivity of 50 gpd/ft^2 or 6.6 ft/d.

The late data showed the same progressive flattening, indicating vertical growth of the cone of depression or leakage from above or below the screened interval.

C-8.3 Well R-56 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 5.6 gpm. Again, slight drainage of a tiny portion of the drop pipe resulted in exaggerated drawdown briefly on startup. The analysis shown on the graph suggested a screen interval transmissivity of 1020 gpd/ft and a hydraulic conductivity of 50 gpd/ft^2 or 6.6 ft/d.

The late drawdown data showed steady flattening over time with a very flat slope after a couple of hours of pumping. This could indicate a large transmissivity for the sediments penetrated by the cone of depression at that time, or may have resulted from leakage from above along with slow drainage of an unconfined zone in the Cerros del Rio basalt.

Figure C-8.3-2 shows the recovery data collected following shutdown of the 24-h constant-rate pumping test. As indicated on the plot, the first second or so of recovery suggested a greater permeability immediately adjacent to the wellbore. The bulk transmissivity computed from the subsequent data was 1040 gpd/ft, making the hydraulic conductivity of 51 gpd/ft^2 or 6.7 ft/d.

The late recovery data showed the same flattening observed in the other tests.

C-8.4 Well R-56 Screen 1 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-56 screen 1. This was done to provide a frame of reference for evaluating the foregoing analyses.

At the end of the 24-h pumping test, the discharge rate was 5.6 gpm with a resulting drawdown of 5.71 ft for a specific capacity of 0.98 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 0.63 ft (inferred from the volume of filter pack required to backfill the screen zone), a screen length of 20.6 ft, a pumping time of 1440 min, and a saturated thickness of 59 ft (from the static water level to the midpoint between screens 1 and 2).

Applying the Brons and Marting method (1961, 098235) to these inputs yielded a lower-bound hydraulic conductivity value of 50 gpd/ft^2 or 6.7 ft/d. The average hydraulic conductivity value from the foregoing pumping test analyses was 49 gpd/ft^2 or 6.6 ft/d, essentially a match to the lower-bound value. Thus, the lower-bound value was consistent with the pumping test results and suggested a high well efficiency. It should be kept in mind that the elevated hydraulic conductivity near the wellbore would have helped increase the specific capacity above what would have been achieved under homogeneous aquifer conditions. This may help explain why the lower-bound hydraulic conductivity was very slightly greater than that obtained from the pumping test analysis rather than nominally lower.

C-9.0 WELL R-56 SCREEN 2 DATA ANALYSIS

This section presents the data obtained from the R-56 screen 2 pumping tests and the results of the analytical interpretations. Data are presented for drawdown and recovery from trial 1, trial 2, and the 24-h constant-rate test.

C-9.1 Well R-56 Screen 2 Trial 1

Figure C-9.1-1 shows a semilog plot of the screen 2 drawdown data collected from trial 1 at a discharge rate of 14.8 gpm. The early drawdown data suggested a transmissivity of 2130 gpd/ft for the 20.5-ft-long screened interval, making the estimated average hydraulic conductivity of the sediments near the borehole 103 gpd/ft^2 or 13.8 ft/day. Within 30 s of pumping, the drawdown curve steepened, reflecting a calculated transmissivity of 1130 gpd/ft and hydraulic conductivity of 55 gpd/ft^2 or 7.3 ft/day.

The steeper slope could have been caused by a lateral reduction in hydraulic conductivity and transmissivity, or might have been an indication of a lateral boundary. The two computed transmissivity values were in a ratio of close to 2:1, characteristic of the expected response near a linear boundary such as a fault or aquifer pinch out. Of note is that the Cerros del Rio basalt extends beneath the regional water table in this area and, thus, the submerged portion of the nearby basalt could act as a local boundary as well.

The two possible scenarios—reduced hydraulic conductivity and transmissivity away from the well versus an aquifer boundary such as a fault—are indistinguishable and either is supported by the test data. However, the 2:1 transmissivity ratio suggests the possibility of a boundary.

The late data showed continued flattening of the drawdown curve, reflective of either vertical growth of the cone of depression or leakage effects.

Figure C-9.1-2 shows the recovery data collected following shutdown of the trial 1 pumping test. The transmissivity estimated from the early data was 2030 gpd/ft, making the computed hydraulic conductivity 99 gpd/ft^2 or 13.2 ft/day. The subsequent data showed a slope increase, as observed in the drawdown data set, with a calculated transmissivity of 1050 gpd/ft and hydraulic conductivity of 51 gpd/ft^2 or 6.8 ft/day, approximately half the early-time values.

The late recovery data showed the same flattening observed in the drawdown data set.

C-9.2 Well R-56 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 14.9 gpm. The transmissivity value computed from the early data was 2060 gpd/ft, making the average hydraulic conductivity of the screened interval 100 gpd/ft^2 or 13.4 ft/day. The subsequent data showed a slope increase, as observed in the trial 1 data set, with a calculated transmissivity of 1080 gpd/ft and hydraulic conductivity of 52 gpd/ft^2 or 7.0 ft/day, again approximately half the early-time values.

The late drawdown data showed steady flattening, consistent with leakage or partial penetration effects (vertical growth of the cone of depression).

Figure C-9.2-2 shows the recovery data collected following shutdown of the trial 2 pumping test. The transmissivity estimated from the early data was 2010 gpd/ft, making the computed hydraulic conductivity 98 gpd/ft^2 or 13.0 ft/day. The subsequent data showed a slope increase, as observed in the drawdown data set, with a calculated transmissivity of 1050 gpd/ft and hydraulic conductivity of 51 gpd/ft^2 or 6.8 ft/day, approximately half the early-time values.

The late recovery data showed steady flattening, consistent with leakage or partial penetration effects.

C-9.3 Well R-56 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 15.0 gpm. The transmissivity value computed from the early data was 2030 gpd/ft, making the average hydraulic conductivity of the screened interval 99 gpd/ft^2 or 13.2 ft/day. The subsequent data showed a slope increase, as observed in the previous tests, with a calculated transmissivity of 1150 gpd/ft and hydraulic conductivity of 56 gpd/ft^2 or 7.5 ft/day, again approximately half the early-time values. The late drawdown data showed steady flattening, consistent with leakage or partial penetration effects, essentially reaching steady state.

Figure C-9.3-2 shows the recovery data collected following shutdown of the 24-h pumping test. The transmissivity estimated from the early data was 2010 gpd/ft, making the computed hydraulic conductivity 98 gpd/ft^2 or 13.0 ft/day. The subsequent data showed a slope increase, as observed in the drawdown data set, with a calculated transmissivity of 1070 gpd/ft and hydraulic conductivity of 52 gpd/ft^2 or 6.9 ft/day, approximately half the early-time values.

The late recovery data mirrored the drawdown data with the curve becoming essentially flat at late time.

The distance-drawdown response to pumping R-56 screen 2 observed in nearby wells R-21, R-53 screen 2, and R-54 screen 2 was analyzed by Theis curve matching as shown on Figure C-9.3-3. The data suggest a contiguous aquifer transmissivity of approximately 1300 gpd/ft and a storage coefficient of 4.2×10^{-4}. The storage coefficient likely includes leakage effects from strata above and/or below the immediate contiguous aquifer zone.

C-9.4 Well R-56 Screen 2 Specific Capacity Data

Specific capacity data and well geometry were used to estimate a lower-bound hydraulic conductivity value for the permeable zone penetrated by R-56 screen 2. This was done to provide a frame of reference for evaluating the foregoing analyses.

At the end of the 24-h pumping test, the discharge rate was 15.0 gpm with a resulting drawdown of 13.2 ft for a specific capacity of 1.14 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 0.61 ft (inferred from the volume of filter pack required to backfill the screen zone), a screen length of 20.5 ft, a pumping time of 1440 min, and a saturated thickness of 100 ft.

Applying the Brons and Marting method (1961, 098235) to these inputs yielded a lower-bound hydraulic conductivity value for the sediments around the well of 53 gpd/ft^2 or 7.1 ft/d. Note that the presence of the boundary effect (either a nearby linear boundary or a lateral reduction in hydraulic conductivity and transmissivity away from the well) reduced the specific capacity of the well somewhat compared to what would have been achieved under homogeneous conditions. Thus, one could argue that the actual lower-bound hydraulic conductivity value is greater than the computed result.

The average hydraulic conductivity determined from the pumping test analyses was 99 gpd/ft^2 or 13.3 ft/d. The lower-bound value of 53 gpd/ft^2 (or higher) was consistent with this result and suggested a well efficiency of better than 50%.

C-10.0 SUMMARY

Constant-rate pumping tests were conducted on R-56 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 for the tests as summarized below.

The static water level observed in screen 1 was substantially higher (4.0 ft) than that in screen 2, showing a strong downward hydraulic gradient, highly resistive sediments separating the screen zones, and little hydraulic connection between the screens. Testing confirmed this, showing no drawdown in either zone due to pumping the other.

A comparison of barometric pressure and R-56 water-level data showed a high barometric efficiency for both zones. Both zones showed a small diurnal effect, however, probably a result of Earth tides.

Pumping screen 1 at 5.6 gpm for 1440 min had no discernable effect on water levels in screen 2. Among the nearby wells, only R-53 screen 1 (906 ft away) showed any response (0.1 ft). No discernable response was observed in any of the other monitored locations.

Analysis of the screen 1 pumping tests showed an average hydraulic conductivity value of 49 gpd/ft^2 or 6.6 ft/d based on the assumption that the early response reflected a sediment thickness equal to the length of screen 1. It is possible that the thickness of the effective contiguous aquifer showing early response may have nominally exceeded the screen length. If so, the actual average hydraulic conductivity value would be somewhat less.

Screen 1 produced 5.6 gpm for 1440 min with 5.71 ft of drawdown for a specific capacity of 0.98 gpm/ft. The lower-bound hydraulic conductivity computed from this information was 50 gpd/ft^2 or 6.7 ft/d, consistent with the pumping tests values. Higher permeability sediments in a limited area around the wellbore likely elevated the specific capacity compared to what would have been achieved for homogeneous conditions and resulted in an overestimate of the lower-bound limit.

Pumping screen 2 at 15.0 gpm for 1440 min had no discernable effect on water levels in screen 1. Among the nearby wells, pumping screen 2 caused a drawdown of 1.1 ft in R-21 (783 ft away), 0.5 ft in R-53 screen 2 (906 ft), and 0.08 ft in R-54 screen 2 (1793 ft). There was no discernable drawdown effect at any of the other monitored locations.

Analysis of the screen 2 pumping tests suggested a near-well hydraulic conductivity of 99 gpd/ft^2 or 13.3 ft/d. Away from the well, the data showed a boundary effect with a corresponding hydraulic conductivity of 53 gpd/ft^2 or 7.1 ft/d, approximately half the early-time value. This may have been an indication of an actual lateral reduction in conductivity of that amount, or may have signaled the presence of an aquifer boundary such as a fault or pinch out, or, as discussed previously, possibly a submerged expanse of tight basalt near the screen zone. The computed 2:1 ratio in conductivity is symptomatic of a linear boundary (truncation of the aquifer).

Screen 2 produced 15.0 gpm for 1440 min with 13.2 ft of drawdown for a specific capacity of 1.14 gpm/ft. The lower-bound hydraulic conductivity computed from this information was 53 gpd/ft^2 or 7.1 ft/d, not inconsistent with the pumping tests values. The presence of the negative boundary reduced the specific capacity from what would have been achieved under homogeneous conditions, correspondingly and artificially reducing the computed lower-bound hydraulic conductivity)

Drawdown and recovery data from all tests from both screen zones showed steady flattening over time, consistent with partial penetration effects and/or leakage.

C-11.0 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.

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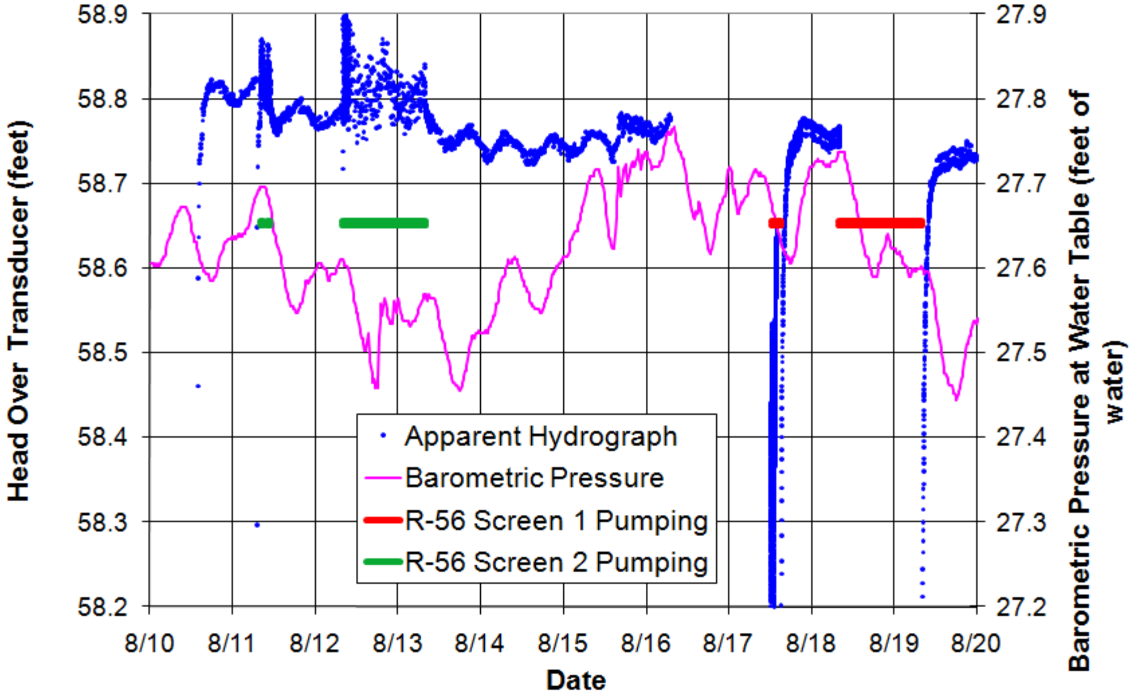


Figure C-7.0-1 Well R-56 screen 1 apparent hydrograph

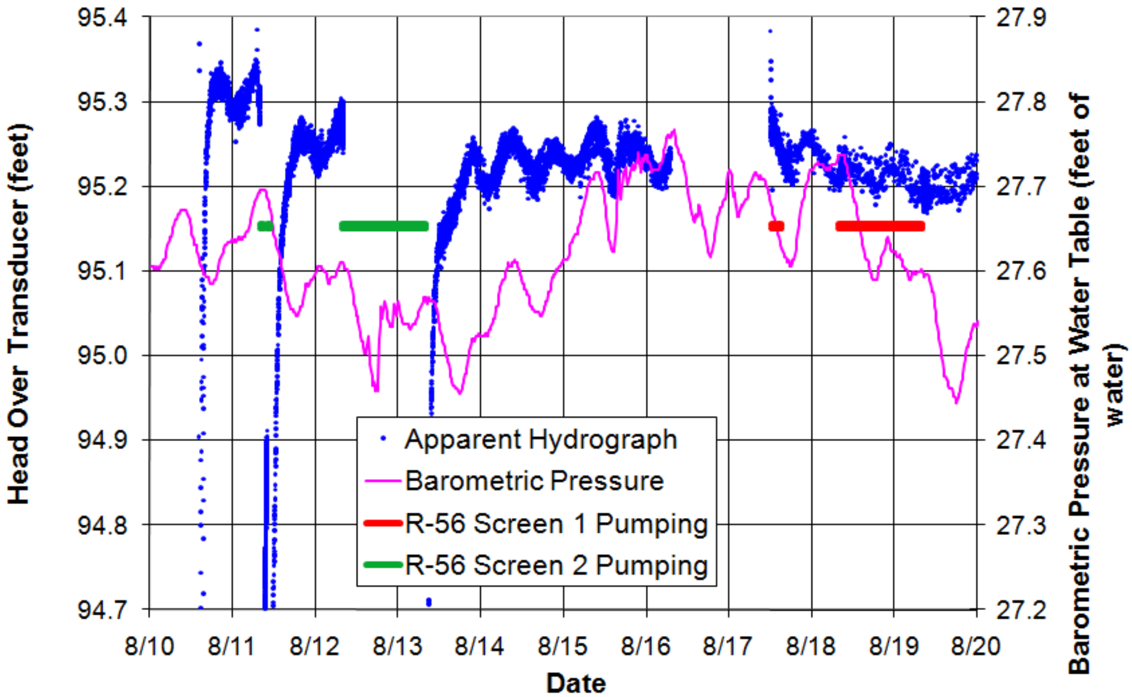


Figure C-7.0-2 Well R-56 screen 2 apparent hydrograph

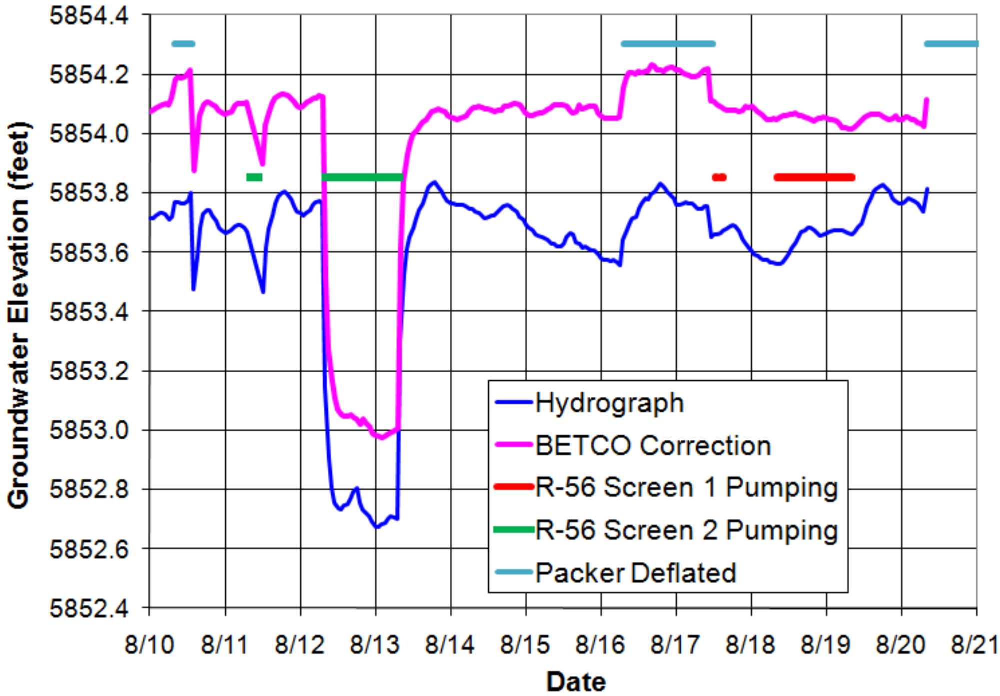


Figure C-7.0-3 Well R-21 hydrograph

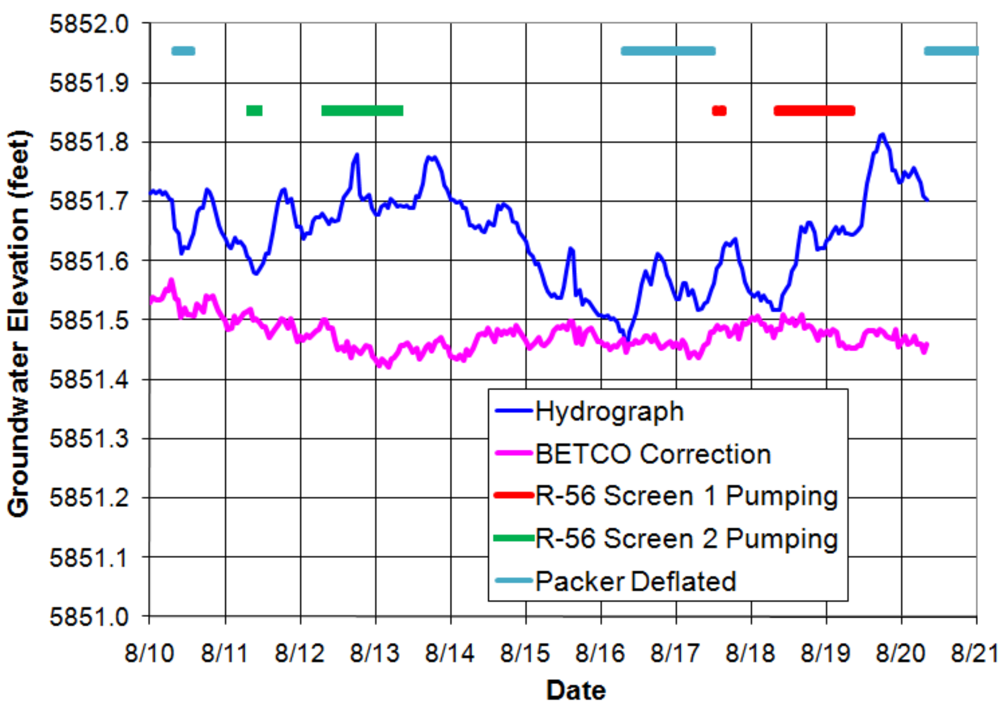


Figure C-7.0-4 Well R-32 screen 1 hydrograph

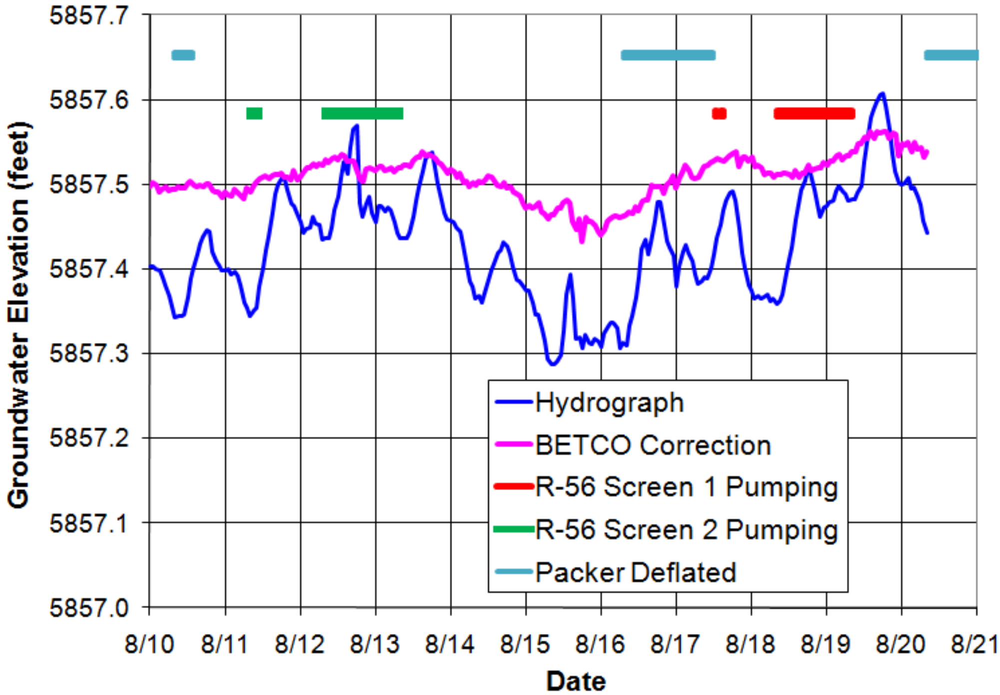


Figure C-7.0-5 Well R-38 hydrograph

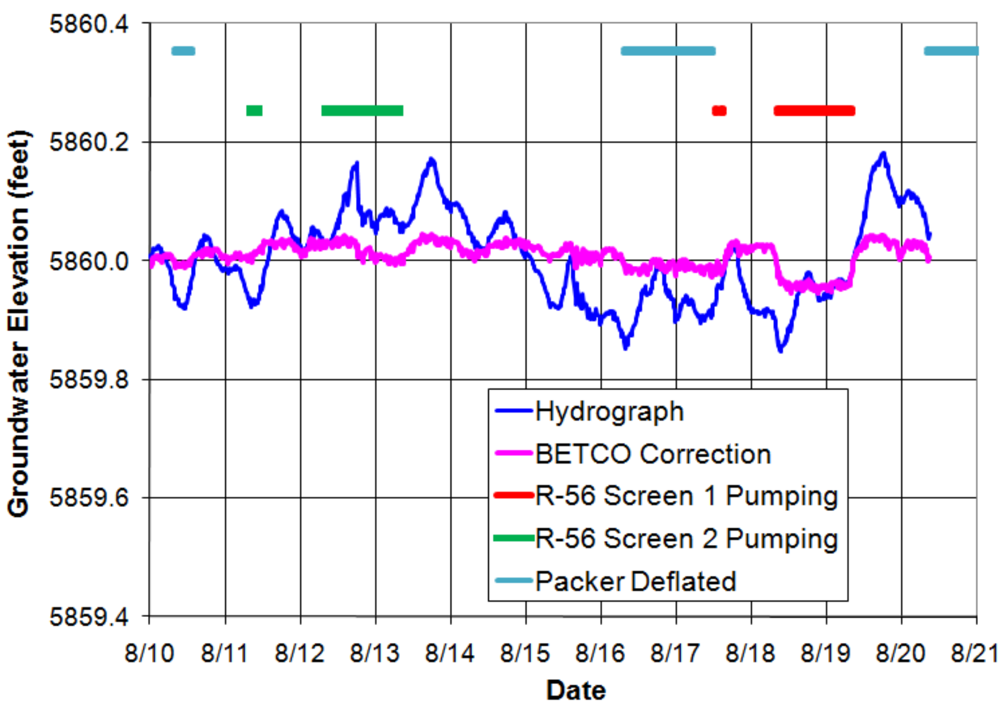


Figure C-7.0-6 Well R-53 screen 1 hydrograph

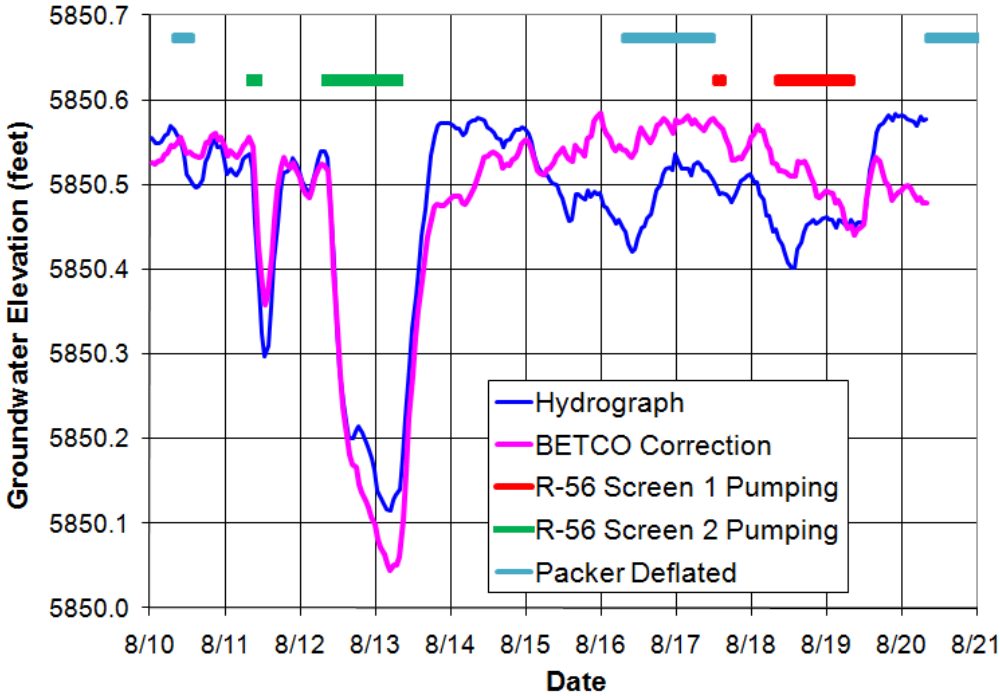


Figure C-7.0-7 Well R-53 screen 2 hydrograph

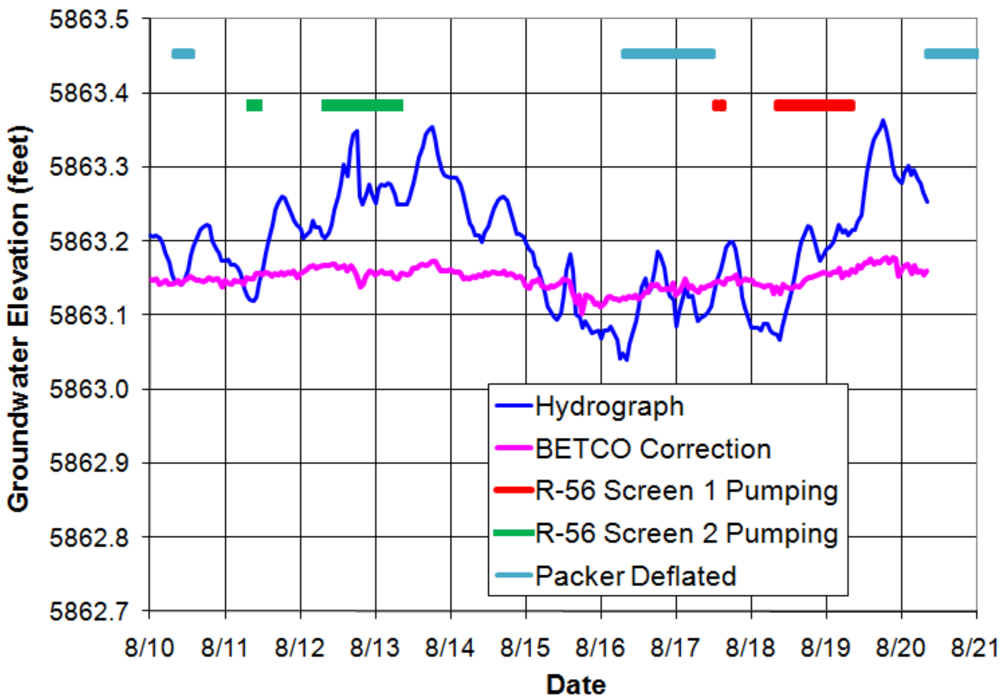


Figure C-7.0-8 Well R-54 screen 1 hydrograph

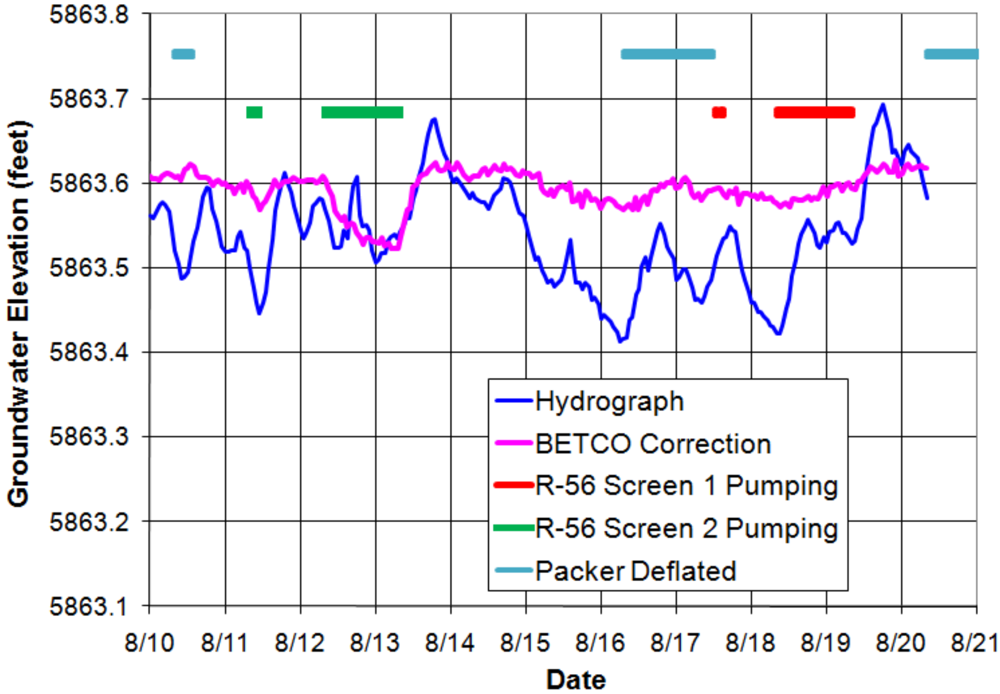


Figure C-7.0-9 Well R-54 screen 2 hydrograph

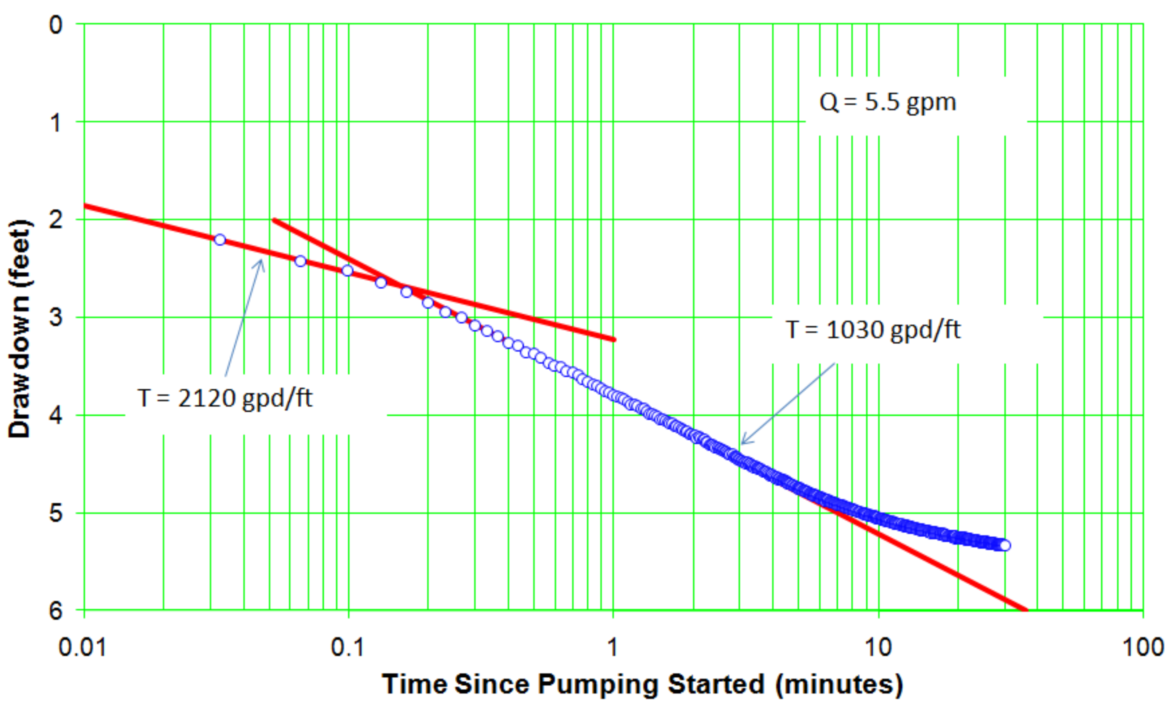


Figure C-8.1-1 Well R-56 screen 1 trial 1 drawdown

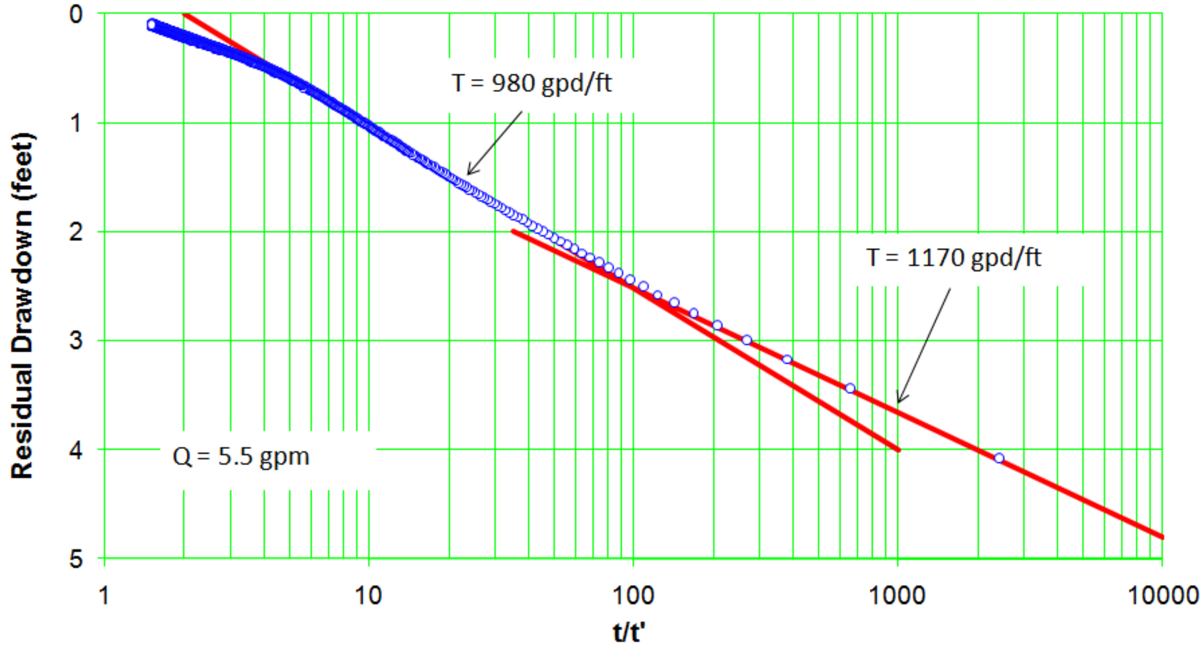


Figure C-8.1-2 Well R-56 screen 1 trial 1 recovery

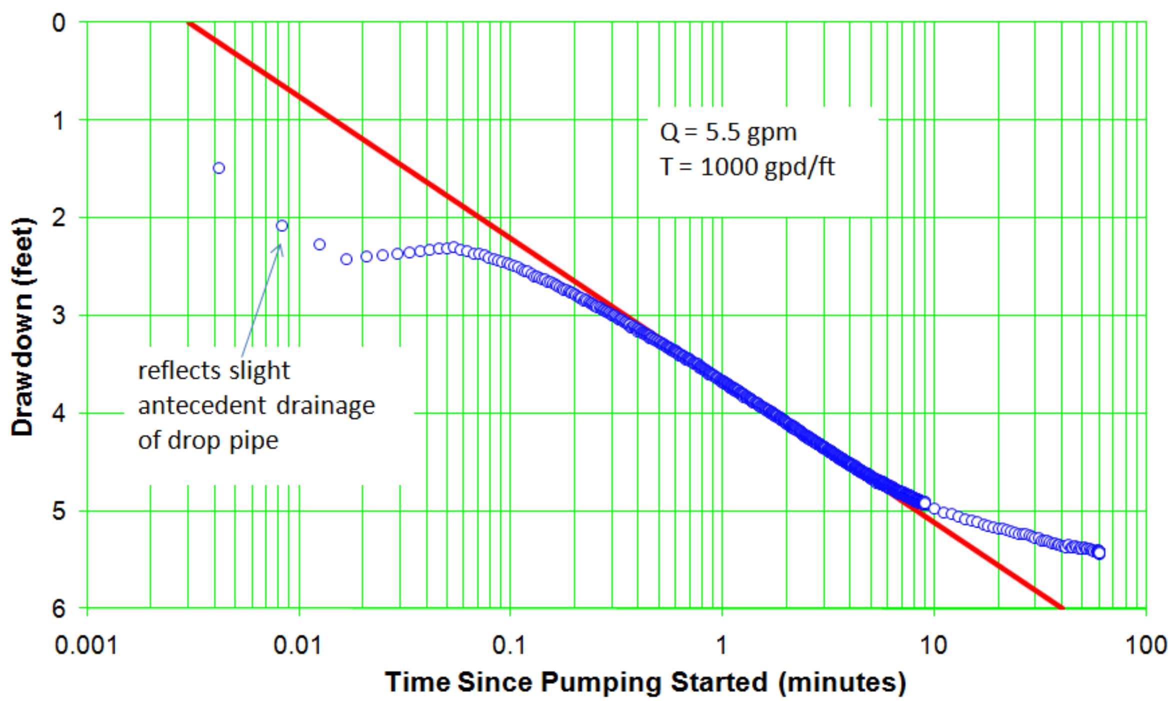


Figure C-8.2-1 Well R-56 screen 1 trial 2 drawdown

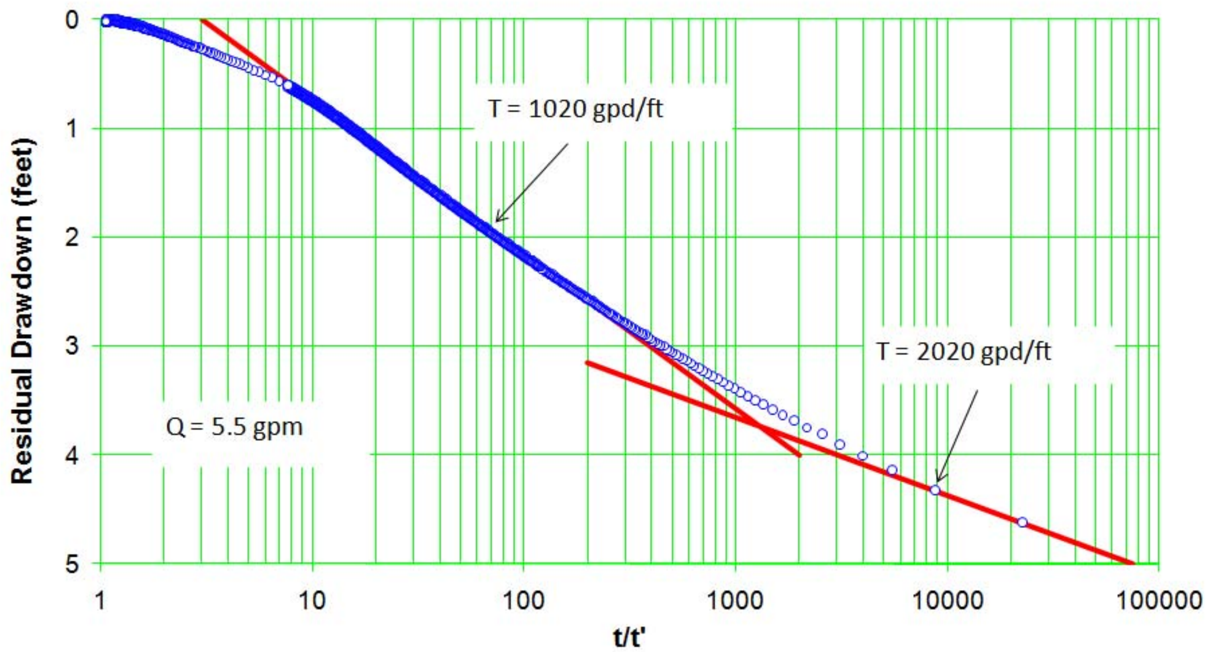


Figure C-8.2-2 Well R-56 screen 1 trial 2 recovery

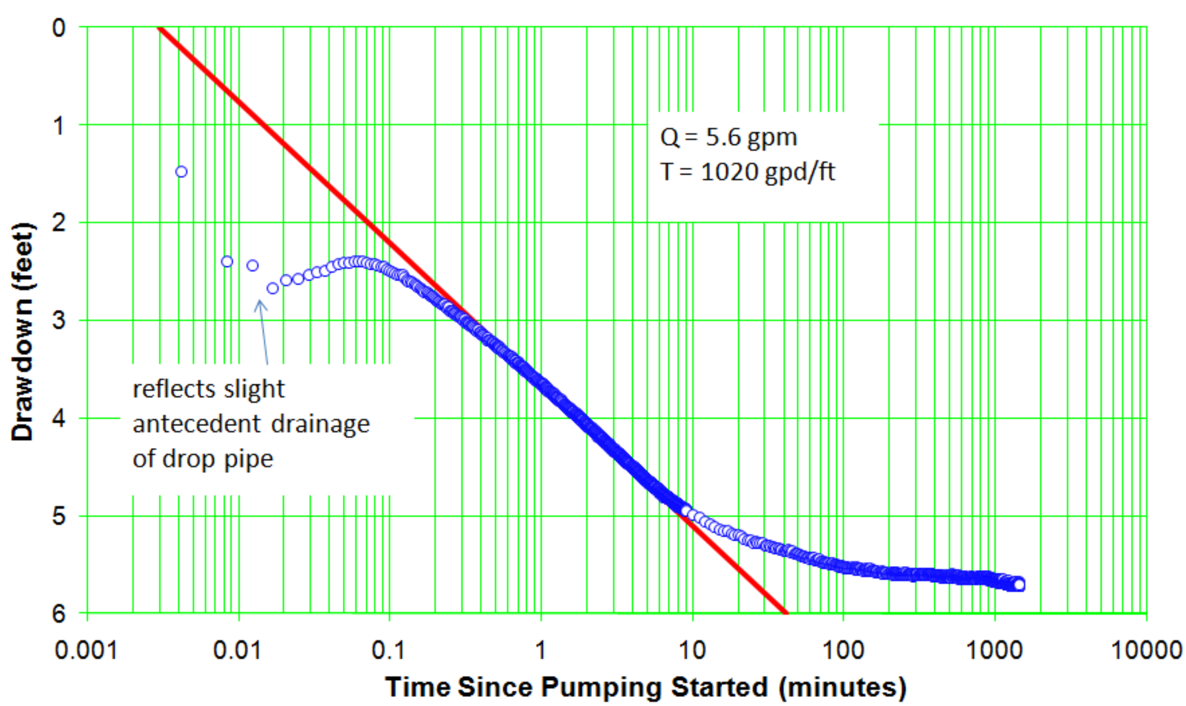


Figure C-8.3-1 Well R-56 screen 1 drawdown

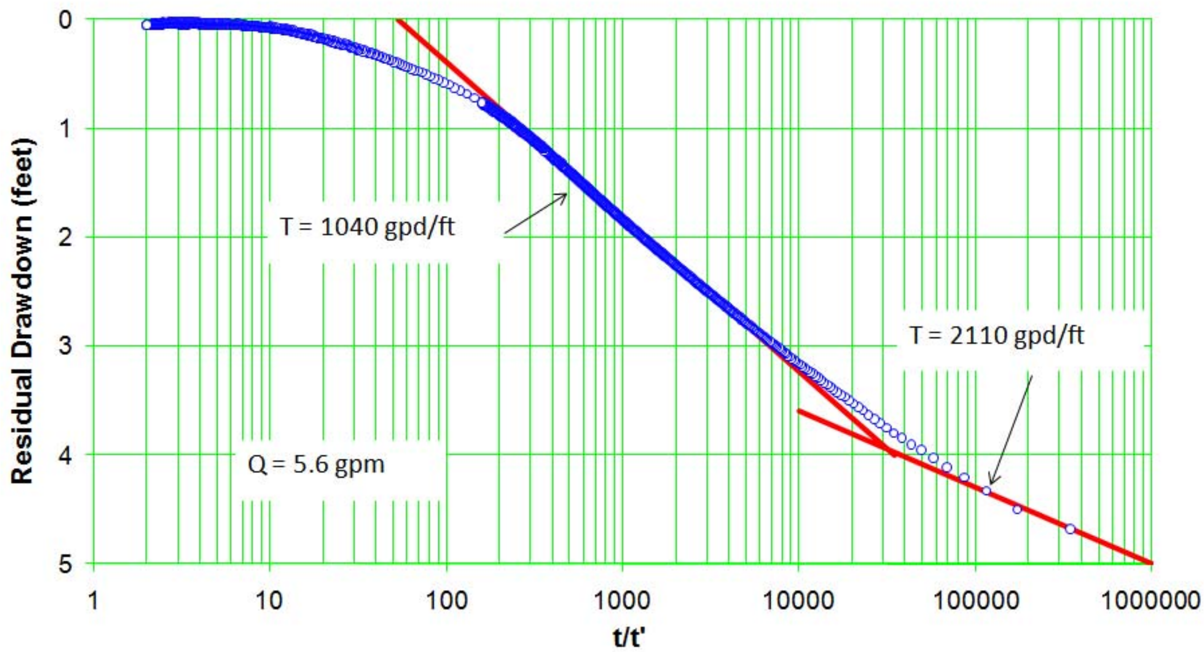


Figure C-8.3-2 Well R-56 screen 1 recovery

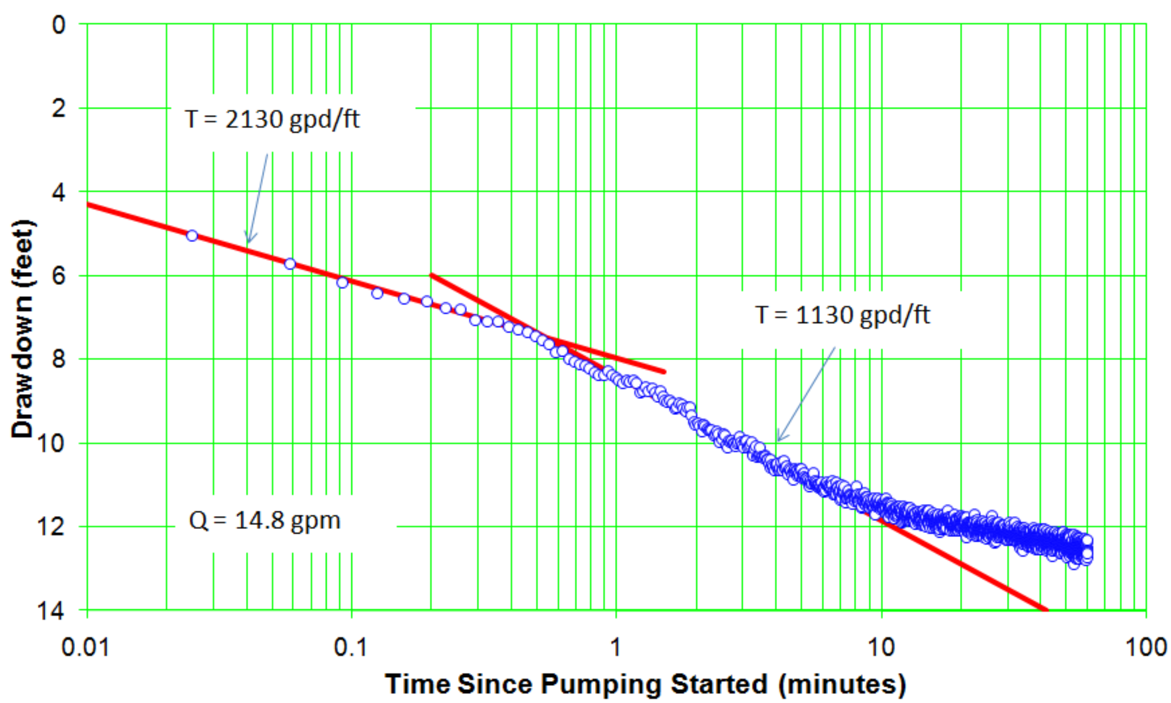


Figure C-9.1-1 Well R-56 screen 2 trial 1 drawdown

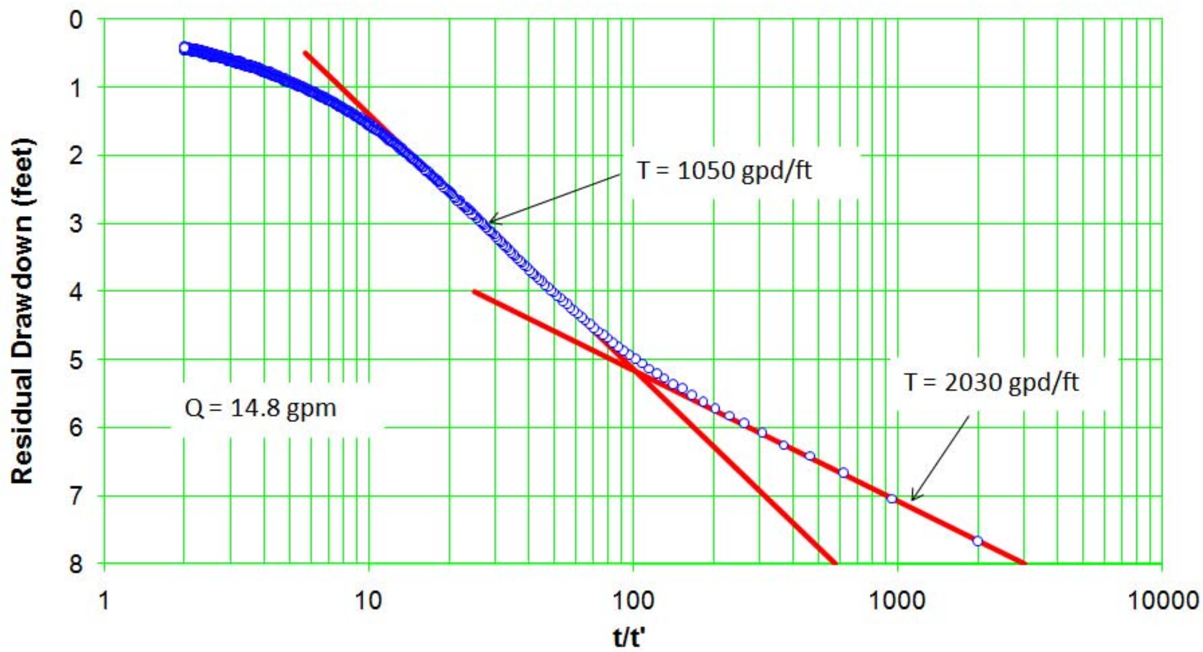


Figure C-9.1-2 Well R-56 screen 2 trial 1 recovery

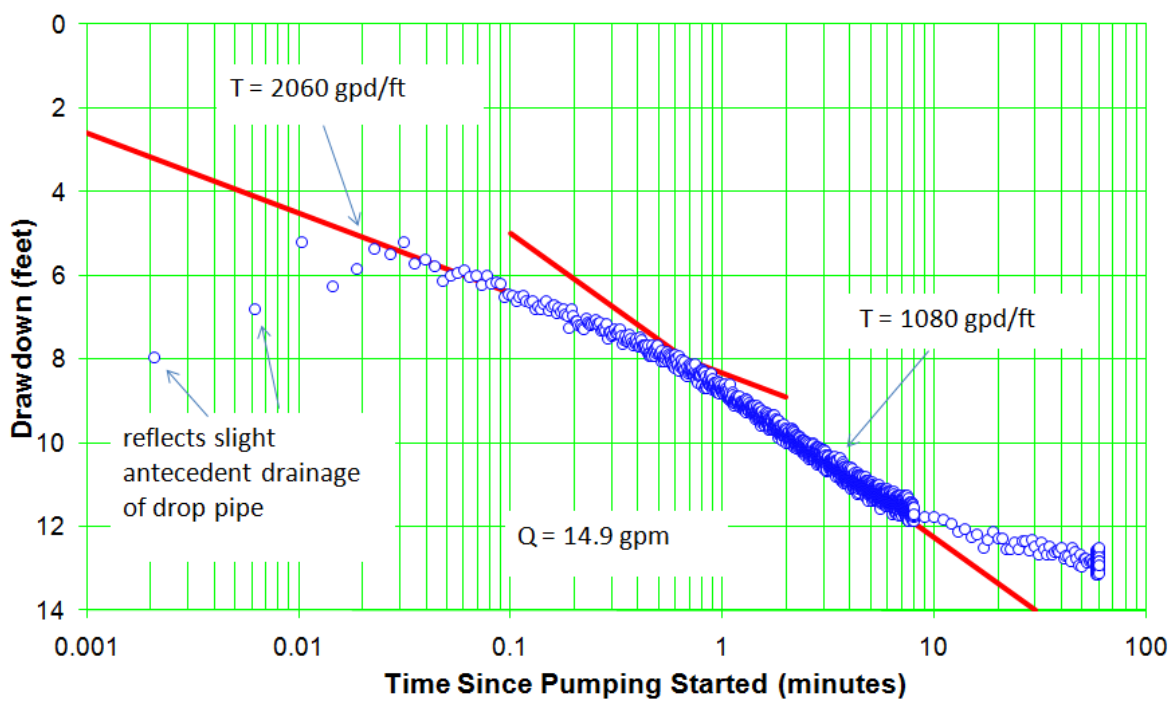
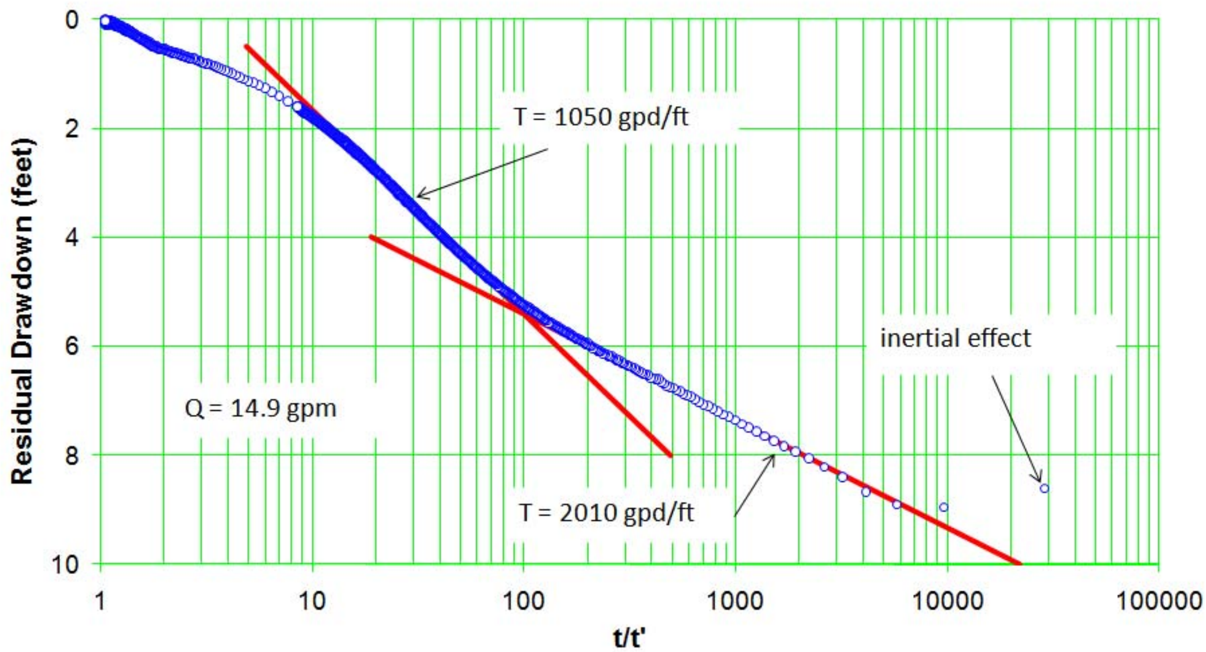


Figure C-9.2-1 Well R-56 screen 2 trial 2 drawdown



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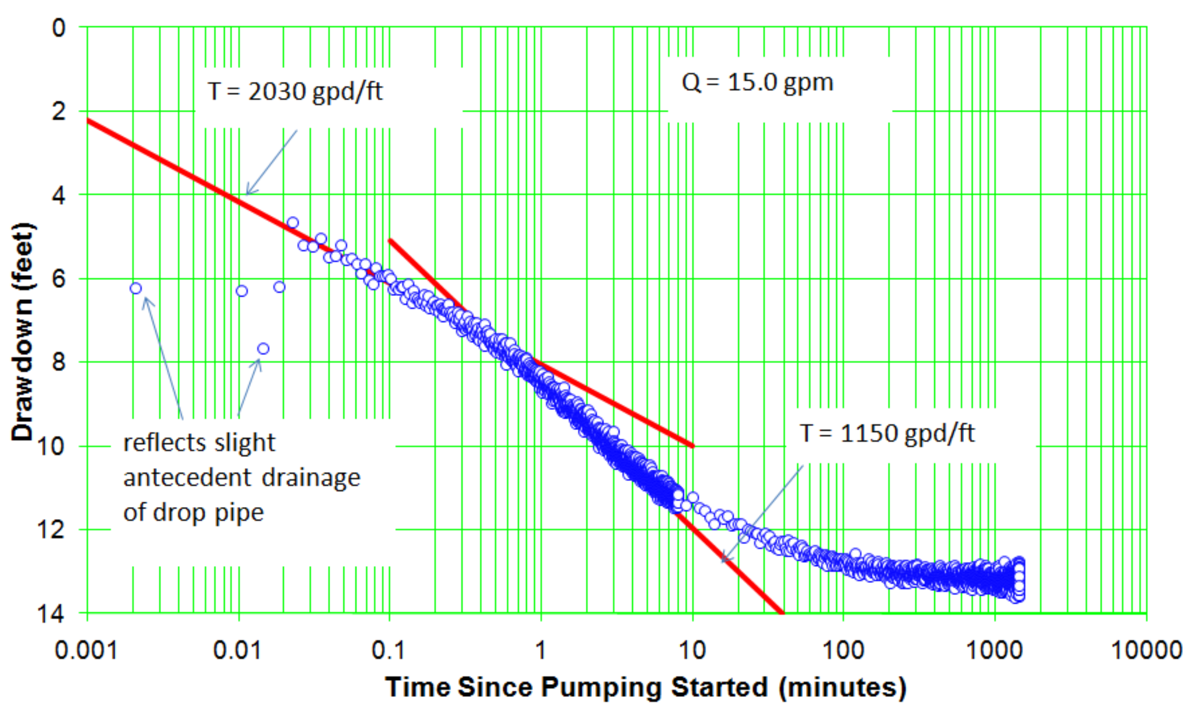
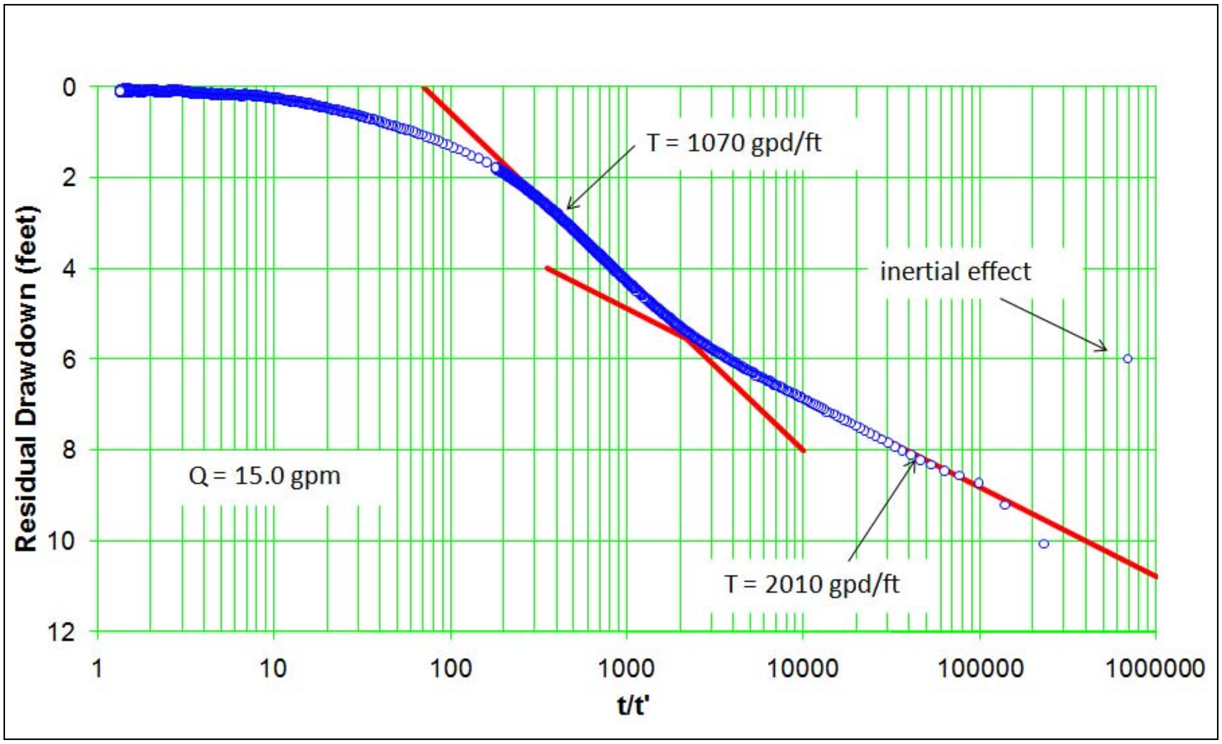


Figure C-9.3-1 Well R-56 screen 2 drawdown



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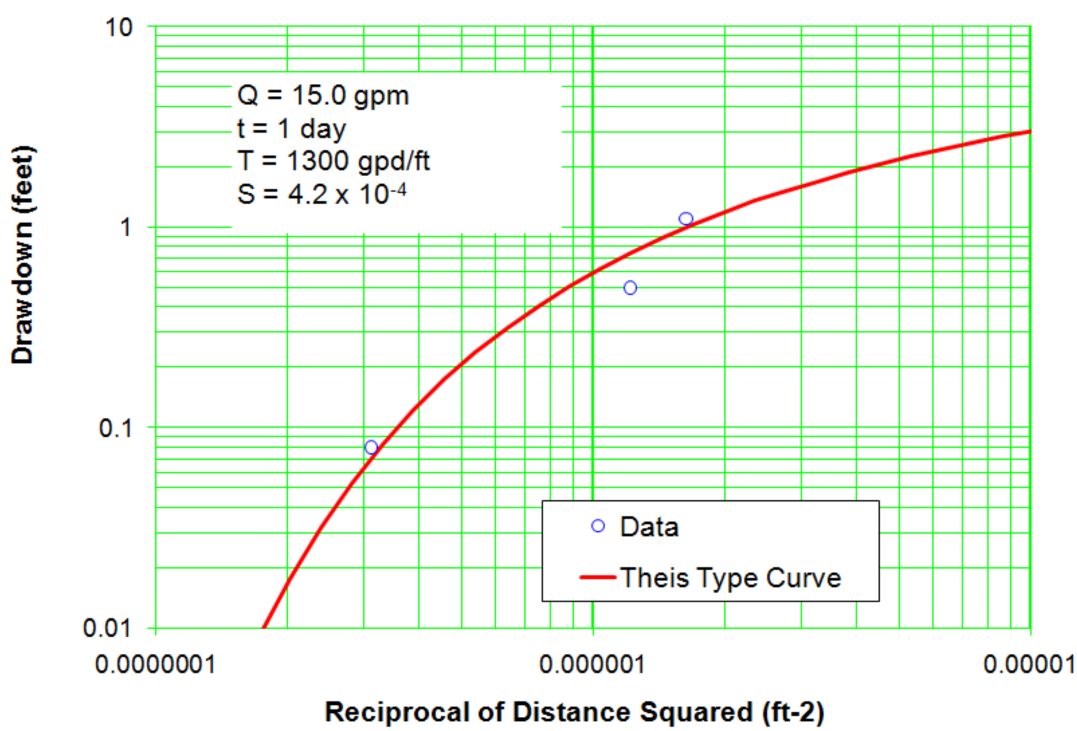

Figure C-9.3-3 Well R-56 screen 2 distance-drawdown graph after 1 day of pumping

Appendix D

Borehole Video Logging
(on DVD included with this document)

Appendix E

Geophysical Logging
(on CD included with this document)

Appendix F

R-56 Final Well Design

Note: Information provided herein was developed before final determination of lithologic contacts presented in the well completion report or final determination of groundwater depths measured after well completion.

F-1.0 PRIMARY PURPOSE

R-56 is a regional groundwater monitoring well located between Material Disposal Area (MDA) L and MDA G at Technical Area- (TA) 54. The R-56 well site is on Mesita del Buey about 400 ft southeast of MDA L (Figure F-1.0-1). Well R-56 is intended to monitor regional aquifer groundwater to the east of MDA L. Well R-56 will supplement groundwater monitoring for MDA L provided by R-21, R-32, R-53, and R-54 wells in the adjacent canyons. Secondary objectives for well R-56 include establishing water levels for the regional aquifer in this area, determining if perched intermediate groundwater occurs in the vicinity of MDA L, 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-56, the upper 10 ft of the regional aquifer is located within basaltic lava, with the remainder in the underlying Puye Formation gravel and sands. The projected groundwater flow direction is toward the east-southeast based on water-table maps using water levels from existing wells in the area. Water-level data collected from R-56 will improve the water-level map in the general area between MDA L and MDA G.

The R-56 well objectives are best met by installing a two-screen well to monitor water quality and water levels in sedimentary deposits near the regional water table and in a deeper part of the regional aquifer downgradient of MDA L.

The R-56 borehole reached a total depth (TD) of 1087 ft with an estimated depth to regional saturation of 925 ft.

F-2.0 R-56 RECOMMENDED WELL DESIGN

It is recommended that R-56 be installed as a two-screen well with an upper screen of 20-ft stainless-steel, 20 slot (0.20-in.), wire-wrapped well screen extending from 945 to 965 ft below ground surface (bgs) and a lower 20-ft stainless-steel, 20 slot, wire-wrapped well screen extending from 1045 to 1065 ft bgs. The depth to top of regional saturation is about 925 ft (see discussion below). The primary filter packs for each screen will consist of 10/20 sand extending 5 ft above and 5 ft below the screen openings. A 2-ft secondary filter pack will be placed above each primary filter pack.

The top of the upper screen is set 20 ft below the regional water table. The lower screen is set 80 ft below the upper screen. The proposed well design is shown in Figure F-2.0-1.

F-3.0 R-56 WELL DESIGN CONSIDERATIONS

Preliminary lithologic logs indicate that the geologic contacts are, in descending stratigraphic order: Tshirege Member of the Bandelier Tuff (0–265 ft bgs), Cerro Toledo interval (265–320 ft bgs), Otowi Member of the Bandelier Tuff (320–375 ft bgs), Guaje Pumice Bed (375–395 ft bgs), gravel deposit (395-400 ft bgs), basaltic and dacitic lavas of the Cerros del Rio volcanic series and associated scoria, cinder, maar, and sedimentary deposits (400–945 ft bgs), and gravel and silty/sandy deposits of the Puye Formation (945–1087 ft TD).

Perched intermediate groundwater was not encountered at R-56. Video logging in the open borehole from 396 to 700 ft bgs showed no indication of perched water. The driller first reported water from the regional aquifer at a depth of 935 ft. Screening groundwater samples were collected from the regional aquifer during drilling at 955 and 1087 ft bgs, or TD, and the analyses are pending.

Examination of cuttings throughout the Puye Formation at R-56 indicates a transition from green pumice-rich gravel mixed with basaltic lavas in the upper section to gravels derived from local volcanic centers to more typical Tschicoma sources mixed with sparse Precambrian granite and quartzite in the lower section. Two intervals of clean gravels and sands (free of silt and other fines) occur at depths of 945 to 975 ft bgs and 1020 to 1070 ft bgs. These are the intervals targeted by the two well screens. Significant siltstone, claystone, and silt- and clay-rich gravels occur at 975–1020 ft bgs, 1035–1045 ft bgs, and 1070–1087 ft bgs that may form prominent poorly transmissive sections. These observations indicate that a screen should not be located within the 975 to 1020 ft bgs, 1035 to 1045 ft bgs, and 1070 to 1087 ft bgs intervals; furthermore, optimal placement of two screens to sample shallower and deeper portions of the regional aquifer should be above and below the 975 to 1020 ft bgs interval, respectively.

F-4.0 ALTERNATIVE DESIGN CONSIDERATIONS

The placement depths for two regional aquifer screens at R-56 is limited by (1) the desire to place the upper screen close to the top of regional saturation yet submerged enough to allow adequate development, and (2) the desire to avoid the silt- and clay-bearing intervals from depths of 975–1020 ft, 1035–1045 ft, and 1070–1087 ft. Figure F-1.0-1 shows screen placements that can vary no more than ~10 ft if these constraints are honored. A significantly altered design would disregard the lower screen (20-ft screen). This would satisfy the major objective of monitoring the first arrival of contaminants entering the regional aquifer from MDA-L. However, the two-screen design provides additional hydrologic monitoring of deeper groundwater pathways and provides information about vertical hydraulic gradients in the vicinity of MDA L and MDA G.

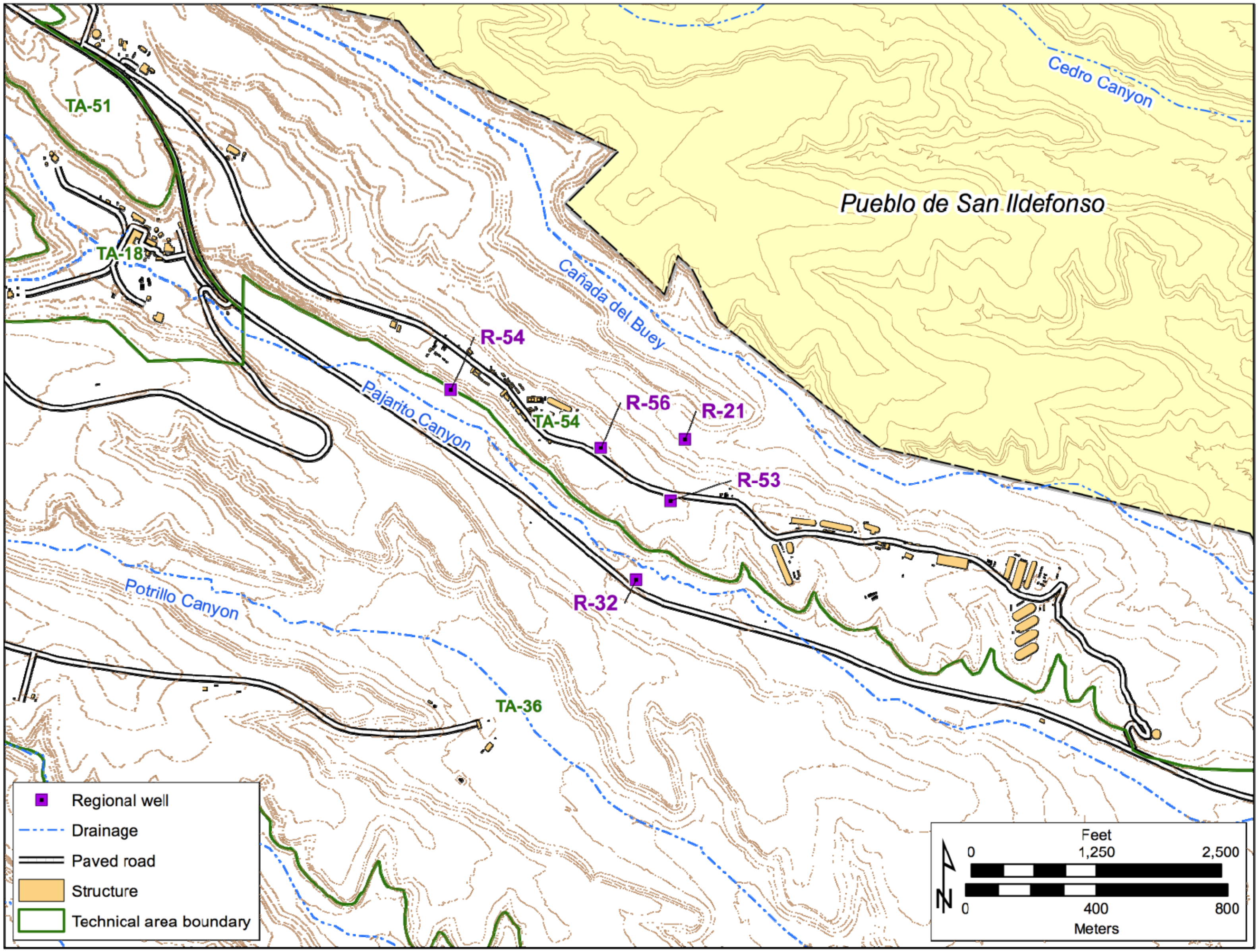

Figure F-1.0-1 Location map for well R-56

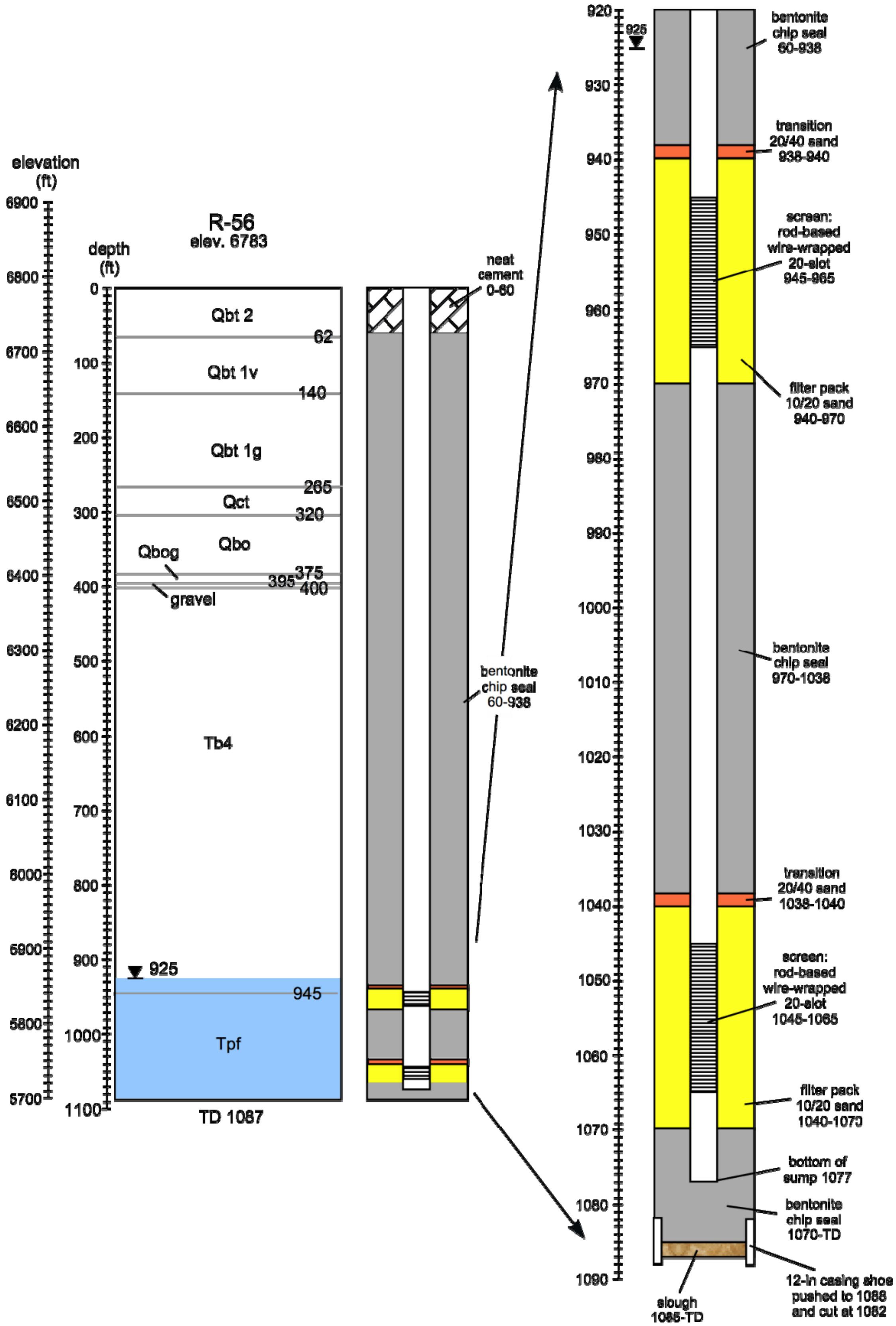

Figure F-2.0-1 Proposed well design, R-56