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Completion Report for Intermediate Aquifer Well TA-53i

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Prepared by the Environmental Programs Directorate

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EXECUTIVE SUMMARY

This well completion report describes the drilling, installation, development, and aquifer testing of Los Alamos National Laboratory's intermediate aquifer monitoring well TA-53i. The TA-53i well is located on Mesita de Los Alamos, close to structures of the Los Alamos Neutron Science Center at Technical Area 53 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 help define the extent of contamination within the perched intermediate groundwater observed in Los Alamos Canyon at wells LADP-3, LAOI-3.2, LAOI-3.2a, and R-6i and to address whether perched groundwater observed at these locations extends beneath the mesa and/or communicates with perched saturation observed to the south in Sandia Canyon.

The TA-53i borehole was drilled using dual-rotary air-drilling methods. Fluid additives used included potable water and foam. Foam-assisted drilling was used only above the anticipated target perched water zone; no drilling-fluid additives other than small amounts of potable water were used below 437.0 ft below ground surface (bgs). Additive-free drilling provides minimal impacts to the groundwater and aquifer materials. The TA-53i borehole was successfully completed to total depth (TD) using dual-rotary casing-advance drilling methods. A retractable 16-in. casing was advanced through the lower units of the Tshirege Member of the Bandelier Tuff to a depth of 294.9 ft bgs to the contact with the Otowi Member tuff. A retractable 12-in. casing was then advanced to a TD of 636.5 ft bgs.

The TA-53i borehole was completed as a single-screen well to evaluate water quality and measure water levels in a perched groundwater interval encountered within the upper portion of the Puye Formation immediately above the Cerros del Rio basalt. The monitoring well has a 10-ft-long screened interval with the top of the screen set at 600.0 ft bgs.

The well was completed in accordance with an NMED-approved well design and was developed and met target water-quality parameters. Hydrogeologic testing indicated that monitoring well TA-53i is productive and will perform effectively to meet the planned objectives. A water-level transducer has been placed in the screened interval in the TA-53i 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
AK	acceptable knowledge
amsl	above mean sea level
ASTM	American Society for Testing and Materials
bgs	below ground surface
Consent Order	Compliance Order on Consent
DO	dissolved oxygen
EES-14	Earth and Environmental Sciences Group
Eh	oxidation-potential reduction
EPA	Environmental Protection Agency (U.S.)
IC	ion chromatography
ICPMS	inductively coupled (argon) plasma mass spectrometry
ICPOES	inductively coupled (argon) plasma optical emission spectroscopy
ID	identification
I.D.	inside diameter
LANL	Los Alamos National Laboratory
LANSCE	Los Alamos Neutron Science Center
MDA	material disposal area
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
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
RPF	Records Processing Facility
SOP	standard operating procedure
SVOC	semivolatile organic compound
TA	technical area
Tb 4	Tertiary Cerros del Rio basalt
TD	total depth
TOC	total organic carbon

Tpf	Tertiary Puye formation
VOC	volatile organic compound
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 monitoring well TA-53i. 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 TA-53i was drilled from February 28 to March 4, 2009, and the well was completed from March 7 to March 10, 2009, at Los Alamos National Laboratory (LANL or the Laboratory) for the LANL Water Stewardship Program.

The TA-53i project site is located on Mesita de Los Alamos, close to structures of the Los Alamos Neutron Science Center (LANSCE) at Technical Area 53 (TA-53) in Los Alamos County, New Mexico (Figure 1.0 1). The purposes of the TA-53i well are to help define the extent of contamination within the perched intermediate groundwater observed in Los Alamos Canyon at wells LADP-3, LAOI-3.2, LAOI-3.2a, and R-6i and to address whether perched groundwater observed in these locations extends beneath the mesa and/or communicates with perched groundwater zones observed to the south in Sandia Canyon (e.g., well SCI-1).

The primary objective of the drilling activities at TA-53i was to drill and install a single-screen intermediate depth perched aquifer monitoring well. Secondary objectives were to collect drill-cutting samples, acquire borehole geophysical data, and sample potential perched groundwater zones, if present.

The TA-53i borehole was drilled to a total depth (TD) of 636.5 ft below ground surface (bgs). A monitoring well was installed with one 10-ft screen between 600.0 and 610.0 ft bgs. The depth to water after well installation was 599.8 ft bgs on March 14, 2009. During drilling, 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, dedicated sample system installation, and geodetic surveying. Future 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 TA-53i 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 the drill site. All preparatory activities were completed in accordance with Laboratory policies and procedures and regulatory requirements.

2.1 Administrative Preparation

The following documents helped guide the implementation of the scope of work for the TA-53i project: "Drilling Plan for Intermediate Well TA-53-1(i)" (TerranearPMC 2009, 106153), "Integrated Work Document for Regional and Intermediate Aquifer Well Drilling (Mobilization, Site Preparation and Setup Stages)" (LANL 2007, 100972), "Storm Water Pollution Prevention Plan for SWMUs and AOCs (Sites) and Storm Water Monitoring Plan" (LANL 2006, 092600), and "Waste Characterization Strategy Form for the Five Spring Wells" (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 27 and 28. Alternative drilling tools and construction materials were staged at the Pajarito Road lay-down yard.

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

3.0 DRILLING ACTIVITIES

This section describes the drilling strategy and approach and provides a chronological summary of field activities conducted at monitoring well TA-53i.

3.1 Drilling Approach

The drilling methodology and selection of equipment and drill-casing sizes for the TA-53i monitoring well were designed to retain the ability to investigate and case off any perched groundwater that may have been encountered above the targeted perched water zone. 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 5.50-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 TA-53i 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. Two sizes of A53 grade B flush-welded mild carbon-steel casing (16-in. and 12-in. inside-diameter [I.D.]) were used for the TA-53i project. The dual-rotary technique at TA-53i 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 within 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 437.0 ft bgs, roughly 100 ft above the expected perched groundwater horizon. No additives other than municipal water were used for drilling below this depth (437.0 ft bgs). A record of the total amounts of drilling fluids introduced into the borehole and those recovered is presented in Table 3.1-1.

3.2 Chronological Drilling Activities

Mobilization of drilling equipment and supplies to the TA-53i drill site occurred on February 27–28, 2009. The TA-53i borehole was initiated at midday (1245 h) on February 28 using dual-rotary methods with 16-in. drill casing and a 15-in. tricone bit. Drilling and advancing 16-in. casing proceeded without incident through surface fill and lower units of the Tshirege Member of the Bandelier Tuff to a depth of 294.9 ft bgs. The 16-in. casing was landed near the base of the Cerro Toledo interval on March 2, 2009 (0810 h). Slight indications of possible perched groundwater observed at or near 294 ft bgs before landing the casing proved to be false; no water could be collected from this interval after the initial indications.

After landing the 16-in. casing, a 12-in. string of drill casing was installed in the borehole and reached the then current TD early the morning of March 3. Dual-rotary drilling recommenced using the 12-in. drill casing and a tricone bit. At a depth of 437 ft bgs (in the Otowi Member), foam use was suspended and reconnaissance for possible perched groundwater began. Stops for air-only circulation at each casing connection showed no indication of groundwater all the way to the borehole's TD in the top of the Cerros del Rio basalt at 636.5 ft bgs. Drill cuttings over this interval were described as "moist" at their wettest, with no water observed from the discharge line.

After reaching TD (636.5 ft bgs) at 2050 h on March 4, the drilling tools were tripped out of the borehole in preparation for video and geophysical logging. Electrical communication problems with the Laboratory logging tools preempted running any surveys; however, a measured depth to water of 635.5 ft bgs was noted. At 1700 h the next day (March 5), Jet West Geophysical arrived at the drill site and ran a natural gamma-ray survey. After pulling the logging tool from the borehole, the 12-in. drill casing was retracted 21.5 ft to 615.0 ft bgs, and a video camera was run in the hole. The video showed no water entry into the open portion of the borehole and revealed a water level of approximately 634 ft bgs. After pulling another 81.5 ft of 12-in. casing (casing shoe at 532 ft bgs), the second video showed water standing at approximately 599 ft bgs (log depth) in the upper portion of the Puye Formation. A manual water-level measurement of 600.0 ft bgs was recorded after Jet West ran an induction/natural gamma-ray log covering the new open-hole interval early in the morning of March 6. A water sample was also taken after bailing about 10 gal. of water from the borehole on March 6.

Five more water samples were obtained that day as bailing proceeded, eventually totaling 226 gal. of water purged. Bailing had no discernible effect on water levels, and depth to water at the conclusion of bailing was 600.1 ft bgs. The dual-rotary drilling rig remained on-site and was utilized during well construction.

During drilling, field crews worked two 12-h shifts per day (24-h operation), 7 d/wk. All associated daily activities proceeded normally without incident or delay.

4.0 SAMPLING ACTIVITIES

This section describes the cuttings and groundwater sampling activities for monitoring well TA-53i. All sampling activities were conducted in accordance with applicable quality procedures.

4.1 Cuttings Sampling

Cuttings samples were collected from the TA-53i borehole at 5-ft intervals from ground surface to the TD of 636.5 ft bgs. At each interval, approximately 500 mL of bulk cuttings was collected by the site geologist from the cyclone discharge, 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 excellent in 100% of the borehole. 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 radiological screening measurements were within the range of background values.

The borehole lithologic log for TA-53i stratigraphy is summarized in section 5.1 and detailed in Appendix A.

4.2 Water Sampling

To evaluate potential perched groundwater zones, groundwater-screening reconnaissance started at 437.0 ft bgs and continued through TD of 636.5 ft bgs. Procedurally, upon reaching the bottom of a 20-ft run of casing, the driller stopped water circulation (if injecting water) and circulated air. As the discharge cleared, and if water was present, a water sample could be collected directly from the discharge hose. As noted in section 3.2, no such groundwater indications occurred within the 437.0–636.5-ft bgs drilling interval.

After reaching TD and retracting the 12-in. drill casing from 103 ft to 532.0 ft bgs (bottom of 12-in. drive shoe), standing water was observed (measured and on video) at 600.0 ft bgs. A total of six samples were obtained by bailing from this perched water column. The samples were analyzed for anions, metals, tritium, and volatile organic compounds (VOCs). Refer to Table 4.2-1 and Appendix B for a summary of screening samples collected at the TA-53i borehole.

Three groundwater-screening samples were collected during well development while pumping. Development-screening samples were analyzed for anions, metals, and total organic carbon (TOC).

Six perched groundwater-screening samples were collected at regular intervals (approximately one sample per 2 or 4 h) during aquifer testing. All were collected from the well's single-screen interval, 600.0–610.0 ft bgs. All samples were collected from the surface discharge line from the submersible development pump. Aquifer-testing screening samples were analyzed for dissolved anions, metals, and TOC.

Groundwater characterization samples were collected from the completed well in accordance with the Consent Order. The samples were analyzed for the full suite of constituents, including radioactive elements, anions/cations, general inorganic chemicals, VOCs, and semivolatile organic compounds (SVOCs); and stable isotopes of hydrogen, nitrogen, and oxygen. The characterization and 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 geologic and hydrogeologic features encountered at the TA-53i monitoring well 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 the TA-53i borehole.

5.1 Stratigraphy

The stratigraphy for the TA-53i borehole is described below in order of youngest to oldest geologic units. Unit descriptions are based on drill 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 TA-53i. A detailed lithologic log based on microscopic examination and analysis of drill cuttings is presented in Appendix A.

Construction Fill (0–7 ft bgs)

Alluvial sediments were not encountered at TA-53i. Drilling encountered sandy gravels containing volcanic and quartzo-feldspathic materials laid down to construct the drill pad from 0 to 7 ft bgs.

Unit 2 of the Tshirege Member of the Bandelier Tuff, Qbt 2 (7–70 ft bgs)

Unit 2 of the Tshirege Member of the Bandelier Tuff, the uppermost rock unit encountered at TA-53i, was identified from 7 to 70 ft bgs as interpreted from cuttings and natural gamma-ray geophysical log data. Unit 2 is a moderately to locally densely welded ash-flow tuff that is crystal-rich, weakly pumiceous, and generally lithic-poor. Drill cuttings from unit 2 typically contain a predominance of welded tuff fragments containing up to 30% by volume quartz and sanidine crystals, minor amounts of small pumice lapilli that are devitrified and moderately deformed (i.e., compressed), and up to 2% volcanic lithics enclosed in a matrix of fine volcanic ash.

Unit 1v of the Tshirege Member of the Bandelier Tuff, Qbt 1v (70–155 ft bgs)

Unit 1v of the Tshirege Member of the Bandelier Tuff was encountered from 70 to 155 ft bgs, as interpreted from cuttings and natural gamma-ray geophysical log data. Unit 1v is characterized by the presence of devitrified glass that occurs in the make-up of both pumice and ash matrix. As observed in TA-53i 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 10% quartz and sanidine crystals and locally up to 20% by volume of pumice lapilli exhibiting devitrified (i.e., granular, recrystallized) textures and minor volcanic (predominantly dacitic) lithics in a matrix of devitrified volcanic ash.

Unit 1g of the Tshirege Member of the Bandelier Tuff, Qbt 1g (155–238 ft bgs)

Unit 1g of the Tshirege Member of the Bandelier Tuff was encountered from 155 to 238 ft bgs, as interpreted from cuttings and natural gamma-ray geophysical log data. Unit 1g is recognized by the appearance of vitric pumices as a primary tuff component. The unit 1g section in TA-53i represents a nonwelded to poorly welded ash-flow tuff that is strongly pumiceous, generally crystal-bearing, and lithic-poor with abundant vitric-ash matrix. Unit 1g cuttings commonly display orange to tan, glassy, fibrous-textured pumice lapilli, subangular volcanic lithic fragments (predominantly dacitic), free quartz and sanidine crystals, and locally abundant orange-tan vitric ash. Intact fragments of unit 1g tuff matrix are seldom preserved in cuttings.

Cerro Toledo Interval, Qct (238–296 ft bgs)

The Cerro Toledo interval, intersected from 238 to 296 ft bgs (as interpreted from cuttings and natural gamma-ray logging data), is estimated to be 58 thick at TA-53i. This unit, consisting of poorly consolidated sediments derived from local tuffaceous and volcanic sources, stratigraphically separates the Tshirege and Otowi Members of the Bandelier Tuff. Locally, the Cerro Toledo interval consists of weakly consolidated silty fine to coarse sands and gravels made up of detrital tuffaceous and volcanic materials (e.g., dacites, minor obsidian), weathered to glassy pumice fragments, and abundant fine-grained quartz and sanidine crystal crystals. The contact between the Cerro Toledo interval and the Otowi Member is uncertain because cuttings of the two units have similar lithologic characteristics. At TA-53i a shift to higher borehole gamma response was used to identify the top of the Otowi Member.

Otowi Member of the Bandelier Tuff, Qbo (296–532 ft bgs)

The Otowi Member of the Bandelier Tuff, encountered in TA-53i from 296 to 532 ft bgs, is 236 ft thick, as interpreted from cuttings and natural gamma-ray geophysical log data. The Otowi Member is a poorly welded, pumiceous, locally lithic-rich, crystal-bearing ash-flow tuff. The Otowi Member locally contains abundant white to pale orange pumice lapilli that are glassy, fibrous-textured and quartz- and sanidine-phyric, along with volcanic lithic fragments (i.e., xenoliths), and moderately abundant quartz and sanidine crystals enclosed in a matrix of vitric ash. Locally abundant subangular lithic fragments (up to 14 mm in diameter) are predominantly of intermediate volcanic compositions (i.e., gray to pinkish gray hornblende-

and/or biotite-phyric dacites, some andesites). Intact fragments of Otowi Member tuff matrix are seldom preserved in cuttings.

Guaje Pumice Bed of the Otowi Member of the Bandelier Tuff, Qbog (532–559 ft bgs)

The Guaje Pumice Bed occurs in TA-53i from 532 to 559 ft bgs on the basis of cuttings and natural gamma-ray log interpretation. Locally, the Guaje tuff unit is nonwelded, pumice-rich, lithic- and crystal-poor, and contains abundant (75%–95% by volume) pristine-appearing white vitric, phenocryst-poor pumice fragments and lapilli. Trace amounts of volcanic lithics, quartz and sanidine phenocrysts, and fine ash are present.

Puye Formation, Tpf (559–634 ft bgs)

A 75-ft-thick section of Puye Formation volcaniclastic sediments was encountered in TA-53i stratigraphically below the Bandelier Tuff from 559 to 634 ft bgs. These sediments are composed of texturally diverse, gray, grayish brown and pinkish tan, poorly sorted, fine to coarse gravels, gravelly sandstones, and silty sandstones with gravel. Significant intervals of silt-rich sediments were observed in drill cuttings intermittently throughout the section. Compositionally, the Puye Formation section is quite uniform throughout. Detrital constituents making up these sediments are generally subangular and predominantly of gray porphyritic hornblende-phyric dacites, dacitic vitrophyre, and lesser andesite.

Cerros del Rio Basalt, Tb4 (634–636.5 bgs)

Basaltic lava and/or basaltic sediments were intersected in the short interval from 634 ft to the TA-53i borehole TD at 636.5 ft bgs. Drill cuttings in this section are mixed broken chips and subangular to subrounded clasts of vesicular olivine-phyric basalt with minor abundances of silty, very fine-grained sandstone fragments. Evidence from cuttings as to the true nature of this interval, whether of basaltic lava or basalt-rich sediments, or both, is inconclusive.

5.2 Groundwater

Depth to groundwater was detected at approximately 600.0–600.1 ft bgs in the Puye Formation sediments on March 5, 2009, after the borehole had been drilled to a final depth of 636.5 ft bgs.

Groundwater-screening samples were collected at the conclusion of drilling, during well development, and during aquifer testing, as discussed in section 4.2 and presented in Table 4.2-1. 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

A video log and a limited suite of geophysical logs (natural gamma-ray and induction) were collected during the TA-53i drilling project by Jet West Geophysical. A summary of video and geophysical logging runs is presented in Table 6.0-1.

6.1 Video Logging

A video survey was run in the TA-53i borehole on March 5, 2009. Before the run, the 12-in. drill casing had been retracted 21.5 ft and no water entry was observed over the open section of the borehole. Later after pulling a total of 103 ft of 12-in. casing (to 532.0 ft bgs) to better allow water to enter the borehole, the camera (second run) revealed standing water at 600.0 ft bgs. The Jet West video log is presented on a DVD as part of Appendix D included with this document.

6.2 Geophysical Logging

In conjunction with the video survey, Jet West Geophysical ran natural gamma-ray and induction logs from TD to surface (induction recorded approximately 535 ft bgs to TD) on March 5–6, 2009. For the second run, the borehole was open below 532.0 ft bgs, the 12-in. casing had been retracted to that depth, and the 16-in. casing remained temporarily set at 294.9 ft bgs. The logs are presented on the CD as part of Appendix E included with this document.

7.0 WELL INSTALLATION TA-53i MONITORING WELL

The TA-53i well was installed between March 7 and March 10, 2009.

7.1 Well Design

The TA-53i well was designed in accordance with the Consent Order. The well design was submitted to NMED on March 6, 2009 (Vaniman 2009, 106087). NMED approved the well design on March 7, 2009 (Dale 2009, 106096). The well was designed with a single-screened interval to monitor perched groundwater quality in the upper part of the Puye Formation lying stratigraphically above the Cerros del Rio basalt.

7.2 Well Construction

The TA-53i intermediate depth monitoring well was constructed of 5.0-in.-I.D./5.56-in.-O.D., type A304 stainless-steel threaded casing fabricated to American Society for Testing and Materials (ASTM) A312 standards. The screened section utilized one 10-ft length of 5.0-in.-I.D. rod-based 0.020-in. wire-wrapped well screen. Compatible external stainless-steel couplings (also type A304 stainless steel fabricated to ASTM A312 standards) were used to join all individual casing and screen sections. The coupled unions between threaded sections were approximately 0.7 ft long. All casing and screen were steam- and pressure-washed on-site before installation. A 2-in.-I.D. steel threaded/coupled tremie pipe string, decontaminated before use, was utilized for delivery of backfill and annular fill materials downhole during well construction. The placement of annular and backfill materials typically had two components: (1) installing materials and retracting the drill casing and (2) 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 ring and slips. All drilling casing and welded-on shoes (i.e., for the 12- and 16-in. strings) were successfully removed from the borehole during well construction. No drill casing remains in the borehole.

One screened interval was chosen for the TA-53i well design. The 10.0-ft-long screened interval had the top of the screen set at 600.0 ft bgs. A 10.8-ft stainless-steel sump was placed below the bottom of the well screen. Stainless-steel centralizers (two sets of four) were welded to the well casing approximately 1.0 ft above and below the screen. The dual-rotary drilling rig remained on-site and was used for well construction activities. Figure 7.2-1 presents an as-built schematic showing construction details for the completed well.

The stainless-steel well casing and screen were decontaminated and well construction materials were mobilized to the site on March 6, 2009. The next day (March 7 at 0200 h) 5-in. well casing was installed in the borehole. After landing the casing at 620.8 ft bgs, the process of installing annular fill materials began midday on March 7.

First, a lower seal composed of ⅜-in. bentonite chips (12.2 ft^3) was placed from 613.2 to 630.1 ft bgs. After the lower seal, a short, lower 20/40 silica sand transition (1.0 ft^3) was installed from 612.2 to 613.2 ft bgs. Using 10/20 silica sand the filter pack was then placed from 598.2 to 612.2ft bgs and surged to promote compaction (total 10/20 sand: 14.5 ft^3). An upper 20/40 silica sand transition was then added on top of the sand pack from 594.6 to 598.2 ft bgs (3.4 ft^3).

The upper bentonite seal (⅜-in. chips) was installed on March 8–March 9 from 297.8 to 594.6 ft bgs using a total of 201.0 ft^3 of bentonite chips. The final surface seal, a mix of 97–98 weight percent (wt%) Portland cement and 2–3 wt% bentonite was placed above the upper bentonite seal from 4.0 to 297.8 ft bgs (592.6 ft^3). This marked NMED well construction completion on March 10, 2009 (at 1700 h). Table 7.2-1 itemizes volumes of all materials used during well construction.

Operationally, well construction proceeded rapidly per plan and without incident, 24 h per day, 7 d/wk, from March 7 to March 10, 2009.

8.0 POSTINSTALLATION ACTIVITIES

Following well installation at TA-53i, the well was developed and an aquifer pumping test performed. Total groundwater purged during well development and aquifer testing was 5063 gal. The wellhead and surface pad were built and a dedicated sampling system was installed. This was followed by a well site geodetic survey. Site restoration activities will be completed following the final disposition of contained drill cuttings and groundwater, per the NMED-approved waste-decision trees and regulatory requirements.

8.1 Well Development

Well development was conducted between March 14 and March 18, 2009. Initially, the screened interval was bailed and swabbed to remove formation fines in the filter pack and sump. Bailing and swabbing continued until water clarity visibly improved. Final development was accomplished using 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. After bailing and swabbing, a 5-hp, 4-in.-Grundfos submersible pump was installed in the well for the final stage of well development. Approximately 2600 gal. of groundwater was purged at TA-53i during well development activities.

During the pumping stage of well development, turbidity, temperature, pH, dissolved oxygen (DO), oxidation-reduction potential (ORP), and specific conductance parameters were measured. In addition, water samples for 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.

A discussion of water removed during well development, field water-quality parameters, and analytical results for samples collected during development is summarized below in section 8.1.1 and detailed in Table B-1.2-1 of Appendix B.

8.1.1 Well Development Field Parameters

Field parameters were measured at well TA-53i by collecting aliquots of groundwater from the pump's surface discharge line. Parameters were measured using a YSI multimeter without the use of a flow-through cell, allowing the samples to be exposed to the atmosphere. This condition probably resulted in a slight variation of field parameters during well development and during the pumping test, most notably, temperature, pH, and DO.

Measurements of pH varied from 7.06 to 7.11 and temperature varied from 19.40°C to 19.62°C. DO varied from 6.24 to 6.55 mg/L, and uncorrected field ORP measurements varied from –1.4 to –18.7 millivolts (mV). Specific conductance ranged from 278 to 312 microsiemens per centimeter (μS/cm) and values of turbidity measured at TA-53i ranged from 0.4 to 0.0 NTU for the unfiltered groundwater.

8.2 Aquifer Testing

Aquifer pumping tests were conducted at TA-53i from April 6 to April 9, 2009. Several short-duration tests with short-duration recovery periods were performed initially. A 24-h test, followed by a 24-h recovery period, completed the testing. A 5-hp Grundfos pump was used to perform the aquifer tests. Approximately 2463 gal. of groundwater was purged at TA-53i during aquifer testing activities.

Turbidity, temperature, pH, DO, ORP, and specific conductance parameters were measured during the 24-h test. In addition, water samples for TOC analysis were collected.

A discussion of water removed during well development, field water-quality parameters, and analytical results for samples collected during development is summarized below in section 8.2.1 and detailed in Table B-1.2-1 of Appendix B. Results of the TA-53i aquifer test are presented in Appendix C.

8.2.1 Aquifer Testing Field Parameters

During aquifer performance testing at well TA-53i, 23 measurements of pH and temperature varied from 7.07 to 7.26 and from 15.87°C to 23.19°C, respectively. Concentrations of DO varied from 6.70 to 8.50 mg/L, and positive, uncorrected ORP values ranged from –35.7 to 63.3 mV during aquifer performance testing of TA-53i. Concentrations of DO varied from 6.70 to 8.50 mg/L. Specific conductance and turbidity generally decreased from 323 to 308 μS/cm and from 6.3 to 0 NTUs for groundwater pumped from TA-53i during aquifer performance testing. Only 2 of the 23 measurements exceeded 5 NTUs during this phase of testing at the well.

8.3 Dedicated Sampling System Installation

The dedicated sampling system for TA-53i was installed on May 8, 2009. The sampling system utilizes a single 1.5-hp, 4-in.-O.D. environmentally retrofitted Grundfos submersible pump that is set near the bottom of the screen interval. Because of the lack of available water above the screen interval, the pump is set in a stainless-steel pump shroud with the bottom of the shroud at 610.8 ft bgs. The pump riser pipe consists of threaded and coupled 1-in.-I.D. schedule 40 stainless steel. Two 1-in.-diameter polyvinyl chloride (PVC) tubes were installed and are banded to the pump riser. One tube is to be used for the dedicated pressure transducer and the other for manual water-level measurements. Both tubes are 1.0-in.-I.D. flush-threaded schedule 80 PVC pipe; each tube has a 6-in.-long 0.010-in. screen-slot interval at the bottom of the tube. One In-Situ Level Troll 500 transducer has been installed in one of the PVC tubes to monitor the water level in the well's screen interval. Postinstallation construction and sampling system component installation details for TA-53i are presented in Figure 8.3-1a. Figure 8.3-1b presents technical notes for the well.

8.4 Wellhead Completion

A reinforced concrete surface pad, 10 ft × 10 ft × 6 in. thick, was installed at the TA-53i wellhead. The pad will provide long-term structural integrity for the well. A brass survey pin was embedded in the northwest corner of the pad. A 10-in.-I.D. steel protective casing with a locking lid was installed around the stainless-steel well riser. The concrete pad was slightly elevated above the ground surface and crowned to promote runoff. Base coarse was graded around the edges of the pad. 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 cap 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 TA-53i project includes drilling fluids, purged groundwater, drill cuttings, decontamination water, and contact waste. A summary of the waste characterization samples collected from the TA-53i well is presented in Table 8.6-1.

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

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

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

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

9.0 DEVIATIONS FROM PLANNED ACTIVITIES

Drilling, sampling, and well construction at TA-53i were performed as specified in "Drilling Plan for Intermediate Well TA-531(i)" (TerranearPMC 2009, 106153).

10.0 ACKNOWLEDGMENTS

Boart Longyear drilled and installed the TA-53i monitoring well.

Patrick Longmire wrote Appendix B, Groundwater Analytical Results.

David Schafer wrote Appendix C, Aquifer Testing Report.

Jet West Geophysical ran all video and geophysical logging equipment.

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 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.

Dale, M., March 6, 2009. RE: Review for approval, well TA-53-1(i) design. E-mail message to D. Vaniman (LANL) from M. Dale (NMED), Santa Fe, New Mexico. (Dale 2009, 106096)

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, February 2009. "Drilling Plan for Intermediate Well TA-53-1(i)," plan prepared for Los Alamos National Laboratory, Los Alamos, New Mexico. (TerranearPMC 2009, 106153)

Vaniman, D., March 6, 2009. Review for approval, well TA-53-1(i) design [and attachment]. E-mail message to M. Dale (NMED) from D. Vaniman (LANL), Los Alamos, New Mexico. (Vaniman 2009, 106087)

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; February 28, 2008.

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

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

Paved Road Arcs; Los Alamos National Laboratory, KSL Site Support Services, Planning, Locating and Mapping Section; January 6, 2004; as published January 4, 2008.

Dirt Road Arcs; Los Alamos National Laboratory, KSL Site Support Services, Planning, Locating and Mapping Section; January 6, 2004; as published January 4, 2008.

Structures; Los Alamos National Laboratory, KSL Site Support Services, Planning, Locating and Mapping Section; January 6, 2004; as published January 4, 2008.

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

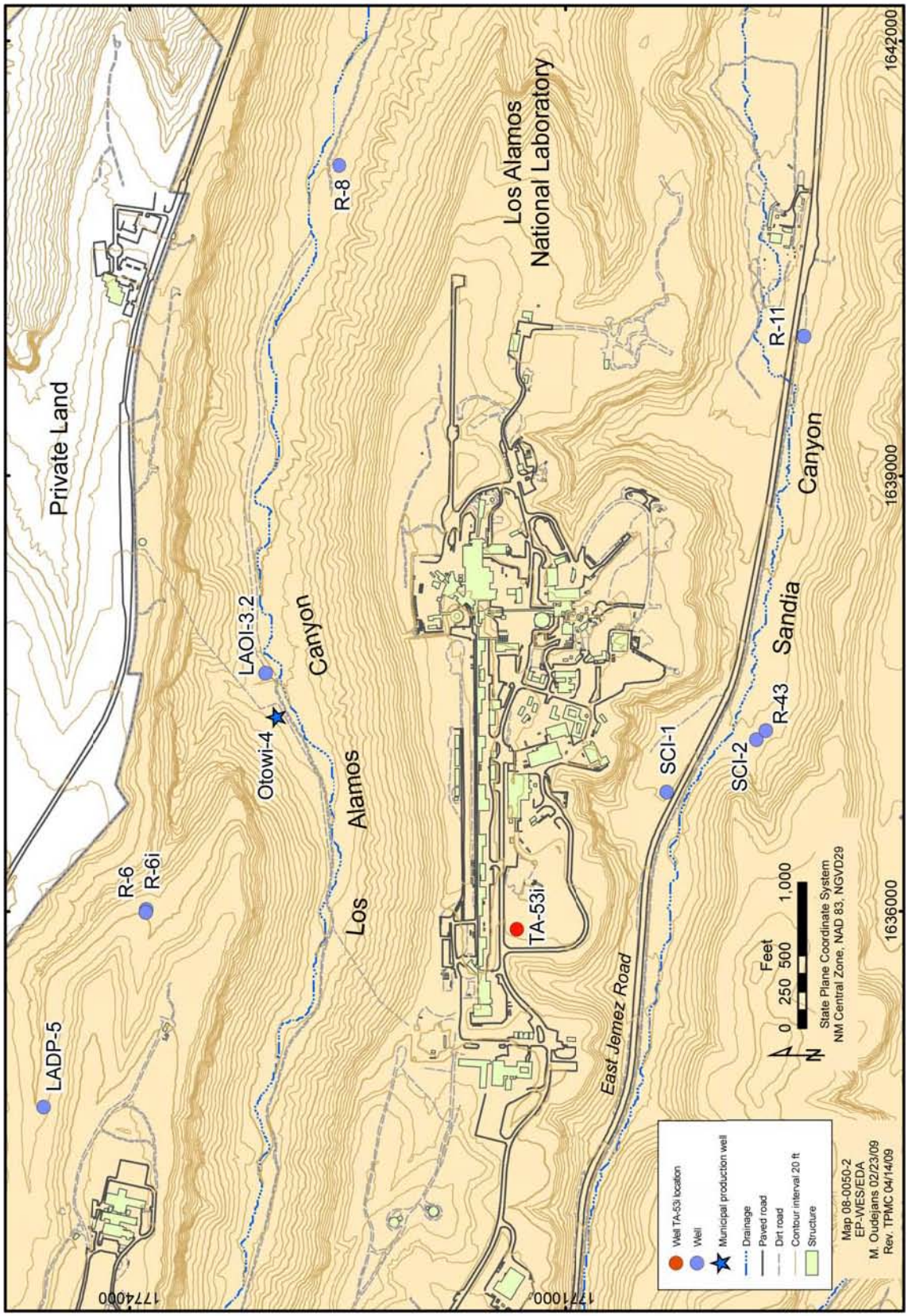


Figure 1.0-1 Location of intermediate perched water-monitoring well TA-53i with respect to LANSCE structures and surrounding wells

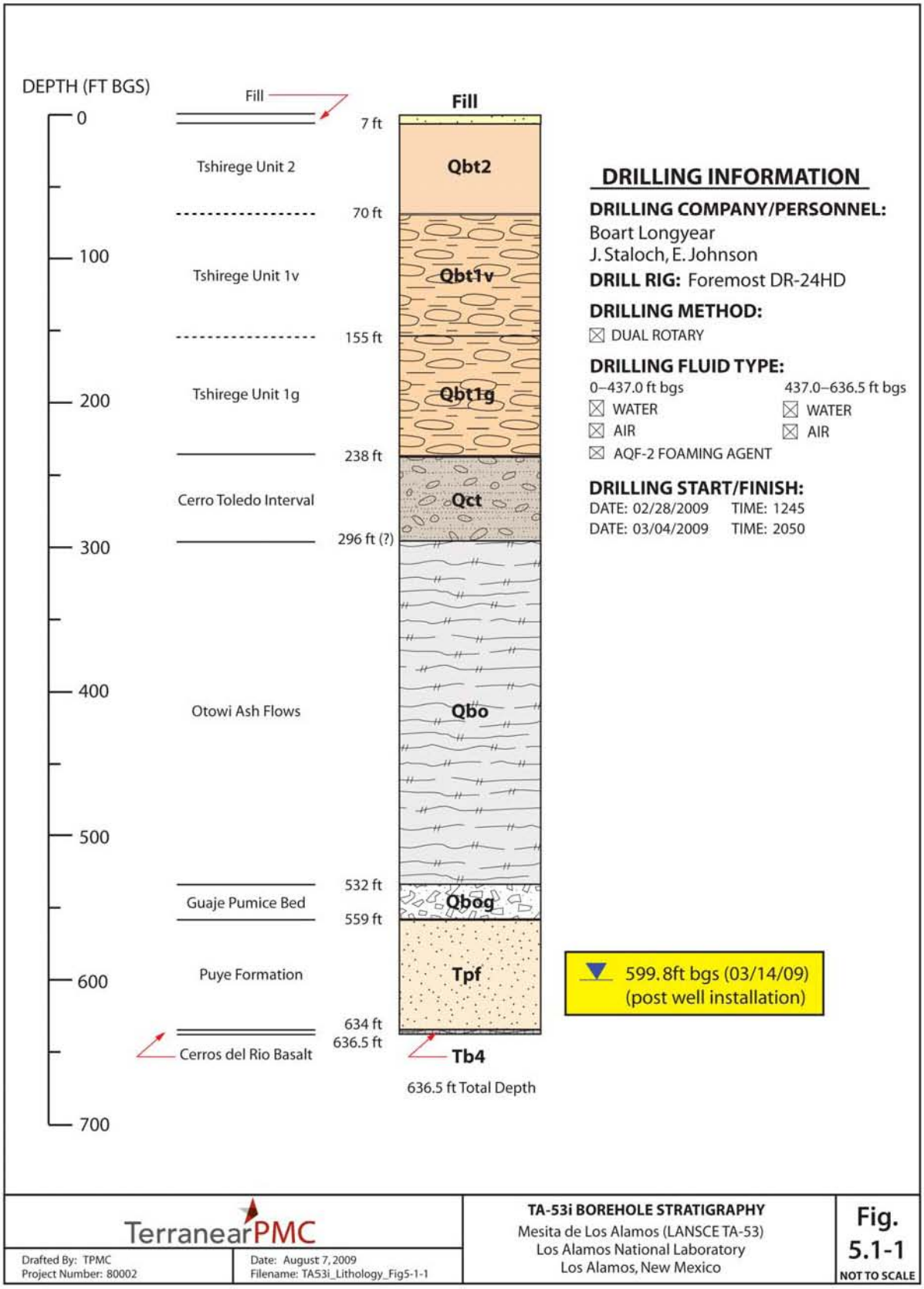


Figure 5.1-1 Monitoring well TA-53i borehole stratigraphy

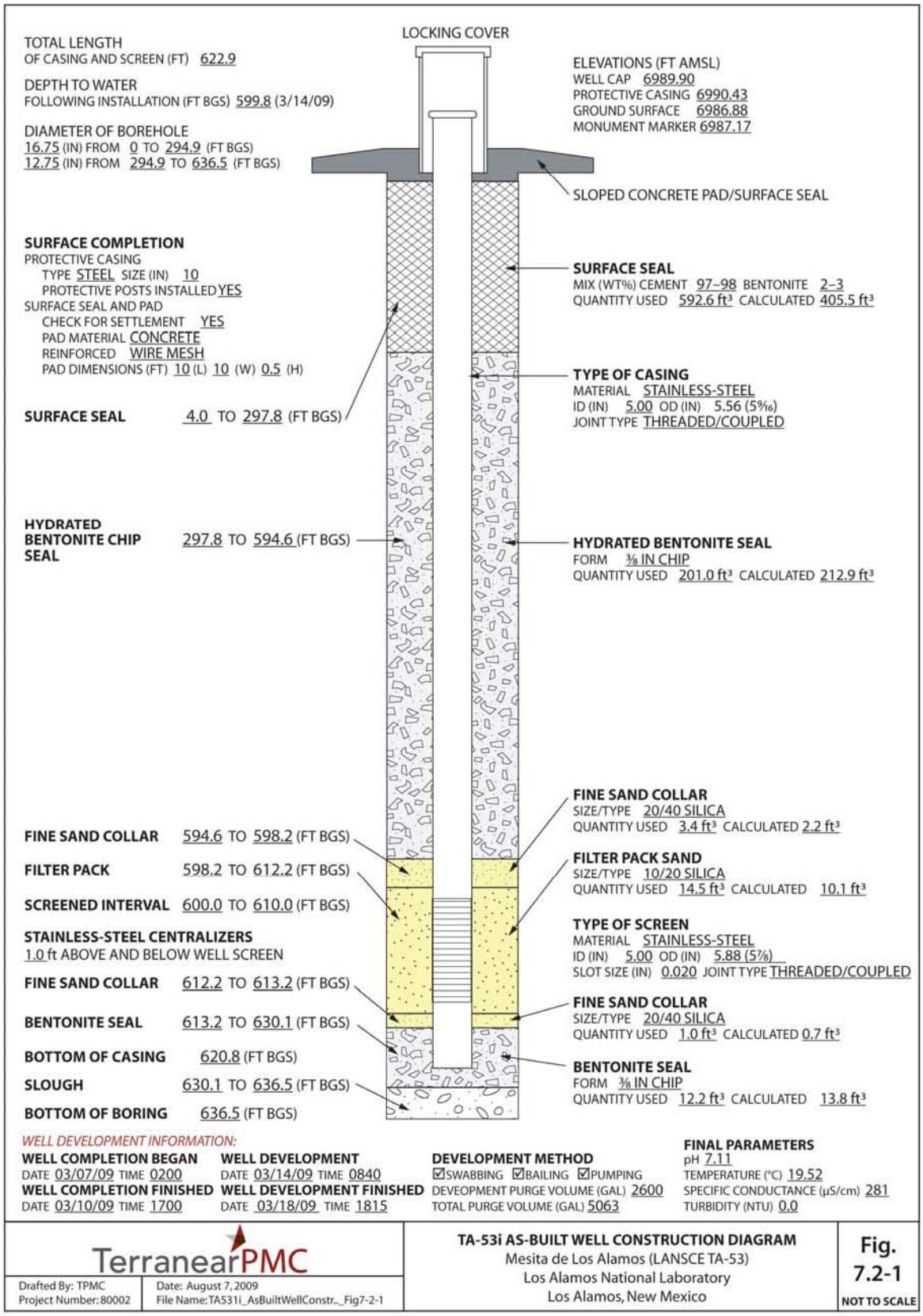


Figure 7.2-1 Monitoring well TA-53i as-built well construction diagram

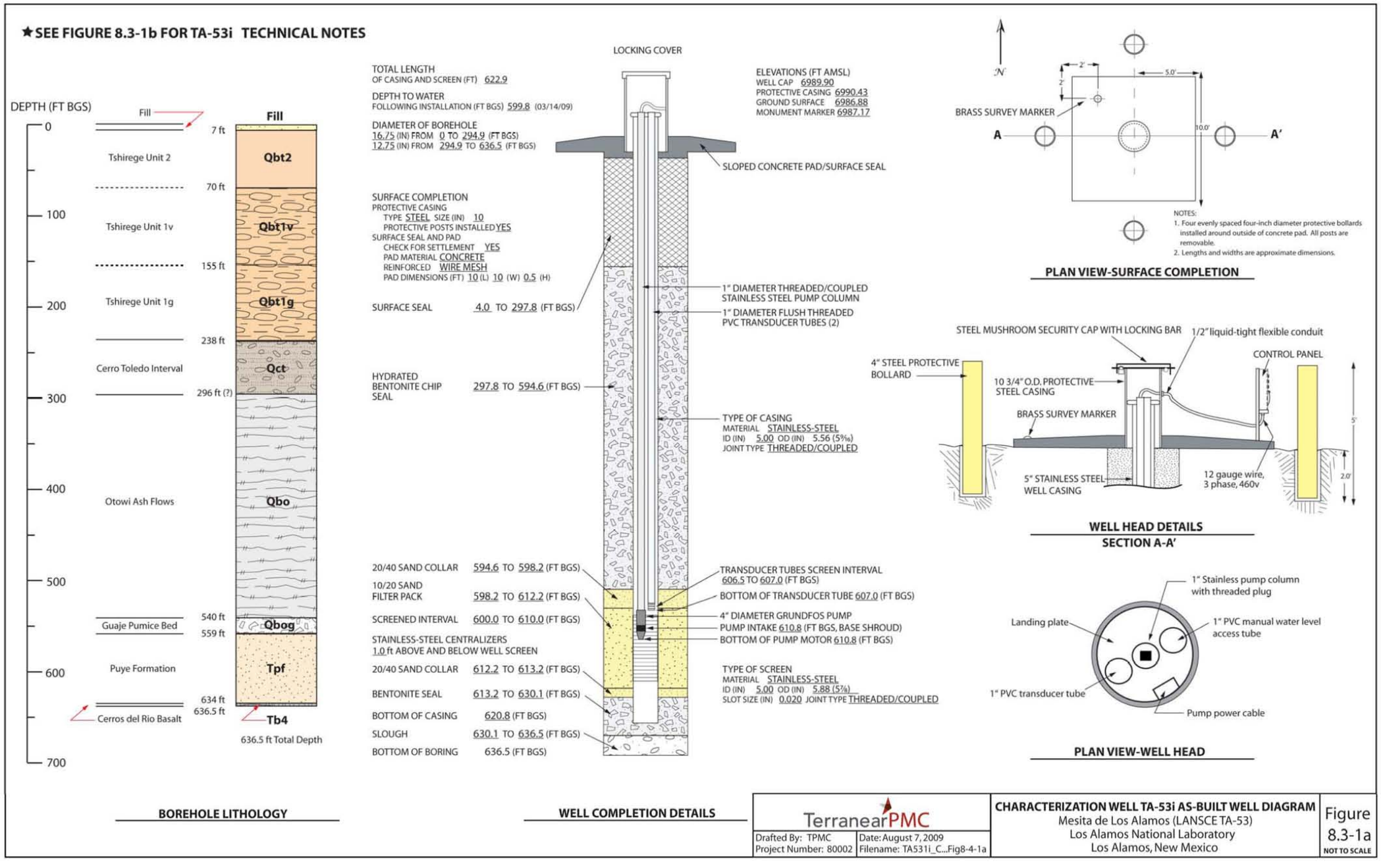


Figure 8.3-1a As-built schematic for intermediate perched water-monitoring well TA-53i

TA-53i TECHNICAL NOTES:

SURVEY INFORMATION*
Brass Marker
Northing: 1771320.08 ft
Easting: 1635850.97 ft
Elevation: 6987.17 ft AMSL

Well Casing (top of stainless steel)
Northing: 1771316.04 ft
Easting: 1635855.05 ft
Elevation: 6989.90 ft AMSL

BOREHOLE GEOPHYSICAL LOGS
Jet West Geophysical: Natural Gamma Ray, Induction, and Video

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: 02/28/2009
Finished: 03/04/2009

Well Completion
Start: 03/07/2009
Finished: 03/10/2009

Well Development
Start: 03/14/2009
Finished: 03/18/2009

WELL DEVELOPMENT
Development Methods
Performed swabbing, bailing, and pumping
Total Volume Purged: 2600 gallons

Parameter Measurments (Final, upper screen/lower screen)
pH: 7.11
Temperature: 19.52˚C
Specific Conductance: 281 µS/cm
Turbidity: 0.0 NTU

AQUIFER TESTING
Constant Rate Pumping Test
Water Produced: 2463 gallons
Average Flow Rate: 1.6 gpm
Performed on: 04/06–09/2009

DEDICATED SAMPLING SYSTEM
Pump
Make: Grundfos
Model: B08110031-P10729191
Capacity: 5 U.S. gpm, intake at 610.8 ft bgs
Environmental Retrofit

Motor
Type: Franklin Electric 1.5 hp
Model: 2345249403
1.5 HP, 3-phase

Pump Column
1-in. threaded/coupled sched. 40 stainless-steel tubing

Transducer Tubes
1-in. flush threaded schd. 80 PVC tubing
0.01-in. slot screen at 606.5–607.0 ft bgs

Transducer
Make: In-Situ, Inc.
Model: Level TROLL 500
30 psig range (vented)
S/N: 114649

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

TerranearPMC		TA-53i TECHNICAL NOTES Mesita de Los Alamos (LANSCE TA-53) Los Alamos National Laboratory Los Alamos, New Mexico	Figure 8.3-1b NOT TO SCALE
Drafted By: TPMC Project Number: 80002	Date: August 7, 2009 Filename: TA53i_TechnicalNotes_Fig8-3-1b		

Figure 8.3-1b As-built technical notes for monitoring well TA-53i

Table 3.1-1
Fluid Quantities Used during Drilling and Well Construction at TA-53i

Date	Water (gal.)	Cumulative Water (gal.)	AQF-2 Foam (gal.)	Cumulative AQF-2 Foam (gal.)
Drilling				
02/28/09	1500	1500	8	8
03/01/09	1200	2700	10	18
03/03/09	3000	5700	20	38
03/04/09	1200	6900	0	38
Well Construction				
03/07/09	5000	11,900	n/a*	38
03/08/09	4800	16,700	n/a	38
03/09/09	1617	18,317	n/a	38
03/10/09	493	18,810	n/a	38
Total Volume (gal.)				
TA-53i	18,810			

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

Table 4.2-1
Summary of Groundwater Screening Samples Collected during Drilling, Well Development, and Aquifer Testing of Monitoring Well TA-53i

Location ID	Sample ID	Date Collected	Collection Depth (ft bgs)	Sample Type	Analysis
Drilling					
TA-53i	GW53-09-5223	03/06/09	600.1	Groundwater	Anions, metals
TA-53i	GW53-09-5224	03/06/09	600.1	Groundwater	Anions, metals
TA-53i	GW53-09-5243	03/06/09	600.1	Groundwater	Tritium
TA-53i	GW53-09-5244	03/06/09	600.1	Groundwater	Tritium
TA-53i	GW53-09-5253	03/06/09	600.1	Groundwater	VOCs
TA-53i	GW53-09-5254	03/06/09	600.1	Groundwater	VOCs
Well Development					
TA-53i	GW53-09-5203	03/18/09	600.0–610.0	Groundwater	Anions, metals, TOC
TA-53i	GW53-09-5204	03/18/09	600.0–610.0	Groundwater	Anions, metals, TOC
TA-53i	GW53-09-5205	03/18/09	600.0–610.0	Groundwater	Anions, metals, TOC
Aquifer Testing					
TA-53i	GW53-09-5206	04/08/09	600.0–610.0	Groundwater	Anions, metals, TOC
TA-53i	GW53-09-5207	04/08/09	600.0–610.0	Groundwater	Anions, metals, TOC
TA-53i	GW53-09-5208	04/08/09	600.0–610.0	Groundwater	Anions, metals, TOC
TA-53i	GW53-09-5209	04/09/09	600.0–610.0	Groundwater	Anions, metals, TOC
TA-53i	GW53-09-5210	04/09/09	600.0–610.0	Groundwater	Anions, metals, TOC
TA-53i	GW53-09-5211	04/09/09	600.0–610.0	Groundwater	Anions, metals, TOC

Note: Tritium was submitted for off-site analysis.

Table 6.0-1
TA-53i Monitoring Well Video and Geophysical Logging Runs

Date	Depth (ft bgs)	Description
03/04/09	n/a*	LANL set up to run video, natural gamma ray, and induction logs—tool communication problems resulted in no logs being run.
03/05–06/09	636.5	Jet West Geophysical ran a natural gamma-ray log inside 12-in. casing, then pulled back 21.5 ft of 12-in. casing to 615.0 ft bgs and ran a video log. Video shows no water entering borehole in open-hole section. Crew pulled an additional 81.5 ft of 12-in. casing (to 532 ft bgs) and reran video tool. Second video log shows water at approximately 599 ft bgs (log depth). Reran natural gamma ray and induction logs over new open-hole section.

*n/a = Not applicable.

Table 7.2-1
TA-53i Monitoring Well Annular Fill Materials

Material	Volume (ft^3)
Surface seal: cement slurry	592.6
Upper seal: bentonite chips	201.0
Upper fine sand collar: 20/40 silica sand	3.4
Filter pack: 10/20 silica sand	14.5
Lower fine sand collar: 20/40 silica sand	1.0
Lower seal: bentonite chips	12.2

Table 8.5-1
TA-53i Monitoring Well Survey Coordinates

Identification	North	East	Elevation
TA-53i brass pin embedded in pad	1771320.08	1635850.97	6987.17
TA-53i ground surface near pad	1771321.63	1635849.62	6986.88
TA-53i top of stainless-steel well casing	1771316.04	1635855.05	6989.90
TA-53i top of 10-in. protective casing	1771315.64	1635855.20	6990.43

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 TA-53i Monitoring Well

Location ID	Sample ID	Date Collected	Description	Sample Type
TA-53i	RC53-09-5675	03/19/09	Decontamination water	Liquid
TA-53i	RC53-09-5676	03/19/09	Decontamination water	Liquid
TA-53i	RC53-09-5677	03/19/09	Decontamination water	Liquid
TA-53i	RC53-09-5678	03/19/09	Decontamination water	Liquid
TA-53i	RC53-09-5715	03/24/09	Drill fluid	Liquid
TA-53i	RC53-09-5716	03/24/09	Drill fluid	Liquid
TA-53i	RC53-09-5717	03/24/09	Drill fluid	Liquid
TA-53i	RC53-09-5718	03/24/09	Drill fluid	Liquid
TA-53i	RC53-09-5727	03/24/09	Development water	Liquid
TA-53i	RC53-09-57287	03/24/09	Development water	Liquid
TA-53i	RC53-09-5729	03/24/09	Development water	Liquid
TA-53i	RC53-09-5730	03/24/09	Development water	Liquid
TA-53i	RC53-09-5739	05/13/09	Drill cuttings	Solid
TA-53i	RC53-09-5740	05/13/09	Drill cuttings	Solid
TA-53i	n/a*	n/a	Contact waste (AK from drill cuttings)	Solid

*n/a = Not applicable.

Appendix A

Borehole TA-53i Lithologic Log

Los Alamos National Laboratory
Regional Hydrogeologic Characterization Project
Borehole Lithologic Log

Borehole Identification (ID): TA-53i	**Technical Area (TA):** 53	**Page:** 1 of 12
DRILLING COMPANY: Boart Longyear Company	**Start Date/Time:** 02/28/2009: 1245 h	**End Date/Time:** 03/04/2009: 2050 h
Drilling Method: Dual Rotary	**MACHINE:** Foremost DR24 HD	**Sampling Method:** Grab
Ground Elevation: 6986.88 ft above mean sea level (amsl)	**TOTAL DEPTH:** 636.5 ft below ground surface (bgs)	
DRILLERS: J. Staloch, C. Johnson	**SITE GEOLOGISTS:** C. Pigman, J. R. Lawrence	

Depth (ft bgs)	Lithology	Lithologic Symbol	Notes
0–7	**CONSTRUCTION FILL:** Unconsolidated gravels with sand. Rounded clasts of various volcanic and quartzo-feldspathic lithologies imported to construction drill pad.		Note: Drill cuttings for microscopic and descriptive analysis were collected at 5-ft intervals from 0 ft to borehole total depth (TD) at 636.5 ft bgs.
7–25	**UNIT 2 OF THE TSHIREGE MEMBER OF THE BANDELIER TUFF**: Tuff—pale pinkish gray (5YR 8/1), moderately welded, crystal-rich, lithic- and pumice-bearing. 7–25 ft WR/+10F: 99%–100% fragments of moderately welded crystal tuff containing 20%–30% quartz and sanidine crystals, up to 1% volcanic lithic fragments (subangular, up to 1 mm in diameter) and less than 1% compressed devitrified pumices (up to 3 mm in diameter) set in a matrix of earthy volcanic ash. +35F: 30%–40% welded tuff fragments; 60%–70% quartz and sanidine crystals.	Qbt 2	Unit 2 of the Tshirege Member of the BandelierTuff, encountered from 7 to 70 ft bgs is locally at least 63 ft thick.
25–35	Tuff—pale pinkish gray (5YR 8/1), moderately welded, crystal-rich, lithic- and pumice-poor. 25–35 ft WR/+10F: 100% fragments of moderately welded crystal tuff composed of 20%–30% quartz and sanidine crystals; trace abundances of devitrified flattened pumices (up to 20 mm in diameter) and small volcanic lithics. +35F: 15%–25% welded tuff fragments; 75%–85% quartz and sanidine crystals.	Qbt 2	

Borehole Lithologic Log (continued)

Borehole ID: TA-53i	**TA:** 53		**Page:** 2 of 12
Depth (ft bgs)	Lithology	Lithologic Symbol	Notes
35–55	Tuff—pale pinkish gray (5YR 8/1), moderately welded, crystal-rich, lithic- and pumice-poor. 35–55 ft WR: moderately abundant ash. +10F: 98%–100% fragments of welded crystal tuff composed of 20%–30% quartz and sanidine crystals, up to 1% subangular dacitic lithics (up to 12 mm in diameter) and up to 1% devitrified (i.e., recrystallized) flattened pumices (up to 5 mm in diameter) in a matrix of earthy volcanic ash; 1%–2% free quartz and sanidine crystals. +35F: 5%–15% welded tuff fragments; 85%–95% quartz and sanidine crystals; up to 1% volcanic lithic fragments.	Qbt 2	
55–70	Tuff—pale pinkish gray (5YR 8/1), moderately to densely welded, crystal-rich, lithic- and pumice-poor. 55–60 ft WR: predominance of quartz and sanidine crystals with minor lithic fragments and volcanic ash. +10F: no sample preserved of this fraction. +35F: 99%–100% quartz and sanidine crystal, trace volcanic lithic grains. 60–70 ft WR: moderately abundant silty ash. +10F: 99%–100% fragments of welded crystal tuff composed of 20%–30% by volume quartz and sanidine crystals, 1%–2% subangular dacitic lithics (up to 7 mm in diameter) and 1%–2% devitrified flattened/compressed pumices (up to 7 mm in diameter) in a matrix of volcanic ash. +35F: 80%–70% quartz and sanidine crystals; 20%–30% welded tuff fragments; up to 1% volcanic lithics.	Qbt 2	The Qbt 2–Qbt 1v contact is estimated to be at 70 ft bgs, based on cuttings and natural gamma log data.
70–90	**UNIT 1v OF THE TSHIREGE MEMBER OF THE BANDELIER TUFF:** Tuff—pale pinkish gray (5YR 8/1), poorly to moderately welded, crystal-bearing, pumice-bearing and lithic-bearing; pumices devitrified. 70–90 ft WR: abundant silty ash matrix. +10F: 50%–80% fragments of welded tuff containing quartz and sanidine crystals (5%–10% by volume), up to 5% flattened devitrified pumices, 2%–3% subangular dacitic lithics enclosed in a matrix of devitrified/earthy volcanic ash; up to 25% subangular dacitic lithics; up to 20% free quartz and sanidine crystals. +35F: 90%–95% quartz and sanidine crystal; 5%–10% fragments of welded tuff, 2%–3% volcanic lithics.	Qbt 1v	Unit 1v of the Tshirege Member of the Bandelier Tuff, encountered from 70 to 155 ft bgs, is estimated to be 85 ft thick.

Borehole Lithologic Log (continued)

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Depth (ft bgs)	Lithology	Lithologic Symbol	Notes
90–100	Tuff—pale pinkish gray (5YR 8/1), poorly to moderately welded, crystal-bearing, pumice-bearing and lithic-bearing; pumices devitrified. 90–95 ft WR: abundant silty ash. +10F: very small sample preserved: 25–35% fragments of welded tuff; 30%–40% quartz and sanidine crystals; 20%–30% dacitic lithics (up to 7 mm in diameter). 95–100 ft+10F: 30–40% welded tuff fragments, 60%–70% subangular dacitic lithics; +35F: 97%–98% quartz and sanidine crystal; 2%–3% fragments of welded tuff and volcanic lithics.	Qbt 1v	
100–115	Tuff—pale pinkish gray (5YR 8/1), poorly to moderately welded, crystal-bearing, pumice-bearing and lithic-bearing; pumices devitrified. 100–105 ft +10F: no sample preserved of this fraction. 105–115 ft +10F: very small sample preserved: 5%–10% fragments of welded tuff; 70%–80% quartz and sanidine crystals; 15%–20% subangular to rounded dacitic lithics. +35F: 98%–99% quartz and sanidine crystals; 1%–2% volcanic lithics and fragments of welded tuff.	Qbt 1v	100–115 ft. Note: Cuttings pulverized by drilling because of the devitrified and consequently weakened nature of the tuff in this interval.
115–135	Tuff—pale pinkish gray (5YR 8/1) to yellowish orange (10YR 8/6), poorly to moderately welded, pumice-bearing, crystal- and lithic-bearing; pumices devitrified. 115–130 ft +10F: 5%–15% fragments of welded tuff; 15%–25% subangular dacitic lithic fragments; 60%–70% quartz and sanidine crystals. +35F: 97%–99% quartz and sanidine crystals; 1%–3% volcanic lithics and fragments of welded tuff. 130–135 ft +10F: 80%–90% subrounded to well rounded lithic fragments predominantly of dacite but also present in minor abundances are yellow chert and granite; 10%–20% ash-coated quartz and sanidine crystals.	Qbt 1v	

Borehole Lithologic Log (continued)

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Depth (ft bgs)	Lithology	Lithologic Symbol	Notes
135–155	Tuff—pale pinkish gray (5YR 8/1) to pale yellowish orange (10YR 8/6), poorly to moderately welded, pumice-bearing, crystal- and lithic-bearing; pumices devitrified. 135–155 ft+10F: 20%–40% fragments of welded tuff composed of quartz and sanidine crystals (5%–7% by volume), 20%–30% undeformed devitrifed pumice fragments and 1%–2% small dacitic lithics enclosed in a matrix of volcanic ash; 60%–70% subangular lithics (up to 24 mm in diameter) of diverse compositions (predominantly dacite, flow-banded dacite, rhyolite, obsidian, andesite). +35F: 70%–80% quartz and sanidine crystals; 10%–15% devitrified pumices; 10%–15% volcanic lithics fragments.	Qbt 1v	The estimated Qbt 1v–Qbt 1g contact, at 155 ft bgs, is based on natural gamma log interpretation and first appearance of vitric pumice.
155–170	**UNIT 1g OF THE TSHIREGE MEMBER OF THE BANDELIERTUFF:** Tuff—dark yellowish orange (10YR 6/6) to very pale orange (10YR 8/2), nonwelded to poorly welded, pumiceous, lithic- and crystal-bearing, pumices characteristically glassy. 155–160 ft +10F: very small sample volume: 80%–85% subangular dacitic lithics; 10%–15% welded tuff fragments composed of small rounded glassy pumices (with streaks of black obsidian glass); 5%–7% quartz and sanidine crystals in a matrix of volcanic ash. 160–165 ft+10F: very small sample volume: 20%–30% rounded to subrounded orange tan to black glassy pumices; 60%–70% subangular to rounded granules (up to 7mm in diameter) of dacite, obsidian; 1%–2% quartz and sanidine crystals. Note: pumices have a typically fibrous texture with streaks of black obsidian. 165–170 ft +10F: no sample preserved.	Qbt 1g	Unit 1g of the Tshirege Member of the Bandelier Tuff, intersected from 155 to 238 ft bgs, is estimated to be 83 ft thick.

Borehole Lithologic Log (continued)

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Depth (ft bgs)	Lithology	Lithologic Symbol	Notes
170–190	Tuff— dark yellowish orange (10YR 6/6) to very pale orange (10YR 8/2), nonwelded to poorly welded, pumiceous, lithic- and crystal-bearing, pumices characteristically glassy. 170–175 ft WR: abundant orange brown ash. +10F: 40%–50% orange tan quartz- and sanidine-phyric glassy pumices commonly with thin rinds of black obsidian; 40%–50% angular lithics of white and pinkish dacite. 175–180 ft WR/10F: 100% pale orange tan, glassy fibrous-textured quartz- and sanidine-phyric pumice with blebs and stringers of black obsidian glass. 175–180 ft +10F: very small sample volume: 90% rounded dacite granules of dacite, black porphyritic vitrophyre and quartzite; 10% quartz and sanidine crystals and pumice fragments.	Qbt 1g	
190–210	Tuff— dark yellowish orange (10YR 6/6) to very pale orange (10YR 8/2), poorly welded, strongly pumiceous, lithic- and crystal-bearing, pumices glassy. 190–195 ft WR: abundant orange brown ash. +10F: 40%–50% orange to white quartz- and sanidine-phyric glassy pumice fragments; 20%–30% subangular volcanic lithics (up to 13 mm in diameter) including andesite, white hornblende-phyric dacite, gray dacite. 195–205 ft WR: abundant orange brown ash. +10F: 40%–50% orange to white quartz- and sanidine-phyric glassy pumice fragments; 20%–30% subangular volcanic lithics (up to 13 mm in diameter) including andesite, white hornblende-phyric dacite, gray dacite. 205–210 ft+10F: 99%–100% white glassy quartz- and sanidine-phyric pumice fragments.	Qbt 1g	
210–230	Tuff— dark yellowish orange (10YR 6/6) to very pale orange (10YR 8/2), poorly welded, strongly pumiceous, lithic- and crystal-bearing. 210–215 ft WR: abundant orange tan ash. +10F: 50%–60% white to pale orange glassy pumice fragments; 20%–30% volcanic lithics, including andesite, dacite, dark gray porphyritic vitrophyre. +35F: 40% vitric pumices; 40% quartz and sanidine crystals; 20% volcanic lithics. 215–220 ft +10F: very small sample preserved: 20% white glassy pumice fragments; 80% dacitic lithics. 220–230 ft +10F: 70%–80% white glassy pumice fragments; 20%–30% dacitic lithics.	Qbt 1g	

Borehole Lithologic Log (continued)

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Depth (ft bgs)	Lithology	Lithologic Symbol	Notes
230–238	Tuff— dark yellowish orange (10YR 6/6) to very pale orange (10YR 8/2), poorly welded, strongly pumiceous, lithic- and crystal-bearing. 230–238 ft WR: abundant orange tan ash. +10F: 100% white to pale orange glassy, quartz- and sanidine-phyric pumice fragments. +35F: 30%–40% vitric pumices; 40%–50% quartz and sanidine crystals; 5%–10% dacitic lithics.	Qbt 1g	Estimated Qbt 1g–Qct contact at 238 ft bgs is based on cuttings and natural gamma log interpretation.
238–260	**CERRO TOLEDO INTERVAL:** Tuffaceous sediments—dark yellow orange to very pale orange (10YR 8/2) silty fine to medium sand with pebble gravel, detritus of pumice and various volcanic lithologies. 238–245 ft WR: silt-rich matrix. +10F: subrounded to rounded granules and small pebbles composed of 40%–50% white vitric pumices; 50%–60% pink and gray dacite and minor quartz and sanidine crystals. 245–260 ft +10F: 70%–90% white to pale orange vitric pumices that are quartz- and sanidine-phyric; 20%–30% subangular dacite clasts.	Qct	The Cerro Toledo Interval, encountered from 238 to 296 ft bgs, is estimated to be 58 ft thick.
260–275	Tuffaceous sediments—pale yellowish orange (10YR 8/6) to very pale orange (10YR 8/2) pumice-rich pebble gravel with coarse to medium sand, detritus of well rounded pumices, tuff-derived crystals and minor dacite grains. 260–275 ft WR: abundant rounded pumices with local quartz and sanidine crystals; generally abundant ash matrix. +10F: 99%–100% rounded to well-rounded (i.e., reworked by fluvial processes) orange to white glassy pumice clasts (pumices are quartz- and sanidine-phyric, up to 12 mm in diameter); up to 1% light gray dacite granules. +35F: 15%–20% grains composed of dacite and minor black obsidian; 40%–50% vitric pumices; 30%–40% quartz and sanidine crystals.	Qct	
275–296	Tuffaceous sediments—pale yellowish orange (10YR 8/6) to very pale orange (10YR 8/2) silty fine sand to sandy silt; generally silt-rich fine tuffaceous sediments. 275–296 ft WR: pale to moderate orange volcanic ash with grains of quartz, sanidine and dacite. +10F: 99%–100% very small volume of this sample fraction preserved throughout the interval; predominantly silt-coated broken and subangular to subrounded dacite granules (up to 3 mm in diameter). +35F: 10%–15% dacite grains; 3%–5% vitric pumices; 80%–90% quartz and sanidine crystals.	Qct	Estimated Qct–Qbo contact at 296 ft bgs is based on cuttings and natural gamma log interpretation.

Borehole Lithologic Log (continued)

Borehole ID: TA-53i	**TA:** 53	**Page:** 7 of 12

Depth (ft bgs)	Lithology	Lithologic Symbol	Notes
296–320	**OTOWI MEMBER OF THE BANDELIER TUFF:** Tuff—very pale orange (10YR 8/2), poorly welded, pumiceous, lithic- and crystal-bearing. 296–305 ft WR: 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. 305–310 ft +10F: 85%–90% orange brown glass, quartz- and sanidine-phyric pumices; 10%–15% volcanic lithics (predominantly gray porphyritic dacites). 310–320 ft similar to 296–305 ft.	Qbo	The Otowi Member of the Bandelier Tuff (Qbo), intersected from 296 to 532 ft bgs, is estimated to be 236 ft thick.
320–340	Tuff—pale yellowish orange (10YR 8/0), poorly welded, pumice-bearing, lithic-rich, crystal-bearing. 320–330 ft WR: abundant orange tan ash. +10F: 85%–90% broken and subangular (up to 14 mm in diameter) volcanic lithic fragments (predominantly gray porphyritic dacites); 5%–10% orange vitric pumice lapilli. +35F: 30%–35% vitric pumice fragments; 30%–35% quartz and sanidine crystals; 30%–35% volcanic lithics. 330–340 ft+10F: 60%–70% broken and subangular (up to 12 mm in diameter) gray dacite lithics; 30%–40% orange, vitric, quartz- and sanidine-phyric pumices.	Qbo	
340–360	Tuff—very pale orange (10YR 8/2), poorly welded, pumiceous, lithic-rich, crystal-bearing. 340–360 ft WR: abundant pale orange volcanic ash matrix. +10F: 10%–30% white to very pale orange vitric pumice fragments that are quartz- and sanidine-bearing and exhibit fibrous texture; 70%–90% coarse broken and subangular volcanic lithics (up to 23 mm in diameter) including biotite and hornblende-phyric dacites and minor flow-banded dacite. +35F: 25%–35% vitric pumice fragments; 30%–40% quartz and sanidine crystals; 30%–40% volcanic lithics.	Qbo	

Borehole Lithologic Log (continued)

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Depth (ft bgs)	Lithology	Lithologic Symbol	Notes
360–375	Tuff—very pale orange (10YR 8/2) to grayish orange (10YR 7/4), poorly welded, pumice-bearing, lithic-rich, crystal-bearing. 360–375 ft+10F: 10%–15% white to pale orange vitric pumice fragments that are quartz- and sanidine-bearing; 85%–90% broken and subangular volcanic lithics (up to 12 mm in diameter) predominantly of porphyritic dacites and minor andesite. +35F: 10%–15% vitric pumice fragments; 50%–60% quartz and sanidine crystals; 25%–35% dacitic lithics.	Qbo	
375–390	Tuff—very pale orange (10YR 8/2) to grayish orange (10YR 7/4), poorly welded, pumiceous, lithic- rich, crystal-bearing. 375–385 ft +10F: 60%–70% pale orange vitric pumice fragments that are quartz- and sanidine-bearing; 30%–40% broken and subangular dacitic lithics (up to 7 mm in diameter); trace flow-banded dacite. +35F: 40%–50% vitric pumice fragments; 20%–30% quartz and sanidine crystals; 20%–30% dacitic lithics. 385–390 ft +10F: 30%–40% pale orange vitric pumices; 60%–70% dacitic lithic fragments, some dark gray porphyritic andesite.	Qbo	
390–410	Tuff—very pale orange (10YR 8/2) to grayish orange (10YR 7/4), poorly welded, pumiceous, lithic-rich, crystal-bearing. 390–400 ft WR: abundant orange volcanic ash. +10F: 60%–70% pale orange vitric pumice fragments that are quartz- and sanidine-bearing; 30%–40% broken and subangular volcanic lithics (up to 10 mm in diameter) composed of dacite, dark gray andesite, black porphyritic vitrophyre; trace flow-banded dacite. +35F: 50%–60% vitric pumice fragments; 10%–15% quartz and sanidine crystals; 20%–30% dacitic lithics. 400–405 ft+10F: 60%–70% volcanic lithic grains; 30%–40% pumice fragments. 405–410 ft+10F: similar to 390–400 ft.	Qbo	

Borehole Lithologic Log (continued)

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Depth (ft bgs)	Lithology	Lithologic Symbol	Notes
410–435	Tuff—dark yellow orange (10YR 6/6) to very pale orange (10YR 8/2), poorly welded, pumiceous, lithic-rich, crystal-bearing. 410–420 ft WR: abundant silty volcanic ash. +10F: 10%–15% pale orange vitric pumice fragments; 85%–90% subangular volcanic lithics (typically up to 5 mm in diameter) composed mostly of light to medium gray dacite, minor dark gray porphyritic andesite. 420–435 ft +10F: 30%–40% vitric pumice fragments; 60%–70% volcanic lithics composed of light gray and pinkish biotite and hornblende-phyric dacites, minor flow-banded dacite.	Qbo	
435–465	Tuff—very pale orange (10YR 8/2), poorly welded, pumiceous, lithic-rich, crystal-bearing. 435–465 ft WR: moderately abundant silty volcanic ash. +10F: 70%–80% pale orange vitric pumice fragments; 20%–30% broken and subangular volcanic lithics (up to 10 mm in diameter) composed predominantly of gray dacite. +35F: 50%–60% vitric pumice fragments; 20%–30% volcanic lithics; 10%–20% quartz and sanidine crystals.	Qbo	
465–480	Tuff—very pale orange (10YR 8/2), poorly welded, pumiceous, lithic-rich, crystal-bearing. 465–480 ft WR: moderately abundant silty volcanic ash. +10F: 65%–75% pale orange vitric , quartz- and sanidine-phyric pumice fragments; 25%–35% subangular volcanic lithics (up to 9 mm in diameter) composed predominantly of gray dacite. +35F: 40%–50% vitric pumice fragments; 20%–25% dacitic lithics; 20%–30% quartz and sanidine crystals.	Qbo	
480–490	Tuff—very pale orange (10YR 8/2), poorly welded, pumiceous, lithic- rich, crystal-bearing. 480–490 ft WR: moderately abundant silty volcanic ash. +10F: 30%–40% vitric , quartz- and sanidine-phyric pumice fragments; 60%–70% broken and subangular dacitic lithics (up to 10 mm in diameter) composed predominantly of gray dacite. +35F: 30%–40% vitric pumice fragments; 30%–35% dacitic lithics; 20%–30% quartz and sanidine crystals.	Qbo	

Borehole Lithologic Log (continued)

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Depth (ft bgs)	Lithology	Lithologic Symbol	Notes
490–510	Tuff—very pale orange (10YR 8/2), poorly welded, strongly pumiceous, lithic- and crystal-bearing. 490–480 ft WR: variable abundances of silty volcanic ash +10F: 80%–90% pale tan vitric, quartz- and sanidine-phyric pumice fragments; 10%–20% subangular dacitic lithics (up to 10 mm in diameter). +35F: 80%–90% vitric pumice fragments; 10%–20% dacitic lithics and quartz and sanidine crystals.	Qbo	
510–532	Tuff—very pale orange (10YR 8/2), poorly welded, strongly pumiceous, lithic- and crystal-bearing. 510–532 ft WR: moderately abundant silty volcanic ash. +10F: 90%–95% pale tan vitric, quartz- and sanidine-phyric pumice fragments; 5%–10% light gray dacitic lithics (up to 5 mm in diameter). +35F: 60%–70% vitric pumice fragments; 10%–15% dacitic lithics; 10%–15% quartz and sanidine crystals.	Qbo	The estimated Qbo–Qbog contact at 532 ft bgs is based on cuttings and natural gamma log interpretation.
532–545	**GUAJE PUMICE BED OF THE OTOWI MEMBER OF THE BANDELIER TUFF:** Tuff—very light gray (N8) to very pale orange (10YR 8/2), unconsolidated, nonwelded, pumice-rich, constituents predominantly of vitric pumice lapilli and lesser dacite fragments. 532–535 ft WR/ +10F: 99% rounded vitric pumice lapilli (up to 12 mm) that are quartz- and sanidine-phyric; up to 1% rounded hornblende-dacite lithics. +35F: 80%–85% pumice fragments; 15%–20% dacite grains. 535–545 ft WR/ +10F: 85%–90% subrounded vitric pumice lapilli (up to 12 mm) that are quartz- and sanidine-phyric; 5%–15% subrounded gray dacitic lithics (up to 9 mm in diameter). +35F: 70%–80% pumice fragments; 15%–25% dacite lithics grains; 5%–10% quartz and sanidine crystals.	Qbog	The Guaje Pumice Bed, intersected from 532 to 559 ft bgs, is estimated to be 27 ft thick.
545–559	Tuff—white (N9), nonwelded, pumice-rich, mainly vitric pumice lapilli. 545–559 ft WR/ +10F: 99%–100% angular to subrounded fragments and lapilli of vitric pumice that are quartz- and sanidine-phyric; up to 1% rounded hornblende-dacite lithics. +35F: 95%–98% pumice fragments; 1%–2% dacite grains, 1%–3% quartz and sanidine crystals.	Qbog	The estimated Qbog Tpf contact at 559 ft bgs is based on analysis of drill cuttings and natural gamma log data.

Borehole Lithologic Log (continued)

Borehole ID: TA-53i	**TA:** 53	**Page:** 11 of 12

Depth (ft bgs)	Lithology	Lithologic Symbol	Notes
559–575	**PUYE FORMATION:** Volcaniclastic sediments—very pale orange (10YR 8/2) silty fine to medium gravels with coarse- to fine-grained sandstone, pumiceous with subordinate dacitic detritus grading rapidly downward in the interval to predominantly dacite-rich sediments with abundant silt. 559–565 ft WR/ +10F: 40%–50% angular glassy pumice fragments; 40%–50% subangular to subrounded dacitic clasts (up to 10 mm in diameter); all detrital clasts silt-coated. 565–575 ft +10F: 5%–10% pumice fragments; 90%–95% subangular to subrounded granules and small pebbles (up to 13 mm in diameter) composed of gray dacite; all detrital clasts silt-coated. +35F: 80%–85% subangular to subrounded grains of dacite and lesser andesite; 2%–3% quartz and sanidine crystals; 5%–15% pumice fragments; 5%–10% fragments of silty sandstone.	Tpf	Puye volcaniclastic sediments, intersected from 559 to 634 ft bgs, are estimated to be 75 ft thick.
575–590	Volcaniclastic sediments—very pale orange (10YR 8/2) to light gray (N6) silty fine to medium gravels with coarse- to fine-grained sandstone; predominantly subangular to subrounded dacitic detritus. 575–590 ft WR/ +10F: 90%–95% subangular to subrounded granules of gray dacitic clasts (up to 17 mm in diameter); 5%–10% fragments of silty very fine-grained volcaniclastic sandstone (sandstone fragments increasingly more abundant downward in this interval); all detrital clasts silt-coated.	Tpf	
590–595	Volcaniclastic sediments—light brown (5YR 6/4) silty very fine-grained sandstone to sandy siltstone with granules and small pebbles; detritus predominantly dacitic. 590–595 ft WR: predominantly silt and fine sand. +10F: 30%–40% silt-coated dacite granules; 60%–70% fragments of very fine-grained sandy silt.	Tpf	

Borehole Lithologic Log (continued)

Borehole ID: TA-53i	**TA:** 53	**Page:** 12 of 12
Depth (ft bgs)	Lithology	Lithologic Symbol	Notes
595–620	Volcaniclastic sediments—very pale orange (10YR 8/2) to light medium gray (N6) silty fine to medium gravels with coarse- to fine-grained sandstone, subangular to subrounded detritus predominantly dacitic. 559–620 ft WR: variable abundances of silt matrix; generally silt-rich. +10F: 100% silt-coated subangular to subrounded granules and larger clasts composed of light gray dacite and locally minor dacitic vitrophyre; frequent larger broken/angular fragments suggest partly medium to coarse gravel constituents.	Tpf	
620–634	Volcaniclastic sediments—very pale orange (10YR 8/2) to light medium gray (N6) silty fine gravels with coarse- to fine-grained sandstone, detritus predominantly gray dacitic; generally silt-rich interval. 620–634 ft WR: silt-rich matrix. +10F: 40%–50% subangular granules and small pebbles of pink and light gray dacites (up to 12 mm in diameter); 40%–50% rounded fragments of silty very fine-grained dacitic sandstone.	Tpf	The estimated Tpf–Tb 4 contact at 634 ft bgs is based on analysis of drill cuttings.
634–636.5	**CERROS DEL RIO BASALT:** Basalt lava and/or basaltic sediments–light medium gray (N6) mixed broken chips and subangular to subrounded clasts composed uniquely of olivine-phyric basalt. 634–636.5 ft WR: angular to subrounded fragments/clasts with moderate silt matrix. +10F: 100% broken chips and subangular to subrounded clasts of vesicular with weakly altered groundmass. +35F: 99%–100% broken and subangular basalt grains; up to 1% small fragments of silty very fine-grained sandstone. (Note: Distinct subrounding of some clasts is evidence of fluvial processes.)	Tb 4	A 2.5-ft interval of the Cerros del Rio basalt was intersected from 634 ft to the bottom of the TA-53i borehole at 636.5 ft bgs.

ABBREVIATIONS

5YR 8/4 = Munsell rock color notation where hue (e.g., 5YR), value (e.g., 8), and chroma (e.g., 4) are expressed. Hue indicates soil color's relation to red, yellow, green, blue, and purple. Value indicates soil color's lightness. Chroma indicates soil color's strength.

% = estimated percent by volume of a given sample constituent

bgs = below ground surface

ft = feet

GM = groundmass

Qal = Quaternary Alluvium

Qbt 2, Qbt 1v, Qbt 1g = subunits of the 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

Tpf = Puye Formation

TD = total depth

+10F = plus No. 10 sieve sample fraction

+35F = plus No. 35 sieve sample fraction

WR = whole rock (unsieved sample)

1 mm = 0.039 in.

1 in. = 25.4 mm

Appendix B

Groundwater Analytical Results

B-1.0 SAMPLING AND ANALYSIS OF GROUNDWATER AT TA-53i

A total of 15 groundwater samples were collected during drilling, well development, and aquifer performance testing at TA-53i. Six groundwater-screening samples were collected at borehole TA-53i during drilling within perched intermediate saturation within the Puye Formation. Three groundwater-screening samples were collected from well TA-53i during development, and six groundwater-screening samples were collected during aquifer performance testing. These groundwater samples were collected between the screened interval from 600.0 to 610.0 ft below ground surface (bgs). The filtered samples collected from TA-53i were analyzed for cations, anions, perchlorate, and metals. A total of 2600 gal. of groundwater was pumped from TA-53i during development, and an additional 2463 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 TA-53i 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 ±5% for complete analyses of the above inorganic chemicals. The negative cation-anion charge balance values indicate excess anions for the filtered samples.

Two borehole water samples collected during drilling of TA-53i 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 TA-53i, are provided in Table B-1.2-1. Ten measurements of pH and temperature varied from 7.06 to 7.11 and from 19.40°C to 19.62°C, respectively, in groundwater pumped from well TA-53i during development. Concentrations of DO ranged from 6.25 to 6.55 mg/L. Corrected Eh

(oxidation-potential reduction) values determined from field ORP measurements generally decreased from 202.5 to 185.2 millivolts (mV) during well development of TA-53i (Table B-1.2-1). Temperature-dependent correction factors for calculating Eh values from field ORP measurements were based on an Ag/AgCl–KCl-saturated filling solution contained in the ORP electrode. The correction factors are 208.9, 203.9, and 201.2 mV at 15.0ºC, 20.0ºC, and 22.5ºC, respectively. These corrected Eh values associated with well TA-53i are considered to be reliable and representative of the known relatively oxidizing conditions characteristic of perched intermediate zones beneath the Pajarito Plateau, based on analytical results for redox-sensitive solutes, including detectable chromium, molybdenum, nitrate, and sulfate provided in Table B-1.3-1. Measurable concentrations of these solutes are consistent with overall oxidizing conditions encountered at the well. Specific conductance varied from 278 to 312 microsiemens per centimeter (μS/cm), and turbidity ranged from 0 to 0.4 nephelometric turbidity unit (NTU) during well development of TA-53i (Table B-1.2-1).

B-1.2.2 Aquifer Performance Testing

During aquifer performance testing at well TA-53i, 23 measurements of pH and temperature varied from 7.07 to 7.26 and from 15.87°C to 23.19°C, respectively (Table B-1.2-1). Concentrations of DO varied from 6.70 to 8.50 mg/L; positive, uncorrected ORP values ranged from –35.7 to 63.3 mV during aquifer performance testing of TA-53i. Concentrations of DO varied from 6.70 to 8.50 mg/L; positive, corrected Eh values ranged from 169.0 to 272.2 mV during aquifer performance testing of TA-53i. The corrected Eh values are consistent with analytical results for redox-sensitive solutes listed above and are provided in Table B-1.3-1. Specific conductance and turbidity generally decreased from 323 to 308 μS/cm and from 6.3 to 0 NTUs for groundwater pumped from TA-53i during aquifer performance testing. Only 2 of the 23 measurements exceeded 5 NTUs during this phase of testing at the well.

B-1.3 Analytical Results for Groundwater-Screening Samples

B-1.3.1 Tritium Analyses of Borehole TA-53i

Concentrations of tritium in two screening borehole samples (GW-53-09-5243 and GW53-09-5244) were 619 ± 19 pCi/L. These concentrations of tritium strongly suggest that a component of groundwater at well TA-53i is derived from Los Alamos Canyon that received industrial effluent containing tritium from the 1940s to the late 1990s.

B-1.3.2 Well Development

Analytical results for groundwater-screening samples collected at TA-53i 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 TA-53i during development. Dissolved concentrations of calcium and sodium ranged from 32.80 to 33.56 ppm or mg/L and from 15.63 to 15.94 ppm, respectively (Table B-1.3-1). Dissolved concentrations of chloride and fluoride ranged from 30.40 to 30.58 ppm and from 0.15 to 0.17 ppm, respectively, during well development. Dissolved concentrations of bromide ranged from 1.24 to 1.26 ppm during well development. The maximum background concentration for dissolved bromide in perched intermediate groundwater is 0.03 mg/L (LANL 2007, 095817). Dissolved concentrations of nitrate(N) and sulfate ranged from 0.93 to 0.94 ppm and from 18.66 to 18.72 ppm, respectively, during this phase. The median background concentration for dissolved fluoride in perched intermediate groundwater is 0.12 mg/L (LANL 2007, 095817). Dissolved concentrations of chloride, nitrate(N), and sulfate exceeded Laboratory median background for perched intermediate groundwater (LANL 2007, 095817). Median background concentrations for dissolved chloride, nitrate plus nitrite(N), and sulfate in perched intermediate groundwater are 1.37 mg/L, 0.29 mg/L, and 4.08 mg/L, respectively (LANL 2007, 095817). Concentrations of TOC ranged from 0.98 to 1.04 mgC/L in groundwater-screening samples collected during development conducted at well TA-53i (Table B-1.3-1). The median background

concentration of TOC is 0.45 mgC/L for perched intermediate groundwater (LANL 2007, 095817). Concentrations of perchlorate were less than analytical detection (<0.005 ppm, IC method) in groundwater-screening samples collected from well TA-53i during development (Table B-1.3-1).

During well development conducted at TA-53i, dissolved concentrations of iron were less than analytical detection (0.010 ppm, 0.010 μg/L, or 10 ppb) using ICPOES (Table B-1.3-1), which did not exceed the median background value of 20.0 μg/L for perched intermediate groundwater (LANL 2007, 095817). Dissolved concentrations of manganese ranged from 0.014 to 0.015 ppm, or 14 to 15 ppb (Table B-1.3-1), which exceeded the median background value of 0.50 μg/L (0.50 ppb, or 0.0005 ppm) for perched intermediate groundwater (LANL 2007, 095817). Dissolved concentrations of boron ranged from 0.022 to 0.037 ppm, or 22 to 37 ppb (Table B-1.3-1), at well TA-53i, which is above the maximum background value of 18.0 μg/L or ppb (0.018 ppm) for perched intermediate groundwater (LANL 2007, 095817). Dissolved concentrations of molybdenum ranged from 0.062 to 0.063 ppm, or 62 to 63 ppb (Table B-1.3-1), at well TA-53i during development, which is above the maximum background value of 4.3 μg/L or ppb (0.0043 ppm) for perched intermediate groundwater (LANL 2007, 095817). Dissolved concentrations of nickel were 0.005 ppm, or 5 ppb (Table B-1.3-1), in three groundwater-screening samples collected during well development conducted at TA-53i. The background median concentration of nickel in filtered samples is 0.50 μg/L or ppb (0.0005 ppm) for perched intermediate groundwater (LANL 2007, 095817). Dissolved concentrations of zinc ranged from 0.033 to 0.038 ppm, or 33 to 38 ppb, in groundwater-screening samples collected at well TA-53i during development (Table B-1.3-1). The background median concentration of zinc in filtered samples is 0.75 μg/L or ppb (0.00075 ppm) for perched intermediate groundwater (LANL 2007, 095817). Total dissolved concentrations of chromium ranged from 0.004 to 0.006 ppm (4 to 6 ppb, or 4 to 6 μg/L) at well TA-53i during well development (Table B-1.3-1). Background mean, median, and maximum concentrations of total dissolved chromium are 0.86 μg/L or ppb (0.00086 ppm), 0.50 μg/L or ppb (0.0005 ppm), and 2.40 μg/L or ppb (0.00240 ppm), respectively, for perched intermediate groundwater (LANL 2007, 095817).

B-1.3.3 Aquifer Performance Testing

Calcium and sodium are the dominant cations in groundwater collected from well TA-53i during aquifer testing. Dissolved concentrations of calcium and sodium ranged from 35.66 to 36.93 ppm or mg/L and from 15.43 to 15.84 ppm, respectively (Table B-1.3-1). Dissolved concentrations of chloride and fluoride ranged from 31.02 to 31.21 ppm and from 0.15 to 0.21 ppm, respectively, during aquifer testing. Dissolved concentrations of nitrate(N) and sulfate ranged from 1.01 to 1.07 ppm and from 18.46 to 18.53 ppm, respectively, during this phase of testing. Dissolved concentrations of bromide ranged from 1.29 to 1.44 ppm during aquifer testing. The maximum background concentration for dissolved bromide in perched intermediate groundwater is 0.03 mg/L (LANL 2007, 095817). The median background concentration for dissolved fluoride in perched intermediate groundwater is 0.12 mg/L (LANL 2007, 095817). Dissolved concentrations of chloride, nitrate(N), and sulfate exceeded Laboratory median background for perched intermediate groundwater (LANL 2007, 095817). Median background concentrations for dissolved chloride, nitrate plus nitrite(N), and sulfate in perched intermediate groundwater are 1.37 mg/L, 0.29 mg/L, and 4.08 mg/L, respectively (LANL 2007, 095817). Concentrations of TOC ranged from 1.03 to 1.25 mgC/L in groundwater-screening samples collected during aquifer testing conducted at well TA-53i (Table B-1.3-1). The median background concentration of TOC is 0.45 mgC/L for perched intermediate groundwater (LANL 2007, 095817). Concentrations of perchlorate were less than analytical detection (<0.005 ppm, IC method) in groundwater-screening samples collected from well TA-53i during aquifer testing (Table B-1.3-1).

During aquifer testing conducted at TA-53i, dissolved concentrations of iron ranged from 0.020 to 0.077 ppm (20 to 77 μg/L, or 20 to 77 ppb) using ICPOES (Table B-1.3-1), which exceeded the median background value of 20.0 μg/L for perched intermediate groundwater (LANL 2007, 095817). Dissolved

concentrations of manganese ranged from 0.006 to 0.012 ppm, or 6 to 12 ppb (Table B-1.3-1), which exceeded the median background value of 0.50 μg/L (0.50 ppb, or 0.0005 ppm) for perched intermediate groundwater (LANL 2007, 095817). Dissolved concentrations of boron decreased from 0.043 to 0.029 ppm, or from 43 to 29 ppb (Table B-1.3-1), at well TA-53i, which is above the maximum background value of 18.0 μg/L or ppb (0.018 ppm) for perched intermediate groundwater (LANL 2007, 095817). Dissolved concentrations of molybdenum ranged from 0.062 to 0.064 ppm, or 62 to 64 ppb (Table B-1.3-1), at well TA-53i during aquifer testing, which is above the maximum background value of 4.3 μg/L or ppb (0.0043 ppm) for perched intermediate groundwater (LANL 2007, 095817). Dissolved concentrations of nickel were 0.002 ppm, or 2 ppb (Table B-1.3-1), in six groundwater-screening samples collected during aquifer testing conducted at TA-53i. The background median concentration of nickel in filtered samples is 0.50 μg/L or ppb (0.0005 ppm) for perched intermediate groundwater (LANL 2007, 095817). Dissolved concentrations of zinc ranged from 0.010 to 0.015 ppm, or 10 to 15 ppb, in groundwater-screening samples collected at well TA-53i during aquifer testing (Table B-1.3-1). The background median concentration of zinc in filtered samples is 0.75 μg/L or ppb (0.00075 ppm) for perched intermediate groundwater (LANL 2007, 095817). Total dissolved concentrations of chromium ranged from 0.001 to 0.002 ppm (1 to 2 ppb, or 1 to 2 μg/L) at well TA-53i during aquifer testing (Table B-1.3-1). Background mean, median, and maximum concentrations of total dissolved chromium are 0.86 μg/L or ppb (0.00086 ppm), 0.50 μg/L or ppb (0.0005 ppm), and 2.40 μg/L or ppb (0.00240 ppm), respectively, for perched intermediate groundwater (LANL 2007, 095817).

In summary, dissolved concentrations of bromide, chloride, molybdenum, nitrate(N), sulfate, and tritium exceed background within perched intermediate groundwater present at well TA-53i. The presence of tritium at well TA-53i strongly suggests that a component of groundwater at the well is derived from Los Alamos Canyon. It is also likely that groundwater associated with Sandia Canyon is also present at well TA-53i, based on measured concentrations of dissolved bromide, chloride, chromium, molybdenum, sulfate, and zinc. Groundwater at well TA-53i is relatively oxidizing, based on corrected Eh values and measurable concentrations of DO, chromium, nitrate(N), molybdenum, and sulfate. Measurable concentrations of TOC are probably associated with a component of treated sewage effluent released to Sandia Canyon over the past five decades. Presence of residual drilling fluid effects are not likely at well TA-53i, based on elevated above-background concentrations of dissolved chromium, molybdenum, and nitrate(N), coupled with low concentrations of dissolved iron and manganese and measurable DO characteristic of oxidizing groundwater.

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 TA-53i

Date	pH	Temp (°C)	DO (mg/L)	ORP, Eh[a] (mV)	Specific Conductivity (µS/cm)	Turbidity (NTU)	Purge Volume between Samples (gal.)	Cumulative Purge Volume (gal.)
Well Development								
03/06/09	n/r[b], bailing						226	226
03/14/09	n/r, bailing						346	572
03/15/09	n/r, bailing						38	610
03/17/09	n/r, pumping with swabbing						480	1090
03/08/09	n/r, pumping						782	1872
03/08/09	7.11	19.45	6.25	-2.0, 201.9	312	0.3	32	1904
	7.10	19.43	6.32	-1.4, 202.5	278	0.4	32	1936
	7.06	19.48	6.30	-5.2, 198.7	279	0.3	33	1969
	7.10	19.53	6.37	-8.3, 195.6	279	0.3	33	2002
	7.10	19.52	6.24	-10.0, 193.9	280	0.2	33	2035
	7.07	19.62	6.55	-9.5, 194.4	281	0.1	133	2168
	7.06	19.62	6.49	-11.4, 192.5	281	0.0	133	2301
	7.11	19.57	6.33	-17.3, 186.6	281	0.0	133	2434
	7.08	19.40	6.30	-17.1, 186.8	281	0.0	133	2567
	7.11	19.52	6.25	-18.7, 185.2	281	0.0	33	2600
Aquifer Pumping Test Volumes								
04/06/09	n/r, pumping mini-tests						211	211
04/08/09	7.26	15.87	7.14	63.3, 272.2	323	6.3	1	212
	7.19	19.54	6.75	-35.7, 168.2	316	5.1	93	305
	7.19	21.95	6.98	-9.2, 194.7	315	1.3	94	399
	7.14	22.87	7.02	-25.8, 175.4	316	0.4	94	493
	7.15	22.36	7.22	-32.2, 169.0	316	0.4	94	587
	7.10	22.78	6.92	-22.4, 178.8	316	0.0	94	681
	7.10	22.97	7.54	-19.2, 182.0	318	0.0	94	775
	7.07	23.19	6.81	-18.7, 182.5	317	0.0	94	869
	7.07	22.10	6.70	-18.5, 182.7	315	0.0	94	963
	7.09	22.03	7.18	-14.3, 186.9	314	0.0	94	1057
	7.08	21.83	6.97	-12.1, 189.1	314	0.0	187	1244
	7.08	20.86	6.91	-16.5, 187.4	313	0.1	94	1338
	7.11	20.50	7.08	-12.7, 191.2	312	0.4	94	1432
	7.08	19.96	7.05	-10.1, 193.8	313	0.4	94	1526
	7.08	20.32	6.70	-7.4, 196.5	311	0.3	94	1620

Table B-1.2-1 (continued)

Date	pH	Temp (°C)	DO (mg/L)	ORP, Eh[a] (mV)	Specific Conductivity (µS/cm)	Turbidity (NTU)	Purge Volume between Samples (gal.)	Cumulative Purge Volume (gal.)
Aquifer Pumping Test Volumes (cont.)								
04/09/09	7.08	20.07	6.75	-4.5, 199.4	310	0.7	94	1714
	7.09	16.21	7.60	0.3, 209.2	308	0.0	94	1808
	7.13	20.10	7.27	-14.7, 189.2	310	0.6	94	1902
	7.11	16.32	7.52	-2.9, 206.0	309	0.5	94	1996
	7.13	19.43	7.53	-8.3, 195.6	314	0.7	187	2183
	7.14	16.59	8.50	-15.7, 193.2	308	0.7	94	2277
	7.12	20.11	7.61	-12.7, 191.2	309	1.3	94	2371
	7.09	20.17	7.49	-19.0, 184.9	314	0.8	92	2463
Postpumping Test Purging								
To be determined								

Note: Cumulative purge volumes calculated for pump test using average pump discharge rate of approximately 1.6 gpm.

[a] Eh (mV) is calculated from an Ag/AgCl-saturated KCl electrode filling solution at 15.0 ºC, 20.0 ºC, and 22.5ºC by adding temperature-sensitive correction factors of 208.9, 203.9, and 201.2 mV, respectively.

[b] n/r = Not recorded.

Table B-1.3-1
Analytical Results for Groundwater-Screening Samples Collected at TA-53i

Sample ID	Date Received	Sample Type	ER/RRES-WQH	Depth (ft)	Ag rslt (ppm)	stdev (Ag)	Al rslt (ppm)	stdev (Al)	As rslt (ppm)	stdev (As)	B rslt (ppm)	stdev (B)	Ba rslt (ppm)	stdev (Ba)	Be rslt (ppm)	stdev (Be)	Br(-) ppm	TOC rslt (ppm)	Ca rslt (ppm)	stdev (Ca)	Cd rslt (ppm)
GW53-09-5223	3/6/2009	Borehole	09-1125	600.1	0.001	U	0.009	0.001	0.0015	0.0002	0.038	0.002	0.034	0.003	0.001	U	1.34	Not appropriate	34.23	0.34	0.001
GW53-09-5224	3/6/2009	Borehole	09-1125	600.1	0.001	U	0.013	0.000	0.0015	0.0000	0.030	0.000	0.033	0.001	0.001	U	1.34	Not appropriate	33.37	0.29	0.001
GW53-09-5203	3/19/2009	Well, development	09-1252	600-610	0.001	U	0.001	U	0.0034	0.0001	0.037	0.000	0.050	0.001	0.001	U	1.25	1.04	33.56	0.28	0.001
GW53-09-5204	3/19/2009	Well, development	09-1252	600-610	0.001	U	0.038	0.001	0.0035	0.0001	0.022	0.000	0.047	0.001	0.001	U	1.24	1.01	32.80	0.36	0.002
GW53-09-5205	3/19/2009	Well, development	09-1252	600-610	0.001	U	0.003	0.000	0.0034	0.0000	0.024	0.001	0.046	0.001	0.001	U	1.26	0.98	33.07	0.25	0.001
GW53-09-5206	4/9/2009	Well, aquifer testing	09-1423	600-610	0.001	U	0.003	0.000	0.0007	0.0000	0.043	0.000	0.049	0.001	0.001	U	1.31	1.10	36.93	0.27	0.001
GW53-09-5207	4/9/2009	Well, aquifer testing	09-1423	600-610	0.001	U	0.005	0.000	0.0008	0.0000	0.036	0.001	0.046	0.000	0.001	U	1.44	1.25	35.77	0.15	0.001
GW53-09-5208	4/9/2009	Well, aquifer testing	09-1423	600-610	0.001	U	0.003	0.000	0.0007	0.0000	0.034	0.000	0.045	0.001	0.001	U	1.43	1.15	35.66	0.18	0.001
GW53-09-5209	4/9/2009	Well, aquifer testing	09-1423	600-610	0.001	U	0.004	0.000	0.0007	0.0000	0.031	0.000	0.043	0.000	0.001	U	1.32	1.07	36.07	0.22	0.001
GW53-09-5210	4/9/2009	Well, aquifer testing	09-1423	600-610	0.001	U	0.004	0.000	0.0007	0.0000	0.030	0.000	0.044	0.001	0.001	U	1.29	1.03	36.00	0.21	0.001
GW53-09-5211	4/9/2009	Well, aquifer testing	09-1423	600-610	0.001	U	0.003	0.000	0.0007	0.0000	0.029	0.000	0.043	0.000	0.001	U	1.31	1.07	35.95	0.21	0.001

Table B-1.3-1 (continued)

Sample ID	Date Received	Sample Type	stdev (Cd)	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)	Hg rslt (ppm)
GW53-09-5223	3/6/2009	Borehole	U	32.22	0.005	U	0.001	U	0.8	U	0.002	0.000	0.001	U	0.001	U	0.26	0.010	U	117	0.00005
GW53-09-5224	3/6/2009	Borehole	U	32.40	0.005	U	0.001	U	0.8	U	0.002	0.000	0.001	U	0.001	U	0.28	0.010	U	117	0.00005
GW53-09-5203	3/19/2009	Well, development	U	30.58	0.005	U	0.001	U	0.8	U	0.005	0.001	0.001	U	0.001	0.000	0.15	0.010	U	121	0.00010
GW53-09-5204	3/19/2009	Well, development	0.000	30.40	0.005	U	0.001	U	0.8	U	0.006	0.000	0.001	U	0.002	0.000	0.15	0.010	U	117	0.00007
GW53-09-5205	3/19/2009	Well, development	U	30.58	0.005	U	0.001	U	0.8	U	0.004	0.000	0.001	U	0.001	U	0.17	0.010	U	117	0.00007
GW53-09-5206	4/9/2009	Well, aquifer testing	U	31.02	0.005	U	0.001	U	0.8	U	0.002	0.000	0.001	U	0.001	0.000	0.15	0.021	0.001	118	0.00005
GW53-09-5207	4/9/2009	Well, aquifer testing	U	31.09	0.005	U	0.001	U	0.8	U	0.002	0.000	0.001	U	0.001	0.000	0.17	0.077	0.001	117	0.00005
GW53-09-5208	4/9/2009	Well, aquifer testing	U	31.14	0.005	U	0.001	U	0.8	U	0.002	0.000	0.001	U	0.001	0.000	0.15	0.073	0.001	116	0.00005
GW53-09-5209	4/9/2009	Well, aquifer testing	U	31.09	0.005	U	0.001	U	0.8	U	0.002	0.000	0.001	U	0.001	0.000	0.21	0.035	0.000	117	0.00005
GW53-09-5210	4/9/2009	Well, aquifer testing	U	31.11	0.005	U	0.001	U	0.8	U	0.002	0.000	0.001	U	0.001	0.000	0.15	0.020	0.000	117	0.00005
GW53-09-5211	4/9/2009	Well, aquifer testing	U	31.21	0.005	U	0.001	U	0.8	U	0.001	0.000	0.001	U	0.001	U	0.15	0.024	0.000	117	0.00005

Table B-1.3-1 (continued)

Sample ID	Date Received	Sample Type	stdev (Hg)	K rslt (ppm)	stdev (K)	Li rslt (ppm)	stdev (Li)	Mg rslt (ppm)	stdev (Mg)	Mn rslt (ppm)	stdev (Mn)	Mo rslt (ppm)	stdev (Mo)	Na rslt (ppm)	stdev (Na)	Ni rslt (ppm)	stdev (Ni)	NO2 (ppm)	NO2-N rslt	NO2-N (U)	NO3 ppm	NO3-N rslt	C2O4 rslt (ppm)
GW53-09-5223	3/6/2009	Borehole	U	5.86	0.32	0.035	0.002	7.94	0.45	0.157	0.008	0.060	0.000	20.05	1.14	0.003	0.000	0.01	0.003	U	4.68	1.06	0.01
GW53-09-5224	3/6/2009	Borehole	0.00001	4.94	0.03	0.029	0.000	6.84	0.00	0.129	0.000	0.063	0.000	16.51	0.03	0.002	0.000	0.01	0.003	U	4.69	1.06	0.01
GW53-09-5203	3/19/2009	Well, development	0.00001	4.60	0.04	0.019	0.000	6.75	0.04	0.015	0.000	0.063	0.000	15.86	0.05	0.005	0.000	0.01	0.003	U	4.12	0.93	0.01
GW53-09-5204	3/19/2009	Well, development	0.00001	4.22	0.01	0.019	0.000	6.63	0.05	0.015	0.000	0.062	0.001	15.63	0.11	0.005	0.000	0.01	0.003	U	4.11	0.93	0.01
GW53-09-5205	3/19/2009	Well, development	0.00000	4.39	0.03	0.019	0.000	6.86	0.07	0.014	0.000	0.063	0.000	15.94	0.10	0.005	0.000	0.01	0.003	U	4.15	0.94	0.01
GW53-09-5206	4/9/2009	Well, aquifer testing	U	5.02	0.05	0.026	0.001	7.44	0.03	0.012	0.000	0.062	0.000	16.59	0.04	0.002	0.000	0.01	0.003	U	4.49	1.01	0.01
GW53-09-5207	4/9/2009	Well, aquifer testing	U	4.83	0.03	0.026	0.001	7.18	0.04	0.009	0.000	0.064	0.001	15.75	0.17	0.002	0.000	0.01	0.003	U	4.69	1.06	0.01
GW53-09-5208	4/9/2009	Well, aquifer testing	U	4.90	0.03	0.027	0.000	7.27	0.01	0.008	0.000	0.062	0.001	15.84	0.04	0.002	0.000	0.01	0.003	U	4.74	1.07	0.01
GW53-09-5209	4/9/2009	Well, aquifer testing	U	4.86	0.01	0.027	0.001	7.16	0.08	0.007	0.000	0.062	0.001	15.59	0.01	0.002	0.000	0.01	0.003	U	4.61	1.04	0.01
GW53-09-5210	4/9/2009	Well, aquifer testing	U	4.91	0.02	0.028	0.001	7.24	0.10	0.007	0.000	0.063	0.001	15.72	0.19	0.002	0.000	0.01	0.003	U	4.59	1.04	0.01
GW53-09-5211	4/9/2009	Well, aquifer testing	U	4.87	0.04	0.028	0.000	7.24	0.03	0.006	0.000	0.062	0.000	15.43	0.08	0.002	0.000	0.01	0.003	U	4.61	1.04	0.01

Table B-1.3-1 (continued)

Sample ID	Date Received	Sample Type	C2O4 (U)	Pb rslt (ppm)	stdev (Pb)	Lab 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)
GW53-09-5223	3/6/2009	Borehole	U	0.0003	0.0000	7.14	0.01	U	0.008	0.001	0.001	U	0.001	0.000	35.2	1.7	75.3	3.6	0.001	U	19.57	0.198	0.009
GW53-09-5224	3/6/2009	Borehole	U	0.0003	0.0000	7.60	0.01	U	0.007	0.000	0.001	U	0.001	0.000	30.2	0.1	64.6	0.2	0.001	U	19.71	0.168	0.002
GW53-09-5203	3/19/2009	Well, development	U	0.0003	0.0000	7.33	0.01	U	0.008	0.000	0.001	U	0.001	U	27.1	0.0	58.0	0.1	0.001	U	18.70	0.172	0.000
GW53-09-5204	3/19/2009	Well, development	U	0.0002	U	7.13	0.01	U	0.008	0.000	0.001	U	0.001	U	23.3	0.2	49.9	0.5	0.001	U	18.66	0.171	0.001
GW53-09-5205	3/19/2009	Well, development	U	0.0002	0.0000	7.17	0.01	U	0.009	0.000	0.001	U	0.001	U	25.8	0.2	55.3	0.4	0.001	U	18.72	0.177	0.001
GW53-09-5206	4/9/2009	Well, aquifer testing	U	0.0002	U	7.28	0.01	U	0.008	0.000	0.001	U	0.001	U	32.3	0.2	69.1	0.4	0.001	U	18.51	0.185	0.002
GW53-09-5207	4/9/2009	Well, aquifer testing	U	0.0002	U	7.41	0.01	U	0.008	0.000	0.001	U	0.001	U	31.0	0.4	66.4	0.8	0.001	U	18.47	0.179	0.001
GW53-09-5208	4/9/2009	Well, aquifer testing	U	0.0002	U	7.26	0.01	U	0.008	0.000	0.001	U	0.001	U	31.3	0.2	67.1	0.4	0.001	U	18.53	0.180	0.003
GW53-09-5209	4/9/2009	Well, aquifer testing	U	0.0002	U	7.28	0.01	U	0.008	0.000	0.001	U	0.001	U	31.4	0.1	67.3	0.3	0.001	U	18.46	0.180	0.001
GW53-09-5210	4/9/2009	Well, aquifer testing	U	0.0002	U	7.36	0.01	U	0.008	0.000	0.001	U	0.001	U	31.6	0.2	67.7	0.5	0.001	U	18.46	0.182	0.001
GW53-09-5211	4/9/2009	Well, aquifer testing	U	0.0002	U	7.42	0.01	U	0.008	0.000	0.001	U	0.001	U	31.3	0.2	67.0	0.4	0.001	U	18.54	0.179	0.001

Table B-1.3-1 (continued)

Sample ID	Date Received	Sample Type	Th rslt (ppm)	Ti rslt (ppm)	stdev (Ti)	Tl rslt (ppm)	stdev (Tl)	U rslt (ppm)	stdev (U)	V rslt (ppm)	stdev (V)	Zn rslt (ppm)	stdev (Zn)	TDS (ppm)	Cations	Anions	Balance
GW53-09-5223	3/6/2009	Borehole	0.001	0.002	U	0.001	U	0.0007	0.0001	0.002	0.000	0.030	0.002	320	3.40	3.40	0.00
GW53-09-5224	3/6/2009	Borehole	0.001	0.002	U	0.001	U	0.0008	0.0000	0.002	0.000	0.046	0.001	303	3.09	3.37	-0.04
GW53-09-5203	3/19/2009	Well, development	0.001	0.002	U	0.001	U	0.0008	0.0000	0.002	0.000	0.038	0.000	296	3.05	3.35	-0.05
GW53-09-5204	3/19/2009	Well, development	0.001	0.002	U	0.001	U	0.0008	0.0000	0.003	0.000	0.037	0.000	282	2.98	3.27	-0.05
GW53-09-5205	3/19/2009	Well, development	0.001	0.002	U	0.001	U	0.0008	0.0000	0.002	0.000	0.033	0.001	289	3.03	3.29	-0.04
GW53-09-5206	4/9/2009	Well, aquifer testing	0.001	0.002	U	0.001	U	0.0009	0.0000	0.002	0.000	0.015	0.000	309	3.31	3.31	0.00
GW53-09-5207	4/9/2009	Well, aquifer testing	0.001	0.002	U	0.001	U	0.0009	0.0000	0.002	0.000	0.014	0.000	304	3.19	3.31	-0.02
GW53-09-5208	4/9/2009	Well, aquifer testing	0.001	0.002	U	0.001	U	0.0008	0.0000	0.002	0.000	0.011	0.000	304	3.20	3.30	-0.02
GW53-09-5209	4/9/2009	Well, aquifer testing	0.001	0.002	U	0.001	U	0.0008	0.0000	0.002	0.000	0.011	0.000	304	3.20	3.30	-0.02
GW53-09-5210	4/9/2009	Well, aquifer testing	0.001	0.002	U	0.001	U	0.0008	0.0000	0.002	0.000	0.011	0.000	305	3.21	3.30	-0.01
GW53-09-5211	4/9/2009	Well, aquifer testing	0.001	0.002	U	0.001	U	0.0008	0.0000	0.002	0.000	0.010	0.000	304	3.19	3.31	-0.02

Appendix C

Aquifer Testing Report

C-1.0 INTRODUCTION

This appendix describes the hydraulic analysis of pumping tests conducted at well TA-53i located at Technical Area 53. The tests on TA-53i were conducted to determine the hydraulic properties of the perched zone penetrated by the well.

Testing consisted of brief trial pumping of TA-53i, background water-level data collection, and a 24-h constant-rate pumping test. Water-level monitoring was restricted to the pumped well. No other wells were monitored during the tests.

Unlike most of the R-well pumping tests conducted on the plateau, an inflatable packer system was not used in TA-53i to minimize the effects of casing storage on the test data. The static water level fell within the screen and thus storage effects on the data were unavoidable.

Conceptual Hydrogeology

Well TA-53i was completed in a perched interval of the Puye Formation above the Cerros del Rio basalt. The screened interval runs from 600 to 610 ft below ground surface (bgs). The static water level measured on April 5, 2009, when the testing program began was 600.4 ft bgs, just below the top of the well screen.

The Puye Formation at this site extends to a depth of 634 ft bgs where it contacts the Cerros del Rio basalt. Thus, the potential saturated thickness of the Puye was 33.6 ft from the static water level of 600.4 ft to the contact with the Cerros del Rio basalt. It is possible that the contact at the top of the Cerros del Rio serves as the perching horizon at this location. It is also possible that tight layers within the Puye formation contribute to perching the groundwater.

TA-53i Testing

Well TA-53i was tested from April 6 to April 10, 2009. Testing consisted of brief trial pumping (trial 1 and trial 2) on April 6, background data collection, and a 24-h constant-rate pumping test that was begun on April 8.

Two trial tests were conducted on April 6. Trial 1 was conducted at variable discharge rates for 90 min from 8:30 to 10:00 a.m. and was followed by 60 min of recovery until 11:00 a.m. Trial 2 was conducted for 60 min from 11:00 a.m. to 12:00 p.m. at 1.58 gpm. Following shutdown, recovery/background was monitored for 44 h until 8:00 a.m. on April 8.

At 8:00 a.m. on April 8, the 24-h pumping test was begun at a rate of 1.59 gpm. Pumping continued until 8:00 a.m. on April 9. Following shutdown, recovery measurements were recorded for 1463 min until 8:23 a.m. on April 10 when the pump was tripped out of the well.

Leaky Drop Pipe Joints

During the TA-53i 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 leaks were caused by either worn or improperly manufactured threads, as well as by the need to avoid wrenching the pipe extremely tight as a precaution against galling the stainless-steel threads.

The leaks were sufficiently minor that they had no obvious effect on trial 2, which was preceded by a short idle period (1 h). There was a noticeable effect, however, on the 24-h test data. The preceding 44-h background monitoring period apparently was long enough to allow drainage of enough water from the drop pipe to have an effect.

Although the antecedent drainage of the drop pipe affected the early portion of the 24-h pumping test, it did not limit or affect analysis of the data. The early data from all tests were corrupted by casing and filter pack storage effects and were therefore unusable.

C-2.0 BACKGROUND DATA

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

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

Previous pumping tests on the plateau have demonstrated a barometric efficiency for most wells 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 TA-53i, 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 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 sea level (amsl), whereas the wellhead elevation is approximately 6983 ft amsl. The static water level in TA-53i was about 600 ft below land surface, making the water-table elevation roughly 6383 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 TA-53i.

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

$$P_{WT} = P_{TA54} \exp\left[-\frac{g}{3.281R}\left(\frac{E_{TA-53i} - E_{TA54}}{T_{TA54}} + \frac{E_{WT} - E_{TA-53i}}{T_{WELL}} \right) \right]$$

Equation C-1

where, P_{WT} = barometric pressure at the water table inside TA-53i

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_{TA-53i} = land-surface elevation at TA-53i site, in feet (6983 ft)

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

E_{WT} = elevation of the water level in TA-53i, in feet (approximately 6383 ft)

T_{TA54} = air temperature near TA-54, in degrees Kelvin (assigned a value of 44.8 degrees Fahrenheit, or 280.2 degrees Kelvin)

T_{WELL} = air temperature inside TA-53i, in degrees Kelvin (assigned a value of 60.4 degrees Fahrenheit, or 288.9 degrees Kelvin)

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

The corrected barometric pressure data reflecting pressure conditions at the water table were compared with the water-level hydrograph to discern the correlation between the two and to determine whether water-level corrections would be needed before data analysis.

C-3.0 IMPORTANCE OF EARLY DATA

When pumping or recovery first begins, the vertical extent of the cone of depression is limited to approximately the well screen length, the filter pack length, or the aquifer thickness in relatively thin permeable strata. For many pumping tests on the plateau, the early pumping period is the only time that the effective height of the cone of depression is known with certainty. 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, including TA-53i, casing-storage effects dominate the early-time data, potentially hindering the effort to determine the transmissivity of the screened interval. The duration of casing-storage effects can be estimated using the following equation (Schafer 1978, 098240):

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

Equation C-2

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

D = 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

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

For wells screened across the water table, such as TA-53i, there is additional storage contribution from the filter pack around the screen. The following equation provides an estimate of the storage duration accounting for both casing- and filter-pack storage:

$$t_c = \frac{0.6\left[\left(D^2 - d^2\right) + S_y\left(D_B^2 - D_C^2\right)\right]}{\frac{Q}{s}} \qquad \textbf{Equation C-3}$$

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

D = diameter of borehole, in inches

D_C = O.D. of well casing, in inches

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

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. Unfortunately, this method was not applicable to TA-53i because the water level fell within the screen and filter pack.

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:

$$s = \frac{114.6Q}{T}W(u) \qquad \textbf{Equation C-4}$$

where,

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

Equation C-5

and

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

Equation C-6

and where, s = drawdown, in feet

Q = discharge rate, in gallons per minute

T = transmissivity, in gallons per day per foot

S = storage coefficient (dimensionless)

t = pumping time, in days

r = distance from center of pumpage, in feet

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

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

Equation C-7

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

Equation C-8

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

S = storage coefficient

Q = discharge rate, in gallons per minute

$W(u)$ = match-point value

s = match-point value, in feet

u = match-point value

t = match-point value, in minutes

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

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

Equation C-9

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

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

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

Equation C-10

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

Q = discharge rate, in gallons per minute

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

Because many of the test wells completed on the plateau are severely partially penetrating, an alternate solution considered for assessing aquifer conditions is the Hantush equation for partially penetrating wells (Hantush 1961, 098237; Hantush 1961, 106003). The Hantush equation is as follows:

Equation C-11

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

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

b = aquifer thickness

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

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

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

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

K_z = vertical hydraulic conductivity

K_r = horizontal hydraulic conductivity

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

$$\beta = \sqrt{\frac{K_z}{K_r}}\frac{n\pi r}{b} \qquad \textbf{Equation C-12}$$

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

C-5.0 RECOVERY METHODS

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

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

$$T = \frac{264Q}{\Delta s} \qquad \textbf{Equation C-13}$$

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.

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:

$$s_P = \frac{1-\frac{L}{b}}{\frac{L}{b}}\left[\ln\frac{b}{r_w} - 2.948 + 7.363\frac{L}{b} - 11.447\left(\frac{L}{b}\right)^2 + 4.675\left(\frac{L}{b}\right)^3\right] \qquad \textbf{Equation C-14}$$

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

$$K = \frac{264Q}{sb}\left(\log\frac{0.3Tt}{r_w^2 S} + \frac{2s_P}{\ln 10}\right) \qquad \textbf{Equation C-15}$$

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

To apply this procedure, a storage coefficient value must be assigned. Unconfined conditions were assumed for TA-53i because the water table fell within the screen. 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 TA-53i.

The analysis also requires assigning a value for the saturated aquifer thickness, *b*. For calculation purposes, initially the aquifer thickness was taken to be the 33.6-ft thickness of the Puye Formation above the Cerros del Rio Basalt. However, as explained below, the pumping test data suggested a thinner producing zone composed of just a fraction of the screen length. Thus, treating the well as fully penetrating was more realistic.

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 UNCONFINED AQUIFER DRAWDOWN CORRECTION

For unconfined aquifers, the saturated aquifer thickness is reduced below the original thickness during testing. This results in drawdown values that deviate from theoretical predictions because well hydraulics formulas are based on 100% aquifer saturation. Before analysis, the actual drawdown values must be corrected for dewatering effects using the following formula (Kruseman et al. 1991, 106681):

$$s_c = s_a - \frac{s_a^2}{2b} \qquad \textbf{Equation C-16}$$

where, s_c = corrected drawdown, in feet

S_a = observed drawdown, in feet

b = saturated aquifer thickness, in feet

Assumptions required for validity of Equation C-16 are (1) homogeneous hydraulic conductivity, (2) full penetration of the producing zone by the well screen, and (3) no head loss associated with vertical flow. This last assumption is satisfied by one of two extremes: either zero permeability in the vertical direction so that there is no flow (and therefore no head loss) vertically or infinite vertical permeability. Failure to meet any of these three assumptions leads to modest errors in application of the drawdown correction equation.

C-8.0 BACKGROUND DATA ANALYSIS

Background aquifer pressure data collected during the TA-53i tests were plotted along with barometric pressure to determine the barometric effect on water levels.

Figure C-8.0-1 shows aquifer pressure data from TA-53i 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 TA-53i 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 TA-53i pumping tests are included in the figure for reference.

It appeared in Figure C-8.0-1 that changes in barometric pressure had little effect on total aquifer pressure. This implied a barometric efficiency of near 100% for the perched zone in TA-53i.

Evident in the figure was that the static water level was pulled down and did not fully recover after the 24-h test. This suggested the possibility that the saturated perched zone was laterally limited. Subsequent data, presented below, supported this idea.

C-9.0 WELL TA-53i DATA ANALYSIS

This section presents the data obtained from the TA-53i pumping tests and the results of the analytical interpretations. Data are presented for drawdown and recovery for trials 1 and 2 and the 24-h constant-rate pumping test.

Analyses were performed using analytical methods that assume that there is no groundwater yield from the vadose zone above the perched interval.

C-9.1 Well TA-53i Trial 1

Figure C-9.1-1 shows a semilog plot of the drawdown data collected from trial 1. As evidenced on the graph, the discharge rate was varied substantially and often. Key information about the permeable zone was obtained from the trial 1 drawdown as described below.

Initial pumping was performed with the discharge valve wide open. The large pump (5 hp, 10 gpm) used for the test quickly dewatered the screen and filter pack, drawing the pumping water level down to the intake of the pump, just above the bottom of the well screen. Once the storage volume in the filter pack and screen was exhausted, the discharge rate declined to the limit dictated by the aquifer yield, about 2.8 gpm. The observed drawdown was 8.34 ft, making the specific capacity 0.34 gpm/ft.

Next, the discharge rate was decreased to 0.78 gpm for several minutes and increased to 0.92 gpm. At these pumping rates, the inflow from the formation exceeded the withdrawal rates and the screen and filter pack slowly refilled. At 0.92 gpm, the drawdown nearly leveled off at about 0.44 ft, making the specific capacity 2.09 gpm/ft. At this point, the water level was still rising slowly. Thus, had the discharge rate of 0.92 been maintained for a longer period, the observed drawdown would have been slightly less and the specific capacity even greater.

The above specific capacity values were contradictory. Theoretically, the specific capacity of an unconfined aquifer will decline as the drawdown increases, reaching a value of 50% of the maximum value that is achieved at negligible drawdown. The maximum theoretical specific capacity from TA-53i must be greater than that observed at 0.92 gpm, that is, greater than 2.09 gpm/ft. Thus, the minimum specific capacity that should be observed is 50% of a number greater than 2.09 gpm/ft. Clearly, the specific capacity of 0.34 gpm/ft (at a pumping rate of 2.8 gpm) observed at early time was anomalously low. This meant that the increased drawdown from 0.44 to 8.34 ft (Q from 0.92 to 2.8 gpm) did not produce the corresponding increase in yield that would be expected theoretically. This is the effect that is observed when the pumping water level in an aquifer is pulled beneath the producing zone. When the water level is lowered beneath the contributing zone, further increases in drawdown produce no additional

flow; thus, the specific capacity declines anomalously. This suggested that the pumping level had been pulled beneath the producing zone at a pumping rate of 2.8 gpm.

Later in trial 1, the discharge rate was increased between 2 and 3 gpm and then reduced to 1.58 gpm for the balance of the pumping period. At 1.58 gpm, the drawdown approached 0.91 ft, making the specific capacity 1.74 gpm/ft.

With two pumping rate and drawdown data points, it is possible to estimate the saturated thickness of the permeable zone. Using Equation C-16, it was possible to derive the following expression for the saturated thickness:

$$b = \frac{\frac{Q_1}{Q_2} s_2^2 - s_1^2}{2\left(\frac{Q_1}{Q_2} s_2 - s_1\right)}$$ **Equation C-17**

where, Q_1 = first discharge rate, in gallons per minute

Q_2 = second discharge rate, in gallons per minute

s_1 = observed drawdown at Q_1, in feet

s_2 = observed drawdown at Q_2, in feet

b = saturated formation thickness, in feet

This equation can be derived by noting that the corrected drawdown described by Equation C-16 is directly proportional to the pumping rate. Thus, for two data points, the direct proportion means that the ratio of the pumping rates equals the ratio of the corrected drawdown values as follows:

$$\frac{Q_1}{Q_2} = \frac{s_1 - \frac{s_1^2}{2b}}{s_2 - \frac{s_2^2}{2b}}$$ **Equation C-18**

Solving Equation C-18 for the unknown, b, yields Equation C-17.

Using the discharge rates of 0.92 and 1.58 gpm and the corresponding drawdown values of 0.44 and 0.91 ft, Equation C-17 was solved, yielding an estimated value for b of 1.6 ft. This result was considered only an approximation because (1) the drawdown values used in the calculations had not stabilized completely, (2) the pumping times for the two data points were different, and (3) antecedent pumping patterns (rates and times) preceding each of the measurements were different. Nevertheless, the result suggested that the permeable pumped zone was composed of a limited thickness of sediment at the top of the screened interval. This was consistent with the dramatically lower specific capacity observed at the initial 2.8-gpm discharge rate.

Figure C-9.1-2 shows a linear plot of a portion of the drawdown data from trial 1, focusing on the responses at 0.78 and 0.92 gpm. Normally, the rate of refill of screen and filter pack should decline steadily with time for each of the discharge rates, producing a steadily flatter curve over time. As indicated in the graph, however, the recovery trends for each of the discharge rates were nearly linear, suggesting that there was no change in refill rate as the drawdown changed. (Note that the refill curve for 0.92 gpm

was flatter than that for 0.78 gpm. This was because the greater discharge rate resulted in less inflow being available to refill the screen and filter pack.) Only when the water level rose to about 2.7 ft of the static water level was there an apparent decline in the refill rate. This suggested that the contribution to flow largely came from the top 2.7 ft or so of saturation. This result was consistent with the specific capacity analysis discussed above and the great loss of specific capacity at the maximum discharge rate of 2.8 gpm.

The conclusion from the drawdown analysis was that most of the production to TA-53i came from the uppermost few feet of saturation. There may be other minor contributing zones throughout the screen length and even from beneath the screen. However, it appears that the combined contribution below about 2.7 ft is negligible.

Figure C-9.1-3 shows the recovery data collected following shutdown of the trial 1 pumping test. The discharge rate shown on the graph was 1.72 gpm, the average discharge rate for trial 1.

The early-recovery data showed the effects of casing- and filter-pack storage. Storage duration times t_c and $t_c/2$ were computed and displayed in the graph at the corresponding values of t/t' to guide the data analysis.

The transmissivity value computed from the valid data (after storage effects) was 3860 gpd/ft. If the thickness of permeable sediments is estimated at about 2.7 ft, the effective hydraulic conductivity is about 1430 gpd/ft^2, or 191 ft/d.

C-9.2 Well TA-53i Trial 2

Figure C-9.2-1 shows a semilog plot of the drawdown data collected from trial 2 conducted at a discharge rate of 1.58 gpm. The graph shows both the observed drawdown measurements as well as the corrected drawdown obtained using Equation C-16. An assumed aquifer thickness of 2.7 ft was used in the correction algorithm. The corrected data and slope of the line of fit would be slightly different for different assumed values of saturated thickness.

The estimated casing-storage times are shown on the graph. The transmissivity value computed from the corrected data following casing- and filter-pack storage was 2980 gpd/ft. Based on an estimated permeable saturated thickness of about 2.7 ft, the corresponding hydraulic conductivity was about 1100 gpd/ft^2, or 148 ft/d.

Figure C-9.2-2 shows the recovery data recorded following the trial 2 test on TA-53i. The effects of casing- and filter-pack storage are clearly evident in the graph along with the computed storage times. The very late data showed a steep rise in level consistent with an indication of boundary conditions.

Figure C-9.2-3 shows an expanded-scale plot of the trial 2 recovery data. The data were not corrected for dewatering because of the small magnitude of the residual drawdown values. The poststorage data showed an early slope and a late slope with a subtle flattening in between, characteristic of delayed yield associated with unconfined aquifers. The transmissivity computed from the early slope was 3660 gpd/ft, with a corresponding hydraulic conductivity of 1360 gpd/ft^2, or 181 ft/d. The late slope revealed a transmissivity of 3060 gpd/ft, making the estimated hydraulic conductivity 1130 gpd/ft^2, or 152 ft/d.

The expanded-scale plot shows more clearly the steep slope associated with the very late recovery data. This response was consistent with a laterally limited/bounded permeable formation.

C-9.3 Well TA-53i 24-H Constant-Rate Pumping Test

Figure C-9.3-1 shows a semilog plot of the drawdown data recorded during the 24-h constant-rate pumping test. The initial discharge rate was around 1.7 gpm for about an hour. Then the rate spontaneously declined to an average of 1.59 gpm for most of the test. It was possible that the electric current frequency output from the generator may have changed slightly, causing the observed change in discharge rate.

The early data showed exaggerated drawdown, indicating that minor antecedent drainage of the drop pipe had occurred during the background monitoring period. The late data showed a slope increase, likely indicative of lateral limits to the permeable perched zone.

Because of the variable discharge rate, noise in the data set and the boundary effect, data from the pumping period were not analyzed. Instead, analysis was performed using the recovery data.

Figure C-9.3-2 shows the recovery data measured following the 24-h constant-rate pumping test. The casing- and filter-pack storage effect is clearly evident in the data plot. Computed casing-storage times are shown on the graph for reference. The very late data showed the boundary effect, indicated by the substantial increase in the slope of the graph.

Figure C-9.3-3 shows an expanded-scale graph of the recovery data along with a second curve showing the data corrected for dewatering effects. The corrected data showed valid early and late slopes with a brief subtle flattening in between, characteristic of delayed yield response associated with unconfined aquifers. The very late data showed the boundary effect seen previously.

The early drawdown slope identified on Figure C-9.3-3 revealed a transmissivity value of 3310 gpd/ft. Based on the assumed saturated thickness of 2.7 ft, the computed hydraulic conductivity was 1230 gpd/ft^2, or 164 ft/d.

The transmissivity computed from the late slope was 3570 gpd/ft, making the hydraulic conductivity 1320 gpd/ft^2, or 177 ft/d.

The last data on Figure C-9.3-3 showed a steep slope associated with boundary conditions. Note that the dashed line in the upper left corner of the graph shows approximately what an extrapolated recovery slope would have to look like in order for the water level to eventually reach the original static level. The steep slope indicated by the dashed line confirms the boundary effect and that the permeable zone is laterally limited.

C-9.4 Well TA-53i Specific Capacity Data

Specific capacity data were used along with well geometry to estimate a lower-bound transmissivity value for the thin permeable zone penetrated by TA-53i. This was done to provide a frame of reference for evaluating the foregoing analyses.

It was necessary to use data before the onset of boundary effects. Therefore, data from trial 2 were used for the calculations.

In addition to specific capacity, other input values used in the calculations included a storage coefficient value of 0.1 and a borehole radius of 0.51 ft.

TA-53i produced 1.58 gpm with a drawdown of 0.88 ft after 60 min of pumping for a specific capacity of 1.8 gpm/ft. The observed drawdown of 0.88 ft was corrected for dewatering effects using Equation C-16. This resulted in a corrected drawdown of 0.737 ft. Applying the Brons and Marting method to these inputs

for the assumed aquifer thickness of 2.7 ft yielded lower-bound transmissivity and hydraulic conductivity values of 1640 gpd/ft and 81 ft/d, respectively.

The lower-bound transmissivity value of 1640 gpd/ft was entirely consistent with the previously presented pumping test analyses. Table C-9.4-1 summarizes the transmissivity values computed from the pumping tests. The average transmissivity value of those computed from the test data was 3410 gpd/ft. Comparing this with the lower-bound value of 1640 gpd/ft suggested a well efficiency of about 50% and implied an inefficiency head loss of a few tenths of a foot at a discharge rate of 1.58 gpm, both reasonable results.

C-10.0 SUMMARY

Constant-rate pumping tests were conducted on TA-53i. The tests were conducted to gain an understanding of the hydraulic characteristics of the perched portion of the Puye Formation in which the well is placed.

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

TA-53i penetrates the upper 9.6 ft of saturated Puye Formation, 33.6 ft thick and perched on the contact with the Cerros del Rio basalt. The test data suggested that essentially all of the production to the well came from the upper few feet of saturation (about 2.7 ft below the static water level). Thus, the perching layer may actually be tight zones within the Puye Formation that may be partially or entirely within the lower part of the screen.

The saturated interval responded to barometric pressure with near 100% barometric efficiency.

The 1 ½-in. stainless-steel drop pipe used recently for numerous pumping tests continued to show minor leakage through the coupling joints, corrupting the early drawdown data. 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.

The average transmissivity computed for the thin permeable zone was 3410 gpd/ft. The average hydraulic conductivity of the productive interval at the top of saturation was 169 ft/d, as calculated using the apparent productive thickness of 2.7 ft.

The drawdown and recovery data showed a prominent boundary effect, implying lateral limits to the saturated permeable zone.

Specific capacity analysis showed that TA-53i produced 1.58 gpm with 0.88 ft of drawdown after 1 h of pumping, for a specific capacity of 1.8 gpm/ft. The lower-bound transmissivity computed from this specific capacity was 1640 gpd/ft after adjusting for dewatering effects. This was consistent with the pumping tests analysis results, being about half of the average transmissivity value determined from the tests. This implied a well efficiency around 50% and an inefficiency head loss of just a few tenths of a foot, both reasonable results.

The late time-drawdown during the 24-h test showed a substantial increase in slope. This was attributable to a combination of the boundary effect (laterally limited permeable zone) and dewatering effects. The late-recovery data showed an increase in slope as well, attributable entirely to the boundary condition.

The recommended operating rate for sampling TA-53i is between about 1 and 1.5 gpm. Lower flow rates than this may overstress the pump bearings and fail to cool the electric motor sufficiently, while greater rates will cause excessive dewatering and aeration of the fragile production zone.

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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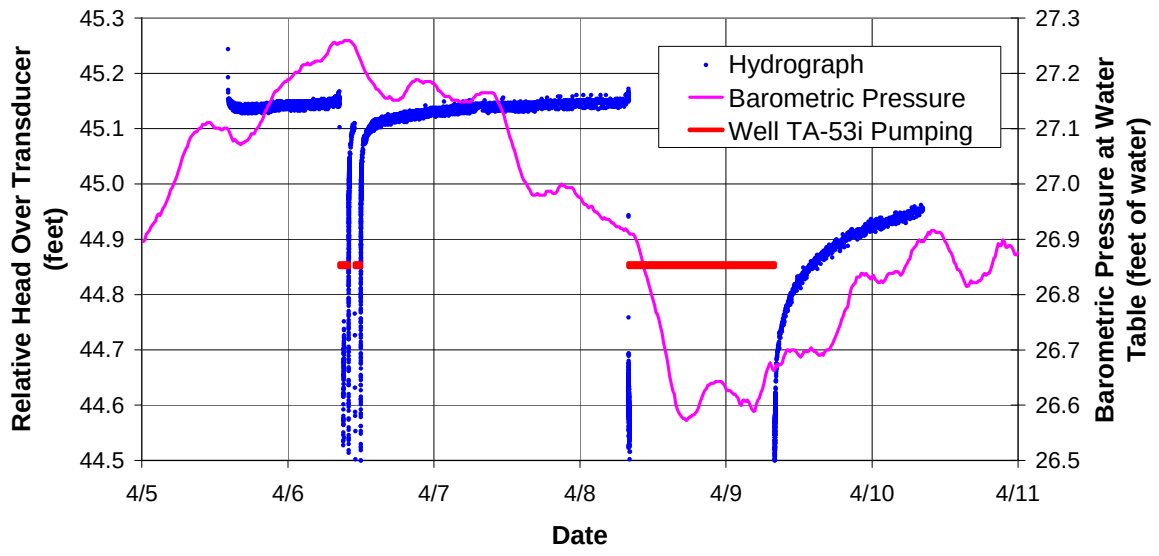


Figure C-8.0-1 Well TA-53i apparent hydrograph

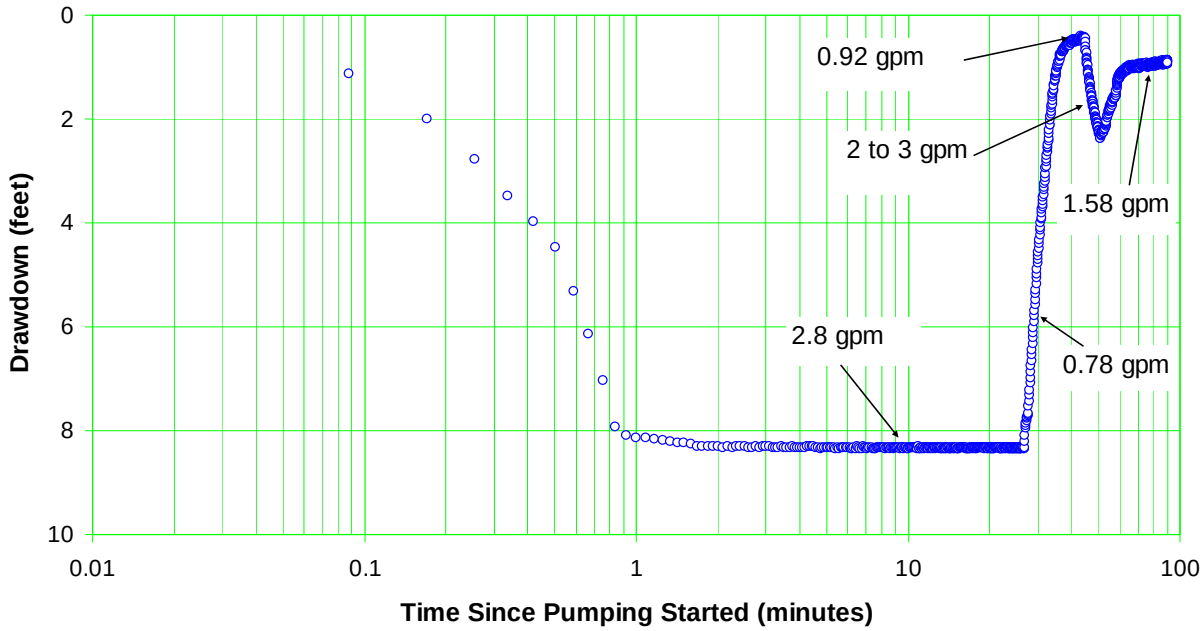


Figure C-9.1-1 Well TA-53i trial 1 drawdown

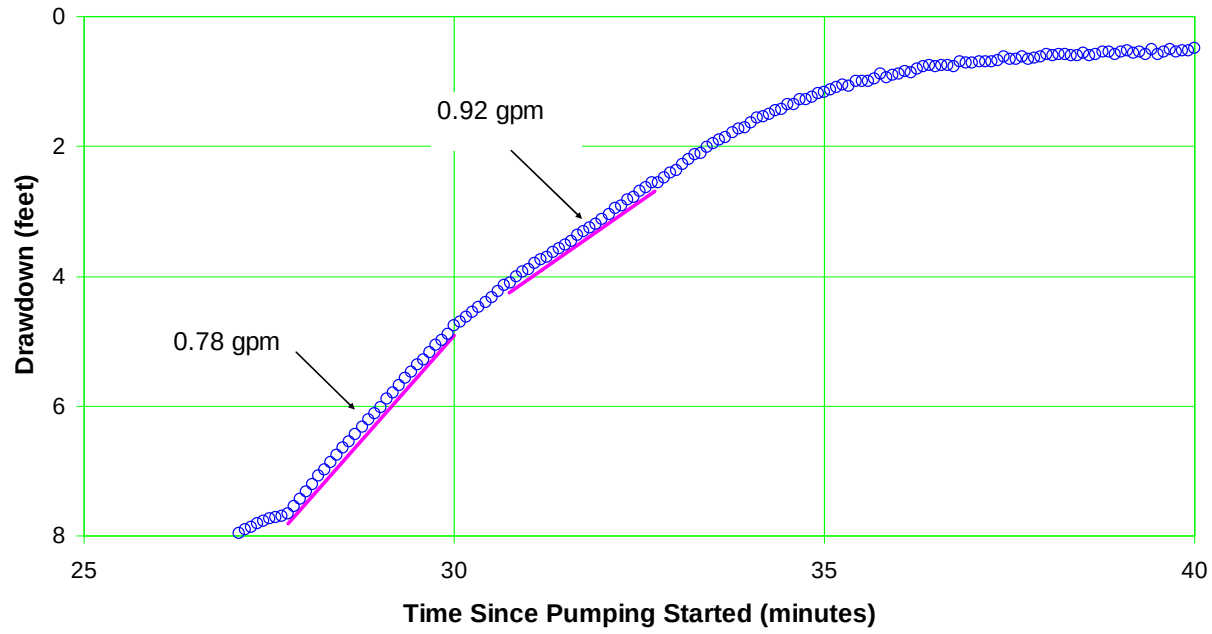


Figure C-9.1-2 Well TA-53i trial 1 drawdown—linear plot

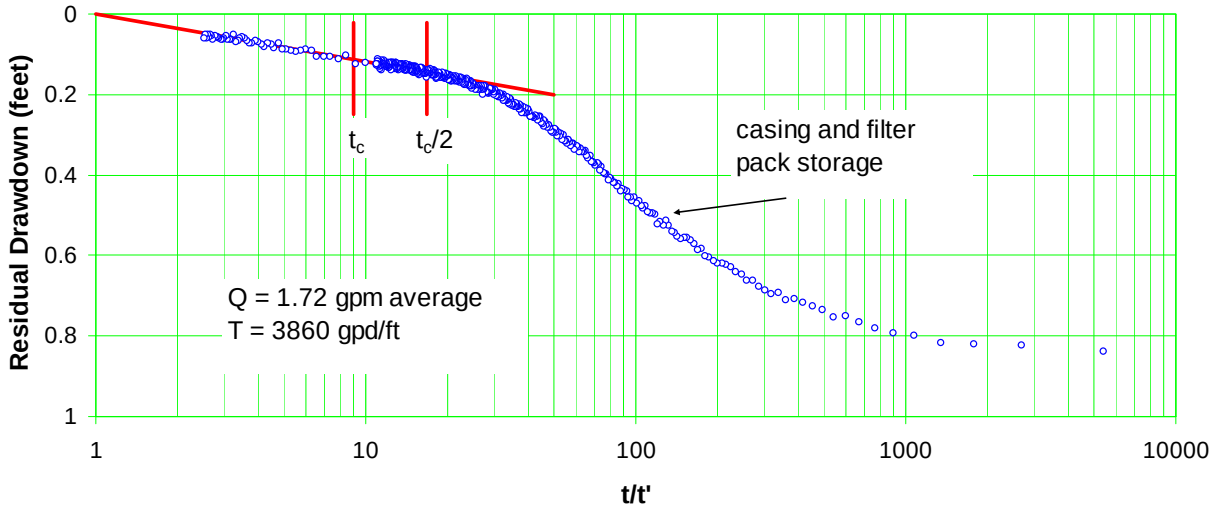


Figure C-9.1-3 Well TA-53i trial 1 recovery

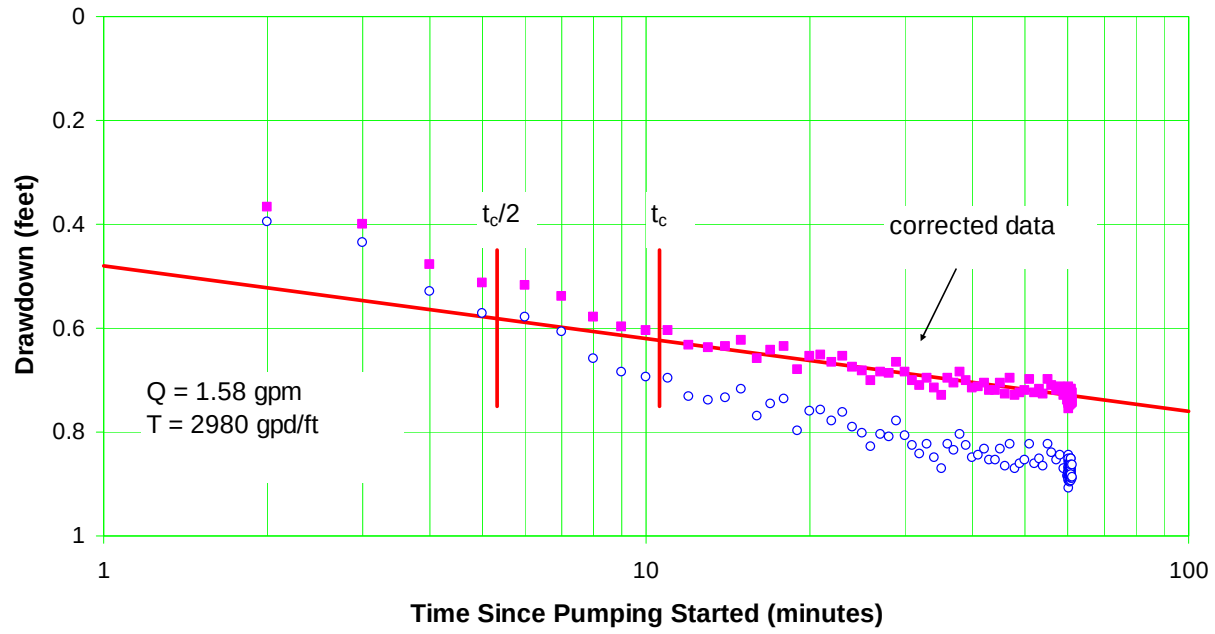


Figure C-9.2-1 Well TA-53i trial 2 drawdown

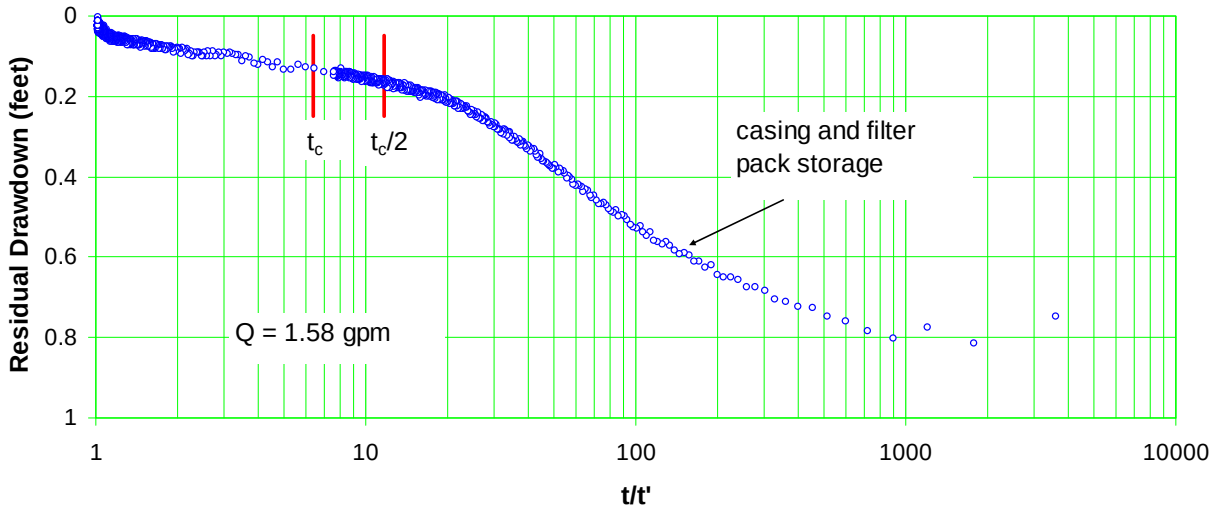


Figure C-9.2-2 Well TA-53i trial 2 recovery

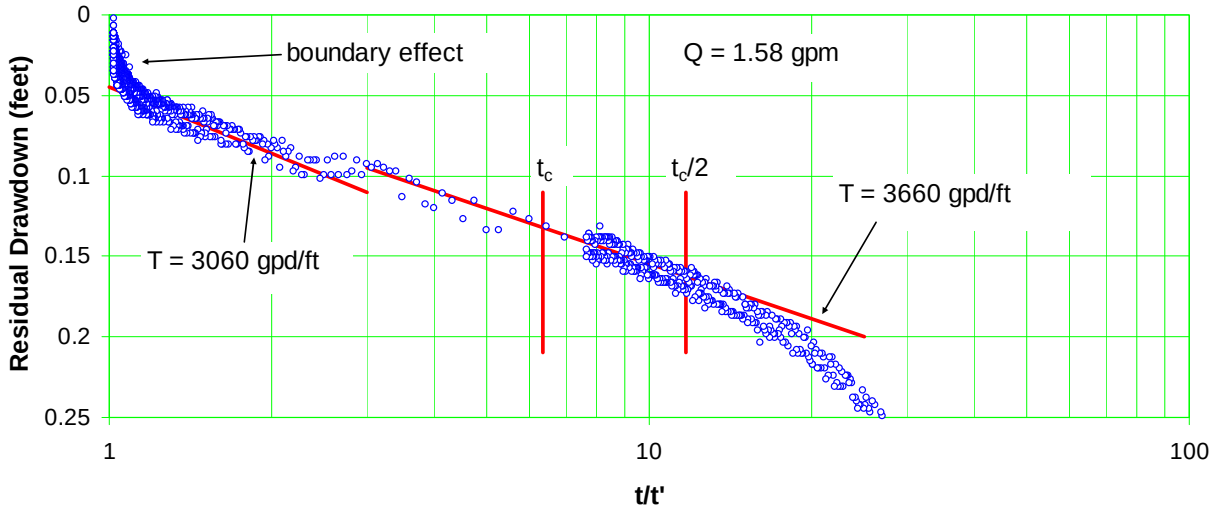


Figure C-9.2-3 Well TA-53i trial 2 recovery—expanded scale

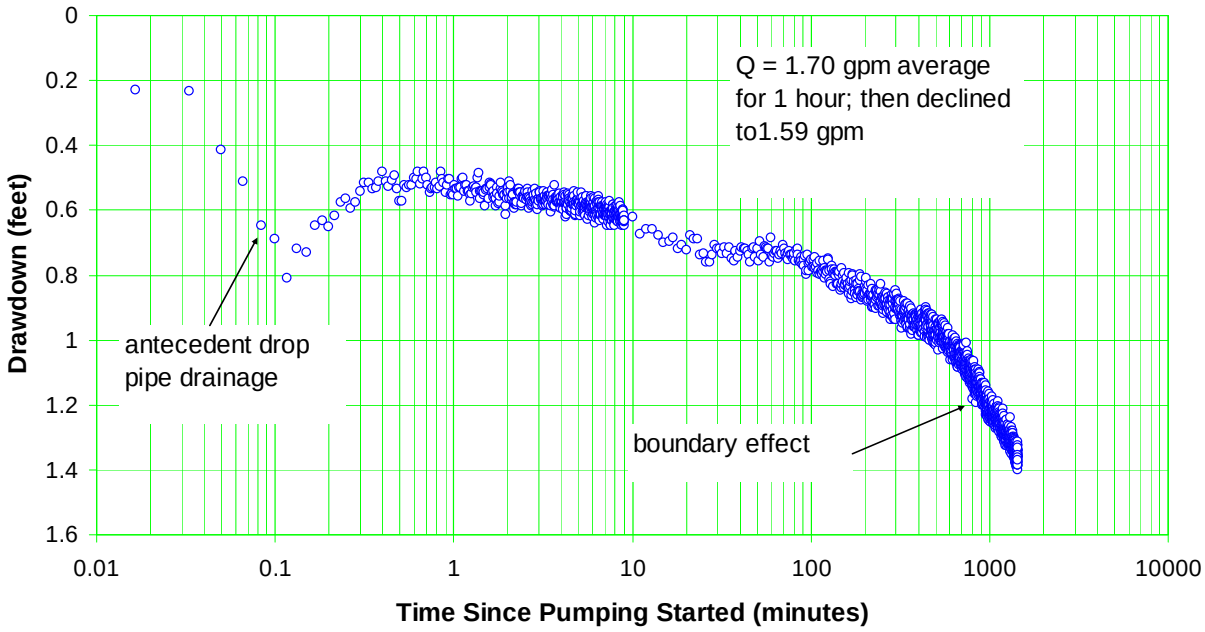


Figure C-9.3-1 Well TA-53i drawdown

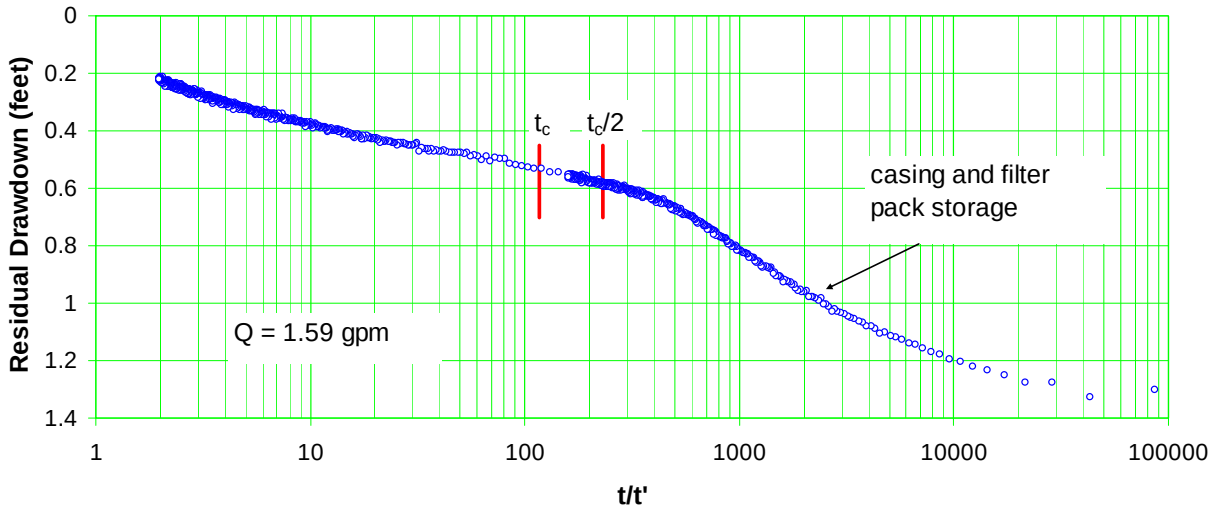


Figure C-9.3-2 Well TA-53i recovery

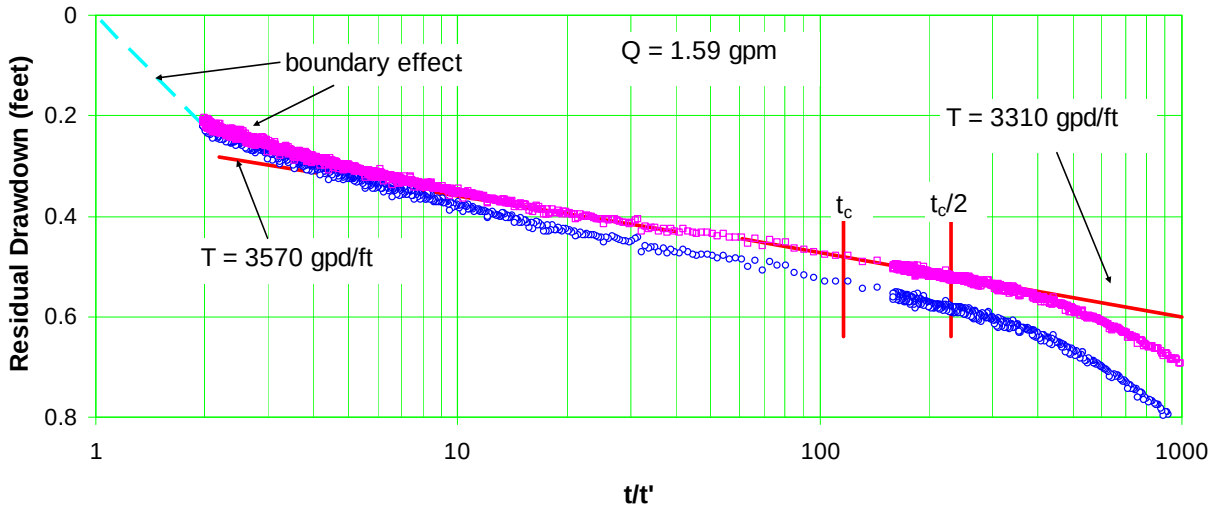


Figure C-9.3-3 Well TA-53i recovery—expanded scale

Table C-9.4-1
Transmissivity Values

Test	Transmissivity (gpd/ft)
Trial 1 Recovery	3860
Trial 2 Drawdown	2980
Trial 2 Early Recovery	3660
Trial 2 Late Recovery	3060
24-H Early Recovery	3310
24-H Late Recovery	3570
Average	3410

Appendix D

Borehole Video Logging
(on DVD included with this document)

Appendix E

Jet West Geophysical Logs
(on CD included with this document)