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Completion Report for Regional Aquifer Well R-41

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July 2009

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EXECUTIVE SUMMARY

This well completion report describes the drilling, installation, development, and aquifer testing of regional aquifer well R-41, located on the eastern end of Mesita del Buey, Technical Area 54 (TA-54), at Los Alamos National Laboratory in Los Alamos County, New Mexico. This report was written in accordance with the requirements in Section IV.A.3.e.iv of the March 1, 2005, Compliance Order on Consent. The well was installed at the direction of the New Mexico Environment Department (NMED) to monitor potential releases of contaminants from Material Disposal Area (MDA) G to groundwater and address key uncertainties in the conceptual model for contaminant fate and transport from TA-54. This well and existing well R-22 will provide downgradient detection monitoring for MDA G.

The R-41 borehole was drilled using dual-rotary fluid-assisted air-drilling methods. Drilling-fluid additives used included potable water and foam. Foam-assisted drilling was used only in the vadose zone; no drilling-fluid additives, other than small amounts of potable water added to the input air, were used within the regional aquifer. Use of foam ceased approximately 100 ft above the regional aquifer. Additive-free drilling provides minimal impacts to the groundwater and aquifer materials. The R-41 borehole was successfully drilled to total depth using casing-advance and open-hole drilling methods.

A retractable 16-in. casing was advanced through the Bandelier Tuff to the basaltic sands and gravels at the top of the Cerros del Rio basalt to a depth of 169.0 ft below ground surface (bgs). A 15-in. open borehole was then advanced with fluid-assisted air-rotary methods and downhole hammer through most of the Cerros del Rio basalt to a depth of 765.0 ft bgs. Then, 12-in. casing was advanced with an 11.62-in. tricone bit using dual-rotary methods to a depth of 857.0 ft bgs, near the base of the basalt. Because of hard drilling conditions, a switch to open-hole drilling with a 12-in. hammer bit advanced the borehole to 1024 ft bgs in semiconsolidated quartzo-feldspathic gravels. A string of 10-in. casing was then installed to control borehole instability and was landed at 1024 ft bgs, the borehole's total depth.

Well R-41, although initially anticipated as a single-screen completion, was completed as a dual-screen well when geophysical log interpretation indicated a potential water-bearing interval above that detected while drilling. The upper nominal 10-ft long screened interval had the top of the screen set at 928.0 ft bgs, and the lower nominal 10-ft long screened interval had the top of the screen set at 965.3 ft bgs. However, it was determined that the upper screened section was nonproductive after well completion. Both intervals were intended to target the top of the regional aquifer in the Puye Formation.

The well was completed in accordance with an NMED-approved well design. Only the lower screen interval produced water and was able to be developed; that screen met target water-quality parameters. Hydrogeologic testing indicated that the lower screen at R-41 is productive and will perform effectively to meet the planned objectives. A water-level transducer will be placed in the lower well screen interval in the R-41 well, and groundwater sampling will be performed as part of the facility-wide groundwater-monitoring program.

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Acronyms and Abbreviations

µS/cm	microsiemens per centimeter
amsl	above mean sea level
APS	Accelerator Porosity Sonde
bgs	below ground surface
Consent Order	Compliance Order on Consent
DO	dissolved oxygen
ECS	Elemental Capture Sonde
EES-14	Environmental and Earth Sciences Group
EPA	Environmental Protection Agency (U.S.)
gAPI	American Petroleum Institute gamma standard units
HNGS	Hostile Natural Gamma Spectroscopy

IC	ion chromatography
ICPOES	inductively coupled (argon) plasma optical emissision spectroscopy
ICPMS	inductively coupled (argon) plasma mass spectrometry
I.D.	inside diameter
LANL	Los Alamos National Laboratory
MDA	material disposal area
MDL	method detection limit
mV	millivolt
n/a	not applicable
NMED	New Mexico Environment Department
NTU	nephelometric turbidity unit
O.D.	outside diameter
ORP	oxidation-reduction potential
PVC	polyvinyl chloride
Qal	Quaternary alluvium
Qbo	Quaternary Otowi Member of the Bandelier Tuff
Qbog	Quaternary Guaje Pumice Bed of Otowi Member of the Bandelier Tuff
Qbt 1g	Quaternary unit 1g of Tshirege Member of the Bandelier Tuff
Qbt 1v	Quaternary unit 1v of Tshirege Member of the Bandelier Tuff
Qbt 2	Quaternary unit 2 of Tshirege Member of the Bandelier Tuff
QC	quality control
RPF	Records Processing Facility
SOP	standard operating procedure
TA	technical area
Tb 4	Tertiary Cerros del Rio basalt
TD	total depth
TDS	total dissolved solids
TLD	Triple Litho-Density Detector
TOC	total organic carbon
Tpf	Tertiary Puye formation
Tjfp	Tertiary (Miocene) pumiceous sediments
Tsfu	Tertiary Santa Fe Group undifferentiated
WCSF	waste characterization strategy form
wt%	weight percent

1.0 INTRODUCTION

This completion report summarizes the site preparation, drilling, well construction, well development, and aquifer testing for well R-41. The report is written in accordance with the requirements in Section IV.A.3.e.iv of the March 1, 2005, Compliance Order on Consent (the Consent Order). Well R-41 was drilled, constructed, and tested from February 10 to April 4, 2009, at Los Alamos National Laboratory (LANL or the Laboratory) for the LANL Water Stewardship Program.

The R-41 project site is located on the eastern end of Mesita del Buey, adjacent to and outside of the east fenceline of the waste storage area at Technical Area 54 (TA-54), Los Alamos County, New Mexico (Figure 1.0-1). The purpose of the R-41 monitoring well is to augment the existing groundwater-monitoring system around Material Disposal Area (MDA) G. The primary objectives of this new well are to monitor potential releases of contaminants from MDA G to groundwater and address key uncertainties in the conceptual model for contaminant fate and transport from TA-54. This well, existing well R-22, and new well R-39 will provide downgradient detection monitoring for MDA G. Secondary objectives of well R-41 are to collect drill-cutting samples, provide borehole geophysical data, and sample potential perched groundwater zones, if present.

The R-41 borehole was drilled to a total depth (TD) of 1024.0 ft below ground surface (bgs). Before drilling, R-41 was anticipated to be constructed as a single-screen well. However, the well was installed with two screens—the result of an additional slightly shallower groundwater-bearing interval indicated by geophysical log interpretation. During well construction, water-level measurements and video logging confirmed that upper screened interval was dry. A dedicated sampling system for the lower screen has been installed. The (dry) upper 10-ft long screened interval is 928.0–937.7 ft bgs, and the lower 10-ft long screened interval is 965.3–975.0 ft bgs. The depth to water after well installation and well development was 960.4 ft bgs, as measured on March 22, 2009. Cuttings samples were collected at 5-ft intervals in the borehole from ground surface to TD. Postinstallation activities included well development, aquifer testing, surface completion, and geodetic surveying. Future construction activities include site restoration and waste management.

The information presented in this report was compiled from field reports and daily activity summaries. Records, including field reports, field logs, and survey information, are on file at the Laboratory's Records Processing Facility (RPF). This report contains brief descriptions of activities and supporting figures, tables, and appendixes completed to date associated with the R-41 project. Information on radioactive materials and radionuclides, including the results of sampling and analysis of radioactive constituents, is voluntarily provided to the New Mexico Environment Department (NMED) in accordance with U.S. Department of Energy policy.

2.0 PRELIMINARY ACTIVITIES

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

2.1 Administrative Preparation

The following documents helped guide the implementation of the scope of work for well R-41: "Final Drilling Plan for Regional Aquifer Well R-41" (TerranearPMC 2009, 106152); "Integrated Work Document for Regional and Intermediate Aquifer Well Drilling" (LANL 2007, 100972); "Storm Water Pollution

Prevention Plan Addendum" (LANL 2006, 092600); and "Waste Characterization Strategy Form for the R-38, R-41, R-44, R-45, and R-46 Regional Groundwater Well Installation and Corehole Drilling" (LANL 2008, 103916).

2.2 Site Preparation

Laboratory personnel prepared the drill pad several weeks before mobilization. The drill rig, air compressors, trailers, and support vehicles were mobilized to the drill site on February 8–10, 2008. Alternative drilling tools and construction materials were staged at the Pajarito Road lay-down yard.

Office trailer, generators, and general field equipment were moved on-site after mobilization of the drilling equipment. Potable water was obtained from a Pajarito Road fire hydrant near TA-18. Safety barriers and signs were installed around the cuttings containment pit and along the perimeter of the work area.

3.0 DRILLING ACTIVITIES

This section describes the drilling strategy and approach and provides a chronological summary of field activities conducted at monitoring well R-41.

3.1 Drilling Approach

The drilling methodology and selection of equipment and drill-casing sizes for R-41 were designed to retain the ability to case off perched groundwater. It was anticipated that if perched groundwater was encountered at R-41, the perched zone would be isolated and sealed off either with casing or by cementing to avoid commingling perched groundwater with the regional aquifer. Further, the drilling approach ensured that a sufficiently sized casing may be used to meet the required 2-in. minimum annular thickness of the filter pack around a 5.56-in. outside diameter (O.D.) well, as required by the Consent Order (Section X.C.2.9).

Dual-rotary air-drilling methods using a Foremost DR-24HD drill rig were employed to drill the R-41 borehole. Dual-rotary drilling has the advantage of simultaneously advancing and casing the borehole. The Foremost DR-24HD drill rig was equipped with conventional drilling rods, tricone bits, downhole hammer bits, one deck-mounted 900 ft^3/min air compressor, and general drilling equipment. Auxiliary equipment included two Sullair 1150 ft^3/min trailer-mounted air compressors. Three sizes of A53 grade B flush-welded mild carbon-steel casing (16-in., 12-in., and 10-in.) were used for the R-41 project. The dual-rotary technique at R-41 used filtered compressed air and fluid-assisted air to evacuate cuttings from the borehole. Cuttings samples were collected at 5-ft intervals in the borehole from ground surface to TD to characterize the hydrostratigraphy of rock units encountered in the borehole.

Drilling fluids, other than air, used in the vadose zone included municipal water and a mixture of municipal water with Baroid AQF-2 foaming agent. The fluids were used to cool the bit and help lift cuttings from the borehole. Use of the foaming agent was terminated at 775 ft bgs, approximately 100 ft above the highest possible predicted top of saturation inferred from adjacent well R-22. No additives other than municipal water were used for drilling within the regional aquifer. Total amounts of drilling fluids introduced into the borehole and those recovered are recorded and presented in Table 3.1-1.

3.2 Chronology of Drilling Activities

Mobilization of necessary drilling equipment and supplies to the R-41 site began on February 8 and continued through February 10, 2009. Laboratory personnel previously prepared the drill pad and pit.

R-41 drilling commenced at 0130 h on February 10 with dual-rotary methods using 16-in. drill casing and a 15-in. tricone bit starting almost immediately in surface exposed Bandelier Tuff. Early in the morning, On February 11, the 16-in. drill casing was landed at 169.0 ft bgs in the top of the Cerros del Rio basalt.

Open-hole drilling utilizing a 15-in. hammer bit then began and reached a depth of 335 ft bgs by crew change (1830 h) on February 11. Several intervals of lost circulation encountered while drilling in the basalt lead to the decision to seal off the zones with approximately 324 ft^3 of Portland cement (with a 4% lime accelerant). Cement was poured down the 16-in. casing on February 12; a cement top was tagged at 161.8 ft bgs, just slightly inside the 16-in. casing.

After giving the cement time to cure, open-hole drilling recommenced on February 12 at 1725 h. As before, a 15-in. hammer bit was utilized and returns were redirected from the pit into rolloff bins while the cemented interval was drilled. Just before midnight on February 12 and at a depth of 335 ft bgs (the base of the cement in the borehole), the hammer bit ceased firing. Removing the bottom-hole assembly revealed that the hammer had broken off and remained downhole. Several attempts to use the drilling contractor's downhole video camera to guide various fishing tools onto or over the lost bit were unsuccessful. The fishing effort was also hampered by poor downhole visibility and minor sloughing. Near midnight on February 14, a "blind" overshot attempt finally brought the broken hammer bit assembly to the surface.

Open-hole drilling again started with a spare 15-in. hammer bit early in the morning on February 15. Drilling proceeded smoothly through that day to a depth of 765 ft bgs. On the morning of February 16, the drilling tools were removed from the hole because the hammer bit stopped firing and there was a loss of circulation. This provided an opportunity to log the open-hole section of the borehole. Jet West Geophysical was on-site that afternoon and ran video, natural gamma ray, and induction logs. The video log showed stacked cinder and flow units (the cinders the likely cause for the lost circulation), several intervals of hole enlargement, and only a slight indication of any water entering the borehole. The hole had collapsed to approximately 649 ft bgs, or about 115 ft short of the current TD. Before Jet West's arrival, the decision had been made to switch to 12-in. dual-rotary drilling and 12-in. drill casing had been started into the borehole.

Welding and installing the 12-in. drill casing continued after cutting off the 16-in. casing shoe (at 154 ft bgs) at midnight on February 16. The 12-in. casing was temporarily landed at 760 ft bgs and the borehole was cleaned out/redrilled with a 12-in. tricone bit to 770.5 ft bgs by 0955 h on February 19. Dual-rotary drilling commenced that evening as did reconnaissance/sampling for potential groundwater bearing intervals. Because of hard drilling conditions, a switch back to open-hole drilling with a 12-in. hammer bit was initiated the evening of February 20. The 12-in. drill casing had been advanced to 857 ft bgs at that time. Open-hole drilling began early in the morning of February 21 at 857 ft bgs.

By 1830 h on February 21, drilling had reached 1024 ft bgs in semiconsolidated quartzo-feldspathic gravels. Planned groundwater reconnaissance intervals (a cessation of drilling accompanied by air-only circulation every 20-ft connection) had shown estimated groundwater flow rates varying between 5 and 10 gpm below 895 ft bgs. The borehole appeared to be sloughing at or near TD fairly rapidly. The hole was cleaned out to TD (1024 ft bgs) on February 22 in preparation for logging by Schlumberger Wireline Services the next day. While running in for the first survey, the logging engineer reported a bridge in the borehole at 951 ft bgs; as a result, the Schlumberger crew was released without running any logs. After the logging crew departed, the 12-in. casing/shoe was cut at 850.0 ft bgs on February 23—a successful cut was verified that evening by using Laboratory video logging equipment.

To stabilize the open-hole interval, the decision was made to advance 10-in. casing and to do so with the Pulstar 100K work-over rig rather than with the drilling rig because the drill rig was needed for service at a nearby location. The 10-in. casing was started in the hole early in the morning of February 24, but the activity was briefly suspended while natural gamma ray and induction surveys using Laboratory logging equipment were run. The borehole bridging at 951 ft bgs Schlumberger reported previously was still present and noted while logging. Ten-inch casing installation resumed and continued through crew change (1830 h) on February 25 when the Pulstar was swapped-out for the dual-rotary drill rig. The next day the 10-in. casing was advanced to 1024 ft bgs, the borehole's former TD.

The Pulstar was again moved back onto the borehole (the drill rig proceeded to the next drilling location), and Schlumberger returned to the site. Cased-hole geophysical logging commenced early in the morning of February 27 and continued through mid-day February 28. Spectral natural gamma ray, Accelerator Porosity Sonde (APS), Triple Litho-Density Detector (TLD), and Elemental Capture Spectroscopy (ECS) logs were run; instrument problems with the latter caused a delay in finishing the planned cased-hole survey suite.

To resolve ongoing uncertain depth-to-water measurements (of approximately 967 ft bgs), the 10-in. casing was pulled back 20 to 1004.0 ft bgs on March 2. Water-level measurements taken over the next day stabilized at 955.4 ft bgs, approximately 24 h after retracting the casing.

On March 4, in an attempt to deal with formation sloughing, a sand bailer (also known as a sand pump or suction bailer) was run to clean out the borehole from the current tag depth of 1003.9 ft bgs. After about 5 h of bailing, the TD had decreased to 998.9 ft bgs—bailing apparently had drawn sediment into the 10-in. casing. A depth to water of 962.4 ft bgs was noted 4 d after cessation of bailing (at 0820 h on March 8) when well construction commenced.

During drilling, field crews worked two 12-h shifts per day, 7 d/wk. Minor progress slowdowns occurred while fishing for the broken hammer bit, while Schlumberger resolved the nonfunctioning ECS logging tool problem and while evaluating the data available for determining actual depth to regional water. Other than Puye Formation sloughing, drilling progressed smoothly.

4.0 SAMPLING ACTIVITIES

This section describes the cuttings and groundwater-sampling activities at well R-41. All sampling activities were conducted in accordance with applicable quality procedures.

4.1 Cuttings Sampling

Cuttings samples were collected from the R-41 borehole at 5-ft intervals from ground surface to the TD of 1024.0 ft bgs. At each interval, approximately 500 mL of bulk cuttings were collected by the site geologist from a 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. Recovery of the cuttings samples was good; total recovery was 95% of the borehole. Intervals with no recovery were as follows: 265–275 ft bgs, 415–420 ft bgs, 770–780 ft bgs, 885–890 ft bgs, 925–930 ft bgs, and 935–950 ft bgs. Radiation control technicians screened cuttings before removal from the site. The core boxes and chip trays were delivered to the Laboratory's archive at the conclusion of drilling activities. All screening measurements were within the range of background values.

The borehole lithologic log for R-41 is presented in Appendix A and summarized in section 5.1.

4.2 Water Sampling

Groundwater-screening samples were collected from the drilling discharge hose at approximate 20-ft intervals starting at 856.0 ft bgs (to evaluate a potential perched zone) and continued to TD at 1024.0 ft bgs. Typically, upon reaching the bottom of a 20-ft run of casing, the driller would stop water circulation (if injecting water) and circulate air to clean out the borehole. As the discharge cleared, a water sample was collected directly from the discharge hose. Not all depth intervals yielded water at the end of each casing run. Alternatively, some water samples were collected upon start-up of the next casing run after the borehole equilibrated.

Twenty groundwater-screening samples, representing seven sampling intervals from depths 856.0 to 1022.0 ft bgs, were collected during drilling operations by bailing or air-lifting water samples through the drill string. Twelve of these samples, from four sampling intervals, represented waters collected while drilling through the vadose zone to evaluate the presence or absence of perched groundwater. Three regional groundwater-screening samples were collected during well development; all from the lower screen interval (965.3–975.0 ft bgs). Drilling screening samples were analyzed for anions, metals, and tritium, while development screening samples were analyzed for anions, metals, and total organic carbon (TOC).

Six regional groundwater-screening samples were collected at regular intervals (approximately one sample per 2 h or 4 h) during aquifer performance testing. All six samples were collected from the lower screen interval (965.3–975.0 ft bgs). The groundwater samples were collected at the surface from the discharge line of the submersible development pump. Groundwater-screening samples collected during drilling, well development, and aquifer performance testing at R-41 were analyzed for dissolved anions, metals, and TOC, and analytical results are provided in Table 4.2-1 and Appendix B.

Groundwater characterization samples will be collected from the completed well in accordance with the Consent Order (Section IX.B.2.i). 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. These groundwater analytical results will be reported in the annual update to the "Interim Facility-Wide Groundwater Monitoring Plan."

5.0 GEOLOGY AND HYDROGEOLOGY

A brief description of the geologic and hydrogeologic features encountered at R-41 is presented below. The Laboratory's geology task leader and site geologists examined cuttings and geophysical logs to determine geologic contacts and hydrogeologic conditions. Drilling observations, video logging, water-level measurements, and geophysical logs were used to characterize groundwater occurrences encountered at R-41.

5.1 Stratigraphy

The stratigraphy for the R-41 borehole is presented below in order of youngest to oldest geologic units. Lithologic descriptions are based on cuttings samples collected from the discharge hose. Cuttings and borehole geophysical logs were used to identify geologic contacts. Figure 5.1-1 illustrates the stratigraphy at R-41. A detailed lithologic log based on analysis of drill cuttings is presented in Appendix A.

Unit 2 of the Tshirege Member of the Bandelier Tuff, Qbt 2 (0–33 ft bgs)

Drilling at R-41 was initiated directly in unit 2 of the Tshirege Member of the Bandelier Tuff. No surficial alluvial sediments are present at the site. Unit 2, intersected from 0 to 33 ft bgs, represents one of several cooling units that make up the Tshirege Member ash-flow tuff. Unit 2 is a moderately to partly poorly welded tuff that is generally crystal-rich, lithic-poor, and weakly pumiceous. Unit 2 drill cuttings locally contain a predominance of welded tuff fragments containing up to 30% by volume quartz and sanidine phenocrysts, minor occurrences of moderately flattened pumice lapilli, and rare volcanic lithics set in a matrix of fine volcanic ash.

Unit 1v of the Tshirege Member of the Bandelier Tuff, Qbt 1v (33–65 ft bgs)

Unit 1 represents the lowest ash-flow stratigraphic unit of the Tshirege Member of the Bandelier Tuff and is divided into an upper vapor-phase devitrified layer (unit 1v) and underlying vitric layer (unit 1g). Unit 1v was encountered from 33 to 65 ft bgs as interpreted from natural gamma ray geophysical log data and from examination of cuttings. Unit 1v is characterized by the presence of devitrified glass that occurs in the makeup of both pumice and ash matrix. As observed in R-41 drill cuttings, unit 1v is a poorly to moderately welded ash-flow tuff that is pumiceous, crystal-bearing, and lithic-poor. Fragments of the tuff typically contain up to 15% quartz and sanidine phenocrysts, pumices displaying sugary (i.e., granular, recrystallized) textures and minor volcanic lithics in a matrix of devitrified volcanic ash.

Unit 1g of the Tshirege Member of the Bandelier Tuff, Qbt 1g (65–115 ft bgs)

Unit 1g of the Tshirege Member of the Bandelier Tuff was encountered from 65 to 115 ft bgs as interpreted from natural gamma ray geophysical log data and by examination of cuttings. Unit 1g is a moderately to poorly welded ash-flow tuff that is strongly pumiceous, generally crystal-bearing and lithic-poor, with abundant vitric ash matrix. The unit 1g section observed in R-41 drill cuttings contains abundant glassy quartz- and sanidine-phyric pumice lapilli, minor (predominantly dacitic) volcanic lithics and abundant quartz and sanidine crystals.

Cerro Toledo Interval, Qct (Not Present)

The Cerro Toledo interval, regionally occurring as a layer of volcaniclastic sediments that stratigraphically separates the Tshirge and Otowi Members of the Bandelier Tuff, was not recognized at R-41.

Otowi Member of the Bandelier Tuff, Qbo (115–160 ft bgs)

The Otowi Member ash flows of the Bandelier Tuff are present in R-41 from 115 to 160 ft bgs as interpreted from natural gamma ray geophysical log data. Cuttings indicate that the Otowi Member is locally a poorly welded, pumiceous, lithic- and crystal-bearing ash-flow tuff. The Otowi Member contains abundant white to very pale orange pumice lapilli that are glassy, fibrous-textured, and quartz- and sanidine-phyric. Locally abundant volcanic lithic fragments (i.e., xenoliths) occur in a matrix of vitric ash. Characteristically abundant lithic fragments (up to 5 mm in diameter) are subangular to subrounded and predominantly of intermediate volcanic composition (i.e., gray to pinkish gray hornblende- and/or biotite-phyric dacites, andesites).

Guaje Pumice Bed of the Otowi Member of the Bandelier Tuff, Qbog (160–169 ft bgs)

The Guaje Pumice Bed occurs in R-41 from 160 to 169 ft bgs on the basis of natural gamma ray log interpretation. Locally, the Guaje tuff unit is nonwelded, pumice-rich, lithic- and crystal-poor, and contains abundant (97%–98% by volume) pristine-appearing white, vitric, phenocryst-poor pumice fragments and lapilli. Trace volumes of volcanic lithics, quartz and sanidine phenocrysts, and fine ash are present.

Cerros del Rio Basalt, Tb 4 (169–925 ft bgs)

The Cerros del Rio basalt section, a complex assemblage of basaltic cinder deposits, individual basaltic lava flows and intercalated basaltic sedimentary layers, was intersected in R-41 from 169 to 795 ft bgs. The large volume of scoria and pyroclastic material present suggests that this location may be proximal to a significant basalt eruptive center.

The uppermost Cerros del Rio basalt encountered in R-41, from 169 to 220 ft bgs, is composed of basalt-rich fine gravels and sands containing small subrounded olivine-basalt pebbles and quartz, pumice, dacite and quartzo-feldspathic detritus. The upper of five discrete lava flows identified within the Cerros del Rio sequence, an olivine-plagiocase-bearing basalt with basal pyroclastic scoria layer, occurs from 220 to 300 ft bgs. Cuttings indicate a thin olivine+clinopyroxene-basalt lava from 300 to 312 ft bgs that is in turn underlain by a thick section of basaltic cinder deposits and scoria from 312 to 420 ft bgs. Significant rounding of basaltic constituents and the presence of quartzo-feldspathic detritus, particularly in the interval from 335 to 370 ft bgs, suggest local reworking of pyroclastic deposits by fluvial processes. Two olivine-clinopyroxene-phyric basalt flows or flow series, each underlain by thin interbeds of basalt-rich sediment, were intersected from 420 to 545 ft bgs.

Pyroclastic deposits of apparent hydromagmatic origin, characterized by mixed basalt, basaltic scoria and scoriaceous glassy basalt lapilli, plus quartz detritus, occur with underlying reworked tuffaceous sediments containing rounded constituents of similar composition from 545 to 630 ft bgs. Clayey basalt-rich fine gravels with coarse- to fine-grained sandstones were encountered from 630 to 670 ft bgs. The lowermost basaltic lava, an olivine-bearing flow with rare clinopyroxene and plagioclase phenocrysts and underlying basaltic sediments, make up the interval from 670 to 795 ft bgs.

A section of dacite-rich sediments and dacitic lava(s) was encountered from 795 to 925 ft bgs. The upper 40 ft of this section consists of silty coarse to fine sands with pebble gravel predominantly composed of detritus derived from glassy, phenocryst-poor, pyroxene-bearing dacite. The entire interval from 795 to 925 ft bgs is made up of light gray massive dacitic lava that is very weakly porphyritic with an aphanitic to glassy groundmass. Compositionally, the dacite contains small (1 to 2 mm in diameter) phenocrysts of black clinopyroxene, translucent amber orthopyroxene, and white plagioclase that comprise no more than 1% of total volume. The three phenocryst phases commonly occur as cumulophyric clusters.

Unassigned Quartzo-Feldspatic Gravels (925–1024 ft bgs)

Riverine gravel sediments comparable to axial-river deposits that comprise the Totavi lentil, locally occurring within the Puye Formation, were encountered from 925 ft to the bottom of the R-41 borehole at 1024 ft bgs. These compositionally diverse sedimentary deposits consist of siity gravels and sands characterized by typically subrounded to well-rounded clasts of quartzite, microcline, granite, chert, and mixed volcanic lithologies, including dacite, andesite, and rhyolite. Significant intervals of silt-rich sediments were observed in drill cuttings from 925 to 1024 ft bgs.

5.2 Groundwater

Potential groundwater was first encountered and sampled at R-41 during drilling at 856.0 ft bgs in the lower portion of the Cerros del Rio basalt (in dacitic lava and sediments) on February 20, 2009. Water samples were collected at roughly 20-ft intervals below 856.0 ft bgs through to TD (1024.0 ft bgs).

Estimated water-flow rates were typically 4–5 gpm at sampling points over the interval and reached a maximum of about 10 gpm at 895.0 ft bgs. After the well was installed, a water level was measured at 960.4 ft bgs.

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

6.0 BOREHOLE LOGGING

Several video logs were collected during the R-41 drilling project by both Jet West Geophysical and Laboratory logging crews. Also, Laboratory and Jet West each ran a natural gamma ray and induction survey. Schlumberger Wireline Services recorded a final suite of cased-hole geophysical logs. A summary of video and geophysical logging runs is presented in Table 6.0-1.

6.1 Video Logging

Video logs were run in the R-41 borehole and well a total of three times. The first instance, by Jet West Geophysical, was on February 16 in the uncased borehole to a depth of 648.9 ft bgs. The log showed stacked cinder and flow units in the Cerros del Rio basalt and indicated several washouts. Little water was observed entering the open borehole; the video also indicated that the hole had collapsed at approximately 649 ft bgs. A second video log, recorded by Laboratory personnel on February 23, verified successful cutting of the 12-in. drill casing at 850 ft bgs, showed possible water entry at 936 ft bgs, and indicated an obstruction in the borehole at 954 ft bgs.

During well construction on March 13, the third video log was run, again using Laboratory equipment, to investigate whether water was entering the upper screened interval. A water-level measurement recorded immediately before running the log indicated a water level of 957.7 ft bgs, roughly 20 ft below the base of the upper screen. The video verified that the upper screen was nonproductive (dry). The video logs are presented on a DVD as part of Appendix D included with this document. Table 6.0-1 details individual video logging runs.

6.2 Geophysical Logging

A suite of Schlumberger geophysical logs was run inside the 10-in. drill casing on February 27–28, 2009. At the time of logging, the terminations of the three casing strings in the R-41 borehole were located at the following depths: 16-in. casing at 169.0 ft bgs, 12-in. casing at 857.0 ft bgs, and 10-in. at approximately 1018 ft bgs. The cased-hole geophysical suite included a TLD log, Hostile Natural Gamma Spectroscopy logs (HNGS), an APS log, and an Elemental Capture Spectroscopy ECS log. Instrument problems with the latter required getting a new tool from an out-of-state location. Interpretation and details of the logging are presented on CD in the Geophysical Logging Report as part of Appendix E.

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

7.0 WELL INSTALLATION

R-41 well casing and annular fill were installed between March 8 and 19, 2009.

7.1 Well Design

The R-41 well was designed in accordance with the Consent Order. NMED approved the well design before installation. Before drilling, R-41 was anticipated to be constructed as a single-screen well.

However, the well was designed and built with dual-screen intervals to monitor groundwater quality in the upper part of the regional aquifer within the Puye Formation-like sediments as a result of geophysical log interpretation. Subsequent determinations by water-level measurements and video logging (March 13, 2009) have shown the upper screen to be dry.

7.2 Well Construction

The R-41 monitoring well was constructed of 5.0-in.-inside diameter (I.D.)/5.56-in.-O.D., type A304 stainless-steel, unthreaded and beveled casing fabricated to American Society for Testing and Materials A312 standards. Screened sections each utilized one 10-ft length of 5.0-in.-I.D. rod-based 0.020-in. wire-wrapped well screen. Welding, using compatible stainless-steel welding rods, was used to join all individual casing and screen sections. All casing and screen were steam-pressure washed on-site before installation. A 2.2-in. O.D. (BQ core-size) steel, flush-threaded tremie pipe string, also decontaminated before use, was used to deliver annular fill materials downhole during well construction. The placement of annular materials typically had two components: installing materials and retracting the drill casing combined with raising the tremie pipe. As each section of drill casing was cut off the string, it was picked up and laid down. During this part of the process, the well casing was hung on a wireline while the drill casing was supported by a pair of rings and slips. Short lengths of 12-in. (7.0-ft casing/shoe) and 16-in. (15.0-ft casing/shoe) drill casing remain in the borehole. The 12-in. casing stub was entombed in bentonite, while the 16-in. casing stub was set in cement. All the 10-in. drill casing (and shoe) were removed from the borehole.

Two screened intervals were chosen for the R-41 well design. The lower 9.7-ft long screened interval had the top of the screen set at 965.3 ft bgs, while the upper 9.7-ft long screened interval had the top of the screen set at 928.0 ft bgs. A 22.1-ft stainless-steel sump was placed below the bottom of the lower well screen. Stainless-steel centralizers (four sets of four) were welded to the well casing approximately 2.0 ft above and below each screen. A Pulstar work-over rig was used for all well construction activities. Figure 7.2-1 presents an as-built schematic showing construction details for the completed well.

The Pulstar rig was moved on location at midnight February 26, 2009. Before starting well construction, the rig was used during final geophysical logging of the borehole (by Schlumberger). Decontamination of the stainless-steel well casing, screens, and tremie pipe along with mobilization of initial well construction materials to the site took place from March 1 to March 3, while the borehole water level was being monitored and the final well design was considered.

On March 8 at 0948 h, the 5-in. well casing was started into the borehole. Each casing and screen joint was welded as it was installed in the borehole; fire-proof matting was used to avoid welding slag falling into the borehole. After landing the casing at 997.0 ft bgs, the borehole was loaded with 2500 gal. of potable water on March 10 to counter formation heaving. A measured depth of 1002.4 ft bgs was recorded after adding the water, 4.6 ft deeper than beforehand (i.e., 997.8 ft bgs).

Later that day (March 10), a lower seal composed of ¼-in. bentonite pellets (10.2 ft^3) was placed from 982.2 to 1002.4 ft bgs. Two feet (1.0 ft^3) of 20/40 silica sand was then installed from 980.2 to 982.2 ft bgs. The lower screen 10/20 silica sand filter pack was then placed from 960.1 to 980.2 bgs and surged to promote compaction. Hole enlargement, perhaps related to formational heaving/sloughing and multiple drilling passes, seems a likely cause for the large amount of filter pack sand required (52.8 ft^3 actual vs. the 9.4 ft^3 calculated volume). A 20/40 silica sand transition was installed on top of the lower sand pack from 957.4 to 960.1 ft bgs (2.8 ft^3).

A seal separating the two screens was then added from 943.9 to 957.4 ft bgs composed of ⅜-in. bentonite chips (3.6 ft^3). Below the upper screen filter pack, a lower 20/40 silica sand transition was installed from 941.5 to 943.9 ft bgs (0.8 ft^3). The upper screen filter pack of 10/20 silica sand was then placed from 922.5 to 941.5 ft bgs. Again, greater than calculated sand required was likely because of borehole enlargement (47.0 ft^3 actual vs. 8.9 ft^3 calculated).

Measurement of depth to water on March 13 showed water in the wellbore at 957.7 ft bgs—20 ft below the bottom of the upper screen. A video log, using Laboratory equipment that day, verified that no water was present or was entering through the slots of the upper screened interval.

Continuing with the annular fill, the upper filter pack was capped with a transition 20/40 silica sand from 918.4 to 922.5 ft bgs (2.5 ft^3). Because the upper screen was deemed dry, no water was added for surging purposes. The upper screen filter pack was not surged.

The well's lengthy upper seal (⅜-in. bentonite chips) was installed from March 14 to March 17 from 300.6 to 918.4 ft bgs and required a total of 659.9 ft^3 of bentonite chips. The bentonite was hydrated with potable water during placement. The final suface seal, a mix of 97–98 weight percent (wt%) Portland cement with 2–3 wt% bentonite, was installed from 3.0 to 300.6 ft bgs (454.2 ft^3). This marked well construction completion on March 19, 2009 (1753 h). Table 7.2-1 itemizes volumes of all materials used during R-41 well construction.

Operationally, well construction proceeded smoothly per plan, typically 24 h/d, 7 d/wk, from March 8 (well casing install) to March 19, 2009. No significant problems slowed progress.

8.0 POSTINSTALLATION ACTIVITIES

Following well installation, the well's lower screened interval was developed, and an aquifer pump test was conducted. As a result of somewhat degraded field turbidity parameters recorded during the aquifer pump test, the lower screen was redeveloped. Total water volume removed during development, aquifer testing, posttest purging, and redevelopment was 22,395 gal. The wellhead and surface pad were completed and a geodetic survey was performed. A dedicated sampling system for the lower screened interval has been installed. Site restoration activities will be completed following final disposition of contained drill cuttings and groundwater as determined in accordance with the NMED-approved waste decision trees and regulatory requirements.

8.1 Well Development

Well development of the lower screen interval was conducted between March 21 and 24, 2009. Initially, the (lower) screened interval was bailed and swabbed to remove formation fines from the filter pack and sump. Bailing and swabbing continued until water clarity visibly improved. Final development was then performed with a submersible pump. The swabbing tool was a 4.5-in.-O.D. 1-in.-thick nylon disc attached to a weighted steel rod. The swabbing tool was lowered by wireline and drawn repeatedly in both directions across the screened interval. Swabbing was followed by one and a half shifts of bailing to remove fines. After bailing, a 5-hp, 4-in.-Grundfos submersible pump was installed in the well for the final stage of well development.

During the pumping stage of well development, turbidity, temperature, pH, dissolved oxygen (DO), oxidation-reduction potential (ORP), and specific conductance parameters were measured and are discussed in Appendix B. In addition, water samples for TOC analysis were collected. The required values for TOC and turbidity to determine adequate well development are less than 2.0 ppm and less than 5 nephelometric turbidity units (NTUs), respectively. The TOC measurements at the end of R-41 well development were less than 1.0 ppm, and the final turbidity values were less than 1.0 NTU for the lower screened interval (Appendix B).

During June 16 to 19, 2009, the lower screen was redeveloped—a result of higher than expected turbidity values observed during the aquifer pump test (see section 8.2). The lower screen was again swabbed (for 1 h) and a 5-hp, 4-in.-Grundfos submersible pump was installed. During the pumping stage of well redevelopment, turbidity, temperature, pH, DO, ORP, and specific conductance parameters were measured. As the TOC development target had been previously met, no samples were collected. The turbidity measurements at the end of R-41 well redevelopment were 4.0 NTUs for the lower screened interval.

The elevated turbidity observed during the aquifer test and the need to continue development activities after aquifer testing was attributed to the lack of submergence at the lower screen as a result of aggressive development pumping. Turbidity values during the original phase of development were likely within specifications due to the pumping water level being below the top of the (lower) screen. During aquifer testing, a lower pumping rate was selected; the upper portion of the (lower) screen and the filter pack interval remained saturated and able to contribute formation fines and increase turbidity. That is, initial development activities were most likely not sufficient to accomplish comprehensive development in the upper portion of the (lower) screen and its filter pack. Postaquifer testing development activities targeted the upper portion of the (lower) screen interval, and lower pumping rates were used. Final turbidity values for the entire screen interval should be considered in the range of 4.0 NTUs and not less than 1.0 NTU.

Approximately 14,555 gal. (11,036 gal. initial development, 3519 gal. redevelopment) of groundwater was purged at R-41 during all development activities. Appendix B presents the volume of water removed during well development and the corresponding water-quality parameters as well as a discussion of analytical results. A brief summary of the water-quality parameters follows (section 8.1.1).

8.1.1 Well Development/Redevelopment Field Parameters

Field parameters, including pH, temperature, DO, ORP, specific conductance, and turbidity, were measured at regular time intervals during well development. Results are listed in Appendix B. Field parameters were measured at well R-41 by collecting aliquots of groundwater from the discharge pipe without the use of a flow-through cell, allowing the samples to be exposed to the atmosphere. This condition probably resulted in a slight variation of field parameters during well development and during the pumping test, most notably, temperature, pH, and DO. Note that the upper screened interval was not developed because of the lack of water (i.e., the interval is dry).

Measurements of pH varied from 7.98 to 8.06 in the lower screened interval at well R-41. Measurements of temperature varied from 21.03°C to 21.77°C in the lower screened interval. DO content varied from 4.83 to 5.56 mg/L in the lower screened interval. ORP measurements varied from –57.4 to 22.7 millivolts (mV) in the lower screened interval. Specific conductance ranged from 209 to 221 microsiemens per centimeter (μS/cm) in the lower screened interval. Values of turbidity of nonfiltered samples measured at R-41 ranged from 23.5 to 0.0 NTUs for the lower screen. Only 3 of the 13 turbidity measurements recorded during well development of the lower screen exceeded 5 NTUs.

Parameters during redevelopment were in addition to those recorded during initial development of the lower screen. Measurements of pH varied from 7.73 to 8.18; temperature varied from 24.19°C to 24.81°C. DO content varied from 2.26 to 4.88 mg/L, and ORP measurements varied from 25.0 to 78.5 mV in the lower screened interval. Specific conductance ranged from 3 to 187 μS/cm; values of turbidity of nonfiltered samples measured at R-41 ranged from 6.0 to 3.6 NTUs. Only 4 of the 12 turbidity measurements recorded during well development of the lower screen exceeded 5 NTUs.

8.2 Aquifer Testing

Aquifer pumping tests of the lower screened interval (only) were conducted at R-41 between March 29 and April 1, 2009. Several short-duration tests with short-duration recovery periods were performed on the first day of testing of the lower screened interval. A 24-h test followed by a 24-h recovery period completed the testing of the lower screened interval. A 7.5-hp Grundfos pump was used to perform the aquifer tests. Approximately 5233 gal. of groundwater was purged during aquifer testing activities. The results of the R-41 aquifer tests are presented in Appendix C. Note that the upper screened interval was not pump-tested because of the lack of water.

8.2.1 Aquifer Testing Field Parameters

Field parameters, including pH, temperature, DO, ORP, specific conductance, and turbidity, were measured at regular time intervals during aquifer testing in the same manner as during well development. Results are provided in Appendix B. Parameters were measured at well R-41 by collecting aliquots of groundwater from the discharge pipe without the use of a flow-through cell, allowing the samples to be exposed to the atmosphere. This condition probably resulted in a slight variation of field parameters during well development and during the pumping test, most notably, temperature, pH, and DO.

Measurements of pH and temperature varied from 7.96 to 8.19 and from 15.16°C to 23.05°C, respectively, for the lower screen. Concentrations of DO and ORP for the lower screen ranged from 5.36 to 7.05 mg/L and from 26.1 to 96.2 mV, respectively. Lower screen specific conductance ranged from 174 to 199 μS/cm. Values of turbidity ranged from 45.8 to 5.5 NTUs for the nonfiltered groundwater pumped in the lower screen.

8.3 Dedicated Sampling System Installation

The dedicated sampling system for R-41 was installed on July 5 and 6, 2009. The system includes a liquid-inflated packer to separate the two screen intervals. The sampling system utilizes a single 3-hp, 4-in.-O.D. environmentally retrofitted Grundfos submersible pump that is set just below the lower screen interval. Because of the lack of available water above the lower screen interval, the pump is set in a stainless-steel pump shroud, with the bottom of the shroud at 978.5 ft bgs. Pump riser pipe consists of threaded and coupled, annealed and pickled, 1-in.-diameter schedule 80 stainless steel. The system includes a viton-wrapped isolation packer between the screen intervals. The packer has two pass-through 1-in. stainless-steel pipes: one for the discharged water and another for the lower screen interval water level transducer. Two 1-in.-diameter polyvinyl chloride (PVC) tubes are installed along with and banded to the pump riser for a dedicated transducer and manual water-level measurements. The tubes are 1.0-in.-I.D. flush-threaded schedule 80 PVC pipe. Each PVC tube has 6-in.-long 0.010-in. screen-slot intervals at the bottom of the tube with threaded bottom caps. One PVC tube passes through the packer and terminates above the pump shroud. The other PVC tube is set with its screen interval at the bottom of the well's upper screen interval. This tube will allow periodic manual water-level measurements at the upper screen. No dedicated transducer will be installed in the upper interval PVC tube. One In-Situ Level Troll 500 transducer will be installed in the lower interval PVC tube to monitor the water level in the well's lower screen interval. Postinstallation construction and sampling system component installation details for R-41 are presented in Figure 8.3-1a. Figure 8.3-1b presents technical notes.

8.4 Wellhead Completion

A reinforced concrete surface pad, 10 ft × 10 ft × 6 in. thick, was installed at R-41. The pad will provide long-term structural integrity for the well. A brass survey monument imprinted with well identification information was placed in the northwest corner of the pad. A 10-in.-I.D. steel protective casing with a locking lid was installed around the stainless-steel well riser. A weep hole was installed to prevent water buildup inside the protective casing. The concrete pad is slightly elevated above the ground surface to promote runoff. A total of four bollards, painted yellow for visibility, are set at the outside corners of the pad to protect the well from traffic. All of the four bollards are designed for easy removal to allow access to the well. Details of the wellhead completion are presented in Figure 8.3-1a.

8.5 Geodetic Survey

A New Mexico licensed professional land surveyor conducted a geodetic survey on June 12, 2009, (Table 8.5-1). The survey data collected conforms to Laboratory Information Architecture project standards IA-CB02, "GIS Horizontal Spatial Reference System," and IA-D802, "Geospatial Positioning Accuracy Standard for A/E/C and Facility Management." All coordinates are expressed as New Mexico State Plane Coordinate System Central Zone (NAD 83); elevation is expressed in feet above mean sea level using the National Geodetic Vertical Datum of 1929. Survey points include ground-surface elevation near the concrete pad, the top of the brass pin in the concrete pad, the top of the well casing, and the top of the protective casing.

8.6 Waste Management and Site Restoration

Waste generated from the R-41 project includes contact waste, decontamination water, drill cuttings, drilling fluids, petroleum-contaminated soil, and purged groundwater. A summary of the waste characterization samples collected from R-41 is presented in Table 8.6-1.

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

Fluids produced during drilling and well development are expected to be land-applied after a review of associated analytical results per the waste characterization strategy form (WCSF, EP2008-0574) and the EP-Directorate Standard Operating Procedure (SOP) 010.0, Land Application of Groundwater (http://www.lanl.gov/environment/all/qa/adep.shtml). If it is determined that drilling fluids are nonhazardous but cannot meet the criterion for land application, the drilling fluids will be evaluated for treatment and disposal at one of the Laboratory's six wastewater treatment facilities. If analytical data indicate that the drilling fluids are hazardous/nonradioactive or mixed low-level waste, the drilling fluids will be disposed of at an authorized facility.

Cuttings produced during drilling are anticipated to be land-applied after a review of associated analytical results per the WCSF and ENV-RCRA SOP-011.0, Land Application of Drill Cuttings (http://www.lanl.gov/environment/all/qa/adep.shtml). If the drill cuttings do not meet the criterion for land application, they will be removed from the pit and disposed of at an authorized facility. The cement slurry waste stream will be managed as industrial nonhazardous waste, pending analytical review. Disposal of this cement slurry will take place at an authorized disposal facility. Characterization of contact waste will be based upon acceptable knowledge (AK), pending analyses of the waste samples collected from the drill cuttings, purge water, and cement slurry. Petroleum-contaminated soil was managed (or is being managed) as a New Mexico Special Waste and disposed of (or will be disposed of) at an authorized facility. Decontamination fluid used for cleaning the drill rig and equipment is containerized. The fluid waste was sampled and will be disposed of at an authorized facility.

Site restoration activities will include removing drilling fluids and cuttings from the pit and managing the fluids and cuttings in accordance with SOP-010.06 (http://www.lanl.gov/environment/all/qa/adep.shtml), removing the polyethylene liner, removing the containment area berms, and backfilling and regrading the containment area, as appropriate.

9.0 DEVIATIONS FROM PLANNED ACTIVITIES

Drilling, sampling, and well construction at R-41 were performed as specified in “Final Drilling Plan for Regional Aquifer Well R-41” (TerranearPMC 2009, 106152); the only significant plan deviation was construction of a two-screen rather than single-screen well.

10.0 ACKNOWLEDGMENTS

Boart Longyear drilled the R-41 borehole and installed the well.

LANL personnel and Jet West Geophysical ran downhole video equipment.

Schlumberger Wireline Services, Jet West Geophysical, and LANL personnel all performed geophysical logging of the borehole.

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

Patrick Longmire wrote Appendix B, Groundwater Analytical Results.

David Schafer wrote Appendix C, Aquifer Testing Report.

Ned Clayton wrote Appendix E, Schlumberger Geophysical Logging Report

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

TerranearPMC, January 2009. “Drilling Plan for Regional Aquifer Well R-41,” plan prepared for Los Alamos National Laboratory, Los Alamos, New Mexico. (TerranearPMC 2009, 106152)

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; 28 February 2008.

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

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

Paved Road Arcs; Los Alamos National Laboratory, KSL Site Support Services, Planning, Locating and Mapping Section; 06 January 2004; as published 04 January 2008.

Dirt Road Arcs; Los Alamos National Laboratory, KSL Site Support Services, Planning, Locating and Mapping Section; 06 January 2004; as published 04 January 2008.

Structures; Los Alamos National Laboratory, KSL Site Support Services, Planning, Locating and Mapping Section; 06 January 2004; as published 04 January 2008.

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

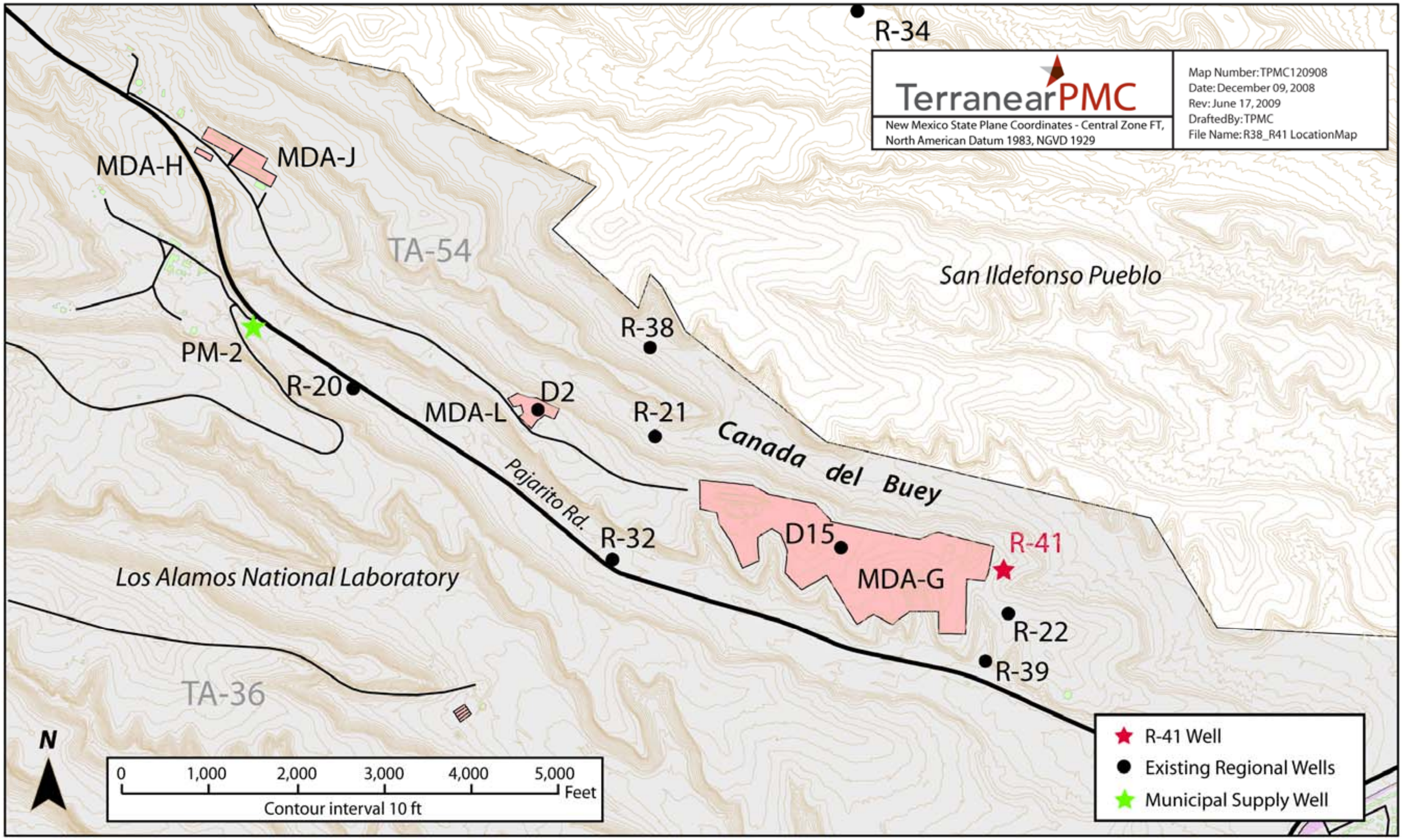

Figure 1.0-1 Regional aquifer well R-41 with respect to surrounding regional wells

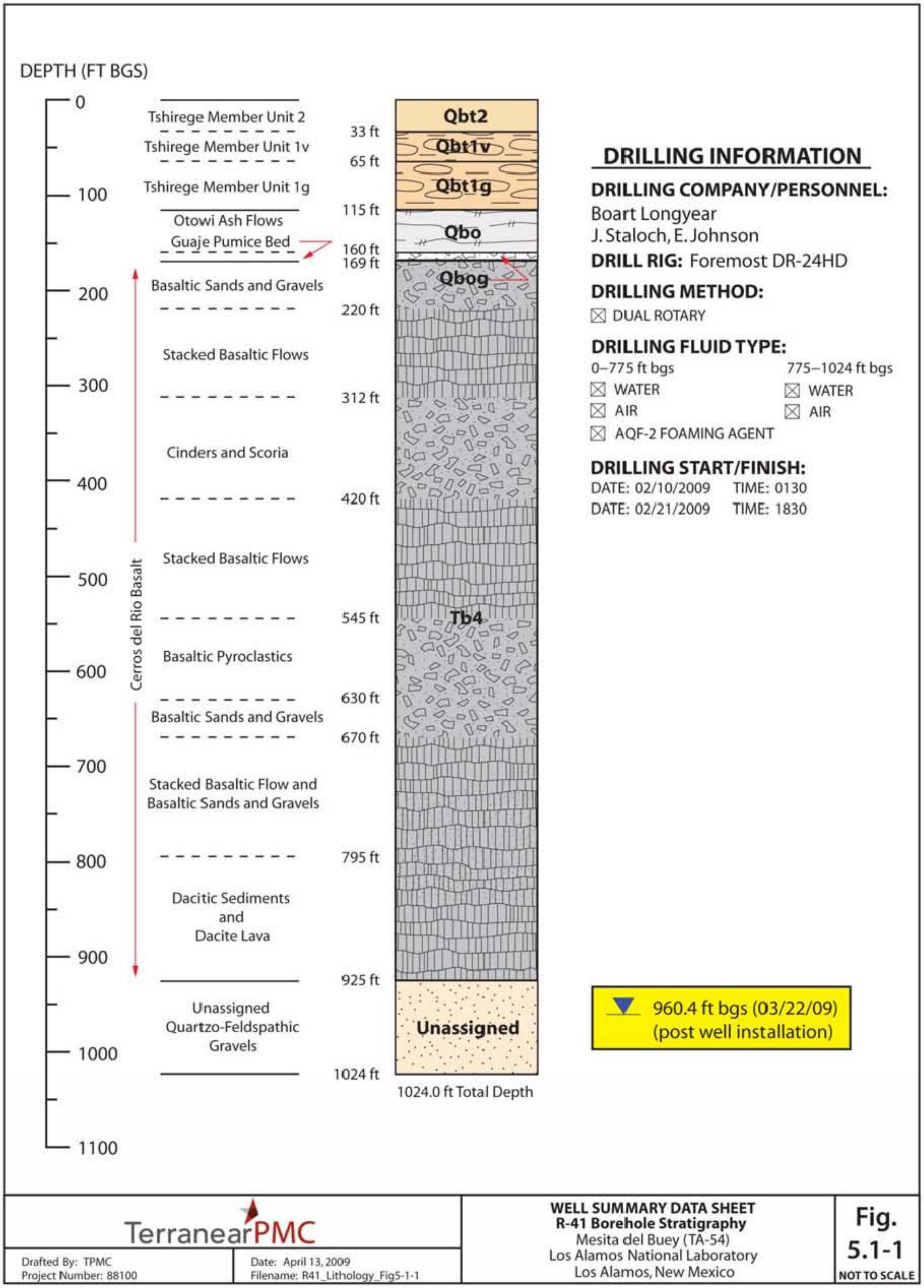

Figure 5.1-1 R-41 borehole stratigraphy

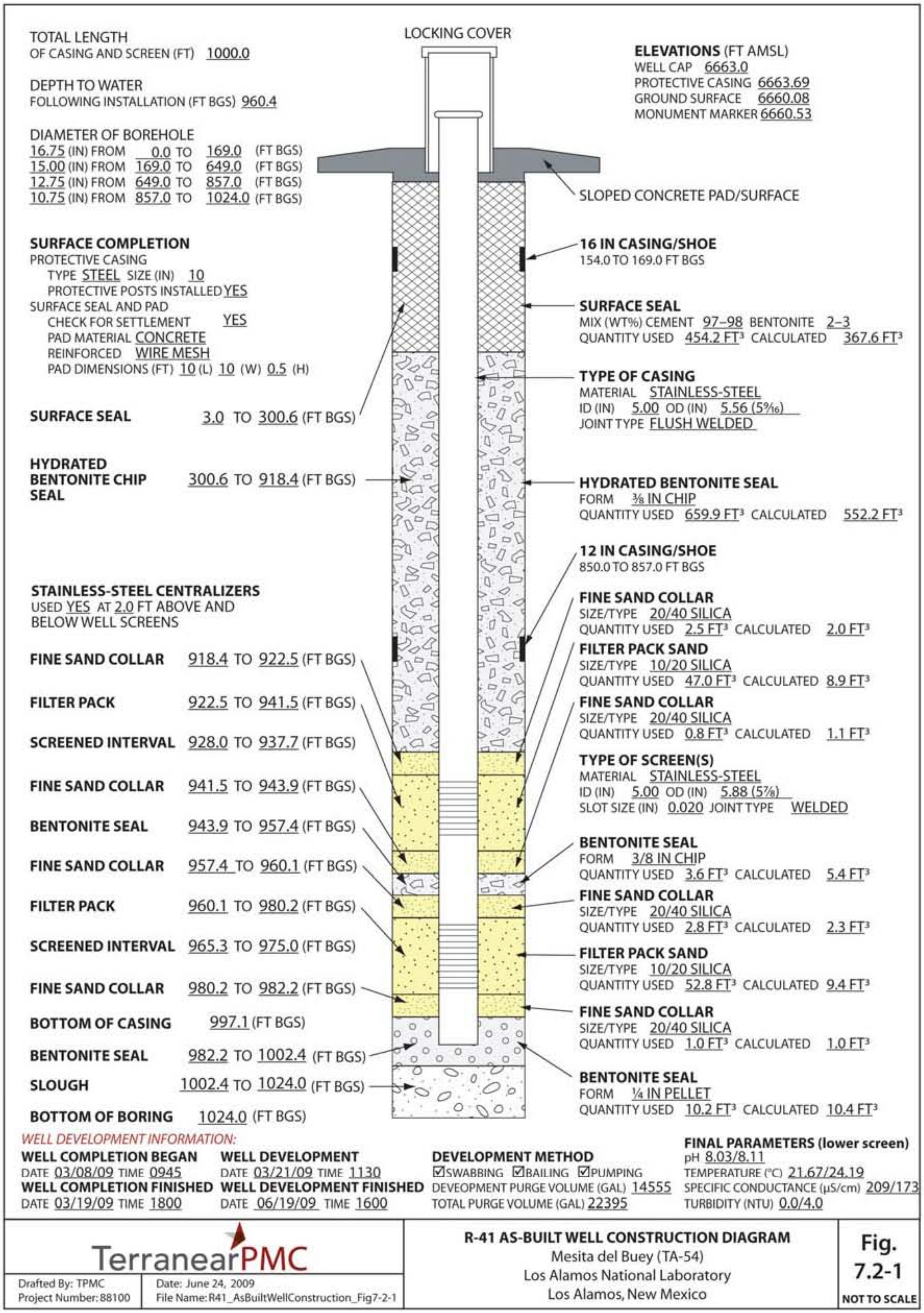

Figure 7.2-1 R-41 as-built well construction diagram

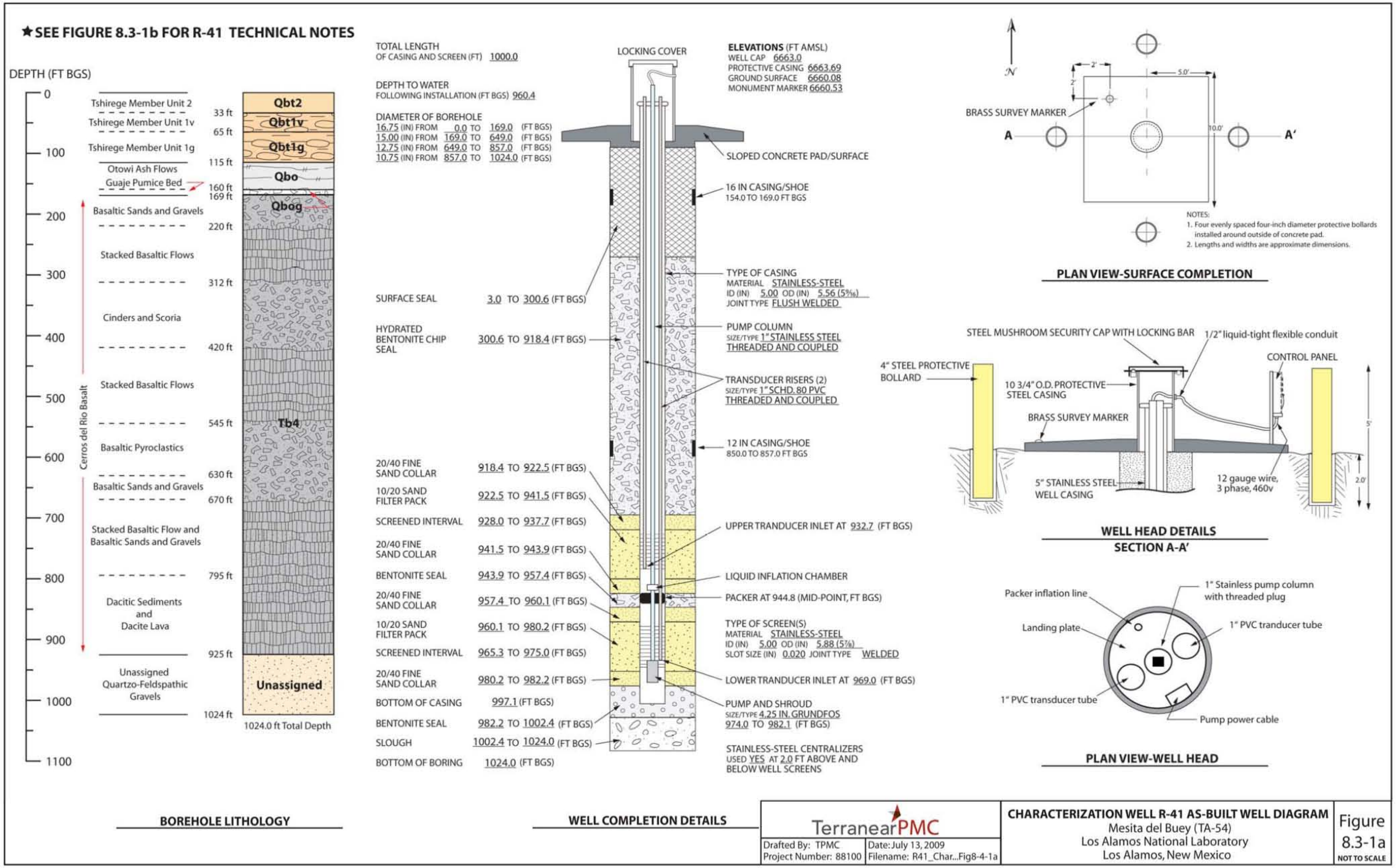

Figure 8.3-1a As-built schematic for regional well R-41

R-41 TECHNICAL NOTES: [1]

SURVEY INFORMATION[2]

Brass Marker

Northing:	1757745.55 ft
Easting:	1645217.12 ft
Elevation:	6660.53 ft AMSL

Well Casing (top of stainless steel)

Northing:	1757740.72 ft
Easting:	1645221.03 ft
Elevation:	6663.00 ft AMSL

BOREHOLE GEOPHYSICAL LOGS

Jet West Geophysical: video, natural gamma ray, induction
LANL: video (×2), natural gamma ray, induction
Schlumberger: HNGS, ECS, TLD, and APS

DRILLING INFORMATION

Drilling Company
Boart Longyear

Drill Rig
Foremost DR-24HD

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

Drilling Fluids
Air, potable water, AQF-2 Foam

MILESTONE DATES

Drilling

Start:	02/10/2009
Finished:	02/26/2009

Well Completion

Start:	03/08/2009
Finished:	03/19/2009

	Well Development	Re-Development
Start:	03/21/2009	06/15/09
Finished:	03/24/2009	06/19/09

WELL DEVELOPMENT

Development Methods
Performed swabbing, bailing, and pumping
Volume Purged: 11036 gallons (lower screen only)
Re-Development Methods
Performed swabbing and pumping
Volume Purged: 3519 gallons (lower screen only)

Parameter Measurments - Lower Screen Only
(Final: Initial Develovment/Re-Development)

pH:	8.03/8.11
Temperature:	21.67°C/24.19°C
Specific Conductance:	209 µS/cm/173 µS/cm
Turbidity:	0.0 NTU/4.0 NTU

AQUIFER TESTING

Constant Rate Pumping Test
Upper Screen
Dry, not tested
Lower Screen

Water Produced:	5233 gallons
Average Flow Rate:	3.2 gpm
Performed on:	03/29–04/01/2009

DEDICATED SAMPLING SYSTEM

Pump
Make: Grundfos, 5S30-820 CBM
Model: B96023161-P10910094
5 U.S. gpm, intake at 978.5 ft bgs
Environmental Retrofit

Motor
Make: Franklin Electric
Model: 2343262604, 3-HP, 3-Phase

Pump Column
1-IN OD Thread/Coupled Schd. 80 Stainless Steel

Transducer Tubes
1-IN OD Flush Threaded Schd. 80 PVC with 6-IN Long 0.010 Screen

Transducer (lower screen only)
Make: In-Situ
Model: Level Troll 500, 30 psig (vented)
S/N: TBD

NOTES:
1) Additional information available in "Final Completion Report, Characterization Well R41, Los Alamos National Laboratory, Los Alamos, New Mexico, TBD 2009".
2) 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: 83100
Date: July 13, 2009
Filename: R41_TechnicalNotes_Fig8-3-1b_r4

R-41 TECHNICAL NOTES
Mesita del Buey (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 R-41

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

Date	Water (gal.)	Cumulative Water (gal.)	AQF-2 Foam (gal.)	Cumulative AQF-2 Foam (gal.)
Drilling				
02/10/09	3550	3550	6	6
02/11/09	3800	7350	27	33
02/12/09	1100	8450	3	36
02/14/09	200	8650	5	41
02/15/09	6500	15,150	90	131
02/16/09	25	15,175	0	131
02/19/09	3000	18,175	5	136
02/20/09	800	18,975	0	136
02/21/09	3100	22,075	0	136
02/22/09	500	22,575	0	136
02/23/09	100	22,675	0	136
02/26/09	200	22,875	0	136
Development				
03/09/09	2500	25,375	n/a*	136
03/10/09	4100	29,475	n/a	136
03/11/09	3550	33,025	n/a	136
03/12/09	3600	36,625	n/a	136
03/13/09	2400	39,025	n/a	136
03/14/09	5000	44,025	n/a	136
03/15/09	1500	45,525	n/a	136
03/16/09	3550	49,075	n/a	136
03/17/09	1200	50,275	n/a	136
03/18/09	1575	51,850	n/a	136
03/19/09	1365	53,215	n/a	136
Total Volume (gal.)				
R-41	**53,215**			

*n/a = Not applicable; foam use discontinued after drilling activities.

Table 4.2-1
Summary of Groundwater Screening Samples Collected during Drilling, Well Development, and Aquifer Testing of Well R-41

Location ID	Sample ID	Date Collected	Collection Depth (ft bgs)	Sample Type	Analysis
Drilling					
R-41	GW41-09-3494	02/20/09	856	Groundwater	Anions, metals
R-41	GW41-09-3514	02/20/09	856	Groundwater	Tritium
R-41	GW41-09-3495	02/21/09	870	Groundwater	Anions, metals
R-41	GW41-09-3515	02/21/09	870	Groundwater	Tritium
R-41	GW41-09-3496	02/21/09	895	Groundwater	Anions, metals
R-41	GW41-09-3516	02/21/09	895	Groundwater	Tritium
R-41	GW41-09-3497	02/21/09	922	Groundwater	Anions, metals
R-41	GW41-09-3517	02/21/09	922	Groundwater	Tritium
R-41	GW41-09-3498	02/21/09	962	Groundwater	Anions, metals
R-41	GW41-09-3518	02/21/09	962	Groundwater	Tritium
R-41	GW41-09-3499	02/21/09	982	Groundwater	Anions, metals
R-41	GW41-09-3519	02/21/09	982	Groundwater	Tritium
R-41	GW41-09-3500	02/21/09	1002	Groundwater	Anions, metals
R-41	GW41-09-3501	02/21/09	1022	Groundwater	Anions, metals
Development					
R-41	GW41-09-3474	03/24/09	965.3–975.0	Groundwater, lower screen	Anions, metals, TOC
R-41	GW41-09-3475	03/25/09	965.3–975.0	Groundwater, lower screen	Anions, metals, TOC
R-41	GW41-09-3476	03/02/09	965.3–975.0	Groundwater, lower screen	Anions, metals, TOC
Pump Testing					
R-41	GW41-09-3477	03/31/09	965.3–975.0	Groundwater, lower screen	Anions, metals, TOC
R-41	GW41-09-3478	03/31/09	965.3–975.0	Groundwater, lower screen	Anions, metals, TOC
R-41	GW41-09-3479	03/31/09	965.3–975.0	Groundwater, lower screen	Anions, metals, TOC
R-41	GW41-09-3480	04/01/09	965.3–975.0	Groundwater, lower screen	Anions, metals, TOC
R-41	GW41-09-3481	04/01/09	965.3–975.0	Groundwater, lower screen	Anions, metals, TOC
R-41	GW41-09-3482	04/01/09	965.3–975.0	Groundwater, lower screen	Anions, metals, TOC

Table 6.0-1
R-41 Video and Geophysical Logging Runs

Date	Depth (ft bgs)	Description
02/13–14/09	~341	Ran drilling contractor's video camera multiple times in an attempt to view a broken bit fragment at current TD and help guide fishing tools into/onto fragment. Foam in the bottom of the borehole and/or cavings obscured the view of the fragment.
02/16/09	169.3–648.9	Jet West Geophysical ran a video, natural gamma ray, and an induction survey of the newly drilled open-hole portion of the borehole. The video revealed the stacked cinder/flow nature of the basalt and indicated several washouts. Little water was observed entering the borehole. Further, logging indicated that the borehole had collapsed approximately 115 ft.
02/23/09	0–951	Schlumberger ran tool in the hole and discovered a bridge in the borehole at 951 ft bgs; as a result, no logging was conducted. A tag depth of 1015.2 ft bgs was recorded before the logging attempt.
02/23/09	0–954	Ran LANL video tool that revealed clean cut of 12-in. casing at 850 ft bgs, possible water in the borehole at 936 ft bgs, and a borehole obstruction at 954 ft bgs (current TD 1015.2 ft bgs).
02/24/09	0–955	Ran LANL natural gamma ray and induction tools. Increased cable tension noted over 937–951-ft bgs interval, possible water indicated in the borehole at 937 ft bgs, and an obstruction at 955 ft bgs noted from the logs.
02/27–28/09	0–1024	Schlumberger returns to site and runs HNGS, APS, TLD, and ECS. Problems with the latter necessitated both an off-site tool replacement and an abridged survey interval of 800–1024 ft bgs. The Schlumberger engineer noted water in the borehole at 974 ft bgs.
03/13/09	≤ 940	Ran LANL video tool inside 5.5-in. well casing. Video showed no water entering upper screen (i.e., it is dry); the current water level in the well was 957.7 ft bgs, approximately 20 ft below the base of the upper screen. The upper screened interval appears dry.

Table 7.2-1
R-41 Annular Fill Materials

Material	Volume
Surface seal: cement slurry	454.2 ft^3
Upper seal: bentonite chips	659.9 ft^3
Upper (upper) fine sand collar: 20/40 silica sand	2.5 ft^3
Upper filter pack: 10/20 silica sand	47.0 ft^3
Lower (upper) fine sand collar: 20/40 silica sand	0.8 ft^3
Middle seal: bentonite chips	3.6 ft^3
Upper (lower) fine sand collar: 20/40 silica sand	2.8 ft^3
Lower filter pack: 10/20 silica sand	52.8 ft^3
Lower (lower) fine sand collar: 20/40 silica sand	1.0 ft^3
Lower seal: bentonite pellets	10.2 ft^3

Table 8.5-1
R-41 Survey Coordinates

Identification	North	East	Elevation
R-41 brass pin embedded in pad	1757745.55	1645217.12	6660.53
R-41 ground surface near pad	1757745.97	1645215.49	6660.08
R-41 top of 10-in. protective casing	1757740.42	1645221.00	6663.69
R-41 top of stainless-steel well casing	1757740.72	1645221.03	6663.0

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

Table 8.6-1
Summary of Waste Samples Collected during Drilling and Development of R-41

Location ID	Sample ID	Date Collected	Description	Sample Type
R-41	n/a*	n/a	Contact waste, use AK from drill cuttings	Solid
R-41	RC54-09-3461	03/02/09	Decon water	Liquid
R-41	RC54-09-3462	03/02/09	Decon water	Liquid
R-41	RC54-09-3463	03/02/09	Decon water	Liquid
R-41	RC54-09-3464	03/02/09	Decon water	Liquid
R-41	RC54-09-3465	03/26/09	Development water	Liquid
R-41	RC54-09-3466	03/26/09	Development water	Liquid
R-41	RC54-09-3467	03/26/09	Development water	Liquid
R-41	RC54-09-3468	03/26/09	Development water	Liquid
R-41	RC54-09-3469	03/04/09	Drilling fluid	Liquid
R-41	RC54-09-3470	03/04/09	Drilling fluid	Liquid
R-41	RC54-09-3471	03/04/09	Drilling fluid	Liquid
R-41	RC54-09-3472	03/04/09	Drilling fluid	Liquid
R-41	RC54-09-3459	03/04/09	Drill cuttings	Solid
R-41	RC54-09-3460	03/04/09	Drill cuttings	Solid
R-41	n/a	n/a	Cement slurry use AK from drill cuttings	Solid
R-41	n/a	n/a	Cement slurry	Solid
R-41	n/a	n/a	Additional decon water, use AK from prior decon water	Liquid

*n/a = Not applicable.

Appendix A

Well R-41 Lithologic Log

Los Alamos National Laboratory
Regional Hydrogeologic Characterization Project
Borehole Lithologic Log

Borehole Identification (ID): R-41	**Technical Area (TA):** 54	**Page:** 1 of 16
DRILLING COMPANY: Boart Longyear Company	**Start Date/Time:** 02/10/2009: 0130	**End Date/Time:** 02/21/2009: 1830
Drilling Method: Dual Rotary	**MACHINE:** Foremost DR24 HD	**Sampling Method:** Grab
Ground Elevation: 6660.08 ft AMSL		**Total Depth:** 1024 ft bgs
DRILLERS: J. Staloch, C. Johnson, E. Rivas	**SITE GEOLOGISTS:** A. Miller, C. Pigman, J. R. Lawrence	

Depth (ft bgs)	Lithology	Lithologic Symbol	Notes
0–15	**UNIT 2 OF THE TSHIREGE MEMBER OF THE BANDELIER TUFF:** Tuff—pale pinkish gray (5YR 7/2), moderately welded, lithic-poor, crystal-bearing, pumice-poor. 0–15 ft WR: predominantly (90% by volume) fine vitric ash. +10F/+35F: 30%–40% fragments of moderately welded crystal tuff; 10%–15% quartz and sanidine crystals; 3%–7% dacitic lithics. +35F: 50%–60% welded tuff fragments; 30%–40% quartz and sanidine crystals; 3%–5% volcanic lithic fragments; trace pumice.	Qbt 2	Note: Drill cuttings for microscopic and descriptive analysis were collected at 5-ft intervals from 0 ft bgs to borehole TD at 1024 ft bgs. Unit 2 of the Tshirege Member of the Bandelier Tuff, encountered from 0 ft to 33 ft bgs, is estimated to be at least 33 ft thick.
15–25	Tuff—light gray (N6) to very pale pinkish gray (5YR 7/2), poorly to moderately welded, crystal-rich, pumice- and lithic-poor. 15–25 ft WR: 90%–95% quartz and sanidine crystals, 5%–7% lithic fragments and ash. +10F: 80%–85% quartz and sanidine crystals; 15%–20% fragments of welded tuff; 2%–3% lithics; trace vitric pumices.	Qbt 2	Note: rounded volcanic and quartzite clasts suggest contaminated sample from surficial construction fill material.
25–33	Tuff—grayish pink (5YR 7/2), poorly to moderately welded, crystal-rich, pumice- and lithic-poor. 25–33 ft + 10F: 40–50% quartz and sanidine crystals; 30%–40% fragments of welded tuff; 20%–25% lithic fragments (including rounded volcanic and quartzo-feldspathic lithologies possibly representing construction fill).	Qbt 2	The Qbt 2–Qbt 1v contact is estimated to be at 33 ft bgs.
33–40	**UNIT 1v OF THE TSHIREGE MEMBER OF THE BANDELIER TUFF:** Tuff—grayish pink (5YR 7/2), moderately welded, crystal-rich, pumice- and lithic-bearing. 33–40 ft WR: abundant quartz and sanidine crystals and moderately abundant ash matrix. +10F: 85%–90% fragments of welded tuff containing quartz and sanidine crystals (10%–15% by volume) and minor small devitrified pumices set in a matrix of ash; 10%–15% light gray dacitic lithics. Note: also occurrences of quartzite and granitic clasts that suggest sample contamination.	Qbt 1v	Unit 1v of the Tshirege Member of the Bandelier Tuff, encountered from 33 ft to 65 ft bgs, is estimated to be 32 ft thick.

Borehole Lithologic Log (continued)

Borehole ID: R-41		**TA:** 54	**Page:** 2 of 16
Depth (ft bgs)	Lithology	Lithologic Symbol	Notes
40–55	Tuff—grayish pink (5YR 7/2), moderately to poorly welded, crystal-rich, pumice-bearing, lithic-poor. 40–55 ft WR: abundant devitrified ash. +10F: 80%–90% welded tuff fragments containing brownish devitrified pumices, quartz and sanidine crystals (10%–15% by volume) in matrix of weathered ash; up to 5% small devitrified pumices. +35F: 85%–90% quartz and sanidine crystals, 10%–15% welded tuff fragments, trace volcanic lithics.	Qbt 1v	
55–60	Tuff—light pinkish gray (5YR 7/2), poorly welded, crystal-rich, pumice- and lithic-bearing. 5–60 ft +10F: 60%–70% quartz and sanidine crystals; 15%–20% volcanic lithics (also trace quartzite); 10%–15% fragments of welded tuff and devitrified pumices.	Qbt 1v	
60–65	Tuff—light pinkish gray (5YR 7/2), moderately to poorly welded, crystal-rich, lithic-bearing, pumiceous. 60–65 ft + 10F: predominantly fragments of welded tuff containing devitrified (i.e., sugary textured, recrystallized glass), quartz and sanidine crystals (up to 7% by volume) and volcanic lithic fragments in matrix of devitrified ash.	Qbt 1v	The estimated Qbt 1v–Qbt 1g contact, at 65 ft bgs, is based on natural gamma log interpretation.
65–70	**UNIT 1g OF THE TSHIREGE MEMBER OF THE BANDELIER TUFF:** Tuff—grayish orange pink (5YR 7/2), poorly welded, strongly pumiceous, lithic-poor, crystal-bearing, pumices characteristically glassy. 65–60 ft WR: abundant vitric pumice fragments and ash. +10F: 80%–85% pale orange tan vitric pumices; 10%–15% quartz and sanidine crystals; 5%–10% small (up to 5 mm in diameter) volcanic lithic fragments.	Qbt 1g	Unit 1g of the Tshirege Member of the Bandelier Tuff, intersected from 65 ft to 115 ft bgs, is estimated to be 50 ft thick.
70–90	Tuff—moderate orange pink (5YR 8/4), poorly welded, strongly pumiceous, lithic-poor, crystal-bearing, pumices characteristically glassy. 70–90 ft + 10F: 99–100% rounded (i.e., milled due to drilling?) orange pink vitric, quartz- and sanidine-phyric pumice fragments, trace free quartz and sanidine crystals, trace volcanic lithics.	Qbt 1g	
90–105	Tuff—moderate orange pink (5YR 8/4), poorly welded, strongly pumiceous, lithic-poor, crystal-bearing, pumices characteristically glassy. 90–105 ft WR/+10F: 97%–98% pale orange to white vitric pumices (up to 20 mm in diameter) that are quartz- and sanidine-phyric; 2%–3% quartz and sanidine crystals; trace volcanic lithic fragments.	Qbt 1g	

Borehole Lithologic Log (continued)

Borehole ID: R-41		**TA:** 54	**Page:** 3 of 16
Depth (ft bgs)	Lithology	Lithologic Symbol	Notes
105–115	Tuff—moderate orange pink (5YR 8/4), poorly welded, strongly pumiceous, lithic-poor, crystal-bearing, pumices characteristically glassy. 105–115 ft WR: moderate volcanic ash matrix. +10F: 75%–90% very pale orange vitric pumice fragments; 10%–20% quartz and sanidine crystals, trace volcanic lithics.	Qbt 1g	Estimated Qbt 1g–Qbo contact at 115 ft bgs is based on natural gamma log interpretation.
115–130	**OTOWI MEMBER OF THE BANDELIER TUFF:** Tuff—very pale orange (10YR 8/2), poorly welded, pumiceous, lithic- and crystal-bearing. 115–130 ft WR: moderate volcanic ash matrix, abundant glassy pumices. +10F: 98%–99% very pale orange vitric pumice fragments that are quartz- and sanidine-bearing; 1%–2% volcanic lithics. +35F: 50%–70% vitric pumice fragments; 20%–30% quartz and sanidine crystals; 5%–10% volcanic lithics.	Qbo	The Otowi Member of the Bandelier Tuff, intersected from 115 ft to 160 ft bgs, is estimated to be 45 ft thick.
130–150	Tuff—very pale orange (10YR 8/2) to pale yellowish gray (5YR 8/1), poorly welded, pumiceous, lithic-bearing, crystal-poor. 130–150 ft WR: moderate to abundant volcanic ash matrix. +10F: 92%–97% very pale orange and white vitric pumice fragments that are quartz- and sanidine-bearing; 3%–8% small (up to 5 mm) volcanic lithics. +35F: 50%–60% vitric pumice fragments; 15%–20% quartz and sanidine crystals; 15% volcanic lithic fragments.	Qbo	
150–160	Tuff—very pale orange (10YR 8/2), poorly welded, pumiceous, lithic-bearing, crystal-poor, pumice characteristically glassy. 150–155 ft WR: abundant fine ash matrix. +10F: 75%–85% very pale orange and white vitric pumice fragments that are quartz- and sanidine-bearing; 15%–25% dacitic lithic fragments. +35F: 15%–25% vitric pumice fragments; 50%–60% quartz and sanidine crystals; 15%–25% volcanic lithic fragments. 155–160 ft +35F: 70–75% vitric pumice fragments; 5%–10% quartz and sanidine crystals; 15%–25% volcanic lithic fragments.	Qbo	The estimated Qbo–Qbog contact at 160 ft bgs is based on natural gamma log interpretation.
160–169	**GUAJE PUMICE BED OF THE OTOWI MEMBER OF THE BANDELIER TUFF:** Tuff—unconsolidated, non-welded, white (N9), pumice-rich, constituents predominantly of vitric pumice lapilli. 160–169 ft WR/ +10F: 95–97% white, pristine-appearing vitric pumices (up to 13 mm) that appear to be crystal-poor; 3%–5% rounded orange-tan pumices.	Qbog	The Guaje Pumice Bed, intersected from 160 ft to 169 ft bgs, is estimated to be 9 ft thick. The estimated Qbog–Tb 4 contact at 169 ft bgs is based on analysis of drill cuttings and natural gamma log data.

Borehole Lithologic Log (continued)

Borehole ID: R-41		**TA:** 54	**Page:** 4 of 16
Depth (ft bgs)	Lithology	Lithologic Symbol	Notes
169–180	**CERROS DEL RIO BASALT:** Basalt lava– white (N9) to medium dark gray (N4). 169–180 ft WR: abundant white clay. +10F: 60%–70% broken and subangular to subrounded clasts of olivine-phyric basalt, altered massive basalt; 30%–40% fragments of white clay and matrix-supported clay-rich basaltic sandstone. +35F: 50% basaltic fragments/grains; 50% white clay fragments with grains of quartz, pumice, dacite and microcline, likely drilling contaminants from Bandelier Tuff.	Tb 4	The Cerros del Rio basalt section of lavas and intercalated sediments and tuff, intersected from 169 ft to 925 ft bgs, is estimated to be 756 ft thick.
180–195	Basaltic sediments– white (N9) to medium dark gray (N4), predominantly basalt chips with lesser clay plus detrital quartz and pumice. 180–185 ft WR/+10F: 99% broken and angular chips of vesicular olivine-phyric basalt; up to 1% fragments of pale tan clay; note white clay coating many basalt fragments. 185–195 ft WR/+10F: 70%–80% broken and angular basalt chips; 20%–25% well-rounded granules of pumice, quartz grains plus fragments of white clay and reddish brown fine-grained sandstone.	Tb 4	
195–220	Basaltic sediments–medium dark (N4) to medium light gray (N6), fine gravels with coarse to fine sand, predominantly basalt. 195–200 ft WR/+10F: 99% broken and angular chips of vesicular olivine-phyric basalt; trace rounded dacite granules; up to 1% rounded to subrounded basalt granules with silt-filled vesicles. 200–220 ft WR/+10F: 90%–95% broken and subrounded to rounded massive basalt (aphanitic, phenocryst-poor, locally strong reddish secondary iron oxides) clasts (up to 15 mm in diameter); 5%–10% subrounded-to-rounded granules and fine pebbles of vesicular basalt, pumice, and fragments of light orange tan silty sandstone.	Tb 4	
220–240	Basalt lava–medium dark (N4) to medium light gray (N6), predominantly chips of vesicular basalt that is phenocryst-poor with aphanitic groundmass. 220–225 ft WR: abundant white silt matrix. 220–240 ft + 10F: 99%–100% broken and angular chips of vesicular to massive basalt containing phenocrysts (up to 1% by volume) of small green resorbed olivine (1–3 mm in diameter), plagioclase (up to 1 mm in diameter) and trace black opaque clinopyroxene set in an aphanitic groundmass; trace amounts of pale red brown clay.	Tb 4	

Borehole Lithologic Log (continued)

Borehole ID: R-41		**TA:** 54	**Page:** 5 of 16
Depth (ft bgs)	Lithology	Lithologic Symbol	Notes
240–260	Basalt lava–medium dark (N4) to medium light gray (N6), predominantly chips of vesicular basalt that is phenocryst poor with weakly altered aphanitic groundmass. 240–260 ft + 10F: 100% broken and angular chips of vesicular to massive basalt containing phenocrysts (1%–2% by volume) of small green anhedral olivine (1–2 mm in diameter), subhedral plagioclase (1–4 mm in diameter) set in a weakly altered aphanitic groundmass.	Tb 4	
260–275	Basalt lava–medium light gray (N6), predominantly chips of olivine-phyric scoriaceous basalt lapilli and cinders. 260–265 ft WR: abundant light gray silt-size particles coating lapilli. +10F: 80% basalt scoria and cinders (lapilli up to 18 mm in diameter) weakly porphyritic, olivine- and plagioclase-phyric; 20% angular and broken chips of massive basalt with altered aphanitic groundmass. 265–275 ft no cuttings available; lost circulation interval.	Tb 4	
275–290	Basalt cinder deposits and scoria–medium dark gray (N4), unconsolidated basaltic scoriaceous lapilli-size ejecta, cinders and ash. 275–285 ft WR/+10F: abundant large (up to 32 mm in diameter) scoriaceous lapilli composed of phenocryst-poor, olivine-phyric olivine basalt with black aphanitic to partly vitric groundmass. +35F: small volume of this sample fraction; predominantly scoriaceous cinders, minor chips of massive basalt and free olivine crystals. 285–290 ft WR/+35F: medium gray to pale reddish gray scoriaceous cinders and free olivine crystals. +10F: no sample preserved.	Tb 4	
290–300	Basalt lava–medium dark (N4) to medium light gray (N6), basaltic scoriaceous lapilli, cinders and ash, and strongly vesicular olivine-basalt chips. 290–295 ft WR/+10F: similar to 275–280 ft 295–300 ft + 10F: 80% basaltic scoriaceous lapilli (up to 12 mm in diameter), 20% strongly vesicular olivine-phyric basalt with altered aphanitic groundmass; locally glassy groundmass; local limonite and hematite coating ejecta surfaces. Broken and angular chips of vesicular to massive basalt containing phenocrysts (1%–2% by volume) of small green anhedral olivine (1–2 mm in diameter), subhedral plagioclase (1–4 mm in diameter) set in a weakly altered aphanitic groundmass.	Tb 4	

Borehole Lithologic Log (continued)

Borehole ID: R-41	**TA:** 54	**Page:** 6 of 16	
Depth (ft bgs)	Lithology	Lithologic Symbol	Notes
300–312	Basalt lava–medium light gray (N6), predominantly massive to vesicular olivine- and clinopyroxene-phyric basalt chips exhibiting altered aphanitic groundmass, subordinate basaltic scoriaceous lapilli. 300–312 ft + 10F: 85–90% subrounded (i.e., apparently milled due to drilling) chips of altered olivine-clinopyroxene-basalt; 10%–15% basaltic scoria, partly glassy.	Tb 4	
312–321	Basalt lava–medium light gray (N6), predominantly broken chips of massive to vesicular olivine- and clinopyroxene-phyric basalt exhibiting altered aphanitic groundmass, subordinate basaltic scoriaceous lapilli. 312–321 ft + 10F: 97%–99% broken chips of massive to vesicular olivine-clinopyroxene-basalt, phenocryst-poor, aphanitic groundmass that is moderately altered; 2%–3% basaltic scoria, partly glassy.	Tb 4	
321–335	Basaltic cinder deposits and reworked sediments–medium light gray (N6) to partly reddish brown (10R 5/4) chips of mixed black, gray and reddish basaltic scoria, lesser massive basalt. 321–335 ft+10F/+35F: mixed basaltic lapilli cinders and ash, including black glassy scoria, reddish (i.e., ferruginous) scoria, lesser massive altered basalt that is clinopyroxene- and olivine-phyric.	Tb 4	
335–345	Basaltic tuff and reworked sediments–white to medium light gray (N6) basaltic scoriaceous lapilli and subrounded granules/grains of quartzo-feldspathic detritus. 335–345 ft + 10F: 98–99% basaltic scoria lapilli strongly coated with white clay; 1%–2% subrounded granules of quartzite and microcline. +35F: 80%–85% angular to subrounded (i.e., reworked detritus) grains of altered basalt, basalt scoria and glassy scoria; 15%–20% subangular to subrounded grains quartz and microcline.	Tb 4	
345–365	Basaltic tuff and reworked sediments–medium dark (N4) to medium light gray (N6) basaltic scoriaceous lapilli (reworked) and minor quartz detritus. 345–360 ft + 10F: 98%–99% basaltic scoria lapilli (up to 8 mm) that are commonly surrounded to rounded indicating tuff reworked by fluvial processes; 1%–2% grains/granules of white quartzite, granite and pumice; most clasts coated with brown secondary iron oxides. 360–365 ft WR/+10F: 85%–90% basaltic scoria lapilli, commonly rounded glassy black scoria; 10%–15% white subrounded to rounded granules of quartzite, granite and pumice.	Tb 4	

Borehole Lithologic Log (continued)

Borehole ID: R-41		**TA:** 54	**Page:** 7 of 16
Depth (ft bgs)	Lithology	Lithologic Symbol	Notes
365–375	Basaltic tuff and reworked sediments–medium dark (N4) to medium light gray (N6) basaltic lapilli of vesicular basalt, scoriaceous vitrophyre and massive basalt. 365–375 ft WR/+10F: subrounded to rounded detrital clasts made up of 70%–80% vesicular to scoriaceous basaltic lapilli; 7%–10% black vitric scoria; 7%–10% massive olivine-phyric basalt; local iron oxide coating of basalt vesicles.+35F: trace abundances of quartzite grains.	Tb 4	
375–390	Basaltic scoria and cinder deposits–medium dark (N4) to medium light gray (N6) chips of vesicular to scoriaceous basalt. 375–390 ft WR/+10F: 100% angular to subangular lapilli and fragments of vesicular to scoriaceous olivine-phyric basalt, local limonite lining vesicles.	Tb 4	
390–420	Basaltic scoria and cinder deposits–medium dark (N4) to reddish brown (5YR 5/6) mixed basaltic scoria lapilli and chips of olivine-basalt. 390–405 ft WR/+10F: 75%–85% scoriaceous basaltic cinders (lapilli, up to 12 mm in diameter) with abundant limonite and/or goethite lining vesicles. ; 15%–25% chips of basalt (olivine-, clinopyroxene- and plagioclase-phyric), trace local pumice grains. 405–415 ft WR/+10F: 60%–70% angular chips of olivine-plagioclase-basalt (olivine frequently weakly replaced by iddingsite); 30%–40% basalt scoria lapilli (up to 15 mm in diameter) exhibiting strong limonite and/or goethite lining vesicles. 415–420 ft no cuttings preserved; lost circulation interval.	Tb 4	
420–435	Basalt lava–medium dark gray (N4) chips and apparent detritus of olivine-phyric basalt and scoriaceous basalt. 420–435 ft WR/+10F/35F: granules and sand-size grains that are in part distinctively subrounded to well rounded, composed of olivine-plagioclase-phyric basalt and vesicular to scoriaceous basalt; trace rounded detrital pumice grains.	Tb 4	
435–460	Basalt lava–medium gray (N5) chips of massive to partly vesicular, clinopyroxene-phryic, weakly porphyritic with aphanitic groundmass; groundmass moderately altered. 435–460 ft WR/+10F: 100% angular chips basalt containing phenocrysts (2%–3% by volume) clinopyroxene, olivine and plagioclase (clinopyroxene occurs as overgrowths on olivine); groundmass moderately altered and bleached. Note: at 455–460 ft occurrence of rounded light tan clay fragments.	Tb 4	

Borehole Lithologic Log (continued)

Borehole ID: R-41		**TA:** 54	**Page:** 8 of 16	
Depth (ft bgs)	Lithology		Lithologic Symbol	Notes
460–475	Basaltic cinders and scoria—medium dark gray (N4) to reddish brown (10R 5/4) mixed rounded granules/grains of massive basalt and scoria. 460–465 ft similar to 435–460 ft. 465–475 ft WR/+10F: subrounded to rounded granules of reddish basaltic scoria and lesser broken chips of massive basalt; locally abundant very pale tan clay fragments.		Tb 4	
475–500	Basalt lava–medium light gray (N6) chips of massive to weakly vesicular basalt, weakly porphyritic with aphanitic groundmass; groundmass moderately altered. 475–500 ft WR/+10F: 99%–100% angular chips of basalt containing phenocrysts (2%–4% by volume) of olivine (up to 1 mm in diameter, commonly iddingsitized), clinopyroxene (1–2 mm in diameter, opaque, black) and minor plagioclase; groundmass moderately altered and bleached; trace light tan clay fragments and reddish iron oxide stained basalt chips.		Tb 4	
500–515	Basalt lava–medium light gray (N6) chips of massive to weakly vesicular basalt, porphyritic with aphanitic groundmass; groundmass moderately altered. 500–515 ft WR/+10F/+35F: 99%–100% angular chips of basalt containing phenocrysts (3%–5% by volume) of olivine (up to 1 mm in diameter, anhedral, commonly iddingsitized), clinopyroxene (up to 2 mm in diameter, subhedral, opaque, black, commonly as overgrowths on olivine); groundmass weakly to moderately altered and bleached; trace light tan clay fragments and iron oxide stained basalt chips.		Tb 4	
515–525	Basalt lava–medium light gray (N6) chips of massive to weakly vesicular basalt, weakly porphyritic with aphanitic groundmass; groundmass moderately altered. 515–525 ft WR/+10F/+35F: 99%–100% angular chips of basalt containing phenocrysts (2%–4% by volume) of olivine, clinopyroxene and minor plagioclase; groundmass moderately altered and bleached; trace ferruginous basaltic scoria.		Tb 4	
525–530	Basaltic sediments–medium light gray (N6) mixed chips of olivine-clinopyroxene-basalt and detrital basaltic granular (i.e., sedimentary) materials. 525–530 ft + 10F: 60%–70% angular basalt chips, olivine- and clinopyroxene-phyric; 30%–40% subangular detrital granules composed variously of basaltic scoria, clay-coated vesicular basalt, trace white quartz with pyrite crystals (vein rock).		Tb 4	

Borehole Lithologic Log (continued)

Borehole ID: R-41		**TA:** 54	**Page:** 9 of 16
Depth (ft bgs)	Lithology	Lithologic Symbol	Notes
530–545	Basaltic sediments–medium light gray (N6) coarse to medium sand with subrounded to rounded granules; basaltic detritus. 530–545 ft WR/+10F: 80%–90% subrounded to rounded detrital grains, granules and small pebbles (up to 10 mm in diameter) olivine-clinopyroxene-10%–20% subrounded granules pink to red-brown iron oxide stained vesicular basalt; trace light tan clay shards and reddish scoria.	Tb 4	
545–555	Reworked hydromagmatic tuff/sediments–varicolored light red (5R 6/6) to medium light gray (N6) fine gravel and very coarse to medium sand; mixed detritus of basalt, scoria, glassy scoria and minor quartz. 545–555 ft WR/+10F: 30%–40% broken and subangular granules of massive olivine-clinopyroxene-phyric basalt; 50%–60% subrounded to rounded detrital granules and small pebbles of basalt scoria, ferruginous basalt scoria; 3%–5% rounded clay-coated glassy scoria; 3%–5% fragments of fine-grained basaltic sandstone; trace quartzite fragments.	Tb 4	
555–565	Reworked hydromagmatic tuff/sediments–varicolored grayish orange (10YR 7/4) to medium light gray (N6) very coarse to medium sand and pebble gravel; mixed subrounded to well rounded detritus of basalt, scoria, glassy scoria and minor quartz. 555–565 ft WR/+10F: 20%–30% broken and subrounded clasts of gray olivine-clinopyroxene-phyric basalt; 50%–60% subrounded to well rounded detrital granules and small pebbles yellowish tan to reddish basalt scoria, clay coated; trace clay shards and quartzo-feldspathic detritus. +35F: contains 20%–30% subangular to subrounded grains of clay-coated (i.e., palagonite) glassy scoria.	Tb 4	
565–585	Reworked hydromagmatic tuff/sediments–varicolored pale yellowish orange (10YR 8/6) to medium light gray (N6) very coarse to medium sand with granules; typically well rounded detritus of mixed clay-coated massive basalt and basaltic scoria. 565–585 ft WR/+10F: detrital clasts are predominantly well rounded and composed of 10%–20% massive gray basalt, 40%–50% yellowish clay-coated basaltic scoria, 20%–30% glassy scoria; 10%–20% fragments of basaltic fine-grained sandstone; trace quartz and granitic grains/granules.	Tb 4	

Borehole Lithologic Log (continued)

Borehole ID: R-41	**TA:** 54		**Page:** 10 of 16
Depth (ft bgs)	Lithology	Lithologic Symbol	Notes
585–600	Reworked hydromagmatic tuff/sediments–light olive gray (5YR 6/1) very coarse to medium sand with granules; rounded detritus of massive basalt and basaltic scoria. 585–600 ft WR/+10F/+35F: 60%–70% subrounded to well rounded granules/grains of glassy scoria commonly coated with yellowish palagonitic clay; 30%–40% granules of basalt and basaltic scoria and minor dacite; trace quartz crystals and quartzite grains.	Tb 4	
600–615	Reworked hydromagmatic tuff/sediments–light olive gray (5YR 6/1) silty very coarse to medium sand with granules; rounded detritus of massive basalt, basaltic scoria and minor quartzo-feldspathic materials 600–615 ft WR/+10F: subrounded to subangular granules and grains are silt coated and composed of 50%–60% glassy black scoria; 40%–50% basalt scoria, massive basalt, dacite; 5%–10% fragments of basaltic fine- to medium-grained sandstone with quartzite grains.	Tb 4	Note: increased abundance of detrital dacite.
615–625	Reworked hydromagmatic tuff/sediments–varicolored light olive gray (5YR 6/1) to medium gray (N5), very fine gravel with fine to coarse sand, rounded detritus predominantly of massive basalt, basaltic scoria. 615–625 ft WR/+10F: subrounded to well rounded detrital granules (3–7 mm in diameter) composed of glassy basalt scoria, vesicular olivine-phyric basalt, fragments of very fine grained basaltic sandstone; trace additional volcanic lithologies (dacite, white pumice, fragments of light tan clay. +35F: noted also abundant grains of olivine crystals, trace quartzite and microcline.	Tb 4	
625–635	Clay-rich basaltic sediments—pale pinkish tan (10YR 8/2) clayey pebble gravel and fine- to coarse-grained sandstone, subrounded clasts composed predominantly of basalt. 625–635 ft WR: abundant clay matrix. +10F: subrounded to subangular detrital clasts (up to 13 mm in diameter) of vesicular to massive olivine-basalt and fragments of basaltic sandstone. +35F: mixed grains of basalt, glassy scoria, tan clay shards, trace olivine crystals.	Tb 4	Note: transition from upper basaltic pyroclastics to lower basaltic sands and gravels placed at 630 ft depth based on elevated gamma ray log in the sands and gravels.
635–650	Clay-rich basaltic sediments—pale pinkish tan (10YR 8/2) clay-rich pebble gravels and fine- to coarse-grained sandstone, basaltic detritus. 635–650 ft WR: clay-rich gravels and sands. +10F: well rounded to subangular pebbles (up to 20 mm in diameter) and granules composed of vesicular to scoriaceous basalt, clay-coated clasts. +35F: clay-coated grains of basalt, scoria and olivine crystals; trace pumice.	Tb 4	

Borehole Lithologic Log (continued)

Borehole ID: R-41		**TA:** 54	**Page:** 11 of 16
Depth (ft bgs)	Lithology	Lithologic Symbol	Notes
650–670	Clay-rich basaltic sediments—pale pinkish tan (10YR 8/2) clayey very coarse to fine sand with granules composed predominantly of basalt. 650–670 ft WR: matrix clayey to clay-rich. +10F: broken, subangular and subrounded granules and pebble-size clasts composed of gray massive to vesicular basalt, red basalt, pale pink clay fragments, fragments of fine-grained basaltic sandstone. +35F: grains of basalt, glassy basalt, red ferruginous basalt and clay shards.	Tb 4	
670–685	Basalt lava—medium dark (N4) to medium light gray (N6) massive (i.e., non-vesicular) basaltic lava, phenocryst-poor. 670–685 ft WR/+10F: 93%–95% angular to subangular basalt chips, phenocrysts (1%–2% by volume) small (1–2 mm in diameter) of anhedral green olivine, minor plagioclase and rare clinopyroxene, aphanitic groundmass partly weakly altered and bleached; 5%–7% fragments of pale tan clay and very fine grained sandy clay. +35F: 85%–90% olivine-phyric basalt chips; 10%–15% fragments of clay and clayey sandstone; up to 1% glassy basaltic scoria.	Tb 4	
685–705	Basalt lava—medium dark (N4) to medium light gray (N6) chips of massive basaltic lava, phenocryst-poor to very weakly porphyritic with partly altered aphanitic groundmass, local clay fragments. 685–705 ft WR/+10F: 85%–90% subangular basalt chips, phenocrysts (up to 1% by volume) small (1–2 mm in diameter) of anhedral pale green olivines (fresh, unaltered), local bleaching and alteration of aphanitic groundmass; 10%–15% fragments of light tan silty clay. +35F: 80%–85% olivine-phyric basalt; 15%–20% silty clay shards.	Tb 4	
705–725	Basalt lava—medium light gray (N6) chips of massive basaltic lava, phenocryst-poor, very weakly porphyritic with weakly altered aphanitic groundmass. 705–725 ft WR/+10F: 93%–97% angular to subangular basalt chips, small (up to 2 mm in diameter) phenocrysts (up to 1%–2% by volume) of anhedral green olivine , rare resorbed black clinopyroxene, aphanitic groundmass weakly altered and bleached.	Tb 4	

Borehole Lithologic Log (continued)

Borehole ID: R-41	**TA:** 54	**Page:** 12 of 16	
Depth (ft bgs)	Lithology	Lithologic Symbol	Notes
725–735	Basaltic sediments—pale pinkish tan (5YR 8/4) silty fine gravel with fine to coarse sand, pebbles and granules typically somewhat rounded. 725–730 ft WR: abundant clay to silty clay matrix. +10F: 75%–85% subangular to subrounded olivine-phyric basalt chips, and clasts; 2%–3% rounded basalt scoria clasts (up to 5 mm in diameter); 15–25% clay and clayey very fine grained basaltic sandstone. +35F: 60%–70% grains composed of massive basalt and lesser basalt scoria; 30%–40% clay shards. 730–735 ft WR: clay content increased. +10F: basaltic granules/pebbles (up to 8 mm in diameter) commonly well rounded.	Tb 4	
735–750	Basaltic sediments—varicolored, medium light gray (N6) to pale pinkish tan (5YR 8/4) silty to clayey fine to medium gravels with fine to coarse sand, clasts of massive basalt and scoria. 735–750 ft WR: abundant clay to silty clay matrix. +10F: 75%–80% broken and angular olivine-phyric basalt chips and rounded basalt scoria (up to 9 mm in diameter); 20%–25% light pink tan fragments of silty clay and very fine grained silty basaltic sandstone.	Tb 4	
750–765	Basaltic sediments—varicolored, medium light gray (N6) to pale pinkish tan (5YR 8/4) silty fine to medium gravels with fine to coarse sand, clasts of massive basalt and scoria. 750–765 ft WR: abundant clay to silty clay matrix. +10F: 75%–80% broken and angular chips of very fine grained phenocryst-poor, olivine-phyric basalt and rounded basalt scoria clasts; 20%–25% fragments of light pinkish tan silty clay. +35F: 30%–40% light tan clay fragments; 10%–15% chips of massive basalt; 50%–60% subangular to subrounded grains of basalt scoria.	Tb 4	
765–780	Basaltic sediments—light pinkish tan (5YR 8/4) very silty pebble gravels with fine to coarse sand, clasts of massive to vesicular basalt and scoria. 765–770 ft WR: abundant clay to silty clay matrix. +10F: 60% broken and angular chips of phenocryst-poor massive basalt and lesser vesicular basalt; 40% fragments light tan clayey silt and silty very fine grained basaltic sandstone with quartzo-feldspathic grains. 770–780 ft no cuttings preserved; lost circulation interval.	Tb 4	

Borehole Lithologic Log (continued)

Borehole ID: R-41		**TA:** 54	**Page:** 13 of 16
Depth (ft bgs)	Lithology	Lithologic Symbol	Notes
780–785	Basaltic sediments—light pinkish tan (5YR 8/4) silty fine to very coarse sandstones with granules, detritus of mixed basalt and dacites. 780–785 ft WR: abundant silt matrix. +10F: 60%–65% pinkish tan siltstone fragments; 35%–40% gray clinopyroxene-phyric dacite(?), light gray glassy dacite scoria and olivine-phyric basalt scoria. Noted also first appearance of glassy vesicular dacite and fibrous organic material (i.e., plant roots?).	Tb 4	
785–795	Basaltic sediments—light pinkish tan (5YR 8/4) very silty fine to coarse sandstones with granules, detritus of mixed basalt and dacites. 785–790 ft WR: abundant silt matrix. +10F/35F: 60%–70% subrounded granules (up to 5 mm in diameter) massive basalt and scoriaceous cinders; 20% fragments of light tan siltstone; 5%–10% very light gray glassy dacitic scoria. 790–795 ft +35F: noted also trace pinkish orange microcline grains.	Tb 4	The estimated contact between the basaltic volcanic and sedimentary section and underlying sequence of dacitic sediments and lavas is placed at 795 ft bgs based on analysis of drill cuttings and natural gamma log data.
795–800	Dacitic sediments—very light gray (N8) silty very coarse to fine sand with granules and pebbles, detritus of mixed light gray clinopyroxene-phyric dacite and lesser basalt. 975–800 ft WR: abundant silt matrix. +10F: subangular to subrounded detrital granules (up to 4 mm in diameter) composed of 85%–90% light gray glassy clinopyroxene-phyric dacites; 10%–15% basalt; 3%–5% tan silty fine-grained volcaniclastic sandstone fragments.	Tb 4	The section of dacitic lavas and sediments, intersected from 795 ft to 930 ft bgs, is estimated to be 135 ft thick.
800–820	Dacitic sediments—very light gray (N8) silty coarse to fine sand with local granules and pebbles, detritus predominantly of glassy clinopyroxene-phyric dacite. 800–820 ft WR: abundant silt matrix. +10F: 97%–98% commonly subrounded to rounded granules (up to 8 mm in diameter) of light gray glassy weakly porphyritic clinopyroxene- and plagioclase-phyric dacite; 2%–3% fragments of light tan siltstone; trace olivine-phyric basalt granules.	Tb 4	
820–835	Dacitic sediments—medium light gray (N6) silty coarse to fine sand with granules, detritus predominantly of glassy clinopyroxene-phyric dacite. 820–835 ft WR: abundant silt matrix. +10F: 85%–95% subrounded to rounded granules of light gray glassy phenocryst-poor, clinopyroxene-phyric dacites; 5%–15% fragments of light tan siltstone.	Tb 4	

Borehole Lithologic Log (continued)

Borehole ID: R-41	**TA:** 54	**Page:** 14 of 16	
Depth (ft bgs)	Lithology	Lithologic Symbol	Notes
835–850	Dacite lava—medium (N5) to medium light gray (N6) chips of massive lava, phenocryst-poor, clinopyroxene-phyric dacite with glassy to microcrystalline groundmass. 835 –850 ft WR: abundant silt particles. +10F: 98% chips of light gray glassy clinopyroxene-phyric dacite lava, phenocrysts (up to 1% by volume) of small (up to 2 mm in diameter) black clinopyroxene, plagioclase (up to 3 mm in diameter) with groundmass that is glassy to aphanitic.	Tb 4	
850–870	Dacite lava—medium (N5) to medium light gray (N6) chips of massive lava, very weakly porphyritic with aphanitic to glassy groundmass, clinopyroxene-phyric dacite. 850–870 ft WR: abundant silt particles. +10F: 99%–100% subangular chips of medium and light gray dacite, phenocrysts (up to 1% by volume) of plagioclase, black clinopyroxene, and amber orthopyroxene; groundmass glassy to microcrystalline; trace fragments of very fine grained sandstone.	Tb 4	
870–880	Dacite lava—light brownish gray (5YR 6/1) chips of massive lava, phenocryst-poor, very weakly porphyritic with aphanitic to partly glassy groundmass. 870–880 ft WR: abundant silt particles. +10F: 98%–99% subangular chips of dark gray and light gray dacite, phenocrysts (1%–2% by volume) black clinopyroxene and amber orthopyroxene that occur as small cumulophyric clusters with minor white plagioclase; 1%–2% rounded fragments of light tan clay and very fine grained silty sandstone.	Tb 4	
880–910	Dacite lava—very pale orange (10YR 8/2) chips of massive lava, phenocryst-poor, very weakly porphyritic with aphanitic to glassy groundmass, abundant silt. 880–885 ft WR: abundant silt particles. +10F: 96%–98% subangular chips of dark gray and light gray dacite, phenocrysts (up to 1% by volume) of clinopyroxene, orthopyroxene and plagioclase; 2%–4% rounded fragments of light tan clay and very fine grained silty sandstone. 885–890 ft no cuttings preserved; lost circulation interval. 890–910 ft similar to 880–885 ft.	Tb 4	
910–920	Dacite lava—very pale orange (10YR 8/2) chips of massive lava, phenocryst-poor, very weakly porphyritic with aphanitic to partly glassy groundmass. +10F: 100% subangular to subrounded chips of dark gray and light gray dacite, phenocrysts(up to 1% by volume) black clinopyroxene, orthopyroxene and plagioclase, chips are silt coated.	Tb 4	

Borehole Lithologic Log (continued)

Borehole ID: R-41		**TA:** 54	**Page:** 15 of 16
Depth (ft bgs)	Lithology	Lithologic Symbol	Notes
920–930	**UNASSIGNED QUARTZO-FELDSPATHIC GRAVELS:** 920–925 ft WR: abundant silt particles. +10F: 99% angular silt-coated chips of dark gray and light gray pyroxene-phyric dacite, phenocrysts (up to 1% by volume); up to 1% siltstone fragments. 925–930 ft no cuttings preserved; lost circulation interval.	N/S	The contact between dacite lava and underlying Totavi-like riverine deposits is placed at 925 ft bgs based on analysis of drill cuttings and natural gamma ray log data.
930–950	Axial river deposits—light pinkish gray (5YR 7/2) silty fine to medium sand with granules, detritus predominantly of dacite plus quartzo-feldspathic grains. 930–950 ft WR: silt-rich sample. +10F: 40%–50% fragments of indurated pale tan siltstone and fine to medium-grained sandstone; 40%–50% subangular granules (up to 7 mm in diameter) predominantly of gray dacite; clasts silt coated. +35F: contains 15%–20% subangular to subrounded grains quartzite and microcline. 935–950 ft no cuttings preserved; lost circulation interval.	N/S	A 99-ft-thick interval of Totavi-like riverine deposits was encountered from 925 ft to the TD of the R-41 borehole at 1024 ft bgs
950–965	Axial river deposits—light pinkish tan (7.5YR 8/3) silty fine to medium sand with minor fine gravel, rounded detritus of diverse volcanic and quartzo-feldspathic materials. 950–965 ft WR: abundant silt matrix. +10F: subrounded to well rounded pebbles (up to 21 mm in diameter) of quartzite, granite and various volcanic rocks (andesite, rhyolite, dacite). +35F: detrital grains include abundant volcanics, lesser quartzite, microcline, chert and fragments of silty very fine grained sandstone. Note: abundance of quartzo-feldspathic constituents increases relative to volcanics downward in the interval.	N/S	
965–980	Axial river deposits—pinkish white (7.5YR 8/2) silty pebble gravels with fine to coarse sand, detritus of mixed Precambrian quartzo-feldspathic and diverse volcanic lithologies. 965–980 ft WR: silt-rich sample. +10F: subangular to subrounded pebbles and granules of quartzite, granite, microcline, chert and various volcanic rocks (gray dacites, andesite); also fragments of indurated fine grained sandstone. +35F: 15%–25% subangular volcanic grains; 80%–85% quartzo-feldspathic sand grains.	N/S	

Borehole Lithologic Log (continued)

Borehole ID: R-41		**TA:** 54	**Page:** 16 of 16
Depth (ft bgs)	Lithology	Lithologic Symbol	Notes
980–995	Axial river deposits—pinkish gray (7.5YR 7/2) silty pebble gravels with fine to coarse sand, locally some clayey silt, detritus composed of abundant Precambrian quartzo-feldspathic and lesser volcanic lithologies. 980–995 ft WR: silt-rich samples. +10F: subangular to subrounded pebbles and granules (up to 20 mm in diameter) of mixed Precambrian (quartzite, granite, microcline) and less abundant volcanic rocks (porphyritic and fine-grained dacites). +35F: subangular to subrounded detrital grains composed of 20%–25% volcanic rocks; 75%–80% quartzite, quartz, microcline, other feldspars and granite.	N/S	
995–1005	Axial river deposits— pinkish gray (7.5YR 7/2) pebble gravels with fine to coarse sand and silt, locally some clayey silt, subangular to subrounded detritus composed of Precambrian quartzo-feldspathic and lesser volcanic lithologies. 995–1005 ft WR: silt-rich matrix. +10F: subangular, subrounded and partly well rounded pebble clasts (up to 33 mm in diameter) predominantly made up of quartzo-feldspathic rocks (quartzite, granite, microcline) and less abundant volcanic rocks (varieties of dacite, andesite). +35F: 85%–90% subangular sand grains of quartz and feldspar; 10%–15% volcanic grains.	N/S	
1005–1024	Axial river deposits— pinkish gray (7.5YR 7/2) silty fine gravels with fine to coarse sand, commonly well rounded detritus composed of mixed Precambrian quartzo-feldspathic and lesser volcanic lithologies. 1005–1024 ft. +10F: subrounded to well rounded pebbles (up to 23 mm in diameter) composed of quartzite, chert, granite and various volcanic lithologies (pink and gray dacites, rhyolites). +35F: 10%–15% volcanic grains; 85–90% grains of quartz, feldspar and granite.	N/S	

Borehole Lithologic Log (continued)

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.

ft = feet.

GM = groundmass

Qbt 2 = Unit 2 of Tshirege Member of the Bandelier Tuff

Qbt 1v= Unit 1v of Tshirege Member of the Bandelier Tuff

Qbt 1g= Unit 1g of Tshirege Member of the Bandelier Tuff

Qct = Cerro Toledo Interval

Qbo = Otowi Member of Bandelier Tuff.

Qbog = Guaje Pumice Bed.

Tb 4 = Cerros del Rio basalt.

N/S = no assigned symbol for geologic unit.

WR = whole rock (unsieved sample)

+10F = plus No. 10 sieve sample fraction

+35F = plus No. 35 sieve sample fraction

1 mm = 0.039 in

1 in = 25.4 mm

Appendix B

Groundwater Analytical Results

B-1.0 SAMPLING AND ANALYSIS OF GROUNDWATER AT R-41

A total of 17 groundwater samples were collected during drilling, well development, and aquifer performance testing at R-41. Eight groundwater-screening samples were collected at borehole R-41 during drilling within the regional aquifer. Three groundwater-screening samples were collected from well R-41 during development, and six groundwater-screening samples were collected during aquifer performance testing. These groundwater samples were collected between the lower screened interval from 965.3 to 975.0 ft below ground surface (bgs). Well R-41 screen 1 became dry before sampling; consequently, no groundwater samples could be collected for chemical analyses. The filtered samples collected from R-41 screen 2 were analyzed for cations, anions, perchlorate, and metals. A total of 11,036 gal. of groundwater was pumped from R-41 screen 2 during development, and an additional 5233 gal. of groundwater was pumped from this screen during aquifer performance testing.

B-1.1 Field Preparation and Analytical Techniques

Chemical analyses of groundwater-screening samples were performed at Los Alamos National Laboratory's (LANL's or the Laboratory's) Earth and Environmental Sciences Group 14 (EES-14). Groundwater samples were filtered (0.45-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 (IC) (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 (EPA Method 314.0, rev. 1). Inductively coupled (argon) plasma optical emission spectroscopy (ICPOES) (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 (ICPMS) (EPA Method 200.8, rev. 5.4). The precision limits (analytical error) for major ions and trace elements were generally less than ±7% using ICPOES and ICPMS. Total carbonate alkalinity (EPA Method 310.1) was measured using standard titration techniques. No groundwater samples were collected for total organic carbon (TOC) analyses at R-41 before well development. Analyses of TOC were performed on groundwater samples collected during well development and aquifer performance testing following EPA Method 415.1. Charge balance errors for total cations and anions were generally less than ±6% for complete analyses of the above inorganic chemicals. The negative cation-anion charge balance values indicate excess anions for the filtered samples.

Six borehole water samples collected during drilling of R-41 were analyzed for tritium using the direct counting method performed by the University of Miami.

B-1.2 Field Parameters

B-1.2.1 Well Development

Water samples were drawn from the pump flow 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 well development at R-41 screen 2, are provided in Table B-1.2-1. Thirteen measurements of pH and temperature varied from 7.98 to 8.06 and from 21.03°C to 21.77°C, respectively, in groundwater pumped from well R-41 screen 2 during development. Concentrations of DO ranged from 4.83 to 5.56 mg/L. Uncorrected ORP values varied from –57.4 to +22.7 millivolts (mV) during well development of R-41 screen 2 (Table B-1.2-1). These ORP measurements taken during well development are not considered to be entirely reliable and representative of the known relatively oxidizing conditions characteristic of the regional aquifer beneath the Pajarito Plateau, based on analytical results for redox-sensitive solutes, including detectable chromium, nitrate, sulfate, and uranium provided in Table B-1.3-1. Measurable concentrations of these solutes are consistent with overall oxidizing conditions encountered at the well. Specific conductance decreased from 221 to 209 microsiemens per centimeter (μS/cm), and turbidity ranged from 0 to 23.5 nephelometric turbidity units (NTUs) during well development of R-41 screen 2 (Table B-1.2-1).

B-1.2.2 Aquifer Performance Testing

During aquifer performance testing at well R-41 screen 2, 23 measurements of pH and temperature varied from 7.96 to 8.19 and from 15.16°C to 23.05°C, respectively (Table B-1.2-1). Concentrations of DO varied from 5.36 to 7.05 mg/L and positive, uncorrected ORP values ranged from 26.1 to 96.2 mV during aquifer performance testing of R-41 screen 2. The uncorrected ORP values are generally consistent with both the DO measurements and analytical results for redox-sensitive solutes listed above and are provided in Table B-1.3-1. Specific conductance and turbidity generally decreased from 199 to 174 μS/cm and from 45.8 to 5.8 NTUs for groundwater pumped from R-41 screen 2 during aquifer performance testing.

B-1.3 Analytical Results for Groundwater-Screening Samples

B-1.3.1 Tritium Analyses of Borehole R-41

Concentrations of tritium in five of six screening borehole samples were less than analytical detection (10 pCi/L). The nondetect tritium values ranged from 0±10 (1 sigma error) pCi/L to 6±10 pCi/L. One sample (GW-41-09-3516) collected at 985 ft bgs, however, contained 13±10 pCi/L of tritium.

B-1.3.2 Well Development

Analytical results for groundwater-screening samples collected at R-41 during drilling, well development, and aquifer performance testing are provided in Table B-1.3-1. Calcium and sodium are the dominant cations in groundwater collected from well R-41 screen 2 during development. Dissolved concentrations of calcium and sodium ranged from 13.82 to 14.52 ppm or mg/L and from 21.6 to 26.5 ppm, respectively (Table B-1.3-1). Dissolved concentrations of chloride and fluoride ranged from 6.63 to 7.71 ppm and from 0.40 to 0.41 ppm, respectively, during well development. Dissolved concentrations of nitrate(N) and sulfate ranged from 0.37 to 0.65 ppm and from 10.74 to 13.75 ppm, respectively, during this phase. The median background concentration for dissolved fluoride in the regional aquifer is 0.37 mg/L (LANL 2007, 095817). Dissolved concentrations of chloride, nitrate(N), and sulfate exceeded Laboratory median background for regional aquifer groundwater (LANL 2007, 095817). Median background concentrations for dissolved chloride, nitrate plus nitrite(N), and sulfate in the regional aquifer are 2.17 mg/L, 0.31 mg/L, and 2.83 mg/L, respectively (LANL 2007, 095817). Concentrations of TOC ranged from 0.21 to 0.29 mgC/L in groundwater-screening samples collected during development conducted at well R-41 screen 2 (Table B-1.3-1). The median background concentration of TOC is 0.34 mgC/L for regional aquifer groundwater (LANL 2007, 095817). Concentrations of perchlorate were less than analytical detection (<0.005 ppm, IC method) in groundwater-screening samples collected from well R-41 screen 2 during development (Table B-1.3-1).

During well development conducted at R-41 screen 2, dissolved concentrations of iron ranged from 0.029 to 0.135 ppm (29 to 135 μg/L, or 29 to 135 ppb) using ICPOES (Table B-1.3-1), which exceeded the median background value of 9.5 μg/L for regional aquifer groundwater (LANL 2007, 095817). Dissolved concentrations of manganese ranged from 0.060 to 0.065 ppm or 60 to 65 ppb (Table B-1.3-1), which exceeded the median background value of 1.0 μg/L (1 ppb or 0.001 ppm) for regional aquifer groundwater (LANL 2007, 095817). A carbon-steel discharge pipe was used during well development at R-41 screen 2, which contributed some iron and manganese in the form of colloidal rust to the filtered groundwater samples. Dissolved concentrations of boron ranged from 0.034 to 0.043 ppm or 34 to 43 ppb (Table B-1.3-1) at well R-41 screen 2, which is below the maximum background value of 51.6 μg/L or ppb (0.0516 ppm) for the regional aquifer (LANL 2007, 095817). Dissolved concentrations of nickel were 0.003 ppm or 3 ppb (Table B-1.3-1) in three groundwater-screening samples collected during well development conducted at R-41 screen 2. Dissolved concentrations of zinc ranged from 0.003 to 0.006 ppm or 3 to 6 ppb in groundwater-screening samples collected at well R-41 screen 2 during development (Table B-1.3-1). The background median concentration of zinc in filtered samples is 1.45 μg/L or ppb (0.00145 ppm) for the regional aquifer (LANL 2007, 095817). Total dissolved concentrations of chromium were 0.001 ppm (1 ppb or 1 μg/L) at well R-41 screen 2 during well development (Table B-1.3-1). Background mean, median, and maximum concentrations of total dissolved chromium are 3.07 μg/L or ppb (0.00307 ppm), 3.05 μg/L or ppb (0.00305 ppm), and 7.20 μg/L or ppb (0.00720 ppm), respectively, for the regional aquifer (LANL 2007, 095817).

B-1.3.3 Aquifer Performance Testing

Calcium and sodium are the dominant cations in groundwater collected from well R-41 screen 2 during aquifer performance testing. Dissolved concentrations of calcium and sodium ranged from 12.96 to 13.96 ppm and from 18.2 to 22.1 ppm, respectively (Table B-1.3-1). Dissolved concentrations of chloride and fluoride ranged from 4.71 to 4.85 ppm and from 0.50 to 0.56 ppm, respectively, during aquifer performance testing. Dissolved concentrations of nitrate(N) and sulfate ranged from 0.45 to 0.56 ppm and from 7.08 to 8.0 ppm, respectively, during this phase. Dissolved concentrations of chloride, nitrate(N), and sulfate exceeded Laboratory median background for regional aquifer groundwater (LANL 2007, 095817). Median background concentrations for dissolved chloride, nitrate plus nitrite(N), and sulfate in the regional aquifer are 2.17 mg/L or ppm, 0.31 mg/L or ppm, and 2.83 mg/L or ppm, respectively (LANL 2007, 095817). Concentrations of TOC ranged from 0.20 to 0.24 mgC/L in groundwater-screening samples collected during aquifer performance testing conducted at well R-41 screen 2 (Table B-1.3-1). Concentrations of perchlorate were less than analytical detection (<0.005 ppm, IC method) in groundwater-screening samples collected from well R-41 screen 2 during aquifer performance testing (Table B-1.3-1).

During aquifer performance testing conducted at R-41 screen 2, detectable dissolved concentrations of iron decreased from 0.064 to 0.017 ppm (64 to 17 ppb) using ICPOES (Table B-1.3-1), which exceeded the median background value of 9.5 μg/L or ppb (0.0095 ppm) for regional aquifer groundwater (LANL 2007, 095817). Dissolved concentrations of manganese generally decreased from 0.039 to 0.034 ppm (Table B-1.3-1), which exceeded the median background value of 1.0 μg/L or ppb (0.001 ppm) for regional aquifer groundwater (LANL 2007, 095817). Dissolved concentrations of boron decreased from 0.029 to 0.016 ppm (29 to 16 ppb) (Table B-1.3-1) at well R-41 screen 2, which is below the maximum background value of 51.6 μg/L or ppb (0.0516 ppm) for the regional aquifer (LANL 2007, 095817). Dissolved concentrations of nickel ranged from 0.004 to 0.005 ppm (4 to 5 ppb) (Table B-1.3-1) in six groundwater-screening samples collected during aquifer performance testing conducted at R-41 screen 2. Dissolved concentrations of zinc ranged from 0.006 to 0.008 ppm (6 to 8 ppb) in groundwater-screening samples collected at well R-41 screen 2 during this phase of testing (Table B-1.3-1). The background median concentration of zinc in filtered samples is 1.45 μg/L or ppb (0.00145 ppm) for the regional aquifer (LANL 2007, 095817). Total dissolved concentrations of chromium ranged from 0.002 to

0.003 ppm (2 to 3 μg/L or ppb) at well R-41 screen 2 during well development (Table B-1.3-1). Background mean, median, and maximum concentrations of total dissolved chromium are 3.07 μg/L or ppb (0.00307 ppm), 3.05 μg/L, or ppb (0.00305 ppm) and 7.20 μg/L or ppb (0.00720 ppm), respectively, for the regional aquifer (LANL 2007, 095817).

B-2.0 REFERENCE

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

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

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

Table B-1.2-1
Well Development Volumes, Aquifer Pumping Test Volumes, and Associated Field Water-Quality Parameters for R-41

Date	pH	Temp (°C)	DO (mg/L)	ORP (mV)	Specific Conductivity (µS/cm)	Turbidity (NTU)	Purge Volume between Samples (gal.)	Cumulative Purge Volume (gal.)
Well Development								
03/21/09	n/r,* bailing						270	270
03/22/09	n/r, bailing						605	875
03/23/09	n/r, pumping with swabbing						1030	1905
03/24/09	n/r, pumping with swabbing						756	2661
03/024/09 (lower screen)	8.02	21.03	4.89	-0.8	221	5.5	663	3324
	8.00	21.43	4.96	-57.4	219	23.5	204	3528
	8.05	21.44	4.98	11.9	210	7.2	153	3681
	8.05	21.41	4.94	3.8	217	0.4	153	3834
	8.05	21.41	4.97	1.8	216	2.8	153	3987
	8.05	21.59	4.94	2.7	215	3.0	153	4140
	8.04	21.61	4.96	16.0	214	0.0	153	4293
	7.98	21.57	4.83	22.7	213	0.0	153	4446
	8.05	21.50	5.01	19.0	213	0.0	153	4599
	8.04	21.63	4.95	19.7	212	0.0	153	4752
	8.06	21.77	4.84	15.4	211	0.0	153	4905
	8.03	21.63	5.44	-18.1	209	0.0	153	5058
	8.03	21.67	5.56	-16.7	209	0.0	77	5135
03/25/09	n/r, pumping						3354	8489
03/26/09	n/r, pumping						2547	11,036
Aquifer Pumping Test Volumes								
03/29/09	n/r, pumping, test pump operation						120	120
03/30/09	n/r, pumping, mini-test						555	675
03/31/09	7.98	15.16	5.45	96.2	185	36.1	1	676
	8.18	16.57	5.36	75.6	199	27.7	189	865
	8.15	19.03	5.83	89.8	190	45.8	189	1054
	8.14	19.87	5.90	85.3	186	26.7	189	1243
	8.13	20.40	5.87	76.6	187	20.6	189	1432
	8.10	21.58	6.24	53.8	183	14.9	189	1621
	8.13	21.41	6.34	56.9	182	13.1	189	1810
	8.11	22.14	6.41	61.5	180	10.6	189	1999
	8.15	20.66	6.56	55.5	181	10.9	189	2188
	8.19	18.39	6.78	53.3	181	10.3	189	2377
	8.11	20.66	6.73	53.7	179	9.5	368	2745
	8.12	20.72	6.82	68.6	179	7.3	189	2934
	8.11	19.58	6.79	41.4	178	8.3	189	3123
	8.06	21.60	6.82	26.1	177	8.2	189	3312
	8.12	20.78	7.05	32.4	178	7.2	189	3501
	8.12	21.33	6.62	35.7	178	7.7	189	3690

Table B-1.2-1 (continued)

Date	pH	Temp (°C)	DO (mg/L)	ORP (mV)	Specific Conductivity (µS/cm)	Turbidity (NTU)	Purge Volume between Samples (gal.)	Cumulative Purge Volume (gal.)
04/01/09	7.96	22.26	6.45	39.0	176	7.7	189	3879
	8.07	21.55	6.84	38.4	175	5.5	189	4068
	8.07	22.12	6.98	43.3	177	6.7	189	4257
	8.11	22.52	6.93	39.0	177	6.7	189	4446
	n/r	n/r	n/r	n/r	n/r	n/r	189	4635
	8.08	22.70	6.85	52.3	176	7.0	189	4824
	8.12	22.09	7.00	46.7	174	7.5	189	5013
	8.13	23.05	6.85	65.3	175	5.8	189	5202
	n/r	n/r	n/r	n/r	n/r	n/r	31	5233
Postpumping Test Purging								
04/03/09	n/r, pumping						2479	2479
04/04/09	n/r, pumping						128	2607

Notes: Upper well screen is nonproductive. Cumulative purge volumes calculated using average pump discharge rate of 3.2 gpm during 24-h pump test.

*n/r = Not recorded.

Table B-1.3-1
Analytical Results for Groundwater-Screening Samples Collected at R-41 Screen 2, Pajarito Canyon, New Mexico

Sample ID	Date Received	ER/RRES-WQH	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)	TOC rslt (ppm)	Ca rslt (ppm)	stdev (Ca)	Cd rslt (ppm)	stdev (Cd)
GW41-09-3494	2/24/2009	09-973	Borehole	856	0.001	U[b]	1.689	0.011	0.0007	0.0000	0.032	0.000	0.053	0.000	0.001	U	0.03	Not applicable	9.55	0.06	0.001	U
GW41-09-3495	2/24/2009	09-973	Borehole	870	0.001	U	4.829	0.015	0.0007	0.0000	0.028	0.000	0.163	0.001	0.001	U	0.04	Not applicable	16.92	0.10	0.001	U
GW41-09-3496	2/24/2009	09-973	Borehole	895	0.001	U	1.816	0.020	0.0007	0.0000	0.023	0.001	0.072	0.001	0.001	U	0.06	Not applicable	17.53	0.10	0.001	U
GW41-09-3497	2/24/2009	09-973	Borehole	922	0.001	U	1.139	0.017	0.0006	0.0000	0.020	0.001	0.055	0.001	0.001	U	0.03	Not applicable	18.18	0.09	0.001	U
GW41-09-3498	2/24/2009	09-973	Borehole	962	0.001	U	0.031	0.000	0.0005	0.0000	0.022	0.001	0.037	0.000	0.001	U	0.05	Not applicable	18.79	0.15	0.001	U
GW41-09-3499	2/24/2009	09-973	Borehole	982	0.001	U	0.018	0.000	0.0006	0.0000	0.025	0.000	0.040	0.000	0.001	U	0.06	Not applicable	19.14	0.15	0.001	U
GW41-09-3500	2/24/2009	09-973	Borehole	1002	0.001	U	0.372	0.001	0.0007	0.0000	0.026	0.001	0.054	0.000	0.001	U	0.06	Not applicable	15.77	0.10	0.001	U
GW41-09-3501	2/24/2009	09-973	Borehole	1022	0.001	U	0.164	0.002	0.0006	0.0000	0.026	0.001	0.045	0.000	0.001	U	0.07	Not applicable	15.70	0.08	0.001	U
GW41-09-3474	3/26/2009	09-1308	Development	973	0.001	U	0.005	0.000	0.0016	0.0000	0.043	0.001	0.039	0.001	0.001	U	0.03	0.29	14.52	0.16	0.001	U
GW41-09-3475	3/26/2009	09-1308	Development	973	0.001	U	0.004	0.000	0.0013	0.0000	0.039	0.000	0.032	0.000	0.001	U	0.04	0.24	13.99	0.13	0.001	U
GW41-09-3476	3/26/2009	09-1308	Development	973	0.001	U	0.005	0.000	0.0012	0.0001	0.034	0.000	0.029	0.000	0.001	U	0.04	0.21	13.82	0.04	0.001	U
GW41-09-3477	4/2/2009	09-1362	Pumping Test	973	0.001	U	0.005	0.000	0.0019	0.0001	0.029	0.001	0.037	0.001	0.001	U	0.04	0.24	12.96	0.04	0.001	U
GW41-09-3478	4/2/2009	09-1362	Pumping Test	973	0.001	U	0.005	0.000	0.0018	0.0000	0.023	0.001	0.033	0.000	0.001	U	0.11	0.21	13.29	0.03	0.001	U
GW41-09-3479	4/2/2009	09-1362	Pumping Test	973	0.001	U	0.079	0.001	0.0015	0.0001	0.021	0.001	0.029	0.001	0.001	U	0.04	0.22	13.45	0.10	0.001	U
GW41-09-3480	4/2/2009	09-1362	Pumping Test	973	0.001	U	0.005	0.000	0.0015	0.0001	0.019	0.000	0.028	0.001	0.001	U	0.04	0.21	13.49	0.06	0.001	U
GW41-09-3481	4/2/2009	09-1362	Pumping Test	973	0.001	U	0.006	0.000	0.0015	0.0000	0.020	0.001	0.028	0.001	0.001	U	0.04	0.22	13.77	0.09	0.001	U
GW41-09-3482	4/2/2009	09-1362	Pumping Test	973	0.001	U	0.005	0.000	0.0014	0.0001	0.016	0.000	0.026	0.001	0.001	U	0.04	0.20	13.96	0.04	0.001	U

Table B-1.3-1 (continued)

Sample ID	Date Received	ER/RRES-WQH	Sample Type	Cl(-) (ppm)	ClO4(-) (ppm)	ClO4(-) (U)	Co rslt (ppm)	stdev (Co)	Alk-CO3 rslt (ppm)	ALK-CO3 (U)	Cr rslt (ppm)	stdev (Cr)	Cs rslt (ppm)	stdev (Cs)	Cu rslt (ppm)	stdev (Cu)	F(-) (ppm)	Fe rslt (ppm)	stdev (Fe)	Alk-CO3+HCO3 rslt (ppm)	HCO3 rslt (ppm)	Hg rslt (ppm)	stdev (Hg)
GW41-09-3494	2/24/2009	09-973	Borehole	10.95	0.005	U	0.001	U	0.8	U	0.006	0.000	0.001	U	0.033	0.000	1.64	0.816	0.005	111	135	0.00040	0.00001
GW41-09-3495	2/24/2009	09-973	Borehole	10.26	0.005	U	0.001	U	0.8	U	0.003	0.000	0.001	U	0.020	0.000	1.25	1.220	0.013	146	178	0.00044	0.00001
GW41-09-3496	2/24/2009	09-973	Borehole	8.22	0.005	U	0.001	U	0.8	U	0.003	0.001	0.001	U	0.001	0.000	0.78	0.493	0.006	125	152	0.00027	0.00001
GW41-09-3497	2/24/2009	09-973	Borehole	9.39	0.005	U	0.001	U	0.8	U	0.001	0.001	0.001	U	0.002	0.000	0.97	0.245	0.004	149	182	0.00020	0.00001
GW41-09-3498	2/24/2009	09-973	Borehole	10.74	0.005	U	0.001	U	0.8	U	0.001	0.000	0.001	U	0.001	U	0.86	0.010	U	133	162	0.00024	0.00001
GW41-09-3499	2/24/2009	09-973	Borehole	12.53	0.005	U	0.001	U	0.8	U	0.004	0.002	0.001	U	0.001	U	1.04	0.010	U	141	172	0.00029	0.00001
GW41-09-3500	2/24/2009	09-973	Borehole	9.68	0.005	U	0.001	U	0.8	U	0.002	0.000	0.001	U	0.001	U	0.83	0.205	0.001	133	162	0.00027	0.00000
GW41-09-3501	2/24/2009	09-973	Borehole	10.95	0.005	U	0.001	U	0.8	U	0.003	0.001	0.001	U	0.004	0.000	0.96	0.066	0.001	125	152	0.00031	0.00000
GW41-09-3474	3/26/2009	09-1308	Development	7.71	0.005	U	0.001	U	0.8	U	0.001	0.000	0.001	U	0.001	0.000	0.40	0.045	0.001	119	145	0.00005	U
GW41-09-3475	3/26/2009	09-1308	Development	7.17	0.005	U	0.001	U	0.8	U	0.001	0.000	0.001	U	0.001	0.000	0.41	0.029	0.001	112	137	0.00005	U
GW41-09-3476	3/26/2009	09-1308	Development	6.63	0.005	U	0.001	U	0.8	U	0.001	0.000	0.001	U	0.002	0.000	0.41	0.135	0.001	104	127	0.00005	U
GW41-09-3477	4/2/2009	09-1362	Pumping Test	4.85	0.005	U	0.001	U	0.8	U	0.002	0.000	0.001	U	0.002	0.000	0.56	0.010	U	103	126	0.00005	U
GW41-09-3478	4/2/2009	09-1362	Pumping Test	4.84	0.005	U	0.001	U	0.8	U	0.002	0.000	0.001	U	0.002	0.000	0.52	0.010	U	98	120	0.00005	U
GW41-09-3479	4/2/2009	09-1362	Pumping Test	4.80	0.005	U	0.001	U	0.8	U	0.002	0.000	0.001	U	0.002	0.001	0.52	0.064	0.001	97	118	0.00005	U
GW41-09-3480	4/2/2009	09-1362	Pumping Test	4.71	0.005	U	0.001	U	0.8	U	0.002	0.000	0.001	U	0.002	0.000	0.51	0.022	0.000	96	117	0.00005	U
GW41-09-3481	4/2/2009	09-1362	Pumping Test	4.77	0.005	U	0.001	U	0.8	U	0.003	0.000	0.001	U	0.002	0.000	0.50	0.020	0.000	96	117	0.00005	U
GW41-09-3482	4/2/2009	09-1362	Pumping Test	4.74	0.005	U	0.001	U	0.8	U	0.002	0.000	0.001	U	0.002	0.000	0.54	0.017	0.000	96	117	0.00005	U

Table B-1.3-1 (continued)

Sample ID	Date Received	ER/RRES-WQH	Sample Type	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)	Ni rslt (ppm)	stdev (Ni)	NO2 (ppm)	NO2-N rslt (ppm)	NO2-N (U)	NO3 (ppm)	NO3-N rslt (ppm)	C2O4 rslt (ppm)	C2O4 (U)
GW41-09-3494	2/24/2009	09-973	Borehole	5.95	0.03	0.038	0.000	2.69	0.01	0.102	0.001	0.001	U	36.02	0.29	0.002	0.000	0.06	0.02	>MDL[c]	2.38	0.54	0.56	>MDL
GW41-09-3495	2/24/2009	09-973	Borehole	6.50	0.03	0.039	0.000	4.25	0.01	0.188	0.002	0.001	U	33.71	0.04	0.003	0.000	0.15	0.04	>MDL	2.35	0.53	0.17	>MDL
GW41-09-3496	2/24/2009	09-973	Borehole	4.21	0.05	0.032	0.000	4.34	0.06	0.037	0.000	0.138	0.000	22.73	0.26	0.002	0.000	0.25	0.07	>MDL	2.82	0.64	0.04	>MDL
GW41-09-3497	2/24/2009	09-973	Borehole	4.83	0.06	0.041	0.001	4.98	0.04	0.075	0.001	0.001	U	24.99	0.46	0.002	0.000	0.47	0.14	>MDL	3.00	0.68	0.06	>MDL
GW41-09-3498	2/24/2009	09-973	Borehole	4.06	0.03	0.042	0.000	5.18	0.04	0.180	0.001	0.001	U	20.09	0.15	0.002	0.000	0.01	0.00	>MDL	1.66	0.38	0.06	>MDL
GW41-09-3499	2/24/2009	09-973	Borehole	5.84	0.06	0.050	0.000	5.37	0.03	0.244	0.002	0.001	U	24.00	0.15	0.002	0.000	0.01	0.00	>MDL	2.13	0.48	0.06	>MDL
GW41-09-3500	2/24/2009	09-973	Borehole	6.15	0.03	0.042	0.000	4.59	0.03	0.304	0.001	0.108	0.001	21.61	0.17	0.002	0.000	0.04	0.01	>MDL	1.97	0.45	0.03	>MDL
GW41-09-3501	2/24/2009	09-973	Borehole	5.72	0.05	0.043	0.000	4.91	0.06	0.230	0.001	0.161	0.001	23.57	0.12	0.002	0.000	0.01	0.00	U	2.25	0.51	0.04	>MDL
GW41-09-3474	3/26/2009	09-1308	Development	1.86	0.00	0.025	0.001	4.17	0.03	0.065	0.001	0.007	0.000	26.52	0.25	0.003	0.000	0.01	0.00	U	2.22	0.50	0.01	U
GW41-09-3475	3/26/2009	09-1308	Development	1.78	0.02	0.024	0.000	3.84	0.03	0.060	0.001	0.006	0.000	23.25	0.14	0.003	0.000	0.01	0.00	U	1.62	0.37	0.01	U
GW41-09-3476	3/26/2009	09-1308	Development	1.79	0.02	0.023	0.000	3.87	0.02	0.062	0.000	0.005	0.000	21.57	0.15	0.003	0.000	0.01	0.00	U	2.86	0.65	0.01	U
GW41-09-3477	4/2/2009	09-1362	Pumping Test	1.81	0.01	0.021	0.001	3.65	0.01	0.038	0.001	0.006	0.000	22.06	0.02	0.004	0.000	0.01	0.00	U	1.98	0.45	0.01	U
GW41-09-3478	4/2/2009	09-1362	Pumping Test	1.76	0.01	0.023	0.000	3.64	0.04	0.039	0.001	0.004	0.000	20.04	0.14	0.005	0.000	0.01	0.00	U	2.03	0.46	0.01	U
GW41-09-3479	4/2/2009	09-1362	Pumping Test	1.79	0.01	0.022	0.000	3.79	0.02	0.037	0.001	0.004	0.000	19.63	0.12	0.004	0.000	0.01	0.00	U	2.31	0.52	0.01	U
GW41-09-3480	4/2/2009	09-1362	Pumping Test	1.77	0.01	0.023	0.000	3.77	0.00	0.036	0.001	0.004	0.000	18.86	0.04	0.004	0.000	0.01	0.00	U	2.51	0.57	0.01	U
GW41-09-3481	4/2/2009	09-1362	Pumping Test	1.78	0.00	0.023	0.001	3.83	0.01	0.036	0.000	0.004	0.000	19.08	0.09	0.004	0.000	0.01	0.00	U	2.48	0.56	0.01	U
GW41-09-3482	4/2/2009	09-1362	Pumping Test	1.78	0.01	0.023	0.000	3.85	0.03	0.034	0.001	0.003	0.000	18.24	0.15	0.004	0.000	0.01	0.00	U	2.39	0.54	0.01	U

Table B-1.3-1 (continued)

Sample ID	Date Received	ER/RRES-WQH	Sample Type	Pb rslt (ppm)	stdev (Pb)	pH	PO4(-3) rslt (ppm)	PO4(-3) (U)	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)	Sr rslt (ppm)	stdev (Sr)	Th rslt (ppm)
GW41-09-3494	2/24/2009	09-973	Borehole	0.0007	0.0000	8.38	0.01	U	0.007	0.000	0.002	0.000	0.001	U	19.7	0.0	42.2	0.1	0.001	U	13.70	0.056	0.001	0.001
GW41-09-3495	2/24/2009	09-973	Borehole	0.0025	0.0000	8.35	0.01	U	0.010	0.000	0.001	U	0.001	U	41.2	0.1	88.1	0.2	0.001	U	9.85	0.111	0.001	0.001
GW41-09-3496	2/24/2009	09-973	Borehole	0.0017	0.0000	8.22	0.17	>MDL	0.006	0.000	0.001	U	0.001	U	30.4	0.3	65.1	0.6	0.001	U	6.26	0.094	0.001	0.001
GW41-09-3497	2/24/2009	09-973	Borehole	0.0006	0.0000	8.18	0.08	>MDL	0.006	0.000	0.001	U	0.001	U	25.7	0.2	55.0	0.5	0.001	U	8.09	0.092	0.001	0.001
GW41-09-3498	2/24/2009	09-973	Borehole	0.0002	U	8.19	0.01	U	0.004	0.000	0.001	U	0.001	U	14.9	0.1	31.9	0.1	0.001	U	7.29	0.091	0.000	0.001
GW41-09-3499	2/24/2009	09-973	Borehole	0.0002	U	8.32	0.01	U	0.005	0.000	0.001	U	0.001	U	13.2	0.1	28.3	0.3	0.001	U	9.02	0.090	0.000	0.001
GW41-09-3500	2/24/2009	09-973	Borehole	0.0006	0.0000	8.25	0.01	U	0.005	0.000	0.001	U	0.001	U	19.8	0.2	42.3	0.5	0.001	U	6.10	0.081	0.001	0.001
GW41-09-3501	2/24/2009	09-973	Borehole	0.0002	0.0000	8.29	0.01	U	0.005	0.000	0.001	U	0.001	U	15.6	0.2	33.4	0.4	0.001	U	7.85	0.081	0.000	0.001
GW41-09-3474	3/26/2009	09-1308	Development	0.0002	U	7.95	0.22	>MDL	0.002	0.000	0.001	U	0.001	U	31.9	0.3	68.3	0.6	0.001	U	13.75	0.078	0.001	0.001
GW41-09-3475	3/26/2009	09-1308	Development	0.0002	U	7.84	0.19	>MDL	0.002	0.000	0.001	U	0.001	U	30.5	0.1	65.3	0.2	0.001	U	11.86	0.072	0.000	0.001
GW41-09-3476	3/26/2009	09-1308	Development	0.0002	U	7.37	0.17	>MDL	0.002	0.000	0.001	U	0.001	U	31.2	0.0	66.7	0.1	0.001	U	10.74	0.068	0.000	0.001
GW41-09-3477	4/2/2009	09-1362	Pumping Test	0.0002	U	7.86	0.08	>MDL	0.002	0.000	0.001	U	0.001	U	33.0	0.3	70.5	0.7	0.001	U	8.00	0.066	0.002	0.001
GW41-09-3478	4/2/2009	09-1362	Pumping Test	0.0002	U	7.63	0.01	U	0.002	0.000	0.001	U	0.001	U	32.6	0.2	69.8	0.4	0.001	U	7.59	0.067	0.001	0.001
GW41-09-3479	4/2/2009	09-1362	Pumping Test	0.0002	U	7.58	0.02	>MDL	0.002	0.000	0.001	U	0.001	U	33.7	0.2	72.1	0.4	0.001	U	7.40	0.064	0.002	0.001
GW41-09-3480	4/2/2009	09-1362	Pumping Test	0.0002	U	7.68	0.08	>MDL	0.002	0.000	0.001	U	0.001	U	33.2	0.1	71.0	0.1	0.001	U	7.20	0.064	0.001	0.001
GW41-09-3481	4/2/2009	09-1362	Pumping Test	0.0002	U	7.64	0.07	>MDL	0.002	0.000	0.001	U	0.001	U	33.8	0.1	72.3	0.2	0.001	U	7.17	0.067	0.000	0.001
GW41-09-3482	4/2/2009	09-1362	Pumping Test	0.0002	U	7.79	0.06	>MDL	0.002	0.000	0.001	U	0.001	U	33.4	0.3	71.4	0.7	0.001	U	7.08	0.068	0.001	0.001

Table B-1.3-1 (continued)

Sample ID	Date Received	ER/RRES-WQH	Sample Type	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[a] (ppm)	Cations	Anions	Balance
GW41-09-3494	2/24/2009	09-973	Borehole	U	0.105	0.000	0.001	U	0.0004	0.0000	0.002	0.000	0.003	0.001	239	2.43	2.59	-0.03
GW41-09-3495	2/24/2009	09-973	Borehole	U	0.311	0.002	0.001	U	0.0011	0.0000	0.004	0.000	0.011	0.000	327	2.84	3.10	-0.04
GW41-09-3496	2/24/2009	09-973	Borehole	U	0.119	0.001	0.001	U	0.0010	0.0000	0.004	0.000	0.005	0.001	261	2.34	2.57	-0.05
GW41-09-3497	2/24/2009	09-973	Borehole	U	0.057	0.001	0.001	U	0.0011	0.0000	0.003	0.000	0.001	0.002	281	2.54	3.03	-0.09
GW41-09-3498	2/24/2009	09-973	Borehole	U	0.003	0.000	0.001	U	0.0012	0.0000	0.002	0.000	0.001	U	235	2.36	2.73	-0.07
GW41-09-3499	2/24/2009	09-973	Borehole	U	0.002	U	0.001	U	0.0012	0.0000	0.002	0.000	0.001	U	249	2.61	2.97	-0.06
GW41-09-3500	2/24/2009	09-973	Borehole	U	0.026	0.000	0.001	U	0.0011	0.0000	0.002	0.000	0.007	0.002	244	2.28	2.69	-0.08
GW41-09-3501	2/24/2009	09-973	Borehole	U	0.010	0.000	0.001	U	0.0006	0.0000	0.002	0.000	0.003	0.002	232	2.38	2.63	-0.05
GW41-09-3474	3/26/2009	09-1308	Development	U	0.002	U	0.001	U	0.0022	0.0000	0.006	0.000	0.006	0.000	260	2.28	2.54	-0.06
GW41-09-3475	3/26/2009	09-1308	Development	U	0.002	U	0.001	U	0.0016	0.0000	0.006	0.000	0.004	0.001	243	2.08	2.37	-0.07
GW41-09-3476	3/26/2009	09-1308	Development	U	0.002	U	0.001	U	0.0013	0.0001	0.006	0.000	0.006	0.001	234	2.00	2.22	-0.05
GW41-09-3477	4/2/2009	09-1362	Pumping Test	U	0.002	U	0.001	U	0.0013	0.0000	0.007	0.000	0.007	0.002	231	1.96	2.08	-0.03
GW41-09-3478	4/2/2009	09-1362	Pumping Test	U	0.002	U	0.001	U	0.0013	0.0000	0.007	0.000	0.006	0.001	222	1.89	1.99	-0.03
GW41-09-3479	4/2/2009	09-1362	Pumping Test	U	0.002	U	0.001	U	0.0011	0.0000	0.007	0.000	0.008	0.001	224	1.89	1.97	-0.02
GW41-09-3480	4/2/2009	09-1362	Pumping Test	U	0.002	U	0.001	U	0.0011	0.0000	0.007	0.000	0.006	0.000	221	1.86	1.95	-0.02
GW41-09-3481	4/2/2009	09-1362	Pumping Test	U	0.002	U	0.001	U	0.0011	0.0001	0.007	0.000	0.007	0.001	223	1.88	1.95	-0.02
GW41-09-3482	4/2/2009	09-1362	Pumping Test	U	0.002	U	0.001	U	0.0010	0.0000	0.007	0.000	0.007	0.001	221	1.86	1.95	-0.02

[a] TDS = Total dissolved solids.

[b] U = Not detected.

[c] >MDL = Greater than the method detection limit.

Appendix C

Aquifer Testing Report

C-1.0 INTRODUCTION

This appendix describes the hydraulic analysis of pumping tests at well R-41 screen 2 located above Pajarito Canyon near R-22. These pumping tests were conducted in accordance with EP-ERSS-SOP-5039, Pumping Test, Revision 0.0, accessible at http://www.lanl.gov/environment/all/qa/adep.shtml. Screen 1 proved to be dry and was not tested. Nevertheless, the screen 1 interval was monitored during the test to confirm whether saturated conditions existed there. The tests on screen 2 were conducted to determine the hydraulic properties of the screen zone. A secondary objective was to look for a cross-connection between R-41 and the screen zones in R-22.

Testing consisted primarily of constant-rate pumping tests conducted on R-41 screen 2. During the tests, water levels were monitored in both screens 1 and 2. In addition, water levels were downloaded from the R-22 transducers. The R-22 data showed a muted response to barometric pressure changes but no discernible response to pumping R-41 screen 2. Therefore, the R-22 data are not included here.

Consistent with most of the R-well pumping tests conducted on the plateau, an inflatable packer system was used in R-41 to isolate the screens and to try to minimize the effects of casing storage on the test data.

Conceptual Hydrogeology

R-41 is a dual-screen well completed in Pliocene riverine silts, sands, and gravels that were encountered from 920 to 1024 ft below ground surface (bgs). The static water level measured in screen 2 at the time of testing was 960.37 ft bgs on March 29, 2009.

Screen 1 is 9.7 ft long, extending from 928.0 to 937.7 ft bgs, well above the water table. Screen 2 also is 9.7 ft long and runs from 965.3 to 975 ft bgs. At the time of testing, the static water level provided less than 5 ft of water height above screen 2. The filter pack outside screen 2 extended above the water table; thus, it was expected that some filter-pack drainage would occur during testing. It was expected that this would somewhat interfere with data analysis by inducing a casing-storagelike effect on the test data.

R-41 Screen 1 Monitoring

A transducer was installed in screen 1 to verify that this zone was dry. During testing, however, water head built up over the transducer. As described below, it was determined that the source of the water was leakage through the drop pipe coupling joints. An analysis of the data confirmed that there was no water contribution from screen 1.

R-41 Screen 2 Testing

R-41 screen 2 was tested from March 30 to April 4, 2009. Testing consisted of brief trial pumping (trial 1 and trial 2) on March 30, background data collection, a 24-h constant-rate pumping test started on April 1, postrecovery purge development on April 3, and a final brief pumping event (trial 3) before pulling the pump on April 4.

Two trial tests were conducted on March 30. Trial 1 was conducted at a discharge rate of 3.17 gpm for 60 min from 8:00 to 9:00 a.m. and was followed by 60 min of recovery until 10:00 a.m. Trial 2 was conducted for 120 min from 10:00 a.m. to 12:00 p.m. at 3.14 gpm. Following shutdown, recovery/background was monitored for 44 h until 8:00 a.m. on April 1.

At 8:00 a.m. on April 1, the 24-h pumping test was begun at a rate of 3.19 gpm. Pumping continued until 8:00 a.m. on April 2. Following shutdown, recovery measurements were recorded for 24 h until 8:00 a.m. on April 3 when the packer separating screens 1 and 2 was deflated.

At 8:30 a.m. on April 3, purge development was performed in an effort to clear the well of persistent turbidity. The initial rate was 3.2 gpm, was increased to 9.6 gpm, and eventually was reduced to an average of about 4 gpm throughout most of the development period. Pump shutoff occurred at 6:30 p.m.

On April 4, brief pumping (trial 3) was performed at variable rates from 7:05 to 7:20 a.m.

Leaky Drop Pipe Joints

During the R-41 testing, there was leakage through the threaded joints on the 1 ½-in. stainless-steel drop pipe (1.90-in. outside diameter [O.D.] × 1.61-in. inside diameter [I.D.]), creating downhole voids inside the drop pipe beneath the check valves. This allowed initial pump operation against reduced head until the voids were refilled. The result was an elevated pumping rate for a brief period at the beginning of most of the tests. The leaks were caused by either worn or improperly manufactured threads, as well as by the need to avoid wrenching the pipe extremely as a precaution against galling the stainless-steel threads.

A result of the leakage was that water filled the sump between screen 1 and the inflatable packer, allowing detection of water head over the screen 1 transducer. As described below, this outcome was useful in documenting the lack of water contribution from screen 1.

C-2.0 BACKGROUND DATA

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

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

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

Subsequent pumping tests, including R-41, have utilized nonvented transducers. These devices simply record the total pressure on the transducer, that is, the sum of the water height plus the barometric pressure. This results in an attenuated “apparent” hydrograph in a barometrically efficient well. Take as an example a 90% barometrically efficient well. When monitored using a vented transducer, an increase in barometric pressure of 1 unit causes a decrease in recorded downhole pressure of 0.9 unit because the water level is forced downward 0.9 unit by the barometric pressure change. However, using a nonvented transducer, the total measured pressure increases by 0.1 unit (the combination of the barometric pressure increase and the water-level decrease). Thus, the resulting apparent hydrograph changes by a factor of 100 minus the barometric efficiency and in the same direction as the barometric pressure change, rather than in the opposite direction.

Barometric pressure data were obtained from the Technical Area 54 (TA-54) tower site from the Waste and Environmental Services Division–Environmental Data and Analysis. The TA-54 measurement location is at an elevation of 6548 ft above mean seal level (amsl), whereas the wellhead elevation is approximately 6650 ft amsl. The static water level of screen 1 is about 960 ft below land surface, making the water-table elevation roughly 5690 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-41.

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

$$P_{WT} = P_{TA54} \exp\left[-\frac{g}{3.281R} \left(\frac{E_{R41} - E_{TA54}}{T_{TA54}} + \frac{E_{WT} - E_{R41}}{T_{WELL}} \right) \right] \quad \textbf{Equation C-1}$$

Where, P_{WT} = barometric pressure at the water table inside R-41

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

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

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

E_{R41} = land-surface elevation at R-41 site, in feet (6650 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-41, in feet (approximately 5690 ft)

T_{TA54} = air temperature near TA-54, in degrees Kelvin (assigned a value of 39.5 degrees Fahrenheit, or 277.3 degrees Kelvin)

T_{WELL} = air temperature inside R-41, in degrees Kelvin (assigned a value of 64.8 degrees Fahrenheit, or 291.4 degrees Kelvin)

This formula is an adaptation of the ideal gas law and standard physics principles. Inherent assumptions in the derivation of the equation are that the air temperature between TA-54 and the well is temporally and spatially constant and that the temperature of the air column in the well is similarly constant.

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

C-3.0 IMPORTANCE OF EARLY DATA

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

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

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

Equation C-2

Where, t_c = duration of casing-storage effect, in minutes

D = I.D. of well casing, in inches

d = O.D. of column pipe, in inches

Q = discharge rate, in gallons per minute

S = drawdown observed in pumped well at time t_c, in feet

In some instances, it is possible to eliminate casing-storage effects by setting an inflatable packer above the tested screen interval before conducting the test. Therefore, this option has been implemented for the R-well testing program, including the R-41 pumping tests. Unfortunately, as described below, filter-pack drainage induced a storage effect on the data.

When drainage of the filter pack contributes to storage effects, the duration of the effect can be calculated by multiplying the t_c value associated with the casing volume alone by the ratio of the total drained volume (casing plus filter pack) to the drained casing volume.

C-4.0 TIME-DRAWDOWN METHODS

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

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

Equation C-3

Where,

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

Equation C-4

and

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

Equation C-5

and where, s = drawdown, in feet

Q = discharge rate, in gallons per minute

T = transmissivity, in gallons per day per foot

S = storage coefficient (dimensionless)

t = pumping time, in days

r = distance from center of pumpage, in feet

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

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

Equation C-6

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

Equation C-7

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

S = storage coefficient

Q = discharge rate, in gallons per minute

W(u) = match-point value

s = match-point value, in feet

u = match-point value

t = match-point value, in minutes

An alternative solution method applicable to time-drawdown data is the Cooper–Jacob method (1946, 098236), a simplification of the Theis equation that is mathematically equivalent to the Theis equation for most pumped well data. The Cooper–Jacob equation describes drawdown around a pumping well as follows:

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

Equation C-8

The Cooper–Jacob equation is a simplified approximation of the Theis equation and is valid whenever the *u* value is less than about 0.05. For small radius values (e.g., corresponding to borehole radii), *u* is less than 0.05 at very early pumping times and therefore is less than 0.05 for most or all measured drawdown values. Thus, for the pumped well, the Cooper–Jacob equation usually can be considered a valid approximation of the Theis equation.

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

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

Equation C-9

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

Q = discharge rate, in gallons per minute

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

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

Equation C-10

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

Where, in consistent units, s, Q, T, t, r, S, and u are as previously defined and the equation also includes the following:

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 as follows:

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

Equation C-11

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

C-5.0 RECOVERY METHODS

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

In this method, residual drawdown is plotted on a semilog graph versus the ratio t/t' where t is the time since pumping began and t' is the time since pumping stopped. A straight line of best fit is constructed through the data points, and T is calculated from the slope of the line as follows:

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

The recovery data are particularly useful compared with time-drawdown data. Because the pump is not running, spurious data responses associated with dynamic discharge rate fluctuations are eliminated. The result is that the data set is generally “smoother” and easier to analyze. This was of paramount importance in the R-41 pumping tests because of the entrained air-induced discharge rate fluctuations.

C-6.0 SPECIFIC CAPACITY METHOD

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

For fully penetrating wells, the Cooper–Jacob equation can be iterated to solve for the lower-bound hydraulic conductivity. However, the Cooper–Jacob equation (assuming full penetration) ignores the contribution to well yield from permeable sediments above and below the screened interval. To account for this contribution, it is necessary to use a computation algorithm that includes the effects of partial penetration. One such approach was introduced by Brons and Marting (1961, 098235) and augmented by Bradbury and Rothchild (1985, 098234).

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

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

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

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

To apply this procedure, a storage coefficient value must be assigned. Unconfined conditions were assumed for screen 2 because the water table was close to the screen. Also, as discussed below, the data suggested that some contribution to the well was obtained from the shallowest saturated sediments. Storage coefficient values for unconfined conditions can be expected to range from about 0.01 to 0.25 (Driscoll 1986, 104226). The calculation result is not particularly sensitive to the choice of storage coefficient value, so a rough estimate of the storage coefficient is generally adequate to support the calculations. An assumed value of 0.1 was used in the calculations for screen 2.

The analysis also requires assigning a value for the saturated aquifer thickness, b. For calculation purposes, the screen 2 zone was assumed to extend from the water table, at around 960 ft bgs, to the reported depth of the Pliocene sediments of 1024 ft. This resulted in an assigned aquifer thickness of 64 ft for screen 2. The computed result is not particularly sensitive to the exact aquifer thickness because sediments far above or below the screen have little effect on yield and drawdown response. Therefore, the calculation based on the assumed aquifer thickness value was deemed to be adequate. Nevertheless, a second scenario was addressed, assuming that tight sediments beneath the well screen isolated the pumped zone from deeper aquifer. For this scenario, the aquifer thickness was assumed to be the distance from the water table to the bottom of the well screen—14.63 ft. The two scenarios were expected to produce similar hydraulic conductivity values. However, the computed transmissivity values would vary substantially because of the different assumptions regarding total contiguous aquifer thickness.

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

C-7.0 BACKGROUND DATA ANALYSIS

Background aquifer pressure data collected during the R-41 tests were plotted along with barometric pressure to determine the barometric effect on water levels.

Figure C-7.0-1 shows aquifer pressure data from R-41 screen 2 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-41 data are referred to in the figure as the “apparent hydrograph” because the measurements reflect the sum of water pressure and barometric pressure, having been recorded using a nonvented pressure transducer. The times of the pumping periods for the screen 2 pumping tests are included in the figure for reference.

It appeared in Figure C-7.0-1 that changes in barometric pressure had little effect on total aquifer pressure. This implied a barometric efficiency of near 100% for the screen 2 aquifer.

The figure showed that the static water level was pulled down and did not fully recover, following each of the two extended periods of pumping: the 24-h test and the subsequent purge development. This suggested the possibility that the screen 2 aquifer was laterally limited and perhaps not well connected hydraulically to the deeper regional aquifer. Subsequent data, presented below, implied the possibility that testing had partially dewatered a thin layer of permeable sediment at the water table.

Figure C-7.0-2 shows the apparent hydrograph for R-41 screen 2 along with pumping times for the Los Alamos County production wells. The production well pumping pattern was fairly regular. There was no discernible short-term relationship between the production well operation and water levels measured in screen 2.

C-8.0 R-41 SCREEN 1 DATA ANALYSIS

This section presents the data obtained from R-41 screen 1 during the screen 2 pumping tests and the results of the interpretations. As stated above, operating the pump caused leakage of water through the drop pipe coupling joints, allowing water to enter the screen 1 zone above the inflatable packer.

Figure C-8.0-1 shows the screen 1 transducer response along with the barometric pressure response and the times of pumping screen 1. Until 11:00 a.m. on March 30, the screen 1 transducer reflected atmospheric pressure. At 11:00 a.m., the pressure over the transducer increased, indicating that leaked drop pipe water had filled the space between the packer and the transducer sensor and was now filling the annulus above the transducer. When pumping stopped (12:00 p.m. on March 30), the head buildup ceased, indicating that water was no longer leaking through the pipe joints.

Under pumping conditions, the pressure inside the drop pipe ranged from 260 psi at ground surface to 680 psi at total depth. These pressures were sufficient to cause leakage. Under nonpumping conditions with check valves in the drop pipe at roughly 200-ft intervals, the pressure on any joint would have ranged between about 0 and 90 psi, apparently insufficient to cause leaks.

When the 24-h pumping test began on April 1, leakage resumed, and the water level above the screen 1 transducer continued to increase until water began entering screen 1.

Figure C-8.0-2 shows an expanded-scale graph of the early transducer response in screen 1. The response measured before the water reached the transducer reflected barometric pressure changes. Note that the graphical scales are different on the transducer axis and on the barometric pressure axis.

Figure C-8.0-3 shows the transducer and barometric pressure data plotted at the same scale. It is apparent that the two curves essentially coincide.

Figure C-8.0-4 shows greater detail for the rise in water level over the transducer during trial test 2. It took 2 h of pumping (trial 1 plus the first half of trial 2) to fill the space between the top of the packer and the transducer sensor. The volume of the intervening void was estimated to be 2.81 gal., based on the geometry of the well and installed components. The total leakage volume as of 11:00 a.m. was the sum of 2.81 gal. plus the volume of water in transit, along the outer surface of the drop pipe between the leaky joint(s) and the water level. Note that after pumping stopped (12:00 p.m.), the water level continued to rise as the water in transit along the outer surface of the drop pipe flowed down to the water level. Based on the incremental water-level rise that occurred after 12:00 p.m., the transit volume was estimated at 0.40 gal., bringing the total leakage as of 11:00 a.m. to 2.81 + 0.40 = 3.21 gal. This leakage occurred in 120 min, making the computed leakage rate 0.0268 gpm.

The rate of rise in water level from 11:00 a.m. to 12:00 p.m. was used along with the annular volume between the well casing and the drop pipe to compute the average leakage rate during this period. The calculations revealed an average leakage rate of 0.0278 gpm, in good agreement with the earlier rate.

After trial 2 and before the start of the 24-h pumping test, the pressure over the transducer fluctuated, as shown in Figure C-8.0-2. These data were replotted in Figure C-8.0-5 with the transducer data and barometric pressure at the same scale. It was apparent that the two curves coincide. This implied two things. First, no leakage occurred from the drop pipe when the pump was shut down. Second, and more important, no water was contributed from screen 1; otherwise, the head over the transducer would have increased relative to the barometric pressure. This confirmed that the screen 1 interval was dry, contributing no measurable volume of water to the well.

Figure C-8.0-6 shows the late data recorded in screen 1. When the pump was started for the 24-h test, leakage of water through the drop pipe joints resumed and the head over the transducer increased. Based on the rate of rise of the water level and the annular volume between the well casing and the drop pipe, the leakage rate was calculated at 0.0351 gpm. This was somewhat greater than the previous calculated rates and suggested that the leak(s) had become worse. Once the rising water level reached about a foot into screen 1, it ceased rising as water flowed through the screen and into the formation.

When pumping stopped, the water level dropped to the bottom of screen 1 and remained there. This provided further confirmation that the screen 1 zone produced no water.

C-9.0 R-41 SCREEN 2 DATA ANALYSIS

This section presents the data obtained from the R-41 screen 2 pumping tests and the results of the analytical interpretations. Data are presented for drawdown and recovery for trials 1 and 2, the 24-h constant-rate pumping test, the purge development episode, and trial 3.

C-9.1 R-41 Screen 2 Specific Capacity Data

Specific capacity data were used along with well geometry to estimate a lower-bound conductivity value for the R-41 screen 2 zone. This was done to provide a frame of reference for use in interpreting subsequent analyses.

In addition to specific capacity, other input values used in the calculations included the assumed aquifer thickness alternatives of 14.63 and 64 ft, a storage coefficient value of 0.1, and a borehole radius of 1 ft. The drilled borehole had a diameter of 10.75 in. (radius of 0.45 ft), but, as described below, washouts in the borehole resulted in an effective borehole size much larger, approximately 1 ft.

R-41 screen 2 produced 3.19 gpm with a drawdown of 7.06 ft after 24 h of pumping for a specific capacity of 0.45 gpm/ft. Applying the Brons and Marting method (1961, 098235) to these inputs for the assumed aquifer thickness of 14.63 ft yielded lower-bound transmissivity and hydraulic conductivity values of 420 gpd/ft and 3.8 ft/d, respectively. Applying the method to these inputs for the assumed aquifer thickness of 64 ft yielded lower-bound transmissivity and hydraulic conductivity values of 1650 gpd/ft and 3.4 ft/d, respectively. The estimated hydraulic conductivity values were similar, but the transmissivity values diverged because of the different aquifer thickness assumptions.

C-9.2 R-41 Screen 2 Trial 1

Figure C-9.2-1 shows a semilog plot of the drawdown data collected from trial 1 conducted at a discharge rate of 3.17 gpm. The early data showed exaggerated drawdown because of antecedent drainage of a small portion of the drop pipe before pumping. The pumping rate was elevated briefly as the slight void in the drop pipe was being filled, and the pump operated against reduced head.

The form of the drawdown curve appeared normal and capable of supporting a conventional analysis. However, as described below, the entire data set was affected by storage associated with drainage of the filter pack around the casing above the well screen. Therefore, analytical calculations were not included on the graph.

Figure C-9.2-2 shows the recovery data collected following shutdown of the trial 1 pumping test. The form of the recovery curve was highly unusual. Between 1 and 2 ft of residual drawdown, the slope of the graph declined. Subsequently, it increased rapidly. As shown in the figure, as well as the expanded-scale plot in Figure C-9.2-3, water levels recovered to the static level more rapidly than would be predicted theoretically.

To gain additional insight into the unusual water-level response, the recovery data were plotted on a linear scale as shown in Figures C-9.2-4 (entire data set) and C-9.2-5 (expanded scale). As is evident in Figure C-9.2-5, the recovery rate slowed from a residual drawdown of a little less than 2 ft to a little less than 1 ft. Then, from less than 1 ft of residual drawdown to less than 0.5 ft, the recovery rate increased.

Figure C-9.2-6 shows another view of the linear residual drawdown along with a plot of the calculated recovery rate, in feet per minute. Normally, the recovery rate should be monotonically decreasing over time. The result here was very different, with the rate showing a decline, then an increase, and finally a decline.

This unusual response suggested the possibility of an enlarged borehole at a depth corresponding to an interval from less than 2 ft to less than 1 ft below the static water level. The reduction in recovery rate may have been a manifestation of the extra time required to refill the filter-packed annulus in this area. Note that the zone in question is above the well screen, behind the blank casing.

To check the idea of an enlarged borehole, logbook records from the well construction period were examined to determine the volume of filter pack required for various depths in the vicinity of the well screen. Table C-9.2-1 summarizes the available data on the installed filter-pack volumes, showing the number of bags of filter pack per foot of borehole length required to fill the annular space between the borehole and the casing or screen. (One bag of filter pack has a volume of 0.5 ft^3.) To put the values shown in the table in perspective, the theoretical volume between the casing and drilled hole was about 0.92 bags per foot. All intervals shown in Table C-9.2-1 indicated that substantially greater volumes than this were required. For most of the annulus, the average filter-pack volume requirement was about quadruple the theoretical requirement. Note, however, that the requirements for the intervals from 961.17 to 961.82 ft and from 961.82 to 962.42 ft were 15.4 and 39.2 bags per foot, respectively, between 1 and 2 orders of magnitude greater than the theoretical prediction. These depth intervals corresponded to a residual drawdown interval of 0.8 to 2.05 ft. This interval agreed well with the residual drawdown interval in which the recovery rate dropped precipitously. The implication was that the sluggish recovery rate in this area was attributable to the time it took to refill the drained filter pack in this portion of the borehole. (Note that the zones of borehole enlargement and sluggish recovery response need not match perfectly. There are measurement errors inherent in tagging the top of the filter pack during construction, as a function of the accuracy of the particular tape used for the task.)

Once the enlarged portion of the borehole was refilled, the recovery rate increased substantially until the residual drawdown was just a few tenths of a foot. This, coupled with the premature recovery of the water levels to near the static level, suggested the idea of a thin layer of preferentially permeable sediment right at the water table. Such a zone providing water “spilling over” somewhat tighter underlying materials into the borehole would create the recovery pattern shown in the figures.

The borehole volume implied by the filter-pack requirements shown in Table C-9.2-1 was used to estimate the duration of storage effects for the various tests conducted on screen 2. Calculations were based on an assumed drainable porosity of 20% for the filter pack. The results of the calculations revealed storage effects ranging from about 2 to 4 h, depending on the test. This meant that the entire drawdown and recovery data sets from trial 1 were storage-affected and could not support calculation of aquifer parameters.

C-9.3 R-41 Screen 2 Trial 2

Figure C-9.3-1 shows a semilog plot of the drawdown data collected from trial 2 conducted at a discharge rate of 3.14 gpm. The data from the first few seconds of pumping showed exaggerated drawdown associated with refilling the minor antecedent drainage of a portion of the drop pipe through a leaky coupling joint.

The drawdown curve was relatively steeper during the first couple of minutes, flattened slightly, and then steepened again. The subtle slope changes may have been related to the variable borehole diameter and to the time required to drain the filter pack. Note that the drawdown interval corresponding to the subtle flattening was about a foot lower than the known depth of the washout zone outside the well casing. This difference may have represented the head required to move water from the phreatic surface in the filter pack to the inside of the well where the drawdown was measured.

The duration of trial 2 was less than the storage-effect duration cited above; thus, the data could not be analyzed for the purposes of determining aquifer parameters.

Figure C-9.3-2 shows the recovery data recorded following the trial 2 test on R-41 screen 2. As in trial 1, the recovery response was highly unusual, with an interval of sluggish response followed by rapid recovery to near the static level. Figure C-9.3-3 shows an expanded-scale plot of the late-recovery data that shows that a relatively rapid rate of recovery persisted until the water level was within 0.1 ft of the static level.

Linear plots of the recovery data were prepared as shown in Figures C-9.3-4 (entire data set) and C-9.3-5 (expanded scale). Sluggish recovery occurred between residual drawdown values of about 1 and 2 ft, similar to what was observed in trial 1. Again, this effect was a result of the large filter-pack volume in the washout in this area. Also, once the washout zone was refilled, the recovery rate was unusually rapid until the water level was within 0.1 or 0.2 ft of the static level.

Figure C-9.3-6 shows the linear residual drawdown, along with a plot of the calculated recovery rate, in feet per minute. The recovery rate slowed substantially as the water level passed through the washout zone and then increased greatly, with a top recovery rate of about 0.25 ft/min, consistent with what was observed in the trial 1 recovery data set.

C-9.4 R-41 Screen 2 24-H Constant-Rate Pumping Test

Figure C-9.4-1 shows a semilog plot of the drawdown data recorded during the 24-h constant-rate pumping test conducted at a discharge rate of 3.19 gpm. The early data showed that minor antecedent drainage of the drop pipe had occurred during the background monitoring period.

The duration of storage effects was estimated at over 200 min but implied that the late data in the plot were theoretically eligible for mathematical analysis. The transmissivity value computed from the late slope on the graph was 210 gpd/ft. This value was substantially lower than either of the lower-bound transmissivity values cited above (420 and 1650 gpd/ft). This meant that the analysis underestimated the aquifer transmissivity. This suggested that a substantial portion of the transmissivity of the aquifer was contributed from the upper few feet of saturation behind the blank casing. With that portion of the contributing zone dewatered, the resulting transient drawdown slope would be expected to be exaggerated, leading to an underestimate of transmissivity.

After about 330 min of pumping, the drawdown plot showed a brief, subtle stabilization of water levels, difficult to see in Figure C-9.4-1. Figure C-9.4-2 shows an expanded-scale plot of this portion of the drawdown curve. The period of temporary stabilization likely occurred when the pumping water level in the filter pack reached the top of the well screen, allowing air to enter the screen and rise into the casing where it was trapped beneath the inflatable packer. The entry of air likely gradually displaced the volume of water in the casing above the screen between the inflatable packer and the top of the screen. Once this supply of water was exhausted, the normal rate of drawdown was reestablished.

Figure C-9.4-3 shows the recovery data measured following the 24-h constant-rate pumping test. The data showed the same unusual response observed in the trial test recovery data, including the temporary flattening of the curve followed by late, unusually rapid recovery. Figure C-9.4-4 shows an expanded-scale plot of the late-recovery data. As indicated on the graph, the water level recovered rapidly until it was within 0.1 ft of the original static water level. Recovery ceased completely several hundredths of a foot short of the starting level. The unusual rapid recovery followed suddenly by negligible recovery precluded rigorous analysis of the data.

Linear plots of the recovery data were prepared as shown in Figures C-9.4-5 (entire data set) and C-9.4-6 (expanded scale). Sluggish recovery occurred between residual drawdown values of about 1 and 2 ft, similar to what was observed in trials 1 and 2. Again, this effect was a result of the large filter-pack volume in the washout in this area. Also, once the washout zone was refilled, the recovery rate was unusually rapid until the water level was within 0.1 or 0.2 ft of the static level.

Figure C-9.4-7 shows the linear residual drawdown along with a plot of the calculated recovery rate, in feet per minute. The recovery rate slowed substantially as the water level passed through the washout zone and then increased greatly, with a top recovery rate of about 0.20 ft/min. This was a little less than the maximum recovery rate observed in trials 1 and 2 and may have been a result of slight permanent dewatering of the hypothesized thin permeable layer at the very top of the aquifer.

C-9.5 R-41 Screen 2 Purge Development

Following completion of the formal testing of R-41, purge development was performed to try to reduce the persistent turbidity in the screen 2 water. Transducer data were collected during this activity and plotted for analysis.

Figure C-9.5-1 shows the drawdown data recorded during screen 2 purge development. The somewhat chaotic drawdown pattern requires some explanation.

As indicated on the graph, the initial pumping rate with the discharge valve setting left unchanged from the previous testing was 3.2 gpm. After about 27 min, the valve on the discharge line was opened, allowing the pump to operate at its maximum rate of 9.6 gpm. At this pumping rate, the drawdown stabilized near 5.7 ft for about 6 min. At this drawdown, contribution from both the aquifer and filter-pack drainage from the washout zone was able to sustain the 9.6-gpm rate.

However, after 6 min, the drawdown increased suddenly, dropping to the pump intake. It was likely that the filter-pack storage in the washout was depleted at that point and the aquifer could not sustain the previous pumping rate. Once the water level reached the pump intake (about 8.7 ft of drawdown), cavitation occurred. Because the water level could not be pulled down farther, the discharge rate declined to that which was sustainable by the aquifer. With the drawdown maintained at a constant level, the discharge rate gradually declined from 6.0 to 5.3 gpm.

After a little more than an hour of pumping, the discharge valve was closed to curtail the flow rate. Detailed measurements of the discharge rate were not made after that. The average rate over the balance of the pumping period was 4.0 gpm. Immediately after closing the valve, the discharge rate would have been greater than 4.0 gpm and would have declined gradually to less than 4.0 by the end of the pumping period. The exact flow rates at various times were not known.

The late drawdown data were plotted on an expanded-scale graph as shown in Figure C-9.5-2. The transmissivity computed from the late data was less than 325 gpd/ft, based on the assumption that the discharge rate during that time was less than 4.0 gpm. This result was less than either of the lower-bound estimates determined from the specific capacity data. This meant that the analysis underestimated the formation transmissivity. Again, this was consistent with the idea that a portion of the water contribution to the well originated from above the pumping water level.

Figure C-9.5-3 shows the recovery data measured following the purge development pumping. The data showed the same unusual response observed in the previous tests, including the temporary flattening of the curve followed by late, rapid recovery. Figure C-9.5-4 shows an expanded-scale plot of the late recovery data. As indicated on the graph, the water level recovered rapidly until it was within 0.1 ft of the original static water level. Recovery ceased completely at that point, falling about a tenth of a foot short of the original static level. This implied that additional, permanent, incremental dewatering of the formation occurred. The unusual rapid recovery followed suddenly by negligible recovery precluded rigorous analysis of the data.

Linear plots of the recovery data were prepared as shown in Figures C-9.5-5 (entire data set) and C-9.5-6 (expanded scale). Sluggish recovery occurred between residual drawdown values of about 1 and 2 ft, similar to what was observed in previous testing. Again, this effect was a result of the large filter-pack volume in the washout in this area. Also, once the washout zone was refilled, the recovery rate was rapid until the water level was within 0.1 or 0.2 ft of the static level.

Figure C-9.5-7 shows the linear residual drawdown, along with a plot of the calculated recovery rate, in feet per minute. The recovery rate slowed substantially as the water level passed through the washout zone and then increased, with a top recovery rate of about 0.10 ft/min. This was substantially less than the maximum recovery rate observed in trials 1 and 2 and the 24-h test. The lower-recovery rate must have been caused by the slight reduction (0.1 ft) in saturated thickness (lack of recovery to the original static level). The only way such a tiny reduction in saturated thickness could be significant is if it represented a substantial fraction of the thickness of the zone that had previously contributed to the rapid, final recovery in previous tests. This provided strong evidence of a thin, permeable layer of sediment at the very top of the saturated zone, as had been hypothesized earlier, based on the unusual rapid late recovery observed in all of the tests.

Figure C-9.5-8 shows a final data plot made from the purge development event. It shows a linear graph of the very early recovery data. A striking observation is that the plot was nearly linear (straight line) until the residual drawdown was less than 4 ft, corresponding to a position slightly above the top of the screen. For uniform borehole conditions (uniform diameter), this type of response would imply that all of the recharge refilling the casing and borehole originated from above the screen. If the screen zone were contributing a portion of the flow, its contribution would decrease as the water level rose. Thus, the lack of a decrease in the rate of recovery would imply no screen zone contribution. Because the borehole diameter is not uniform, this conclusion is not certain. However, it would take a remarkable and fortuitous borehole configuration to happen just to produce the linear fill rate depicted on the graph. Thus, the gist of the relationship in Figure C-9.5-8 suggested the possibility that a major portion of the contribution of the flow to the well came from sediments above the screened interval.

C-9.6 R-41 Screen 2 Trial 3

Before pulling the pump from R-41, a final, brief pumping event (trial 3) was performed. Screen 2 was pumped with the discharge valve open to maximize the flow rate. Pumping continued for just 15 min.

Figure C-9.6-1 shows the resulting drawdown graph. Initially, the pump produced 9.2 gpm, presumably the maximum rate for the existing operating conditions (electrical generator performance) at that time. This rate was maintained for about 8 min with a stabilized drawdown of less than 6 ft. Once the washout zone was dewatered, the pumping water level declined, dewatering additional screen and filter-pack length at the maximum rate of the pump until the water level reached the pump intake. At that point, the discharge rate declined to a level sustainable by the aquifer, about 5.1 gpm. A few minutes later, the pump was shut down.

Figure C-9.6-2 shows the recovery following shutdown of trial 3. The general form of the plot was similar to previous results showing a flattening of the curve, followed by more rapid recovery.

A linear plot of the recovery data was prepared, as shown in Figure C-9.6-3. Sluggish recovery occurred at a slightly higher elevation than had been observed in previous testing. It was possible that the very short test did not achieve complete drainage of the pore spaces in the filter pack as had occurred in the longer tests. Once the washout zone was refilled, the recovery rate did not increase as much as in previous tests.

Figure C-9.6-4 shows the linear residual drawdown, along with a plot of the calculated recovery rate, in feet per minute. The recovery rate slowed substantially as the water level passed through the washout zone. However, after the washout zone had refilled, the recovery rate increased only slightly, unlike what was observed in previous tests. The maximum recovery rate was less than 0.05 ft/min. This was less than half of the 0.1 ft/min recovery rate observed after the purge development, which, in turn, was less than half of previous rates. The reason for this last substantial decline in recovery rate was not well understood, as little additional pumping had occurred between this recovery event and the purge development recovery. Nevertheless, the lower-recovery rate may have been related to ongoing dewatering of the hypothesized thin, fragile layer of permeable sediment at the top of the aquifer.

Figure C-9.6-5 shows a final-recovery data plot made from trial 3. It shows a linear graph of the very early recovery data. As observed in the purge development recovery data, the plot was nearly linear (straight line) until the residual drawdown was less than 4 ft, corresponding to a position above the top of the screen. Again, the lack of a significant reduction in recovery rate as the water level rose through the screen was consistent with little contribution coming from the screen and most of the contribution coming from above the screen.

C-10.0 SUMMARY

Constant-rate pumping tests were conducted on R-41 screen 2 above Pajarito Canyon. The tests were conducted to gain an understanding of the hydraulic characteristics of the screen 2 aquifer and verify that screen 1 was dry. Additionally, R-22 was monitored to look for a cross-connection between the wells.

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

- Screen 1 was determined to be dry. Water-level measurements in the sump beneath screen 1 showed no increase in level over time. This conclusion was confirmed by water levels dropping to the bottom of screen 1 after temporarily flooding screen 1 with drop pipe leakage.

- Leaky threaded joints in the drop pipe used to hang the submersible test pump allowed drainage of a tiny portion of the pipe between pumping events. Pumping against reduced head briefly until the void in the drop pipe was refilled resulted in slightly elevated discharge rates at the onset of pumping. These minor effects were caused by insignificant leaks under nonpumping conditions. During pumping, however, the leakage rate increased and was substantial. The leaky joints were likely attributable to a combination of worn threads, improperly manufactured threads, and the need to avoid overtightening the threads to avoid galling of the stainless-steel material.

- None of the screens in R-22 showed any response to pumping R-41 screen 2. This was not surprising because the Theis equation predicts zero drawdown at R-22 (649 ft away) for the unconfined conditions assumed at R-41 and the range of possible transmissivity values (420 gpd/ft or greater).

- Operation of municipal wells showed no discernible short-term effect on the water levels in R-41 screen 2.

- Barometric pressure response showed that R-41 screen 2 has a barometric efficiency near 100%.

- Specific capacity analysis showed that screen 2 produced 3.19 gpm with 7.06 ft of drawdown, for a specific capacity of 0.45 gpm/ft. For the assumption of a hydraulically continuous, isotropic aquifer extending from the water table to the bottom of the riverine sediments at 1024 ft, the lower-bound hydraulic conductivity value computed from the specific capacity was 3.4 ft/d and the lower-bound transmissivity was 1650 gpd/ft. For the assumption that the screened interval was hydraulically isolated from the deeper sediments, the lower-bound hydraulic conductivity and transmissivity values were 3.8 ft/d and 420 gpd/ft, respectively.

- Late-pumping data showed an increase in the time-drawdown slope rather than the flattening normally seen in response to vertical growth of the cone of depression. This may suggest that the screened interval is not well connected to deeper sediments. This effect also is consistent with dewatering, i.e., much of the flow contribution coming from above the pumping water level.
- A large washout zone behind the blank casing above the well screen contributed a significant storage effect associated with drainage of the filter pack. The resulting storage-effect duration precluded analysis of much of the pumping test data.
- Recovery appeared to be affected by a thin layer of permeable material at the water table that rapidly refilled the well during the latter stages of recovery (after the washout zone had refilled). The odd residual drawdown response to this hypothesized feature precluded analysis of the recovery data.
- The analyzable drawdown data from the tests yielded transmissivity values far less than the known lower-bound values, i.e., the data underestimated the transmissivity. This invalidated the analysis and suggested significant water contribution from zones above the screen, behind the blank casing.
- Approximately linear early-recovery responses from a couple of the tests suggested the possibility that the majority of the production to the well came from sediments above the well screen, behind the blank casing.
- Each of two episodes of extended pumping (the 24-h test and purge development) resulted in minor permanent dewatering of the saturated zone. This suggested that the aquifer screened in R-41 may be laterally limited and not well hydraulically connected to the deeper regional aquifer.

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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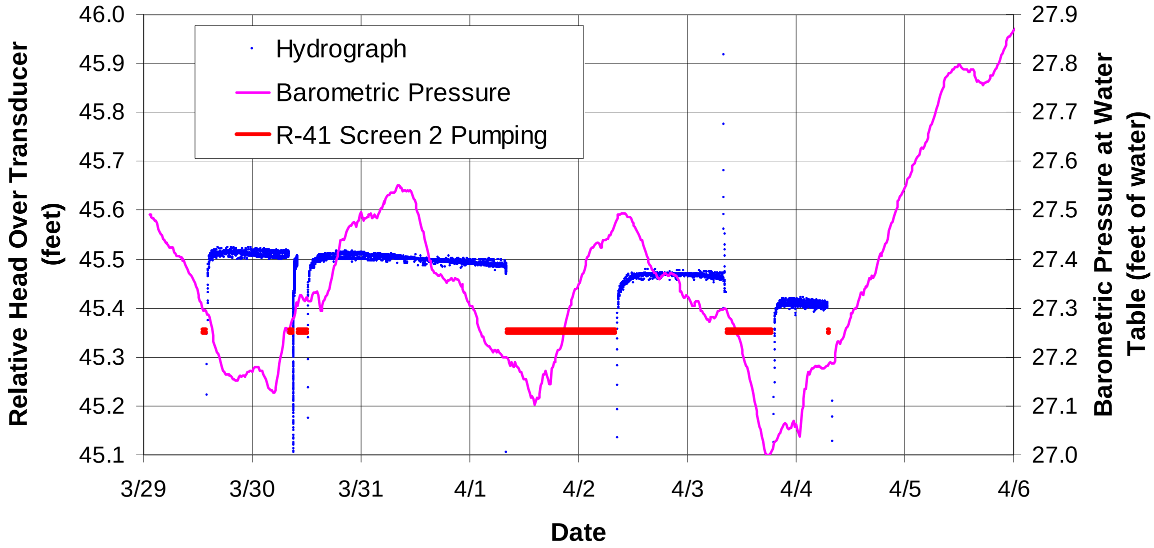

Figure C-7.0-1 R-41 screen 2 apparent hydrograph

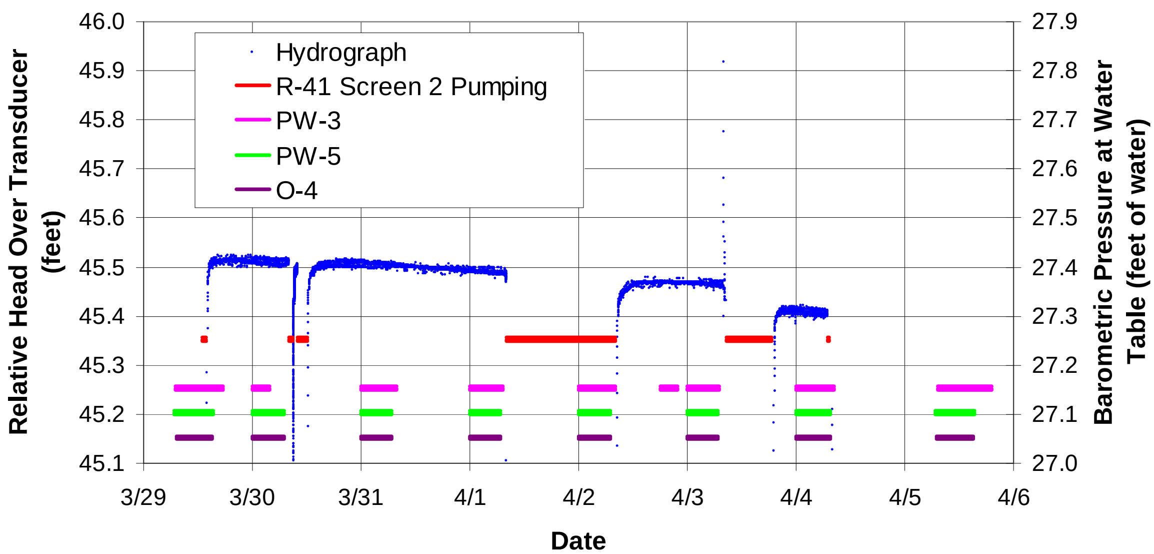

Figure C-7.0-2 R-41 screen 2 apparent hydrograph with Los Alamos County well operation

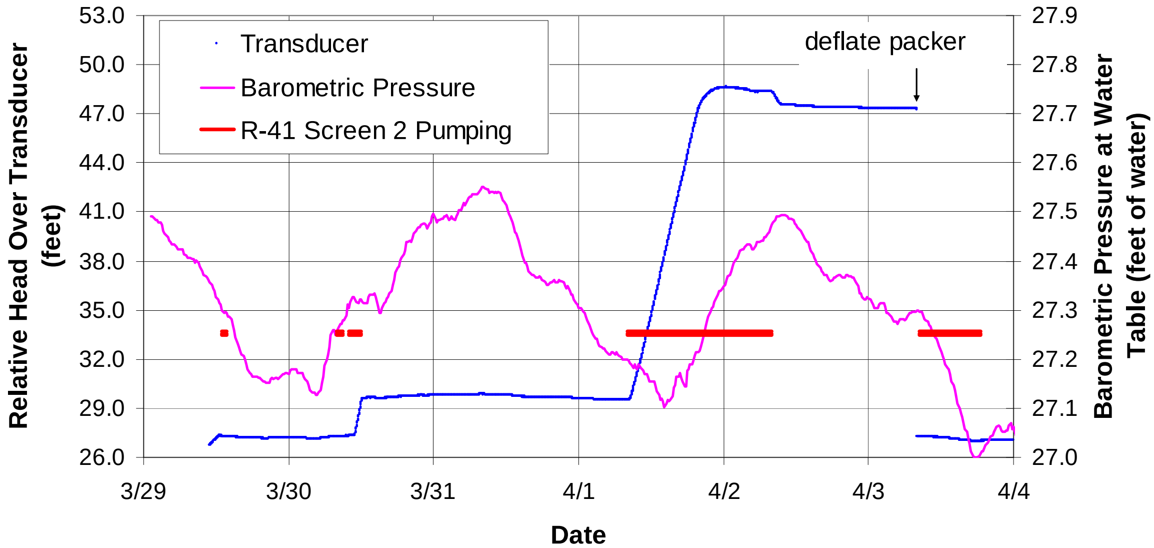

Figure C-8.0-1 R-41 screen 1 transducer response

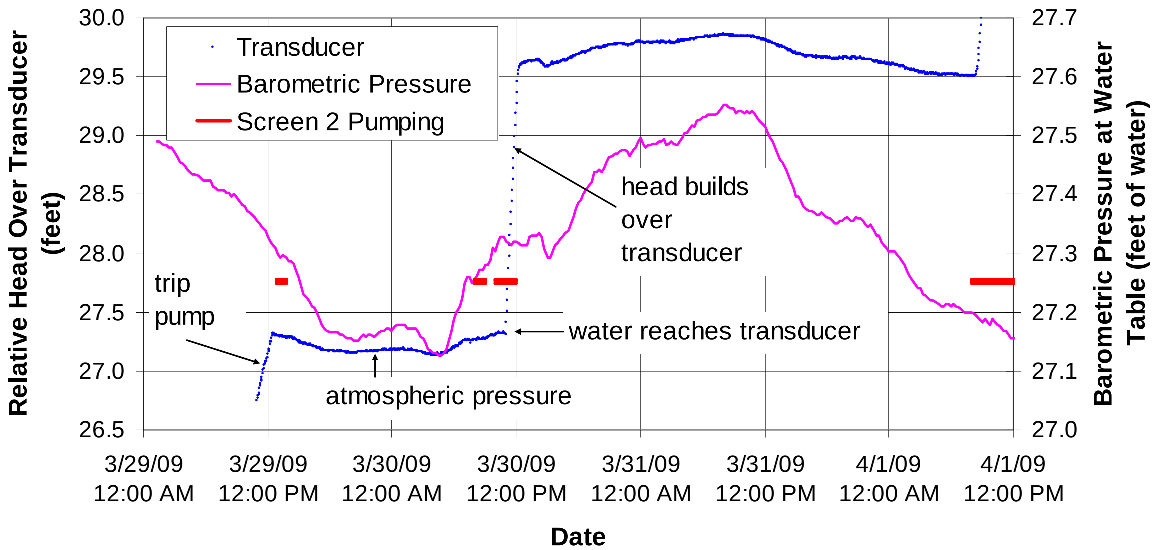

Figure C-8.0-2 R-41 screen 1 early transducer response

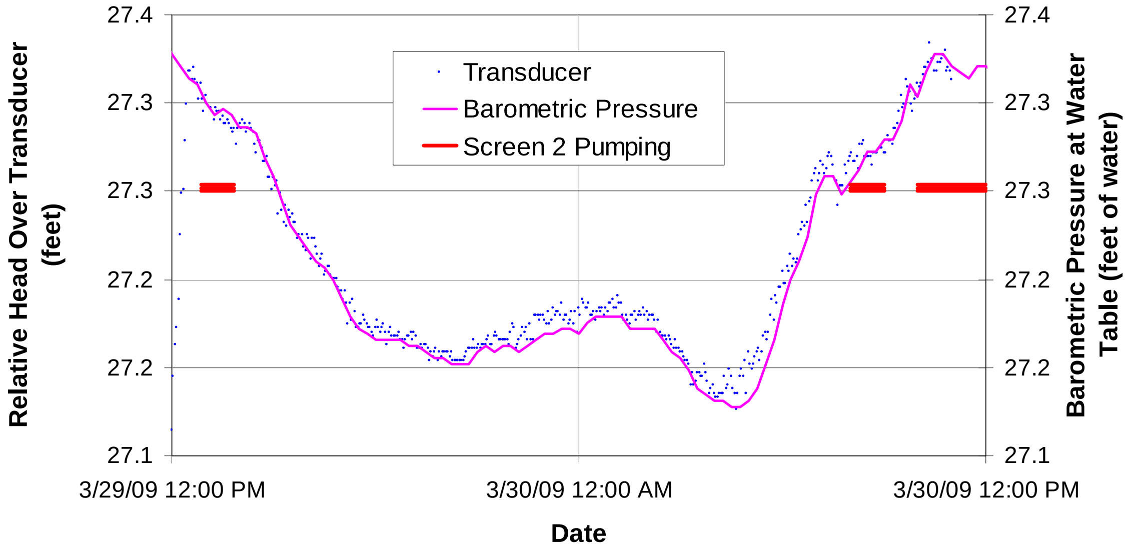

Figure C-8.0-3 R-41 screen 1 atmospheric pressure response

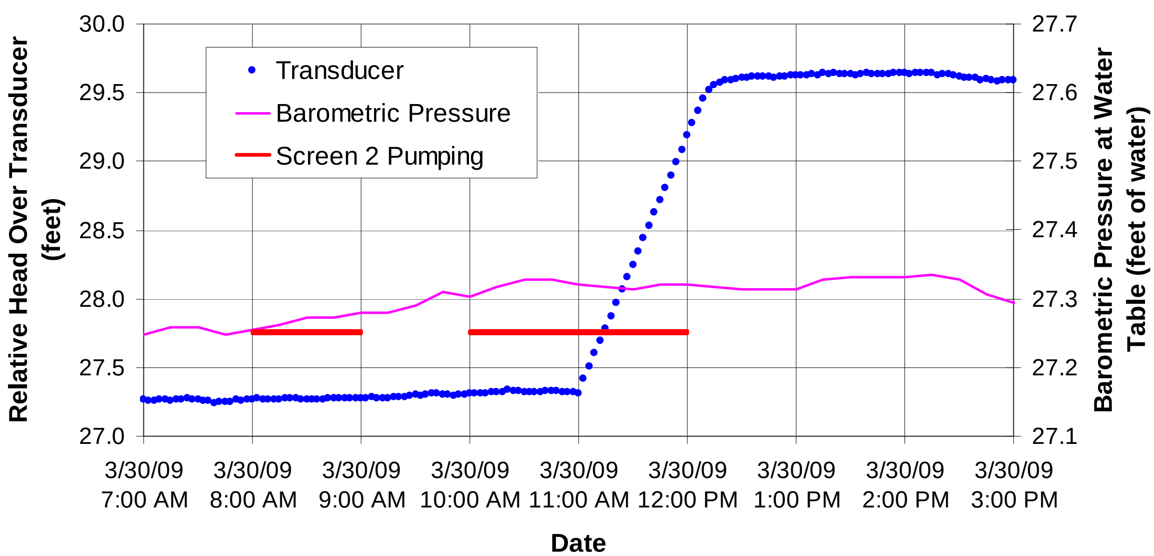

Figure C-8.0-4 R-41 screen 1 initial drop pipe leakage

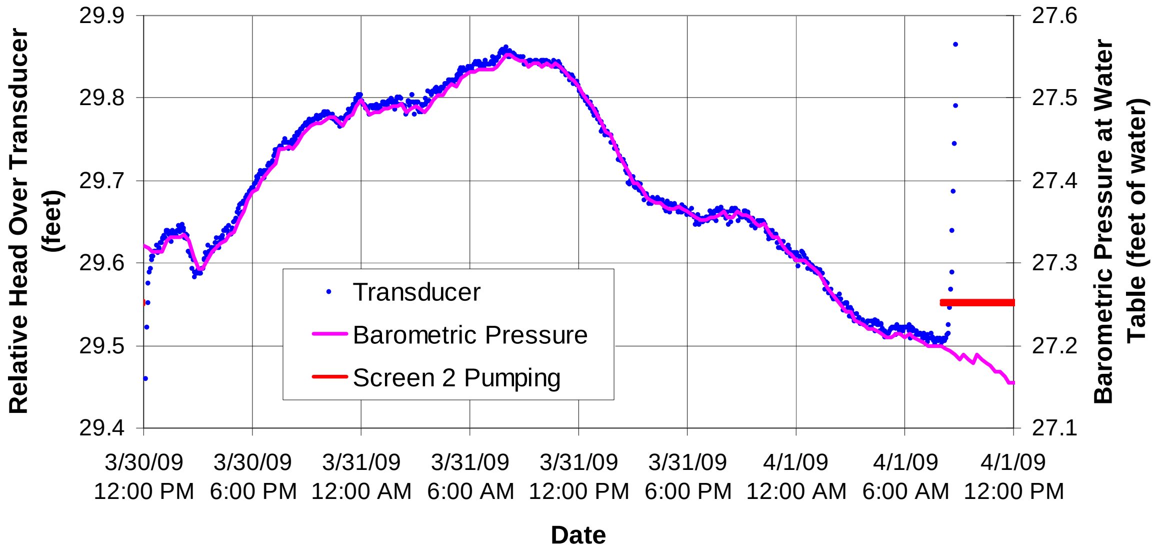

Figure C-8.0-5 R-41 screen 1 static conditions following initial drop pipe leakage

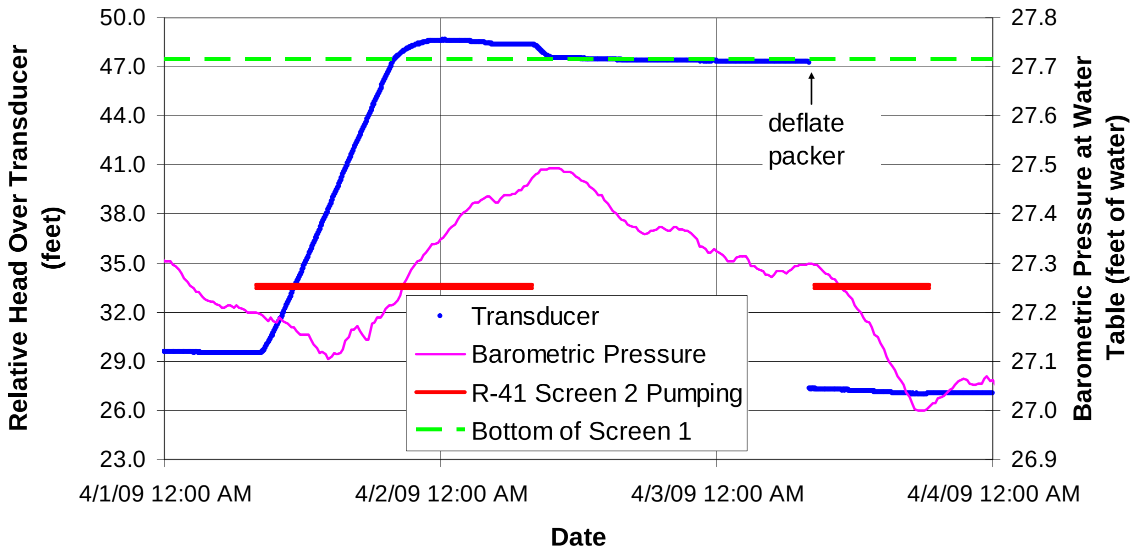

Figure C-8.0-6 R-41 screen 1 late transducer response

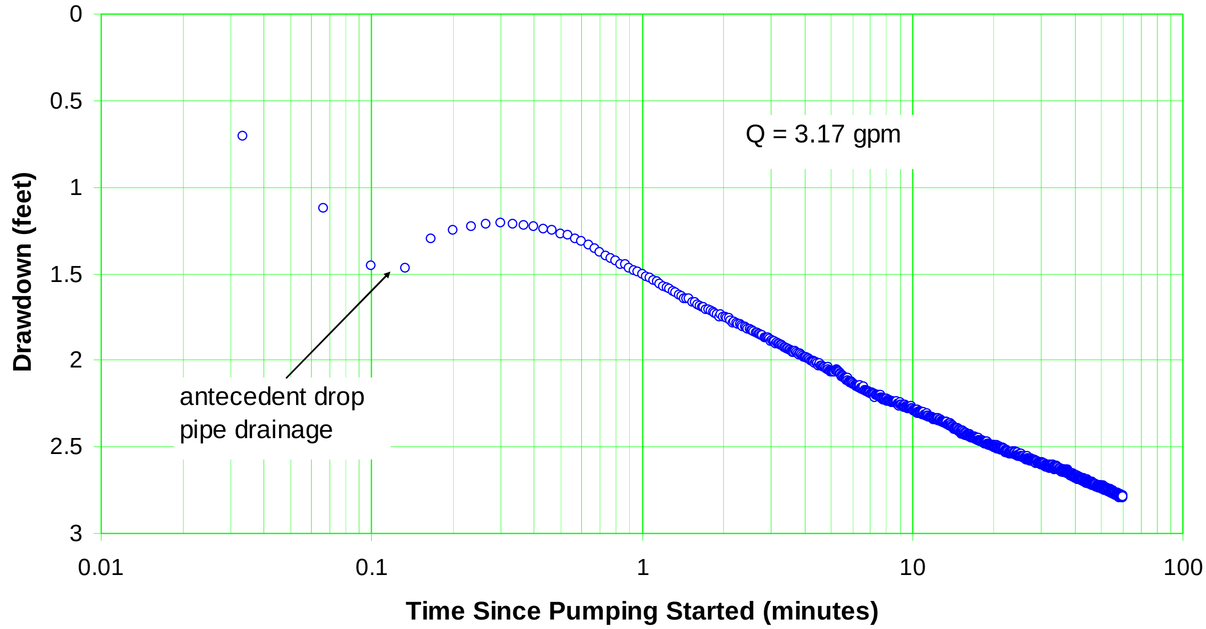

Figure C-9.2-1 Well R-41 screen 2 trial 1 drawdown

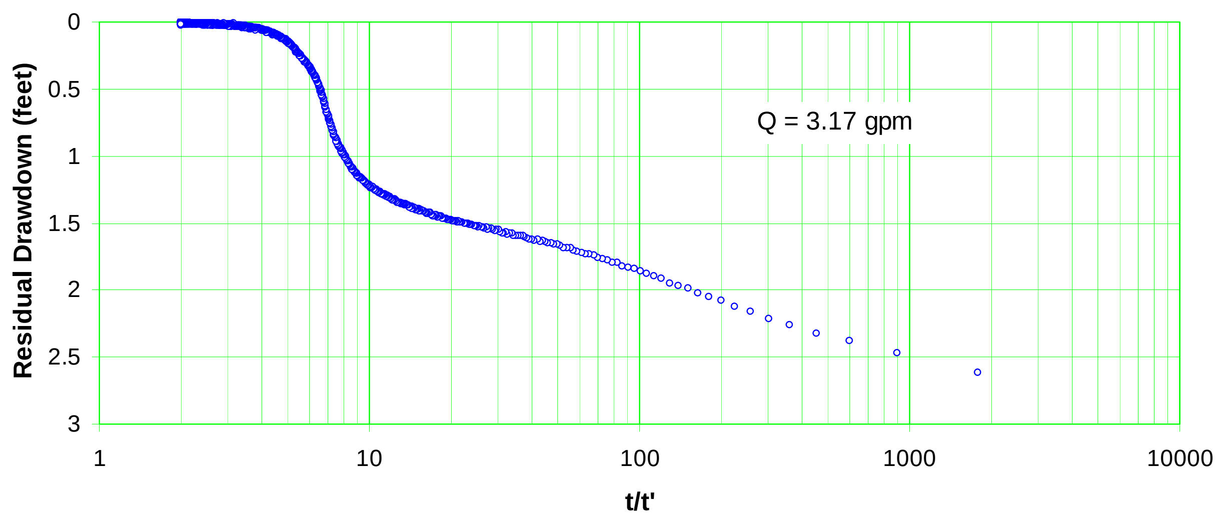

Figure C-9.2-2 Well R-41 screen 2 trial 1 recovery

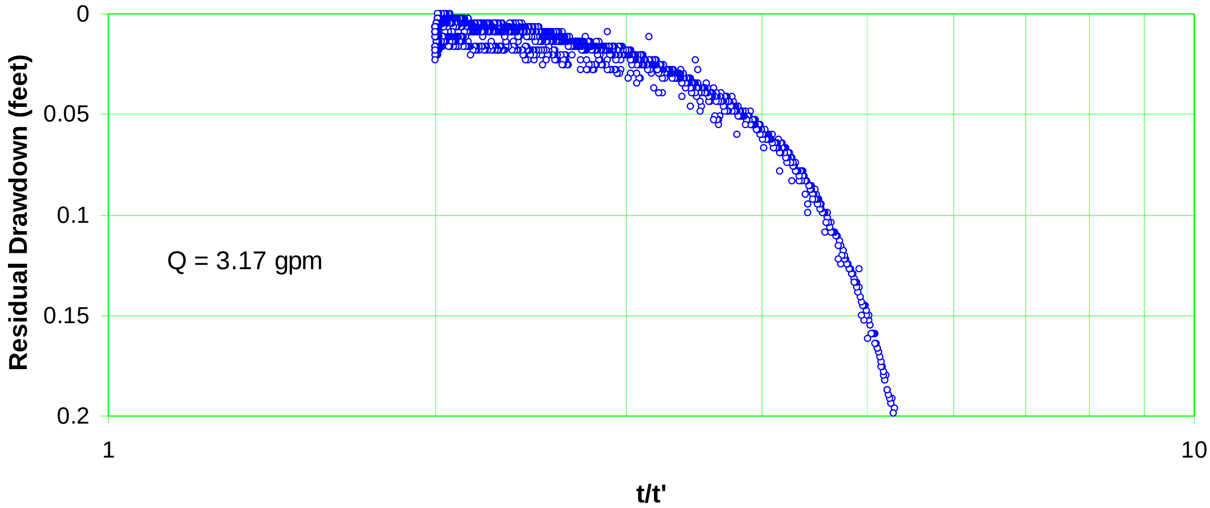

Figure C-9.2-3 Well R-41 screen 2 trial 1 recovery—expanded scale

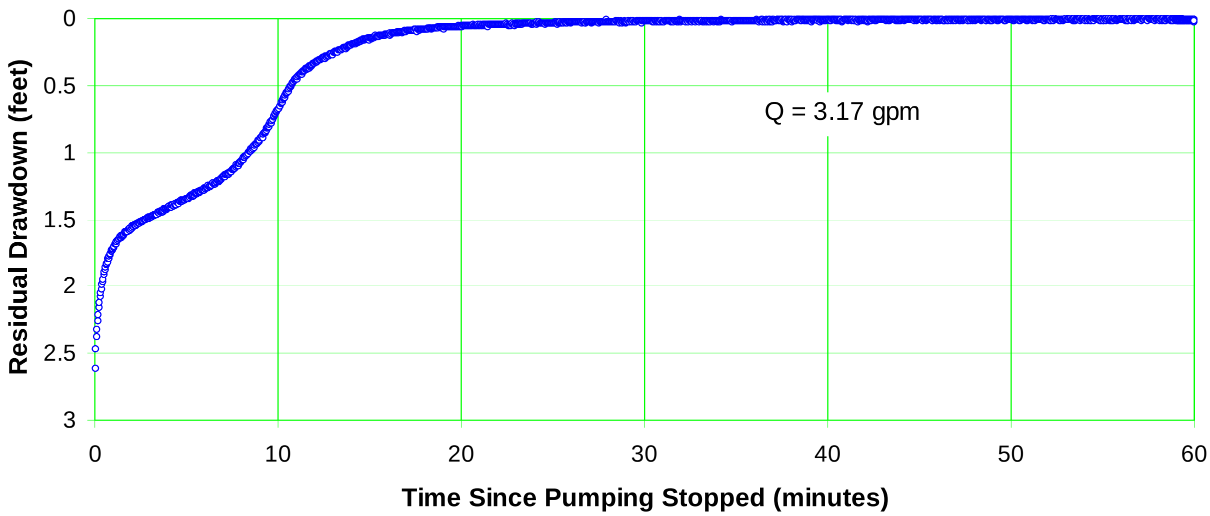

Figure C-9.2-4 Well R-41 screen 2 trial 1 linear recovery

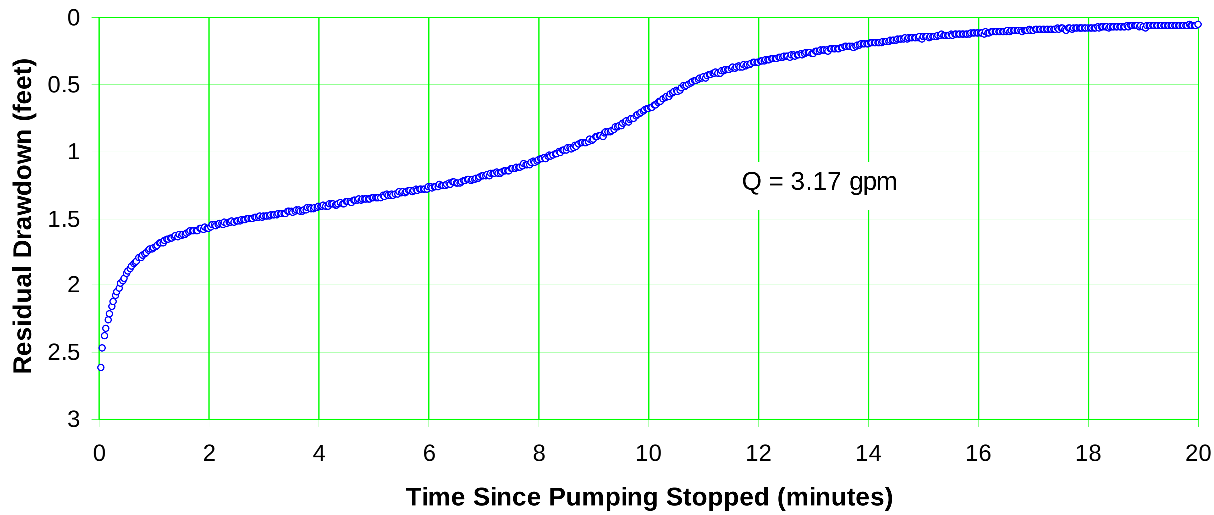

Figure C-9.2-5 Well R-41 screen 2 trial 1 linear recovery—expanded scale

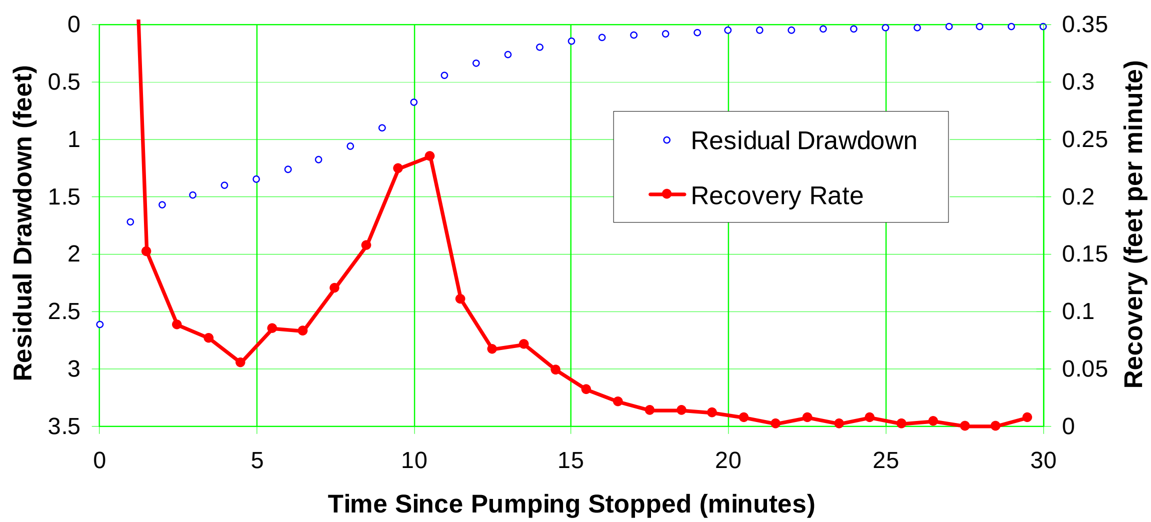

Figure C-9.2-6 Well R-41 screen 2 trial 1 incremental recovery

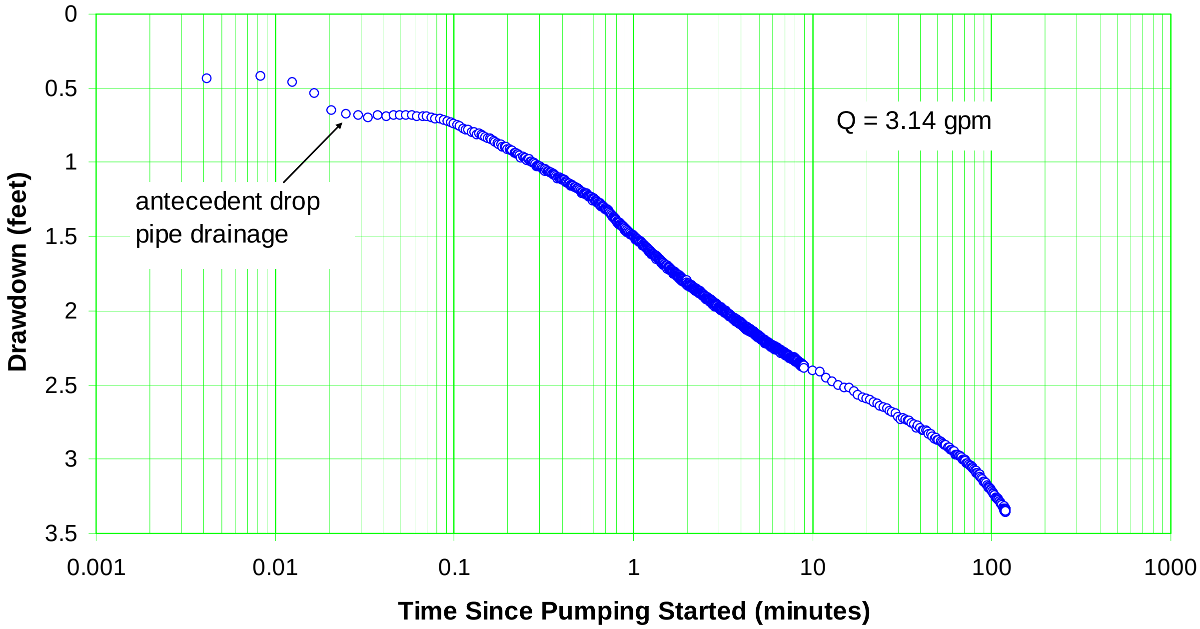

Figure C-9.3-1 Well R-41 screen 2 trial 2 drawdown

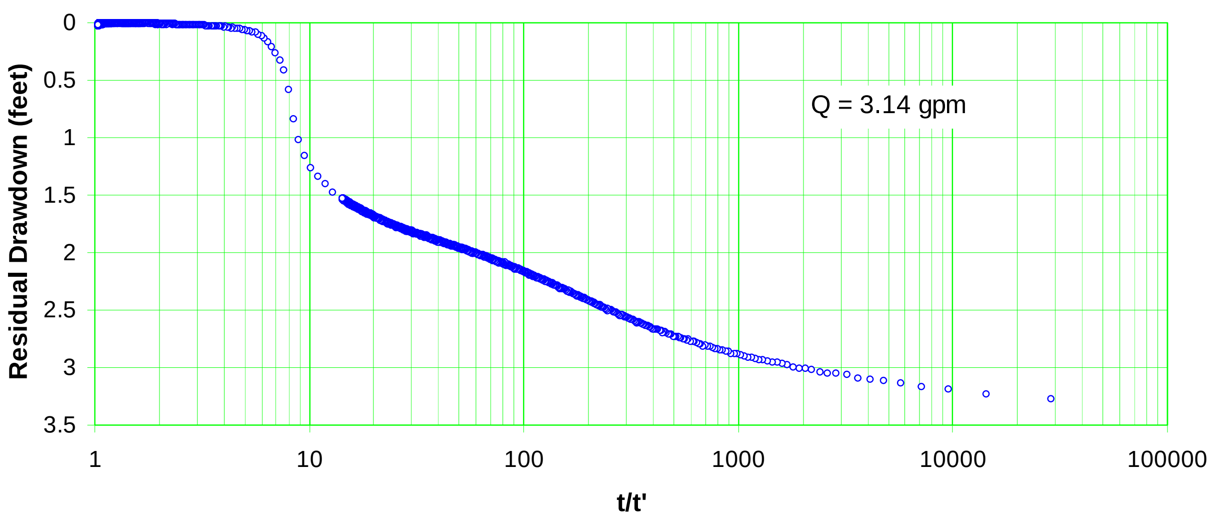

Figure C-9.3-2 Well R-41 screen 2 trial 2 recovery

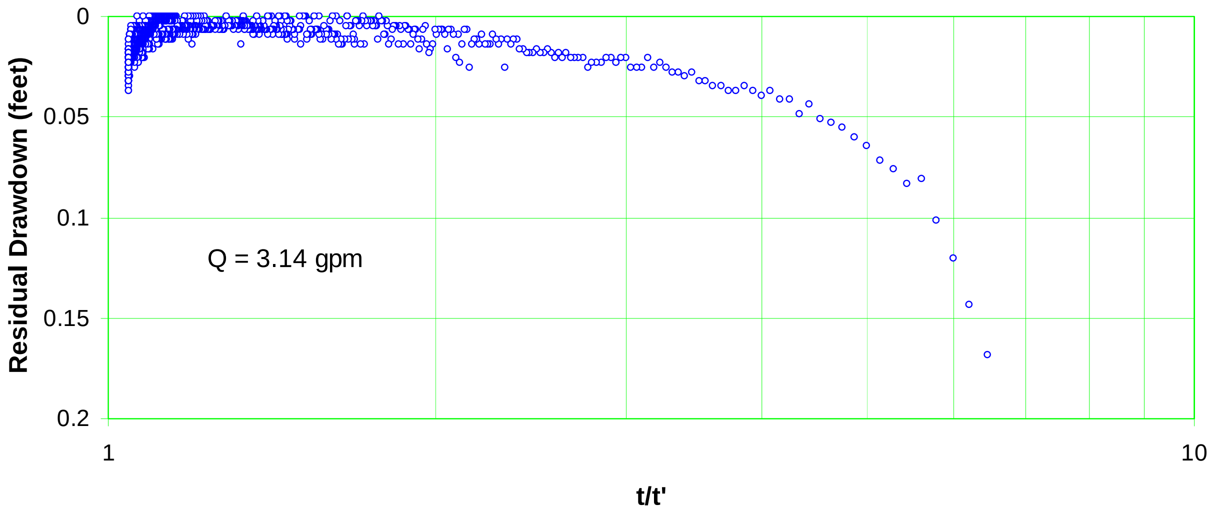

Figure C-9.3-3 Well R-41 screen 2 trial 2 recovery—expanded scale

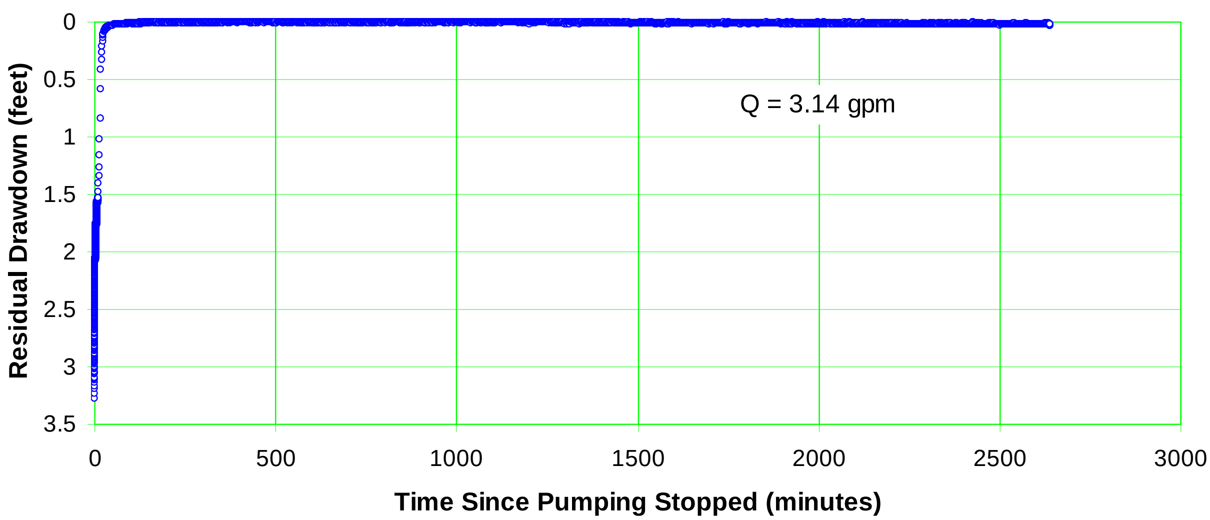

Figure C-9.3-4 Well R-41 screen 2 trial 2 linear recovery

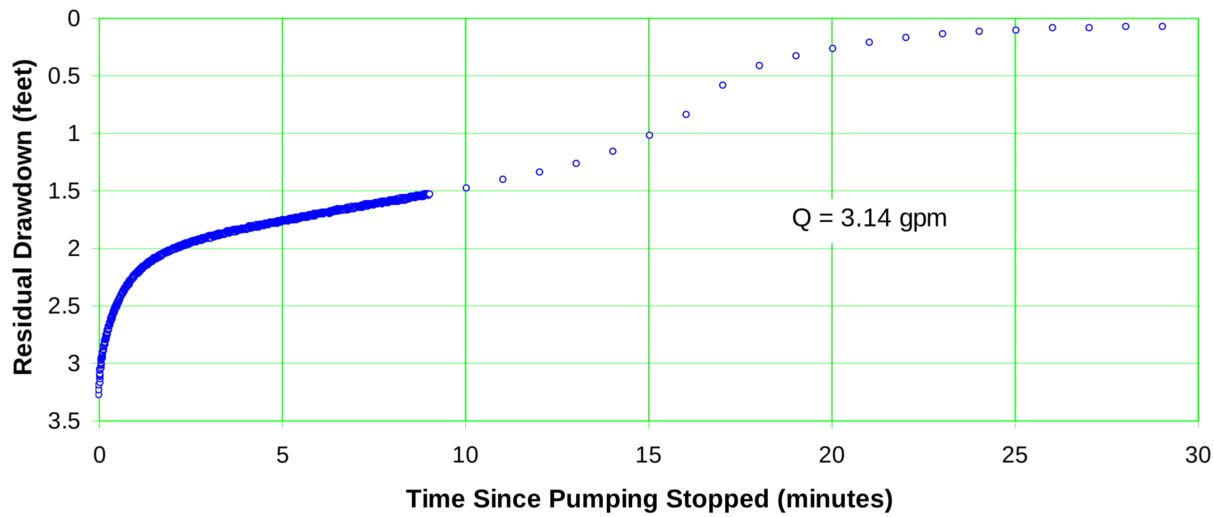

Figure C-9.3-5 Well R-41 screen 2 trial 2 linear recovery—expanded scale

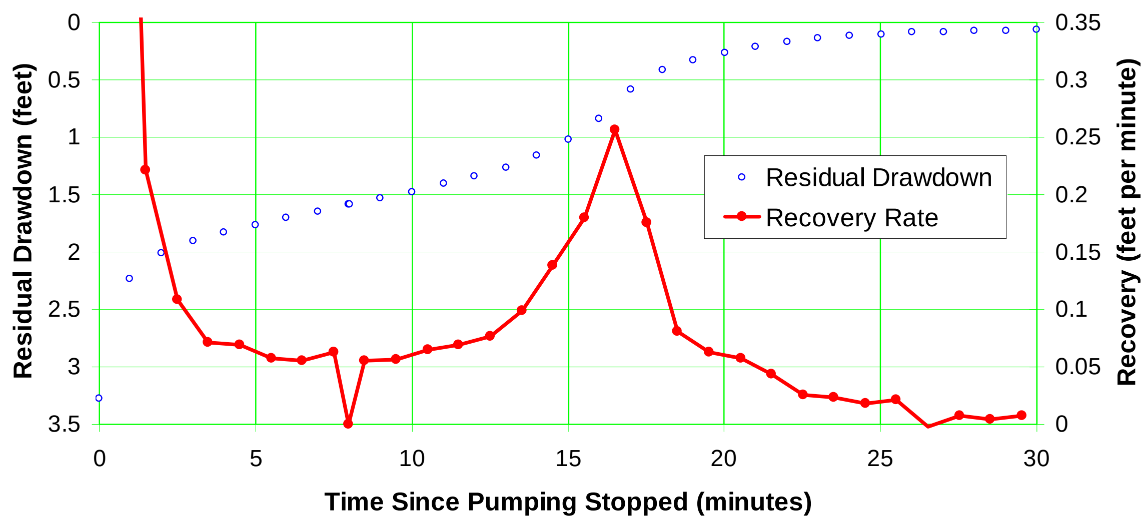

Figure C-9.3-6 Well R-41 screen 2 trial 2 incremental recovery

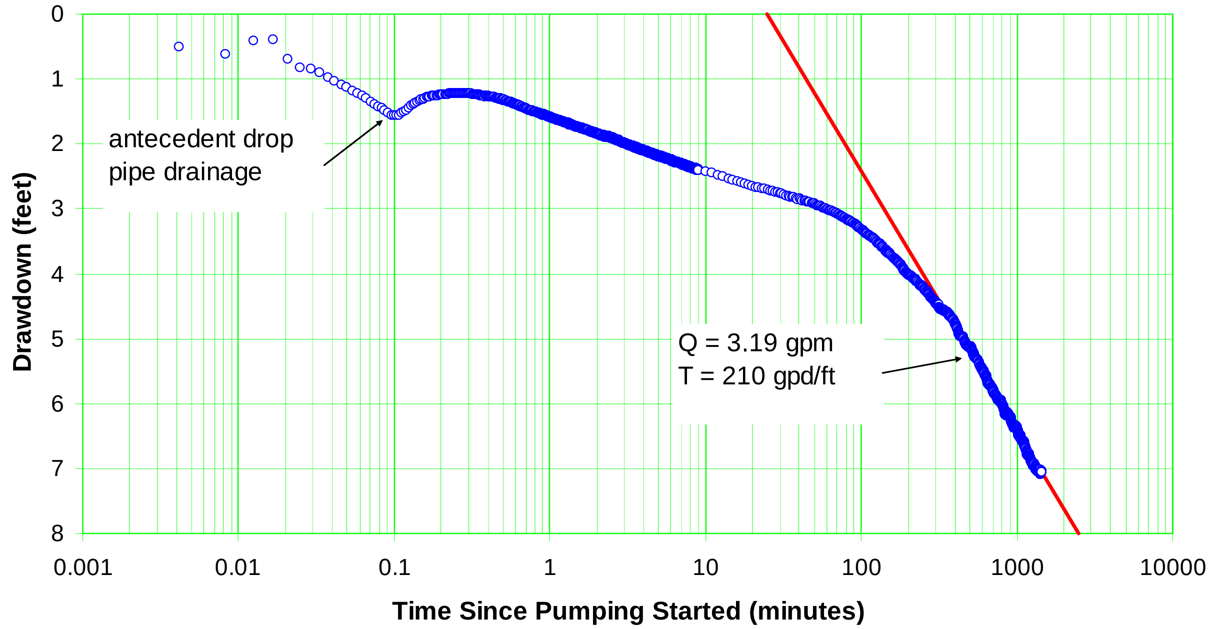

Figure C-9.4-1 Well R-41 screen 2 drawdown

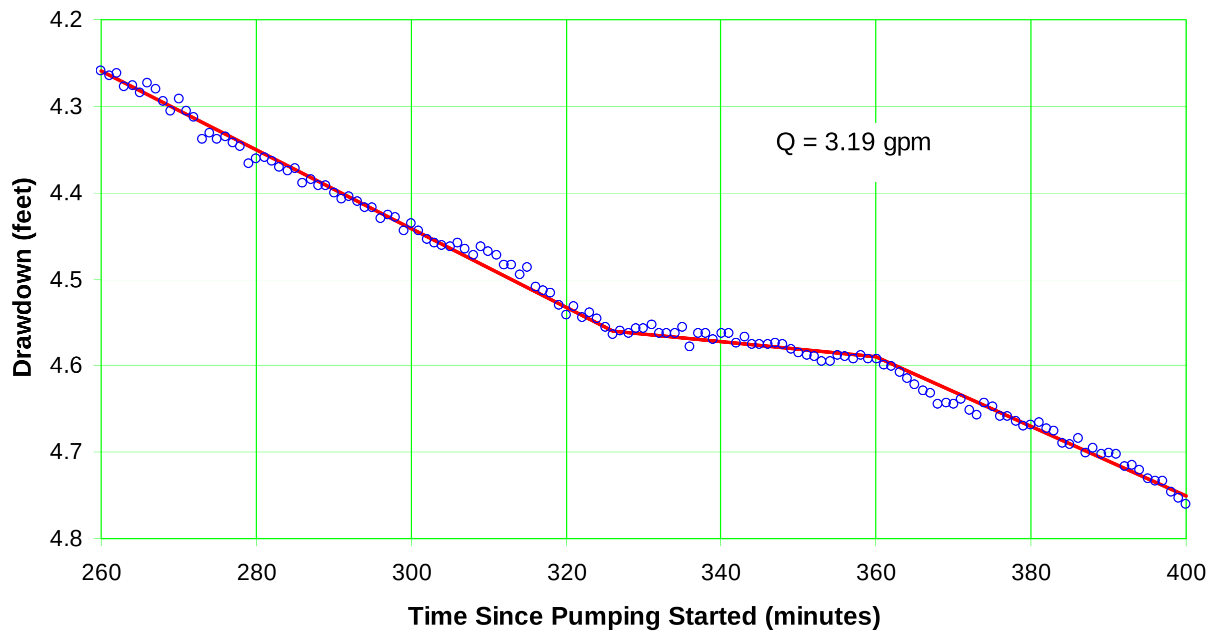

Figure C-9.4-2 Well R-41 screen 2 drawdown—expanded scale

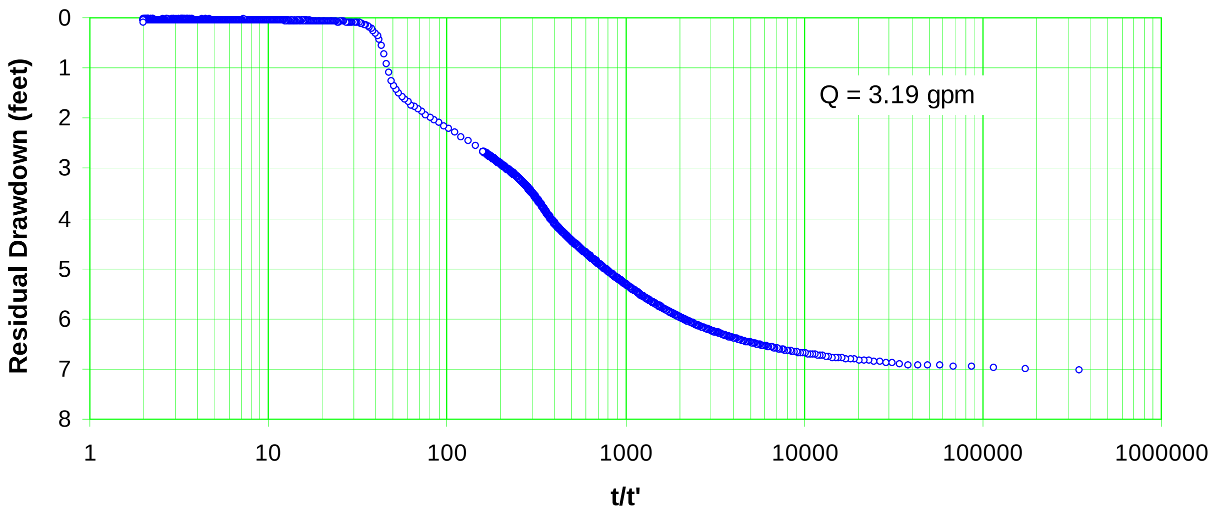

Figure C-9.4-3 Well R-41 screen 2 recovery

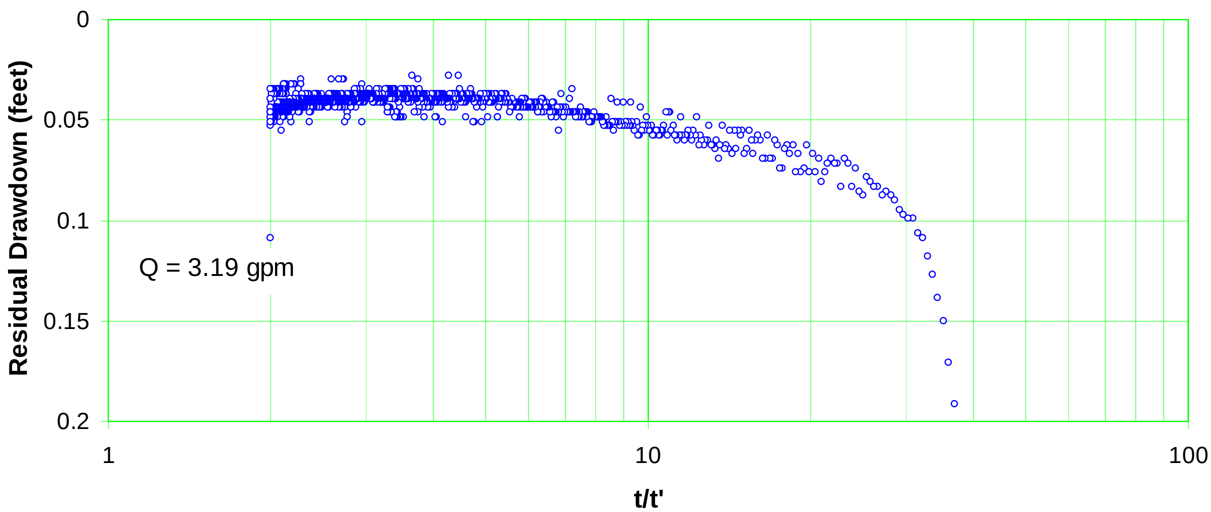

Figure C-9.4-4 Well R-41 screen 2 recovery—expanded scale

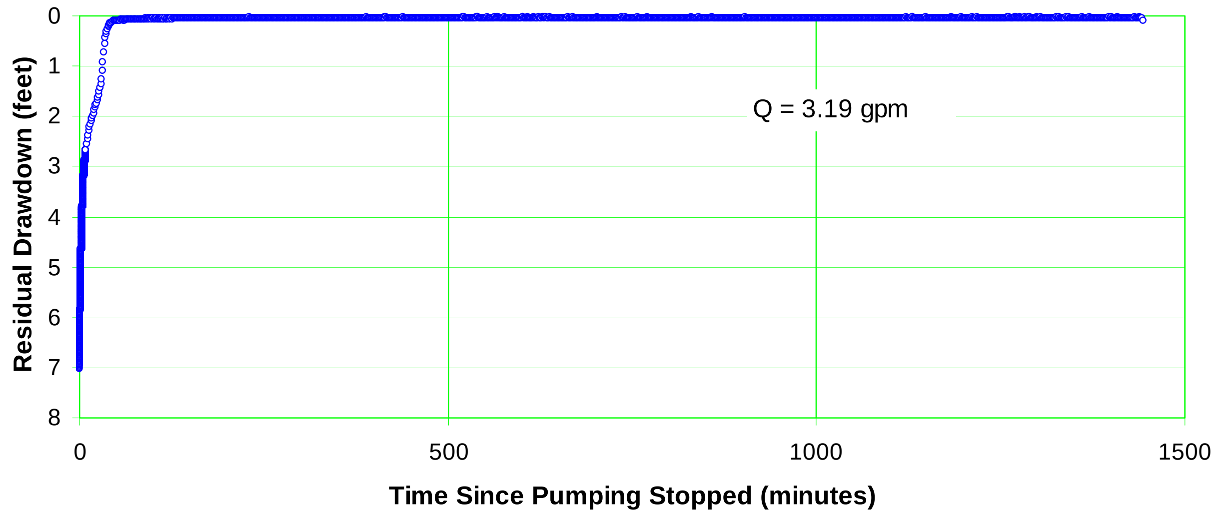

Figure C-9.4-5 Well R-41 screen 2 linear recovery

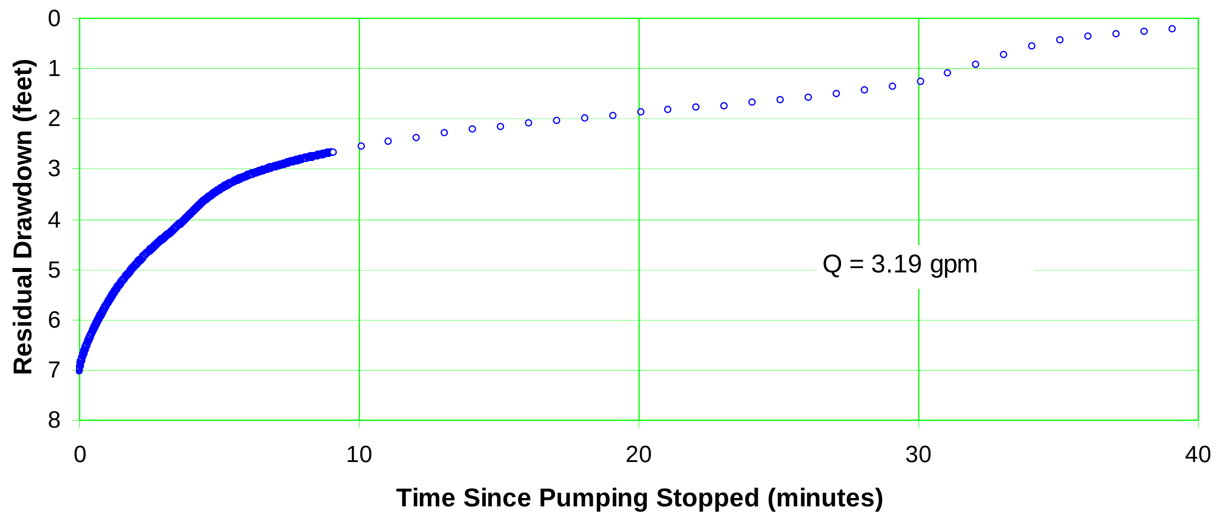

Figure C-9.4-6 Well R-41 screen 2 linear recovery—expanded scale

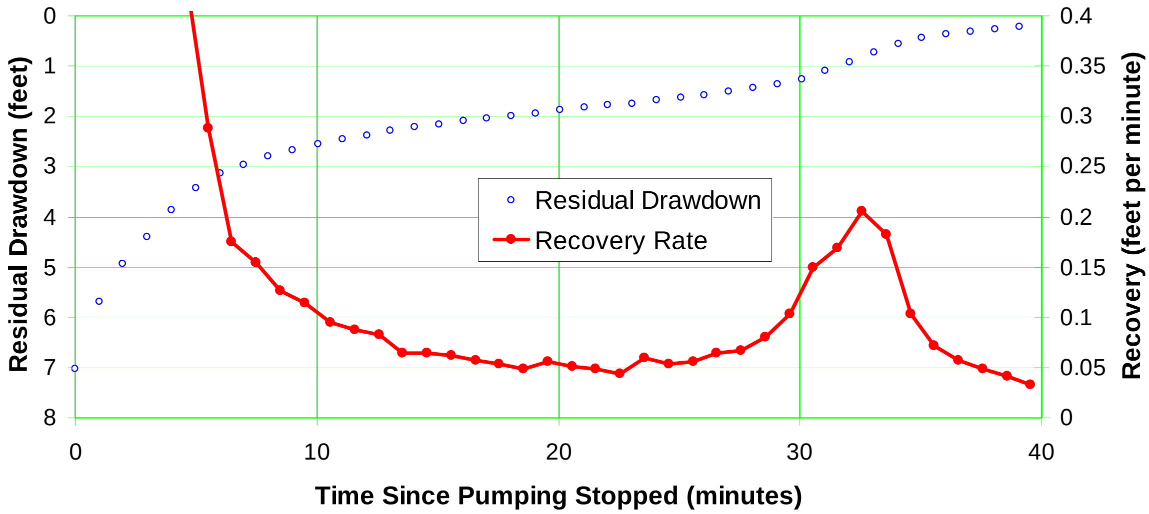

Figure C-9.4-7 Well R-41 screen 2 incremental recovery

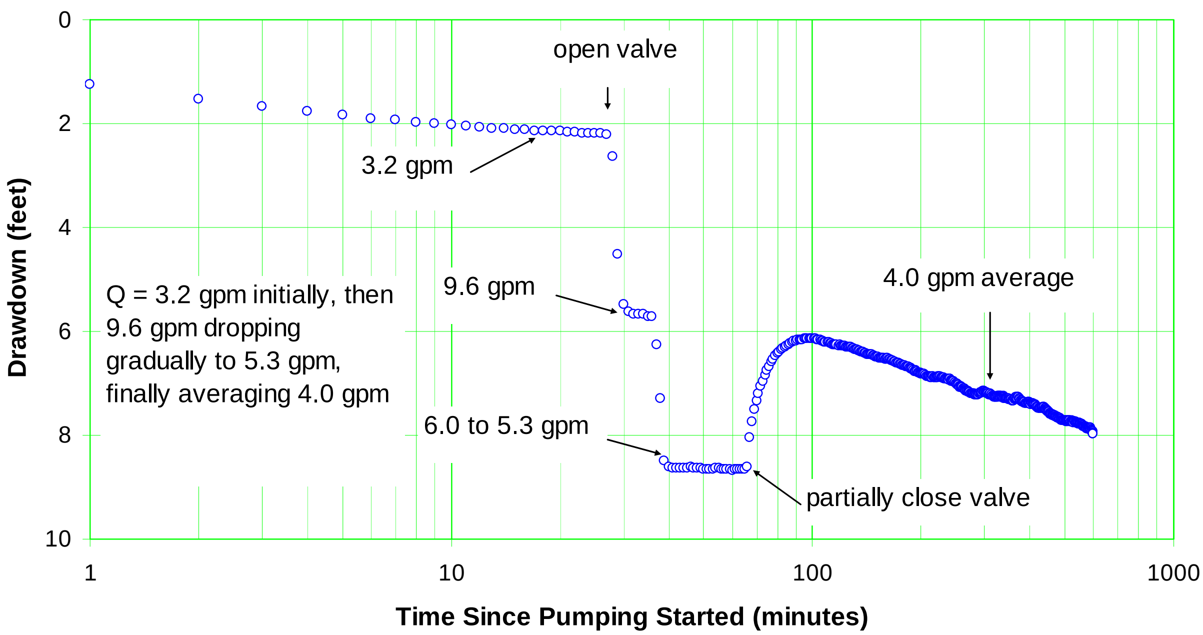

Figure C-9.5-1 Well R-41 screen 2 drawdown during purge development

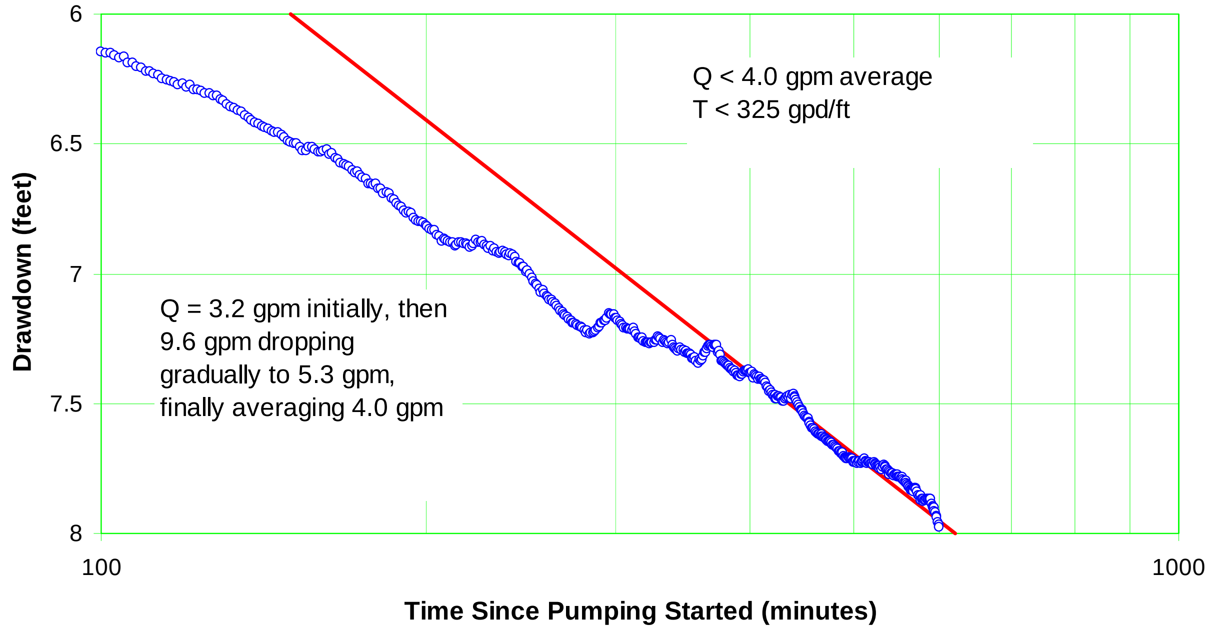

Figure C-9.5-2 Well R-41 screen 2 drawdown during purge development—expanded scale

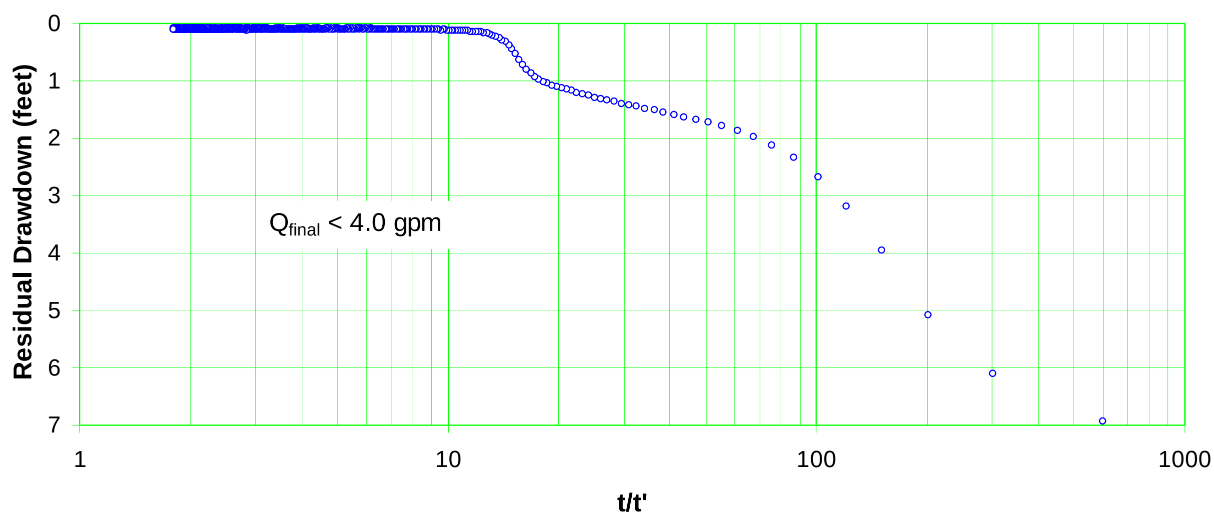

Figure C-9.5-3 Well R-41 screen 2 recovery following purge development

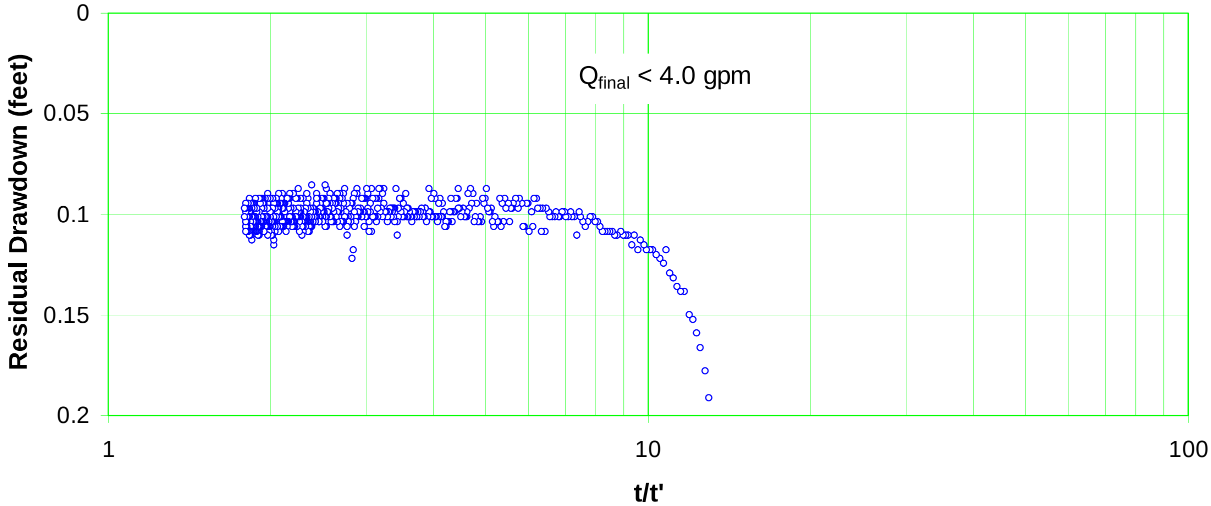

Figure C-9.5-4 Well R-41 screen 2 recovery following purge development—expanded scale

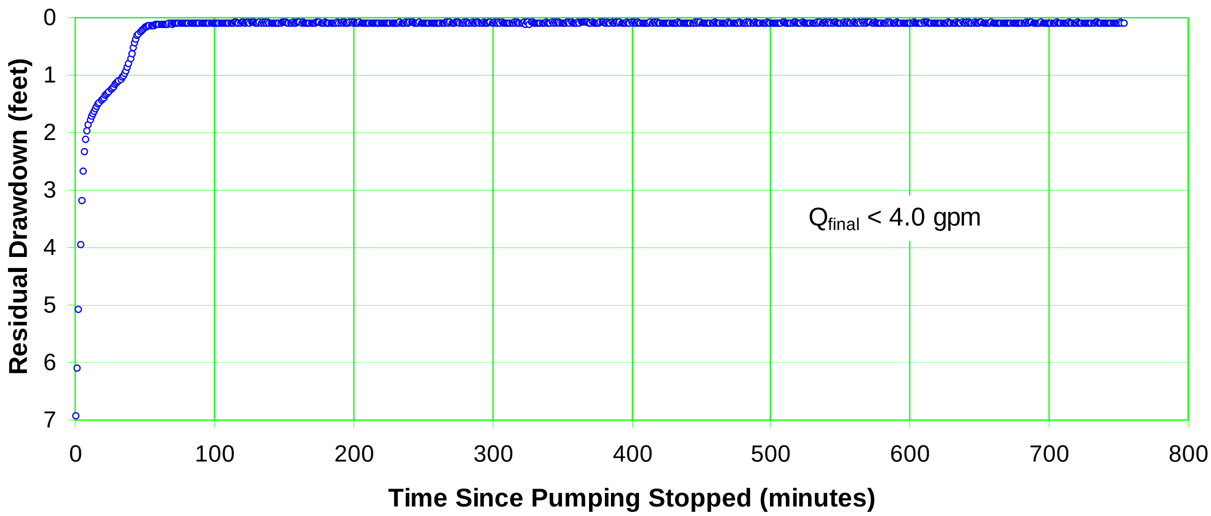

Figure C-9.5-5 Well R-41 screen 2 linear recovery following purge development

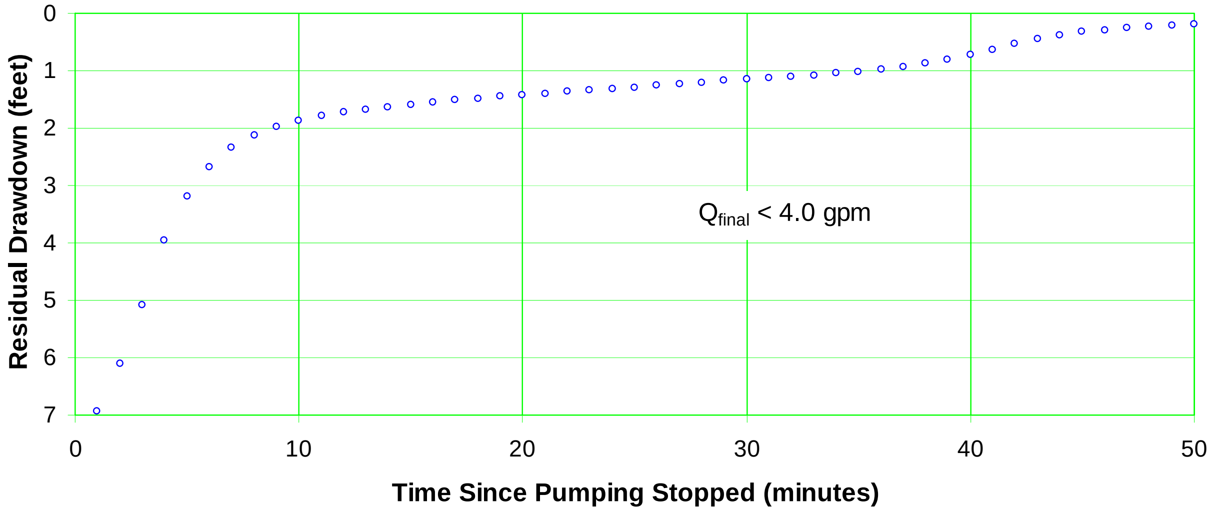

Figure C-9.5-6 Well R-41 screen 2 linear recovery following purge development—expanded scale

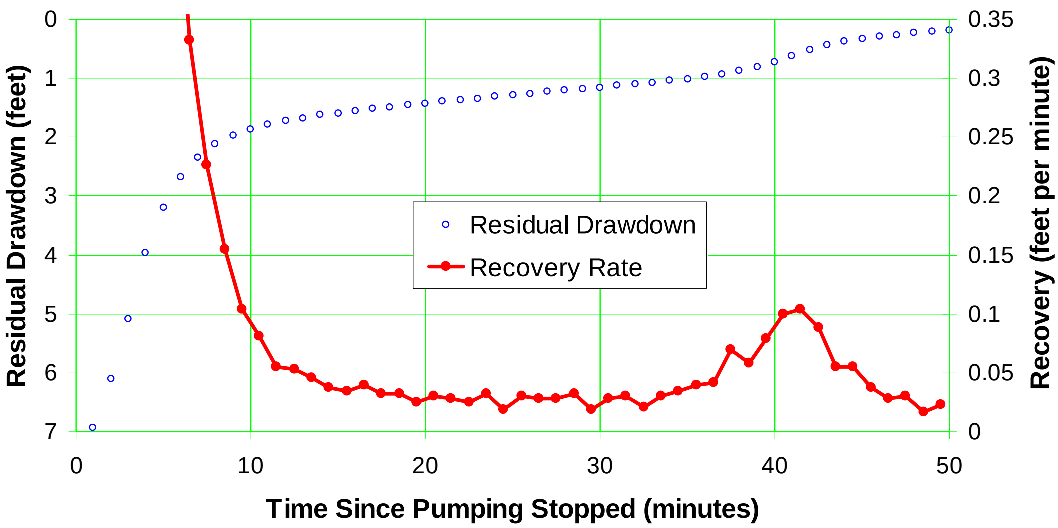

Figure C-9.5-7 Well R-41 screen 2 incremental recovery following purge development

Figure C-9.5-8 Well R-41 screen 2 early recovery following purge development

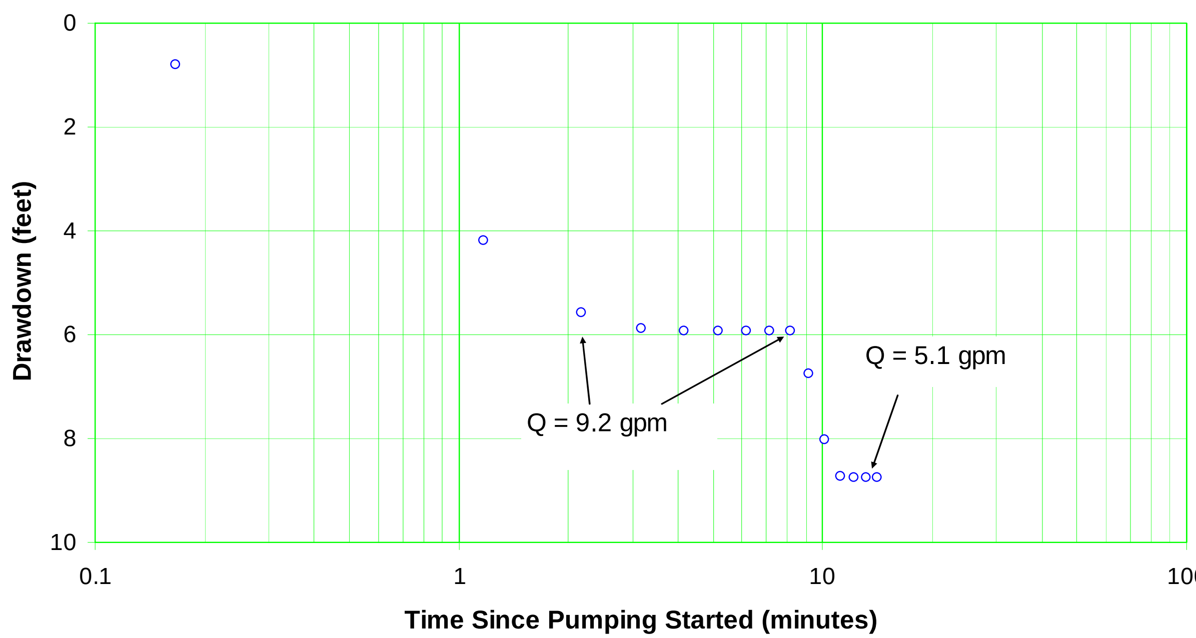

Figure C-9.6-1 Well R-41 screen 2 trial 3 drawdown

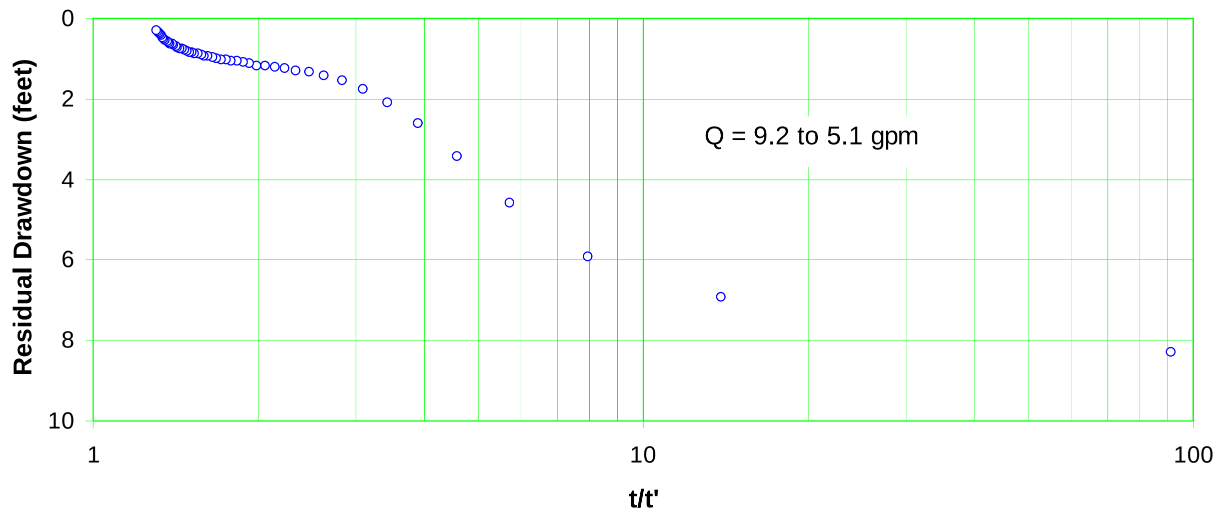

Figure C-9.6-2 Well R-41 screen 2 trial 3 recovery

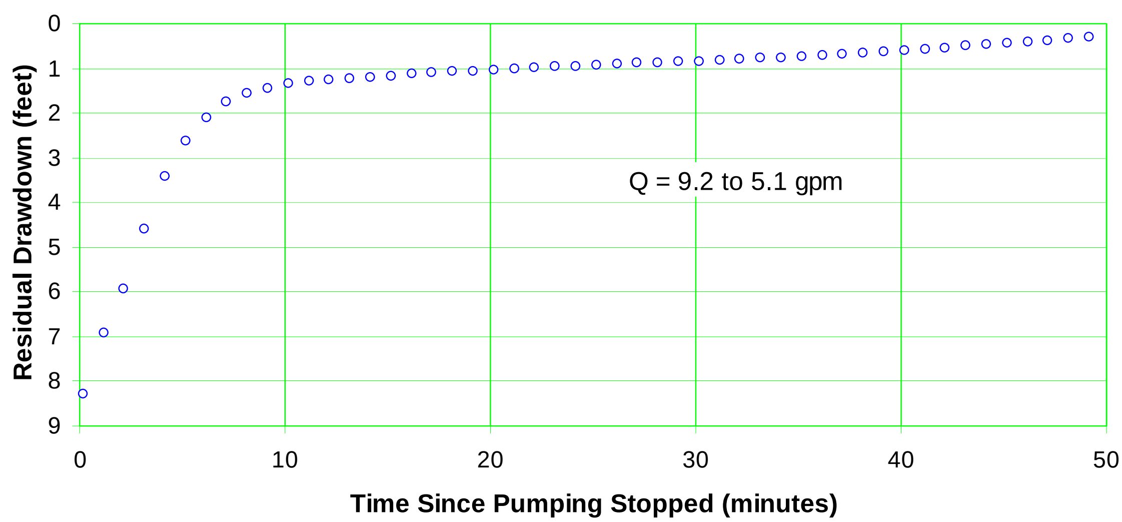

Figure C-9.6-3 Well R-41 screen 2 trial 3 linear recovery

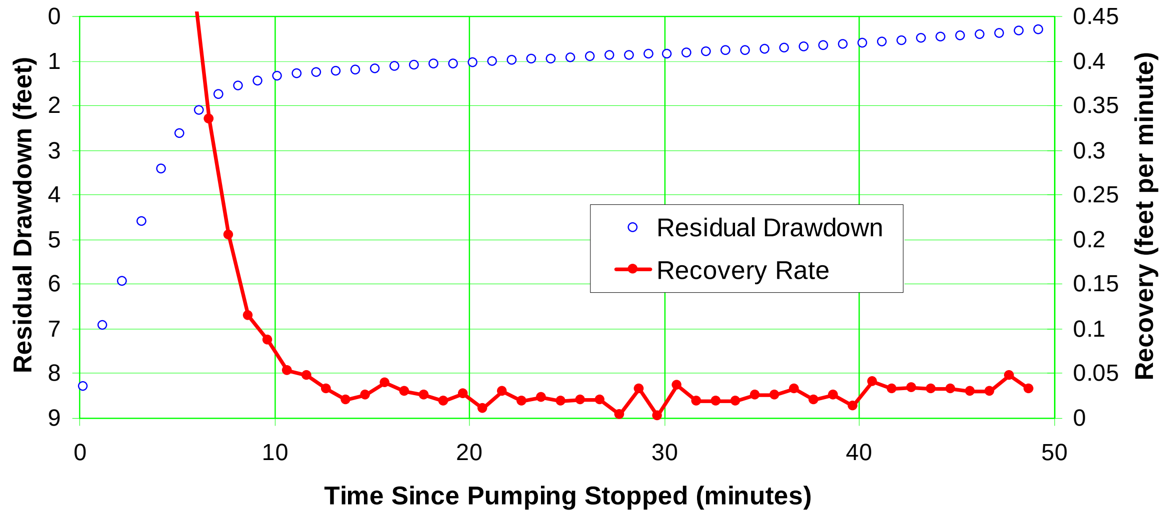

Figure C-9.6-4 Well R-41 screen 2 trial 3 incremental recovery

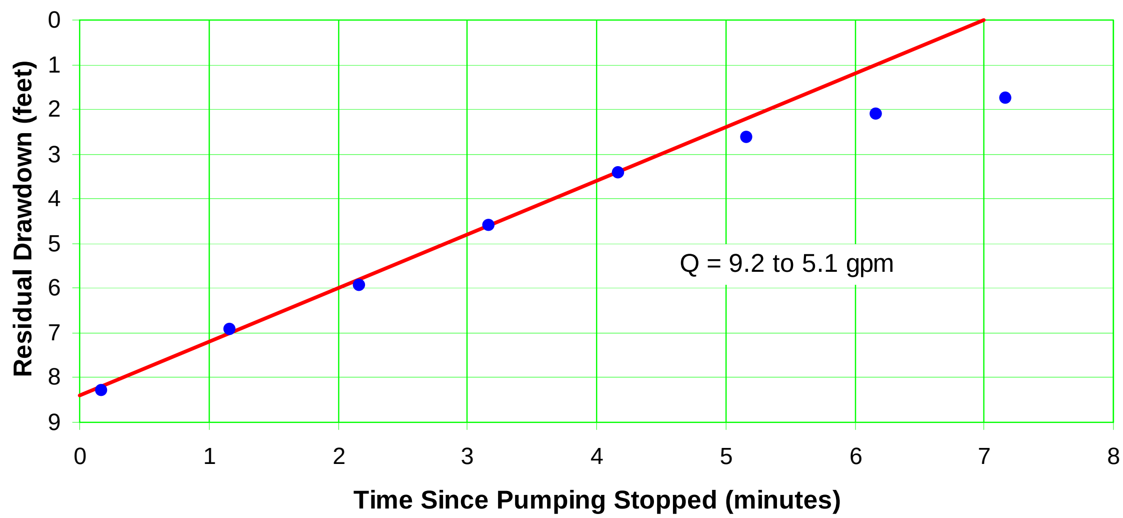

Figure C-9.6-5 Well R-41 screen 2 trial 3 early recovery

Table C-9.2-1
Filter-Pack Volumes

Top (ft)	Bottom (ft)	Thickness (ft)	Bags (0.5 ft^3)	Bags/ft
960	960.77	0.77	2	2.6
960.77	961.17	0.40	4	10.0
961.17	961.82	0.65	10	15.4
961.82	962.42	0.60	23.5	39.2
962.42	965.98	3.56	15	4.2
965.98	969.53	3.55	10	2.8
969.53	970.98	1.45	10	6.9
970.98	971.9	0.92	8	8.7

Appendix D

Borehole Video Logging
(on DVD included with this document)

Appendix E

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