LA-UR-10-3953
July 2010
EP2010-0272

Completion Report for Intermediate Test Well 2Ar

Los Alamos
NATIONAL LABORATORY
EST. 1943

Prepared by the Environmental Programs Directorate

LA-UR-10-3953
EP2010-0272

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July 2010

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EXECUTIVE SUMMARY

This well completion report describes the drilling, well construction, development, aquifer testing, and dedicated sampling system installation of Los Alamos National Laboratory's (the Laboratory's) perched-intermediate monitoring Test Well 2Ar (TW-2Ar), located in Pueblo Canyon in Los Alamos County, New Mexico. The TW-2Ar monitoring well is intended to provide hydrogeologic and groundwater quality data to achieve specific data quality objectives consistent with the Groundwater Protection Program for the Laboratory, the Compliance Order on Consent, and the New Mexico Environment Department– (NMED-) approved work plan. TW-2Ar was drilled to replace TW-2A, a former intermediate-zone monitoring well that was recently abandoned because it did not meet current well-construction criteria.

The TW-2Ar monitoring well borehole was drilled using dual-rotary air-drilling methods. Potable water was used to cool the drilling tools, evacuate cuttings from the borehole, and suppress the discharge of dust. The TW-2Ar borehole was successfully completed to total depth (TD) using dual-rotary casing-advance drilling methods.

During drilling, a retractable 12-in. casing was advanced to a TD of 157.2 ft below ground surface (bgs). Geologic units encountered while drilling TW-2Ar included, in descending stratigraphic order, alluvium, Otowi Member of the Bandelier Tuff, Guaje Pumice Bed, and Puye Formation sediments.

Well TW-2Ar was completed as a single-screen well, allowing evaluation of water quality and water levels in perched-intermediate aquifer within the upper portion of the Puye Formation. The 10-ft-long screened interval is set from 102.0 to 112.0 ft bgs.

The well was completed in accordance with the NMED-approved well design. The well was thoroughly developed, and target water-quality parameters were met. Aquifer testing indicated that monitoring well TW-2Ar is productive and will perform effectively to meet the planned objectives. A permanent pump and a water-level transducer have been installed in the screened interval in TW-2Ar, and groundwater sampling will be performed as part of the Laboratory's facility-wide groundwater-monitoring program.

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Acronyms and Abbreviations

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
DTW	depth to water
EES-14	Earth and Environmental Sciences Group 14
Eh	oxidation-reduction potential
EP	Environmental Programs Directorate
EPA	Environmental Protection Agency (U.S.)
gpm	gallons per minute
hp	horse power
I.D.	inside diameter
LANL	Los Alamos National Laboratory
µS/cm	microsiemens per centimeter
mV	millivolt
NMED	New Mexico Environment Department
NTU	nephelometric turbidity unit
O.D.	outside diameter
ORP	oxidation-reduction potential
PVC	polyvinyl chloride
Qal	alluvium
Qbo	Otowi Member of the Bandelier Tuff
Qbog	Guaje Pumice Bed of Otowi Member of the Bandelier Tuff
RPF	Records Processing Facility
SOP	standard operating procedure
TA	technical Area
TD	total depth
TOC	total organic carbon
Tpf	Puye Formation
WES-EDA	Waste and Environmental Services Division–Environmental Data and Analysis
TW	test well
WCSF	waste characterization strategy form

1.0 INTRODUCTION

This completion report summarizes site preparation, borehole drilling, well construction, well development, aquifer testing, and dedicated sampling system installation for perched intermediate groundwater monitoring Test Well 2Ar (TW-2Ar) at Los Alamos National Laboratory (the Laboratory). The report is written in accordance with the requirements in Section IV.A.3.e.iv of the Compliance Order on Consent (the Consent Order). The TW-2Ar monitoring well borehole was drilled from February 9 to February 12, 2010, and completed from February 16 to March 4, 2010, for the Laboratory's Environmental Programs (EP) Directorate.

Well TW-2Ar is located in Pueblo Canyon in Los Alamos County, New Mexico (Figure 1.0-1). The purpose of the TW-2Ar well is to replace former well TW-2A, which was plugged and abandoned because of its age.

The primary objective of the drilling activities at TW-2Ar was to drill and install a single-screen perched-intermediate zone monitoring well. Secondary objectives were to establish water levels and flow characteristics, to collect drill-cutting samples, and to conduct borehole geophysical logging.

The TW-2Ar borehole was drilled to a total depth (TD) of 157.2 ft below ground surface (bgs). A monitoring well was then installed with one 10-ft screen interval between 102.0 and 112.0 ft bgs. The depth to water (DTW) after well installation was 98.3 ft bgs on March 5, 2010. 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, sampling system installation, and geodetic surveying. Ongoing activities include 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 TW-2Ar project.

2.0 PRELIMINARY ACTIVITIES

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

2.1 Administrative Preparation

The following documents helped guide the implementation of the scope of work for the TW-2Ar project:

- "Drilling Work Plan for Los Alamos and Pueblo Canyons Groundwater Monitoring Wells" (LANL 2008, 103015)
- "Drilling Plan for Intermediate Well TW-2Ar" (TerranearPMC 2010, 108562)
- "Integrated Work Document for Regional and Intermediate Aquifer Well Drilling" (LANL 2007, 100972)
- "Storm Water Pollution Prevention Plan for SWMUs and AOCs (Sites) and Storm Water Monitoring Plan" (LANL 2006, 092600)

- "Waste Characterization Strategy Form for Test Well 2A(r) Replacement Well in Pueblo Canyon, Perched Intermediate Well Installation and Corehole Drilling" (LANL 2010, 108467)

2.2 Site Preparation

Site preparation and access road improvements were performed by Laboratory personnel before rig mobilization. Safety barriers and signs were installed around the perimeter of the work area. Since a shallow borehole was planned, no cuttings containment pit was constructed. A single 20 yd^3 rolloff bin was used to contain the drill cuttings.

The drill rig, air compressors, trailers, and support vehicles were mobilized to the drill site on February 8, 2010. Staging of alternative drilling tools and construction materials occurred at the Pajarito Road lay-down yard. Potable water was obtained from a fire hydrant on East Jemez Rd.

3.0 DRILLING ACTIVITIES

This section describes the drilling approach and provides a chronological summary of field activities conducted at monitoring well TW-2Ar.

3.1 Drilling Approach

The drilling method and selection of equipment and drill-casing sizes for the TW-2Ar monitoring well were designed to retain the ability to investigate and case off perched groundwater above the target perched water zone. Further, the drilling approach ensured that a sufficiently sized drill casing was used to meet the required 2-in.-minimum annular thickness of the filter pack around a 5.0-in.-outside diameter (O.D.) well.

Dual-rotary air-drilling methods using a Foremost DR-24 drill rig were employed to drill the TW-2Ar borehole. Dual-rotary drilling has the advantage of simultaneously advancing and casing the borehole. The Foremost DR-24 drill rig was equipped with conventional drilling rods, tricone bits, a deck-mounted 900 ft^3/min air compressor, and general drilling equipment. Auxiliary equipment included one Ingersoll Rand 1170 ft^3/min trailer-mounted air compressor. A53 grade B flush-welded mild carbon-steel casing (12-in.-inside diameter [I.D.]) was used for the TW-2Ar project.

The dual-rotary technique at TW-2Ar used filtered compressed air and fluid-assisted air to evacuate cuttings from the borehole during drilling. Only potable water was used as an additional drilling fluid to cool the bit and help lift cuttings while the TW-2Ar borehole was drilled. Total amounts of potable water introduced into the borehole are presented in Table 3.1-1.

3.2 Chronological Drilling Activities for the TW-2Ar Well

Drilling equipment and supplies to the TW-2Ar drill site were mobilized on February 8, 2010. Decontamination of the equipment and tooling was performed before mobilization to the site. On February 9, following on-site equipment inspections, the monitoring well borehole was initiated at 1446 h using dual-rotary methods with 12-in. drill casing and an 11.5-in. tricone bit.

Drilling and advancing 12-in. casing proceeded rapidly through canyon-bottom alluvium, the Otowi Member of the Bandelier Tuff, the Guaje Pumice Bed, and into the top of Puye Formation sediments. On February 11, drilling proceeded open-hole from 92.5 to 138.5 ft bgs. Video and natural gamma ray logs were run the same afternoon to document conditions in the open portion of the borehole.

On February 12, drilling with the tricone bit continued to 157.2 ft bgs. The 12-in. drill casing was advanced to 156.5 ft bgs, and the casing shoe was cut off at 150.0 ft bgs in preparation for well construction.

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

4.0 SAMPLING ACTIVITIES

This section describes the cuttings and groundwater sampling activities for monitoring well TW-2Ar. All sampling activities were conducted in accordance with applicable quality procedures.

4.1 Cuttings Sampling

Cuttings samples were collected from the TW-2Ar monitoring well borehole at 5-ft intervals from ground surface to the TD of 157.2 ft bgs. At each interval, approximately 500 mL of bulk cuttings were collected by the site geologist from the drilling discharge cyclone, placed in resealable plastic bags, labeled, and archived in core boxes. Radiation control technicians screened the cuttings before they were removed from the site. All screening measurements were within the range of background values. The core boxes were delivered to the Laboratory's archive at the conclusion of drilling activities.

The stratigraphy encountered at TW-2Ar is summarized in section 5.1, and borehole lithology is detailed in Appendix A.

4.2 Water Sampling

No groundwater-screening samples were collected during the drilling of the TW-2Ar borehole.

One groundwater-screening sample was collected during well development from the development pump's discharge line. The development screening sample was analyzed for total organic carbon (TOC). Table 4.2-1 lists information regarding the screening sample collected during well development.

Groundwater characterization samples will be collected from the completed well in accordance with the Consent Order. For the first year, the samples will be analyzed for the full suite of constituents, including radioactive elements; anions/cations; general inorganic chemicals; volatile and semivolatile organic compounds; and stable isotopes of hydrogen, nitrogen, and oxygen. The analytical results will be included in the appropriate periodic monitoring reports issued by the Laboratory. After the first year, the analytical suite and sample frequency at TW-2Ar will be evaluated and presented in the annual Interim Facility-Wide Groundwater Monitoring Plan.

5.0 GEOLOGY AND HYDROGEOLOGY

A brief description of the geologic and hydrogeologic features encountered at TW-2Ar is presented below. The Laboratory's geology task leader and project site geologists examined cuttings and geophysical logs to determine geologic contacts and hydrogeologic conditions. Drilling observations, video logging, water-level measurements, and geophysical logs were used to characterize groundwater occurrences encountered at TW-2Ar.

5.1 Stratigraphy

Stratigraphic units for the TW-2Ar borehole are presented below in order of youngest to oldest geologic occurrence. Lithologic descriptions are based on microscopic analysis of drill cuttings samples collected from the discharge cyclone. Cuttings and borehole geophysical logs were used to identify unit contacts. Figure 5.1-1 illustrates the stratigraphy at TW-2Ar. A detailed lithologic log is presented in Appendix A.

Quaternary Alluvium, Qal (0–11 ft bgs)

Quaternary alluvium consisting of unconsolidated, poorly sorted fine to coarse sand and fragmented to rounded pebbles of dark volcanic lithics and light brown pumice-rich tuff was encountered from 0 to 11 ft bgs.

Otowi Member of the Bandelier Tuff, Qbo (11–40 ft bgs)

The Otowi Member of the Bandelier Tuff is present in TW-2Ar from 11 to 40 ft bgs and is estimated to be 29 ft thick. The Otowi Member is a poorly welded ash-flow tuff that is pumiceous and lithic-rich. Abundant pumice lapilli are pale brown to brown, glassy, and quartz- and sanidine-phyric. Locally abundant volcanic lithic fragments (up to 35 mm in diameter) are of intermediate volcanic composition and include dacite and andesite.

Guaje Pumice Bed of the Otowi Member of the Bandelier Tuff, Qbog (40–65 ft bgs)

The Guaje Pumice Bed occurs from 40 to 65 ft bgs and is estimated to be 25 ft thick. The pinkish-gray to light brown nonwelded tuffaceous sediment contains mostly pumice lapilli that are quartz-phenocryst–bearing, with trace occurrences of small volcanic lithic fragments.

Puye Formation, Tpf (65–157.2 ft bgs)

Puye Formation volcaniclastic sediments were encountered from 65 ft bgs to the borehole TD at 157.2 ft bgs. This unit has a minimum thickness of 92 ft and contains mostly medium to very coarse sands and gravels, traces of silt and clay, and subrounded to angular lithics of dacite, rhyodacite, and andesite.

5.2 Groundwater

The video log on February 11 recorded water trickling down the borehole wall between approximately 104 and 120 ft bgs. No other indications of perceptible groundwater were noted during drilling to TD. After TD was reached, the depth to water was approximately 156.3 ft bgs (approximately 1 ft above TD) on February 13 before the well was installed.

6.0 BOREHOLE LOGGING

Three video logs and a gamma ray log were collected by Laboratory personnel during the TW-2Ar drilling project using Laboratory-owned equipment. A summary of video and geophysical logging runs is presented in Table 6.0-1.

6.1 Video Logging

A video run was made in the TW-2Ar borehole from ground surface to 138.5 ft bgs on February 11. On February 25, a second video run was made inside the TW-2Ar well casing after the well had been installed and the filter pack and fine sand collar had been set. The video showed approximately 1 ft of water at the bottom of the well but no water entering the well screen.

The video camera was run again on February 28 to document water entering the borehole after the well casing, screen, and annular fill materials had been removed from the borehole.

The video logs are summarized in Table 6.0-1, and the February 11 log is presented in Appendix B on a DVD included with this document.

6.2 Geophysical Logging

A natural gamma ray survey was run in the borehole on February 11 to document conditions in the open portion of the borehole. Logging data are presented in Appendix D on CD included with this document.

7.0 WELL INSTALLATION TW-2Ar MONITORING WELL

The TW-2Ar well was installed between February 16 and March 4, 2010.

7.1 Well Design

The TW-2Ar well was designed in accordance with the requirements of the Consent Order. NMED approved the final well design before it was installed. The well was originally designed with a single screened interval between 112.0 and 122.0 ft bgs to monitor perched groundwater quality and water levels in the Puye Formation. The well design was changed because groundwater was not encountered at that depth during well construction. The well screen interval was raised 10 ft, and the well was constructed with the screened interval between 102.0 and 112.0 ft bgs.

7.2 Well Construction

TW-2Ar was constructed of 4.5-in.-I.D./5.0-in.-O.D., type A304 stainless-steel casing fabricated to American Society for Testing and Materials (ASTM) A312 standards. External couplings, also of type A304 stainless steel fabricated to ASTM A312 standards, were used to connect individual casing and screen joints. The well screen was a 10-ft length of 4.88-in.-I.D., rod-based, 0.020-in., wire-wrapped well screen. The coupled union between the threaded pieces was on average 0.7 ft long. The casing and screen were factory cleaned as well as steam-cleaned on-site. During well construction, 2 in.-I.D. steel threaded/coupled tremie pipe string (decontaminated before use) was used to deliver backfill and annular fill materials. The placement of annular materials typically had two components: installing materials and retracting the drill casing, combined with raising the tremie pipe. As each section of drill casing was cut off the string, it was picked up and laid down. During this part of the process, the well casing was hung on a wireline, while the drill casing was supported by a pair of rings and slips. A short length of 12-in. drill casing and shoe (6.5 ft long) remains in the borehole near TD. This 12-in. casing stub was encased in bentonite.

Decontamination of the stainless-steel well casing, screens, and tremie pipe, along with mobilization of the Pulstar rig and initial well construction materials to the site, took place on February 16, 2010. From February 16 to February 18, 30.6 ft^3 of 3/8-in. bentonite chips was installed in the borehole, bringing the TD to 126.1 ft bgs. On February 19, at 1630 h, the well casing was started into the borehole and was landed at 126.5 ft bgs that same afternoon. The 10-ft-long screened interval was set from 112.5 to 122.5 ft bgs. A 1.9-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 2.0 ft above and below the screen.

On February 20, the filter pack for the screened interval was placed from 107.9 to 126.5 ft bgs using a total of 13.0 ft^3 of 10/20 silica sand. DTW was measured in the partially constructed well at 121.9 ft bgs on February 21. From February 22 to February 23, swabbing was performed while approximately 2500 gal. of water was simultaneously added. A 2.2-ft-thick fine-sand transition collar (105.7 to 107.9 ft bgs) was added on top of the filter pack on February 23 using 1.5 ft^3 of 20/40 silica sand. DTW was measured on February 24 at 121.6 ft bgs. A video log on February 25 showed DTW at 121.5 ft bgs (approximately 1 ft above the bottom of the well screen). The well was bailed on February 26 to evaluate recharge. Three trips with a steel bailer removed approximately 4 gal. of water and completely dewatered the well. DTW before bailing was 122.3 ft bgs. The static water level recovered to 122.3 ft bgs within 5 h.

Because no water was entering the well screen, the decision was made to remove the well casing and screen from the borehole to reset the well screen at a more productive depth. On February 27, the well casing was removed from the borehole, and a sand bailer was run in the borehole to remove the fine sand transition collar and the filter pack. After bailing activities, the top of the backfill material was measured at 124.7 ft bgs. The following day, DTW was measured at 101.2 ft bgs. The borehole was then bailed (approximately 250 gal. of water was removed), and Laboratory personnel conducted a video logging run. The video showed water trickling into the borehole between approximately 110 and 118 ft bgs and the water level at approximately 119 ft bgs. As a result of these observations, it was decided to reset the well with the well screen between 102 and 112 ft bgs.

On March 1, 10.1 ft^3 of 3/8-in. bentonite chips was installed in the borehole bringing TD up to 114.4 ft bgs. The well casing was reinstalled in the borehole on March 2, and the screened interval was set from 102 to 112 ft bgs (approximately 10 ft higher than the original well design). Figure 7.2-1 presents an as-built schematic showing construction details for the completed well.

On March 3, the filter pack for the screened interval was placed from 97.2 to 114.4 ft bgs using 15.8 ft^3 of 10/20 silica sand. The filter pack was surged to promote compaction. This volume exceeded the calculated volume of 12.3 ft^3 by approximately 28% and is likely from some filter sand being pushed into formation voids or washouts and compaction of the filter pack during surging activities. The upper fine-sand collar was then installed on top of the upper filter pack from 95.0 to 97.2 ft bgs using 2.0 ft^3 of 20/40 silica sand. From March 3 to March 4, the upper bentonite seal was installed from 50.0 to 95.0 ft bgs using 30.2 ft^3 of 3/8-in bentonite chips.

On March 4, the surface seal was installed from 3.0 to 50.0 ft bgs using 50.0 ft^3 of Portland Type I/II/V cement. This volume exceeded the calculated volume of 33.4 ft^3 by approximately 50% and is likely from the loss of liquid grout to the dry formation. Installation of the surface seal marked the end of well construction per NMED standards at March 4 at 1250 h. Table 7.2-1 itemizes the types and volumes of all materials used during well construction.

Operationally, well construction proceeded smoothly, 12 h/d, 7 d/wk, from February 19 to March 4.

8.0 POSTINSTALLATION ACTIVITIES

After well installation at TW-2Ar, the well was developed, and an aquifer test was conducted. The wellhead and surface pad were constructed, a geodetic survey was performed, and a dedicated sampling system was installed. Site restoration activities will be completed following the final disposition of contained drill cuttings and groundwater, per the NMED-approved waste-disposal decision trees.

Approximately 2451 gal. of water was removed during development and aquifer testing.

8.1 Well Development

Well development was conducted from March 5 to 8, 2010. 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 improved visibly. Final development was accomplished using a submersible pump. Approximately 1276 gal. of groundwater was purged at TW-2Ar during well development activities. Table 8.1-1 shows the purge volumes and field parameters measured during well development and aquifer testing.

The swabbing tool used was a 3.5-in.-O.D., 1-in.-thick nylon disc attached to a weighted steel rod. The wireline conveyed tool was repeatedly drawn across the screened interval, causing a surging action across the screen/filter pack. The bailing tool used was a 4.0-in.-O.D. by 20.0-ft stainless-steel bailer with a total capacity of 10 gal. The tool was lowered by wireline and repeatedly filled, withdrawn from hole, and dumped into a water-storage tank. After bailing was completed, a 1.5-horse power (hp), 4-in.-Grundfos submersible pump was installed in the well for the final stage of well development.

During the pumping stage of well development, turbidity, temperature, pH, dissolved oxygen (DO), oxidation-reduction potential (ORP), and specific conductance parameters were measured. In addition, one water sample was collected for TOC analysis. The required values for TOC and turbidity to determine adequate well development are less than 2.0 parts per million and less than 5 nephelometric turbidity units (NTUs), respectively. The target values for both parameters were achieved at TW-2Ar.

8.1.1 Well Development Field Parameters

Field parameters were measured during well development at well TW-2Ar by collecting aliquots of groundwater from the discharge pipe using a flow-through cell.

During development, pH and temperature varied from 6.8 to 7.0 and from 15.55 to 18.29°C, respectively. Concentrations of DO ranged from 6.70 to 7.36 mg/L. Corrected oxidation-reduction potential (Eh) values varied from 315.7 to 225.5 millivolts (mV). Specific conductance varied from 228 to 237 microsiemens per centimeter (µS/cm), and turbidity values varied from 3.12 to 1.14 NTU.

8.2 Aquifer Testing

An aquifer pumping test was conducted at TW-2Ar from April 6 to 9, 2010. Initially, a short-duration pumping test was performed. Then a 24-h constant rate test, followed by a 24-h recovery period, completed the testing. A 1.5-hp Grundfos submersible pump was used during testing. Approximately 1175 gal. of groundwater was purged at TW-2Ar during aquifer-testing activities.

Turbidity, temperature, pH, DO, ORP, and specific conductance parameters were measured during the 24-h test. Table 8.1-1 presents the field water-quality parameters and purge volumes measured during aquifer testing. The results of the TW-2Ar aquifer test are presented in Appendix C.

8.3 Dedicated Sampling System Installation

The dedicated sampling system for TW-2Ar was installed on May 2, 2010. The system utilizes a single 0.5-hp., 3-in.-O.D. environmentally retrofitted Grundfos Redi-flow submersible pump housed in a stainless-steel pump shroud. Pump riser pipe consists of threaded and coupled passivated 1-in.-I.D. stainless steel. Two 1-in.-I.D. schedule 80 polyvinyl chloride (PVC) tubes are banded to the pump riser for dedicated transducer and manual water-level measurements. The PVC tubes are equipped with a 6-in. section of 0.010-in. slotted screen and a threaded end cap at the bottom of the tubes. An In-Situ Level Troll 500 transducer was installed in one of the PVC tubes to monitor water levels in the screened interval.

Sampling system component details for TW-2Ar 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 TW-2Ar wellhead. The concrete pad was slightly elevated above the ground surface and crowned to promote runoff. The pad will provide long-term structural integrity for the well. A brass survey pin was embedded in the northwest corner of the pad. A 10-in.-I.D. steel protective casing with a locking lid was installed around the stainless-steel well riser. A total of four bollards, painted yellow for visibility, are set at the outside edges of the pad to protect the well from traffic. All 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 May 14, 2010 (Table 8.5-1). The survey data conform to Laboratory Information Architecture project standards IA-CB02, “GIS Horizontal Spatial Reference System,” and IA-D802, “Geospatial Positioning Accuracy Standard for A/E/C and Facility Management.” All coordinates are relative to New Mexico State Plane Coordinate System Central Zone (NAD 83); elevation is expressed in ft above mean sea level (amsl) using the National Geodetic Vertical Datum of 1929. Survey points include ground-surface elevation near the concrete pad, the top of the brass pin in the concrete pad, the top of the well casing, and the top of the protective casing for the TW-2Ar monitoring well.

8.6 Waste Management and Site Restoration

Waste generated from the TW-2Ar project includes drilling fluids, purged groundwater, drill cuttings, decontamination water, and contact waste. A summary of the waste characterization samples collected during drilling, construction, and development of the TW-2Ar well is presented in Table 8.6-1.

All waste streams produced during drilling and development activities were sampled in accordance with the “Waste Characterization Strategy Form for Test Well 2A(r) Replacement Well in Pueblo Canyon, Perched Intermediate Well Installation and Corehole Drilling” (LANL 2010, 108467).

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

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

Site-restoration activities will include removing drilling fluids and cuttings from the rolloff bin 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 TW-2Ar were performed as specified in the “Drilling Plan for Intermediate Well TW-2Ar” (TerranearPMC 2010, 108562).

10.0 ACKNOWLEDGMENTS

Boart Longyear drilled and installed the TW-2Ar monitoring well.

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

LANL personnel ran downhole video and geophysical logging equipment.

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

11.0 REFERENCES AND MAP DATA SOURCES

11.1 References

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

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

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

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

LANL (Los Alamos National Laboratory), May 2008. "Drilling Work Plan for Los Alamos and Pueblo Canyons Groundwater Monitoring Wells," Los Alamos National Laboratory document LA-UR-08-2738, Los Alamos, New Mexico. (LANL 2008, 103015)

LANL (Los Alamos National Laboratory), January 25, 2010. "Waste Characterization Strategy Form for Test Well 2A(r) Replacement Well in Pueblo Canyon, Perched Intermediate Well Installation and Corehole Drilling," Los Alamos, New Mexico. (LANL 2010, 108467)

TerranearPMC, January 2010. "Drilling Plan for Intermediate Well TW-2A(r)," plan prepared for Los Alamos National Laboratory, Los Alamos, New Mexico. (TerranearPMC 2010, 108562)

11.2 Map Data Sources

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

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

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

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

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

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

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

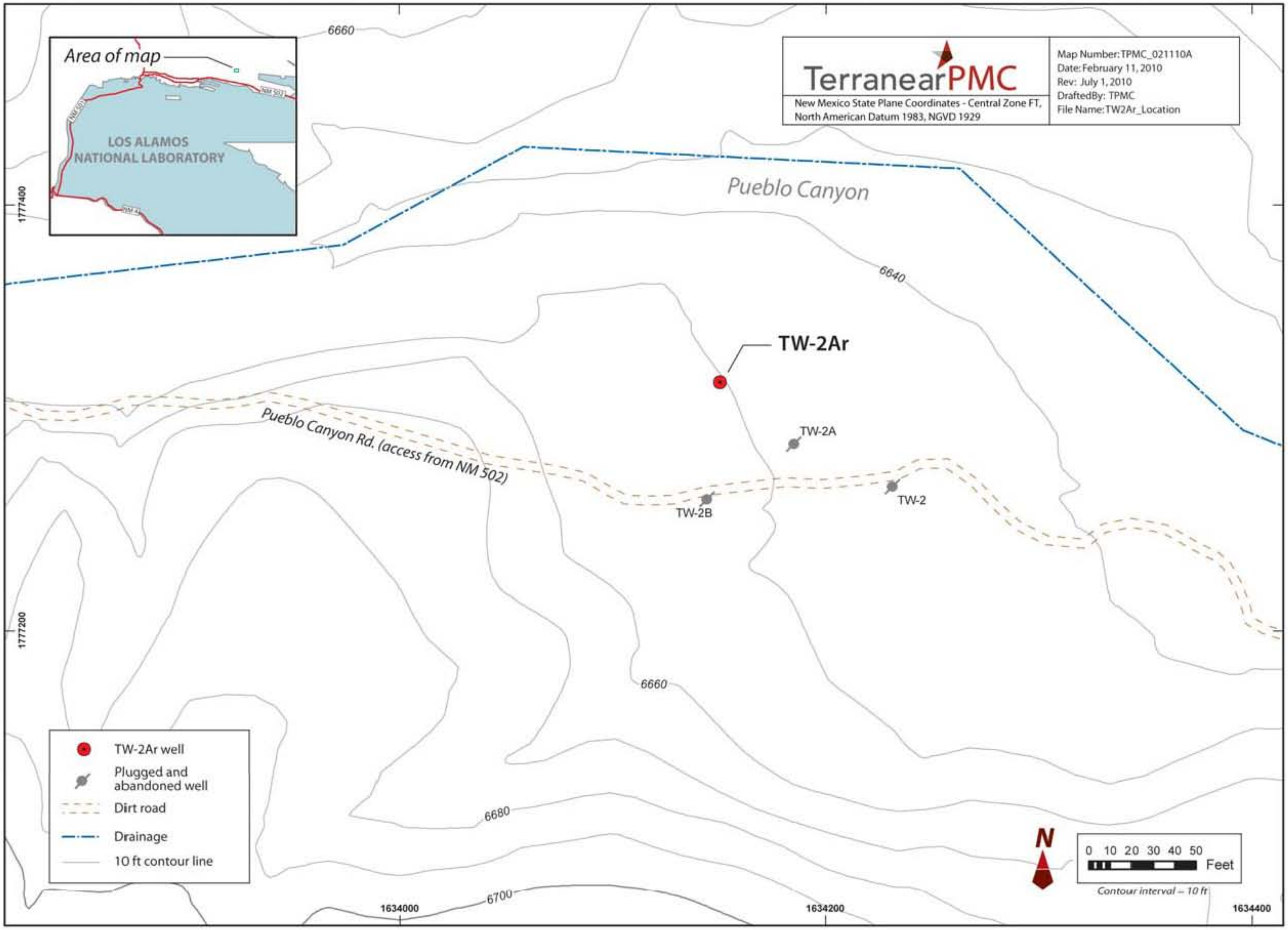

Figure 1.0-1 Location of monitoring well TW-2Ar

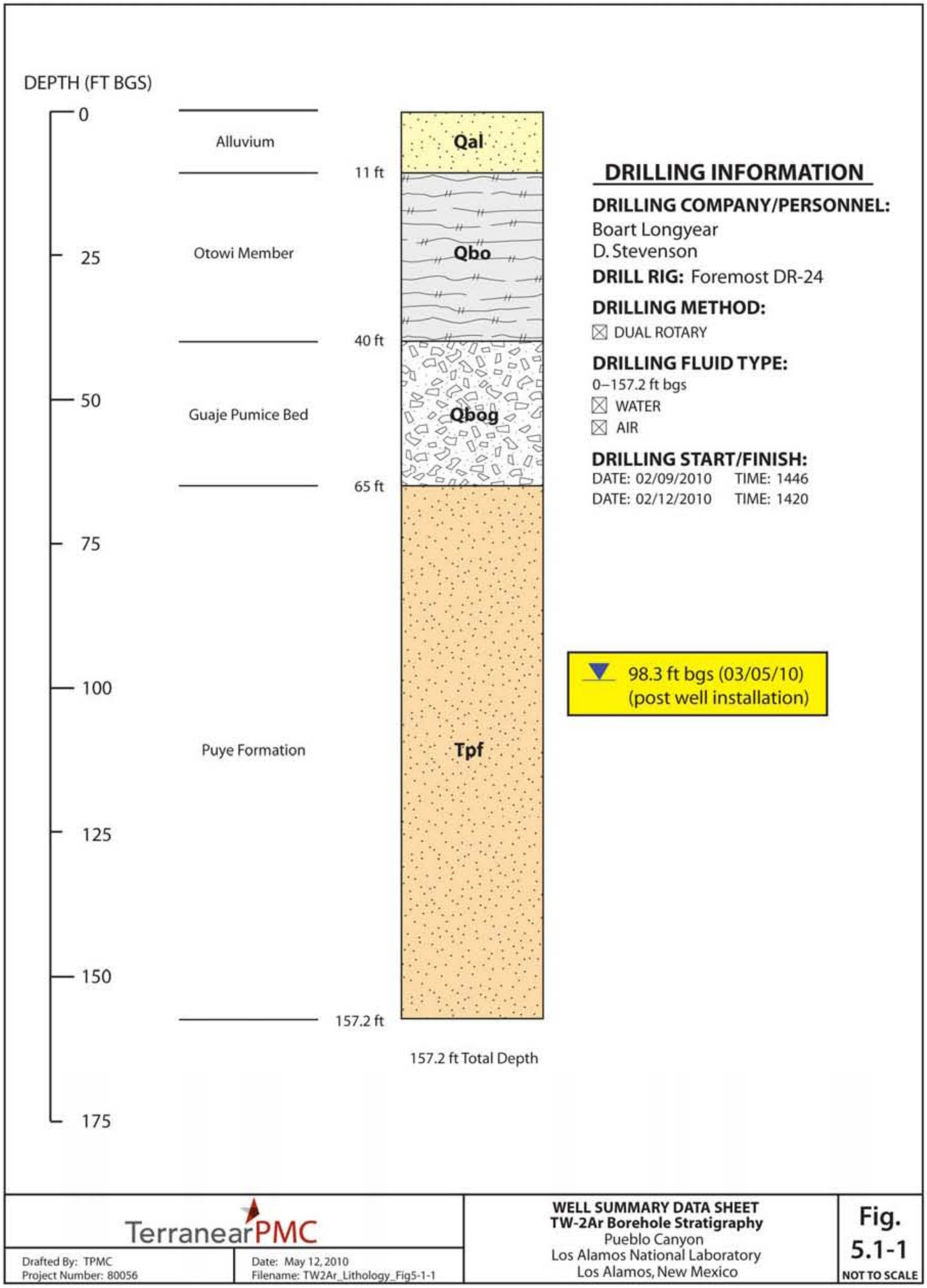

Figure 5.1-1 Monitoring well TW-2Ar borehole stratigraphy

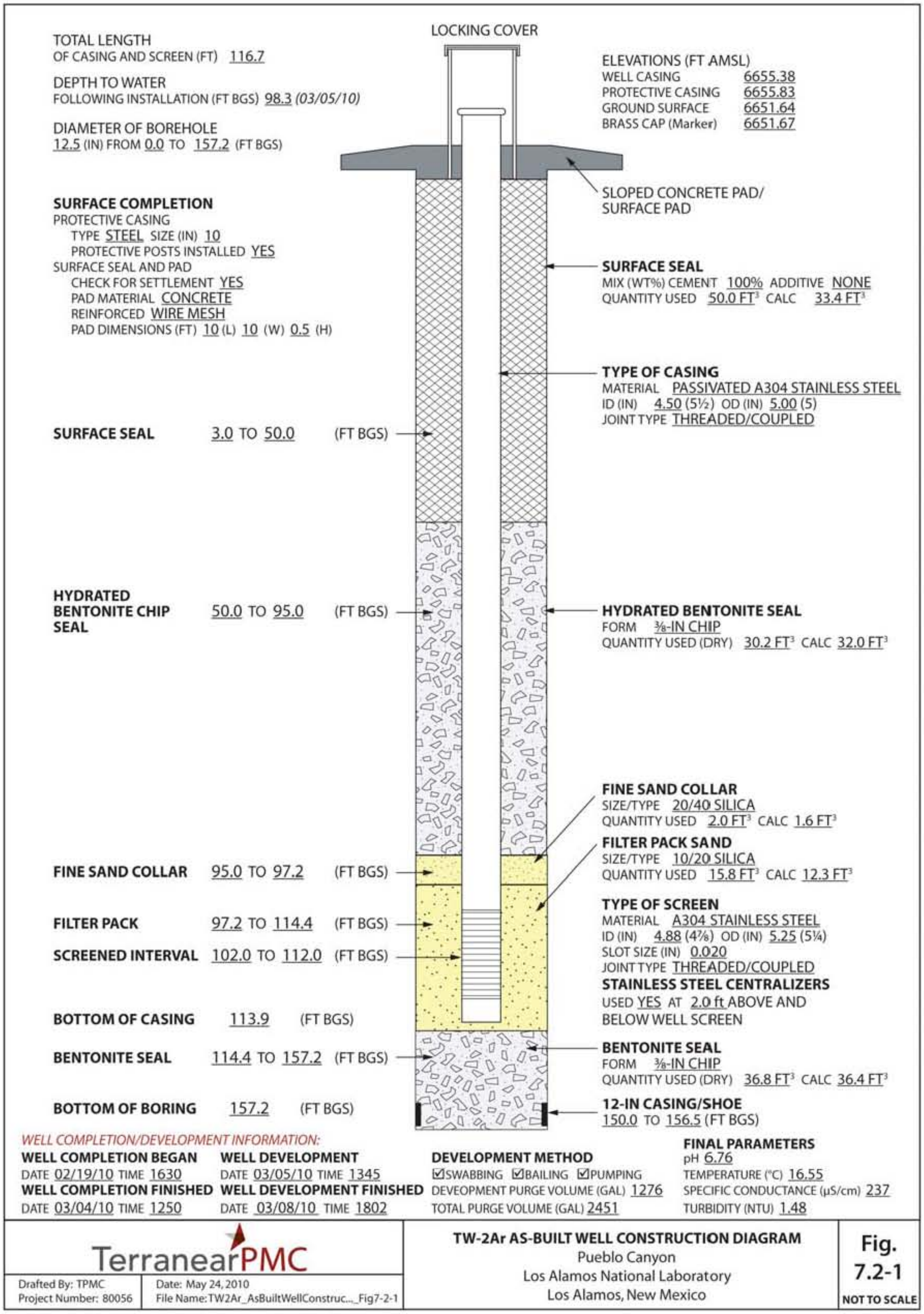

Figure 7.2-1 Monitoring well TW-2Ar as-built well construction diagram

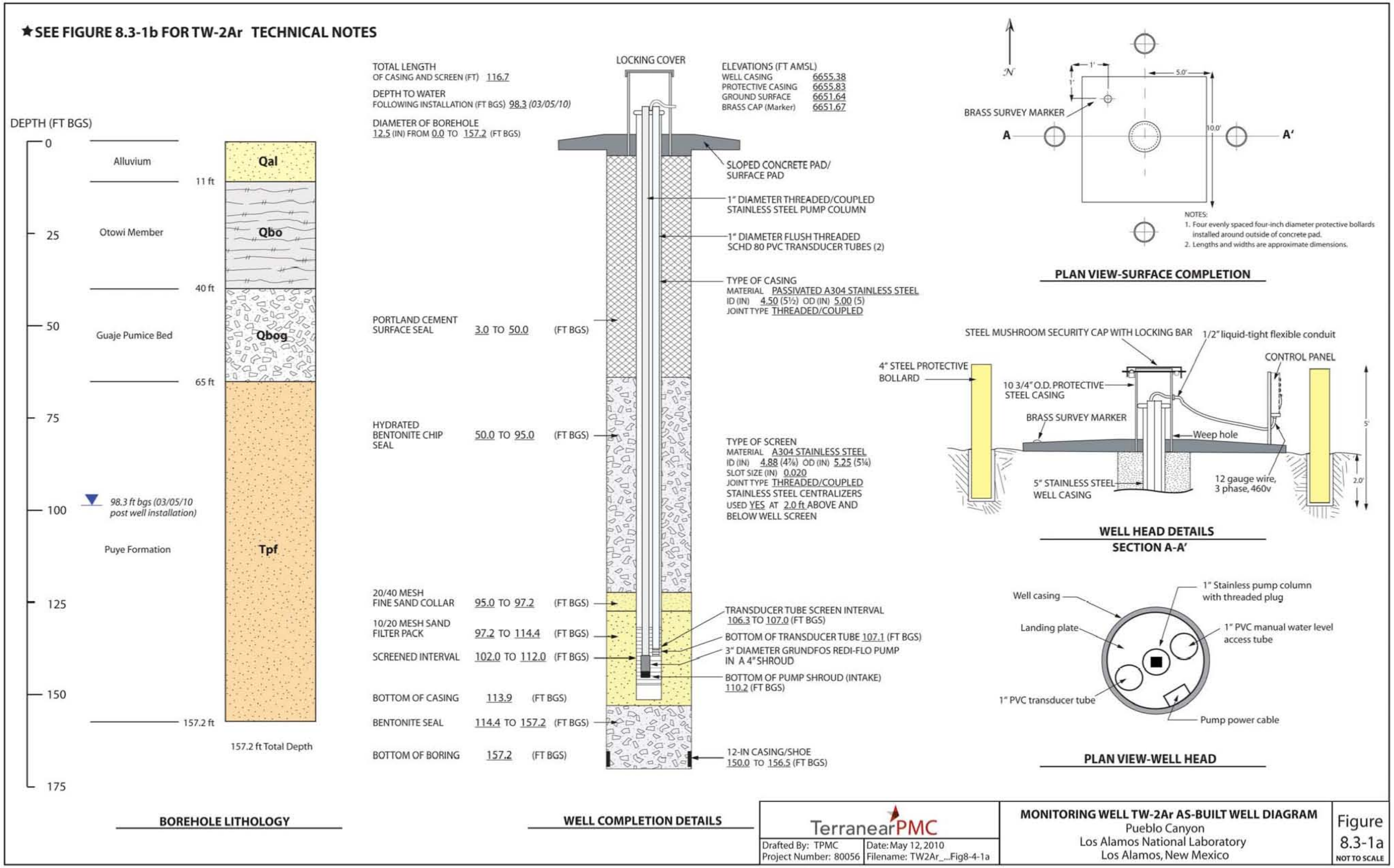

Figure 8.3-1a As-built schematic for monitoring well TW-2Ar

TW-2Ar TECHNICAL NOTES:

SURVEY INFORMATION*

Brass Marker

Northing:	1777349.11 ft
Easting:	1634129.90 ft
Elevation:	6651.67 ft AMSL

Well Casing (top of stainless steel)

Northing:	1777345.27 ft
Easting:	1634133.79 ft
Elevation:	6655.38 ft AMSL

BOREHOLE GEOPHYSICAL LOGS

LANL: video, natural gamma ray

DRILLING INFORMATION

Drilling Company
Boart Longyear

Drill Rig
Foremost DR-24HD

Drilling Methods
Dual Rotary
Fluid-assisted air rotary

Drilling Fluids
Air, potable water

MILESTONE DATES

Drilling

Start:	02/09/2010
Finished:	02/12/2010

Well Completion

Start:	02/19/2010
Finished:	03/04/2010

Well Development

Start:	03/05/2010
Finished:	03/08/2010

WELL DEVELOPMENT

Development Methods
Performed swabbing, bailing, and pumping
Total Volume Purged: 1276 gallons

Parameter Measurements (Final)

pH:	6.8
Temperature:	16.55°C
Specific Conductance:	237 µS/cm
Turbidity:	1.48 NTU

AQUIFER TESTING

Constant Rate Pumping Test

Water Produced:	1175 gallons
Average Flow Rate:	0.75 gpm
Performed on:	04/06–09/2010

DEDICATED SAMPLING SYSTEM

Pump
Make: Grundfos Redi-Flo
Model: PI 0948 10SQE-100NE
10 U.S. gpm, intake (bottom shroud) at 110.2 ft bgs
Environmental Retrofit

Motor
Make: Grundfos
Model: B P10948
0.5 hp, single phase 240 v/60 Hz

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

Transducer Tubes
2 ×1-in. flush threaded schedule 80 PVC tubing

Transducer
Make: In-Situ
Model: Level Troll 500
S/N: 164533

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

TerranearPMC

Drafted By: TPMC
Project Number: 80056

Date: July 1, 2010
Filename: TW2Ar_TechnicalNotes_Fig8-3-1b

TW-2Ar TECHNICAL NOTES
Pueblo Canyon
Los Alamos National Laboratory
Los Alamos, New Mexico

Figure 8.3-1b
NOT TO SCALE

Figure 8.3-1b As-built technical notes for monitoring well TW-2Ar

Table 3.1-1
Fluid Quantities Used during
TW-2Ar Drilling and Well Construction

Date	Water (gal.)	Cumulative Water (gal.)
Drilling		
2/9/10	200	200
2/10/10	400	600
2/11/10	400	1000
2/12/10	600	1600
Well Construction		
2/16/10	30	1630
2/17/10	40	1670
2/18/10	12	1682
2/19/10	50	1732
2/20/10	70	1802
2/22/10	1500	3302
2/23/10	1000	4302
3/3/10	135	4437
3/4/10	244	4681
Total Water Volume (gal.)		
TW-2Ar	4681	

Note: No foam additives used during drilling.

Table 4.2-1
Groundwater Screening Sample Collected during Well Development of TW-2Ar

Location ID	Sample ID	Date Collected	Collection Depth (ft bgs)	Sample Type	Analysis
TW-2Ar	CAPU-10-14152	3/8/10	112	Groundwater, pumped	TOC

Table 6.0-1
TW-2Ar Logging Runs

Date	Type of Log	Depth (ft bgs)	Description
2/11/10	Video, natural gamma	Surface to 138.5	LANL personnel ran video and natural gamma logs after drilling and advancing 12-in. casing to 92.5 ft bgs (open hole from 92.5 to 138.5 ft bgs).
2/25/10	Video	Surface to 126.5	LANL personnel ran a video log inside the well casing after first installation of well screen and casing.
2/28/10	Video	Surface to 119.0	LANL personnel ran a video log in the open borehole from 102.0 to 119.0 ft bgs after removing the well screen and casing from the borehole.

Table 7.2-1
TW-2Ar Monitoring Well Annular Fill Materials

Material	Volume
Surface seal: cement slurry	50.0 ft^3
Hydrated bentonite seal: bentonite chips	30.2 ft^3
Fine sand collar: 20/40 silica sand	2.0 ft^3
Filter pack: 10/20 silica sand	15.8 ft^3
Backfill: bentonite chips	36.8 ft^3

Table 8.1-1
Purge Volumes and Field Water Quality Parameters during Development and Aquifer Testing at TW-2Ar

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								
3/5/10	n/r[b], bailing						165	165
3/6/10	n/r, bailing						370	535
3/7/10	n/r, pumping sump						150	685
3/8/10	6.8	16.97	7.23	106.8, 315.7	228	2.32	100	785
	6.9	17.38	7.31	71.5, 280.4	232	1.60	26	811
	6.8	17.98	7.36	44.1, 248.0	237	2.39	26	837
	6.8	18.29	6.77	35.4, 239.3	234	2.23	30	867
	6.8	18.16	7.28	36.4, 240.3	228	1.93	27	894
	6.8	17.86	6.81	33.9, 237.8	236	1.60	54	948
	6.8	17.44	6.70	29.2, 238.1	237	3.12	54	1002
	6.8	17.65	6.74	21.6, 225.5	237	1.23	54	1056
	6.8	17.94	6.89	27.3, 231.2	237	1.14	54	1110
	7.0	17.84	6.83	55.8, 259.7	233	2.29	56	1166
	6.8	15.89	6.83	56.5, 265.4	233	1.24	54	1220
	6.8	16.55	6.81	31.4, 240.3	237	1.48	56	1276

Table 8.1-1 (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 Pump Test								
4/6/10	n/r, pumping, mini-test						84	1360
4/8/10–4/9/10	7.0	18.58	7.10	35.9, 239.8	702	2.4	90	1450
	7.0	18.20	7.13	17.3, 221.2	703	0.2	39	1489
	7.0	17.48	7.32	11.7, 220.6	524	0.1	47	1536
	7.1	17.70	7.25	–0.8, 203.1	695	0.2	36	1572
	7.1	18.65	7.02	–9.9, 194.0	709	0.0	36	1608
	7.0	17.88	6.90	–0.3, 203.6	703	0.0	46	1654
	7.0	19.07	6.85	–6.6, 197.3	708	0.0	46	1700
	7.0	19.48	6.78	–18.1, 185.8	709	0.0	47	1747
	7.0	19.19	6.68	–16.8, 187.1	694	0.0	47	1794
	7.0	18.86	6.65	–4.8, 199.1	697	0.0	47	1841
	7.0	15.41	6.83	2.3, 211.2	697	0.0	96	1937
	7.0	15.53	6.86	1.0, 209.9	706	0.0	47	1984
	7.0	16.29	6.72	1.1, 210.0	693	0.1	46	2030
	7.0	15.07	6.62	7.7, 216.6	702	0.0	187	2217
	7.0	14.82	6.76	11.3, 220.2	703	0.2	187	2404
	n/r, pumped before pump shut off						47	2451

[a] Eh (mV) is calculated from an Ag/AgCl saturated KCl electrode filling solution at 20.0 by adding temperature-sensitive correction factor of 203.9 mV.

[b] n/r = Not recorded.

Table 8.5-1
TW-2Ar Survey Coordinates

Identification	Northing	Easting	Elevation
TW-2Ar brass cap embedded in pad	1777349.11	1634129.90	6651.67
TW-2Ar ground surface near pad	1777350.04	1634127.73	6651.64
TW-2Ar top of 10-in. protective casing	1777345.28	1634133.77	6655.83
TW-2Ar top of stainless-steel well casing	1777345.27	1634133.79	6655.38

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

Table 8.6-1
Summary of Waste Samples Collected during Drilling and Development of TW-2Ar

Sample ID	Date Collected	Description	Sample Type
n/a*	n/a	Contact waste, use acceptable knowledge from drill cuttings	Solid
02/17/10	WSTPU-10-13243	Drill cuttings	Solid
02/17/10	WSTPU-10-13232	Drilling fluid, filtered	Liquid
02/17/10	WSTPU-10-13231	Drilling fluid, unfiltered	Liquid
02/24/10	WSTPU-10-13398	Decon fluid, unfiltered	Liquid
02/24/10	WSTPU-10-13394	Decon fluid, filtered	Liquid
03/10/10	WSTPU-10-13399	Decon fluid, unfiltered	Liquid
03/10/10	WSTPU-10-13394	Decon fluid, filtered	Liquid
03/09/10	WSTPU-10-13654	Development water, unfiltered	Liquid
03/09/10	WSTPU-10-13653	Development water, filtered	Liquid

*n/a = Not applicable.

Appendix A

TW-2Ar Borehole Lithologic Log

Los Alamos National Laboratory
Borehole Lithologic Log

BOREHOLE IDENTIFICATION (ID): TW-2Ar	**TECHNICAL AREA (TA): NA** Los Alamos County land in Pueblo Canyon.	**PAGE:** 1 of 2
DRILLING COMPANY: Boart Longyear Company	**START DATE:** 2/9/2010 **TIME:** 1446	**END DATE:** 2/12/2010 **TIME:** 1420
DRILLING METHOD: Dual Rotary	**MACHINE**: Foremost DR24-HD	**SAMPLING METHOD:** Grab
GROUND ELEVATION: 6651.64 ft AMSL		**TOTAL DEPTH:** 157.2 ft bgs
DRILLERS: Duane Stevenson	**SITE GEOLOGIST:** L. Rought	

Depth (ft bgs)	Lithology	Lithologic Symbol	Notes
0–5	**ALLUVIUM** Gravel with sand; dark brown (10 YR 3/3); pebbles with 25–30% fine to coarse sand; poorly sorted; fragmented to rounded pebbles to 40 mm diameter of dark volcanic lithics (some crystal-rich) and light brown pumice-rich tuff; tree roots; "earthy" odor of organic matter in soils; rock fragments are strongly weathered, some have iron-oxide (limonite) staining; minor tuff present	Qal	Note: SAA = same as above
5–11	Gravel with sand; dark brown (10 YR 3/3) and pale brown (10 YR 6/3); SAA with 30–35% tuff and pumice fragments to 25 mm diameter; mm-size quartz crystal fragments	Qal	Contact of Qal with the underlying Qbo is 11 ft bgs.
11–15	**OTOWI MEMBER OF THE BANDELIER TUFF** Volcanic tuff; very pale brown (10YR 7/3) to brown (10 YR 5/3) nonwelded to poorly welded; pumice-rich; friable; ashy matrix; 15–20% quartz/sanidine crystals; 15–20% lithics from 0.5–35 mm (dacite/ andesite); 40% vitric pumice/ pumice fragments to 25 mm diameter; vitreous luster; ashy matrix	Qbo	
15–20	Volcanic tuff; SAA	Qbo	
20–25	Volcanic tuff; very pale brown (10YR 7/3) to brown (10 YR 5/3) nonwelded to poorly welded; lithic-rich; 25% ashy matrix; 25–30% quartz/ sanidine crystals; 25–30% pumice fragments with vitreous luster; 25–30% dark colored intermediate volcanic lithics	Qbo	

Borehole ID: TW-2Ar		**TA: TW-2Ar**	**Page:** 2 of 2
Depth (ft bgs)	Lithology	Lithologic Symbol	Notes
25–40	Volcanic tuff; SAA but only 10–15% volcanic lithics present	Qbo	Contact of the Qbo with the underlying Qbog is 40 ft bgs.
40–65	**GUAJE PUMICE BED; BANDELIER TUFF** Ash- and pumice-fall tuff/ tuffaceous deposit; pinkish gray (7.5YR 7/2) to light brown (7.5 YR 6/3); non-welded; mostly pumice lapilli that are quartz phenocryst bearing (pumice fragments); 5% (0.5 mm- 3mm) dark volcanic lithics; pumices have a “fresh” appearance	Qbog	Contact of the Qbog with the underlying Tpf is 65 ft bgs.
65-75	**PUYE FORMATION** Volcaniclastic sediments; gravel with sand (GW); pinkish gray (5 YR 6/2) to reddish gray (5 YR 5/2); pebbles to 20 mm diameter with fine to coarse sand; trace silt/clay; 20% very small pumice fragments; sub-rounded to angular when fragmented; lithics are a variety of intermediate volcanic rocks; including dacite, rhyodacite, andesite	Tpf	Most fines were washed out by drilling fluids (water) Pumice fragments were from overlying Guaje Pumice Bed because of the very long discharge hose.
75–80	Volcaniclastic sediments; SAA, mostly larger lithic fragments, to 20 mm diameter	Tpf	Most fines were washed out by drilling fluids (water)
80–157.2	Volcaniclastic sediments; SAA, mostly mm-size pebbles with medium to very coarse sand; trace silt/clay	Tpf	Most fines were washed out by drilling fluids (water) Bottom of borehole at 1 57.2 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

AMSL = above mean sea level

bgs = below ground surface

ft = feet

SAA = same as above

Qal = Alluvium

Qbo = Otowi Member of the Bandelier Tuff

Qbog = Guaje Pumice Bed

Tpf = Puye Formation

1 mm = 0.039 in

1 in. = 25.4 mm

Appendix B

Borehole Video Logging
(on DVD included with this document)

Appendix C

Aquifer Pumping Test Analysis

C-1.0 INTRODUCTION

This appendix describes the hydraulic analysis of pumping tests conducted in April 2010 at well Test Well 2Ar (TW-2Ar), a shallow perched-zone well located in Pueblo Canyon at Los Alamos National Laboratory (the Laboratory). The tests on TW-2Ar were conducted to evaluate the hydraulic properties of the sediments in which the well is completed.

Testing consisted of a brief step-drawdown test, background water level data collection, and a 24-h constant-rate pumping test. Unlike most of the pumping tests conducted on the Pajarito Plateau (the Plateau), an inflatable packer system was not used in TW-2Ar to minimize the effects of casing storage on the test data. The static water level in TW-2Ar fell within the filter pack, ensuring the observed water-level data would be storage-affected because of drainage and refilling of the filter pack during pumping and recovery. In addition, the static water level was just 4 ft above the top of the well screen, making it likely that the screen would be partially dewatered during pumping, further adding to the potential storage effects.

Conceptual Hydrogeology

Well TW-2Ar is drilled into a shallow perched zone in sediments of the Puye Formation. The well was completed with 10 ft of 5-in. stainless-steel well screen from 102 to 112 ft below ground surface (bgs). The static water level measured on April 6, 2010, was 97.9 ft bgs, 4.1 ft above the top of the well screen. The surface elevation at TW-2Ar was 6651.67 ft above mean sea level (amsl), making the water level elevation 6553.77 ft amsl.

A 3-ft-thick silt zone from 112 to 115 ft bgs was identified as the tight perching layer supporting the saturated zone. (With the borehole open through this zone, it was not possible to saturate the well; however, with the interval plugged, the borehole filled with water.) Therefore, the saturated permeable zone was assumed to be 14.1 ft thick, extending from the static water level at 97.9 ft to the bottom of the well screen at 112 ft bgs. Because of the proximity of the water table to the top of the well screen, the system was analyzed as an unconfined saturated zone. Before the zone was plugged from 112 to 115 ft, water could be seen entering the borehole at a depth of 107.5 ft, suggesting preferential permeability at that depth and a heterogeneous saturated interval.

TW-2Ar Testing

Well TW-2Ar was tested from April 6 to 10, 2010. A brief step-drawdown test was conducted on April 6, followed by background data collection, and a 24-h constant-rate pumping test began on April 8.

The step-drawdown test was begun at 12:10 p.m. on April 6 with no back pressure on the pump, allowing the pump to produce at a maximum discharge rate while maintaining the pumping water level at the pump intake. Once the drop pipe had filled, the discharge rate was measured at about 4 gpm, declining steadily to around 1.3 gpm after 40 min. At 12:50 p.m., the discharge rate was reduced to 0.56 gpm for 20 min and then increased to 0.90 gpm for 30 min, from 1:10 until 1:40 p.m., when the pump was shut off. The average discharge rate of the three pumping steps was 1.0 gpm.

Following shutdown, recovery data were recorded for 2540 min until 8:00 a.m. on April 8 when the 24-h constant-rate test began.

The 24-h pumping test was begun at a rate of 0.58 gpm. After 35 min, some adjustments were made to the flow rate, with the final rate settling in at 0.77 gpm. Pumping continued for 1440 min until 8:00 a.m. on April 9 when the pump was shut off. Following shutdown, recovery data were recorded for 1440 min until 8:00 a.m. on April 10 when the pump was pulled from the well.

C-2.0 BACKGROUND DATA

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

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

Previous pumping tests on the Plateau have demonstrated a barometric efficiency for most wells of between 90% and 100%. Barometric efficiency is defined as the ratio of water-level change divided by barometric pressure change, expressed as a percentage. In initial pumping tests conducted on the early monitoring and characterization 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 TW-2Ar, have utilized nonvented transducers. These devices 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, for example, a 90% barometrically efficient well. When a vented transducer is used for monitoring, 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, when a nonvented transducer is used, 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 Laboratory’s Waste and Environmental Services Division–Environmental Data and Analysis (WES-EDA). The TA-54 measurement location is at an elevation of 6548 ft amsl, whereas the wellhead elevation is 6651.67 ft amsl. The static water level in TW-2Ar was 97.9 ft below land surface, making the water-table elevation 6553.77 ft amsl. The measured barometric pressure data from TA-54 had to be adjusted to reflect the pressure at the elevation of the water table within TW-2Ar.

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

$$P_{WT} = P_{TA54}\exp\left[-\frac{g}{3.281R}\left(\frac{E_{TW-2Ar}-E_{TA54}}{T_{TA54}}+\frac{E_{WT}-E_{TW-2Ar}}{T_{WELL}}\right)\right] \qquad \textbf{Equation C-1}$$

Where P_{WT} = barometric pressure at the water table inside TW-2Ar

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)

$E_{TW\text{-}2Ar}$ = land surface elevation at TW-2Ar site, in feet (6651.67 ft)

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

E_{WT} = elevation of the water level in TW-2Ar, in feet (6553.77 ft)

T_{TA54} = air temperature near TA-54, in degrees kelvin (assigned a value of 41.8 degrees Fahrenheit, or 278.6 degrees kelvin)

T_{WELL} = air temperature inside TW-2Ar, in degrees kelvin (assigned a value of 53.4 degrees Fahrenheit, or 285.0 degrees kelvin)

This formula is an adaptation of an equation WES-EDA provided. It can be derived from the ideal gas law and standard physics principles. An inherent assumption in the derivation of the equation is that the air temperature between TA-54 and the well is temporally and spatially constant and that the temperature of the air column in the well is similarly constant. As it turned out, because the water-table elevation was nearly identical to the TA-54 tower site elevation, the correction proved inconsequential for this particular well.

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

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 the effective height of the cone of depression is known with certainty because soon after startup, the cone of depression expands vertically through permeable materials above and/or below the screened interval. Thus, the early data often offer the best opportunity to obtain hydraulic conductivity information because conductivity would equal the earliest-time transmissivity divided by the well-screen length.

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

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

Equation C-2

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

D = inside diameter of well casing, in inches

d = outside diameter of column pipe, in inches

Q = discharge rate, in gallons per minute

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

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

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

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

where S_y = short term specific yield of filter media (typically 0.1 to 0.2)

D_B = diameter of borehole, in inches

D_C = outside diameter of well casing, in inches

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

In some instances, it is possible to eliminate casing-storage effects by setting an inflatable packer above the tested screen interval before the test is conducted. Unfortunately, this approach was not applicable to TW-2Ar, as noted above, and an inflatable packer was not used.

C-4.0 TIME-DRAWDOWN METHODS

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

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

where

$$W(u) = \int_u^\infty \frac{e^{-x}}{x} dx$$ **Equation C-5**

and

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

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

Equation C-8

where T = transmissivity, in gallons per day per foot

S = storage coefficient

Q = discharge rate, in gallons per minute

$W(u)$ = match-point value

s = match-point value, in feet

u = match-point value

t = match-point value, in minutes

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

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

Equation C-9

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

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

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

Equation C-10

where T = transmissivity, in gallons per day per foot

Q = discharge rate, in gallons per minute

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

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

Equation C-11

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

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

b = aquifer thickness

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

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

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

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

K_z = vertical hydraulic conductivity

K_r = horizontal hydraulic conductivity

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

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

Equation C-12

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

C-5.0 RECOVERY METHODS

Recovery data were analyzed using the Theis recovery method, a semilog analysis method similar to the Cooper-Jacob procedure.

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

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

The recovery data are particularly useful when 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 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 the actual hydraulic conductivity would have to be greater than calculated to compensate for well inefficiency. Thus, because the efficiency is not known, the computed hydraulic conductivity value represents a lower bound. The actual conductivity is known to be greater than, or equal to, the computed value.

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

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

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

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

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

The Brons and Marting procedure 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 TW-2Ar because of the modest water-level rise above the well screen. Storage coefficient values for unconfined conditions can be expected to range from about 0.01 to 0.25 (Driscoll 1986, 104226). A range of values from 0.01 to 0.1 was used for the TW-2Ar calculations. 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.

The analysis also requires assigning a value for the saturated aquifer thickness, b. For the purposes of this exercise, TW-2Ar was considered fully penetrating. The saturated distance above the well screen was only 4.1 ft, and this entire interval was exposed to filter pack. Thus, formation water in this interval could readily enter the filter pack and drain into the screen zone with minimal head loss. Thus, the filter pack interval in this situation was viewed as acting as an extension of the well screen.

C-7.0 BACKGROUND DATA ANALYSIS

Background aquifer pressure data collected during the TW-2Ar tests were plotted along with barometric pressure to determine the barometric effect on water levels.

Figure C-7.0-1 shows aquifer pressure data from TW-2Ar, 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 TW-2Ar 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 TW-2Ar pumping tests are included in the figure for reference.

The data shown in Figure C-7.0-1 indicate significant barometric pressure changes caused virtually no discernable change in the aquifer pressure response. This suggested a barometric efficiency near 100% and implies that water level measurements did not have to be adjusted for changes in barometric pressure.

C-8.0 WELL TW-2Ar DATA ANALYSIS

This section presents the data obtained from the TW-2Ar pumping tests and the results of the analytical interpretations. Data are presented for drawdown and recovery for the step-drawdown test as well as the 24-h constant-rate pumping test.

C-8.1 Well TW-2Ar Step-Drawdown Test

Figure C-8.1-1 shows a semilog plot of the drawdown data collected during the step-drawdown test. Initially, the pump was run at maximum capacity with the pumping water level pulled down to the pump intake. Subsequently, the discharge rate was adjusted to 0.56 gpm for 20 min and then to 0.90 gpm for the final 30 min of pumping.

Unfortunately, casing and filter pack storage effects dominated much of the data. For example, the pumping water level had not nearly stabilized during the middle step at 0.56 gpm; rather, the level was still recovering when the discharge rate was adjusted again. Subsequent evaluation of the pumping data revealed a storage duration on the order of a couple of hours. Thus, each pumping step would have to have been extended to about an hour or two to allow stabilization.

After 90 min of pumping, the discharge rate was 0.9 gpm with a drawdown of 5.6 ft for a specific capacity of 0.16 gpm/ft. During the initial step, after 40 min of pumping, the discharge rate was 1.3 gpm with a drawdown of 10.2 ft for a specific capacity of 0.13 gpm/ft. A simple mathematical extrapolation showed that had the initial discharge rate been maintained for 90 min, the specific capacity likely would have approached about 0.11 gpm/ft. Thus, at equivalent pumping times, the specific capacity at the greater pumping rate would have been substantially less: 0.11 versus 0.16 gpm/ft. Two possible explanations for the specific capacity differences were (1) turbulent flow and (2) dewatering effects. Because of the low pumping rates, turbulent flow seemed unlikely, leaving dewatering effects as the probable cause of the decline in specific capacity at increased drawdown. This implied the likelihood of significant water contribution between the depths of 97.9 ft (static water level) and 108.1 ft (the deeper of the two pumping water levels under analysis). This suggested that even though groundwater could be seen entering the borehole at 107.5 ft from the gravel seam that seemed to produce a disproportionate share of the yield, the shallower portions of the saturated zone likely contributed water to the well also.

Figure C-8.1-2 shows the recovery data collected following shutdown of the step-drawdown test. Estimated storage times are identified on the graph for reference. Analysis of the poststorage data suggested a transmissivity value of about 120 gpd/ft. The subtle “ripple” evident in the data plot could have been a muted delayed yield effect or possibly a result of lateral formation heterogeneity.

C-8.2 Well TW-2Ar 24-H Constant-Rate Pumping Test

Figure C-8.2-1 shows a semilog plot of the drawdown data collected during the 24-h pumping test. The initial discharge rate was 0.58 gpm but was adjusted to 0.77 gpm after about 35 min of pumping. The storage times are indicated on the graph for reference.

The transmissivity determined from the line of fit shown on the plot was 114 gpd/ft. Note that the drawdown data were not corrected for dewatering effects. It was likely that the submerged zone at 107.5 ft produced a disproportionate contribution to the well yield. Thus, a mathematical correction would have overcompensated for dewatering and overestimated the transmissivity. With no correction of the data, however, the computed transmissivity of 114 gpd/ft likely underestimated the true value and was considered a lower-bound estimate of transmissivity.

Figure C-8.2-2 shows a plot of the recovery data recorded following shutdown of the 24-h constant-rate pumping test. Storage times are shown on the graph for reference. The transmissivity value obtained from the recovery analysis was 124 gpd/ft.

C-8.3 Well TW-2Ar Specific Capacity Data

Specific capacity data were used along with well geometry to estimate a lower-bound transmissivity value for the permeable zone penetrated by TW-2Ar to provide a frame of reference for evaluating the foregoing analyses.

During the 24-h pumping test, the discharge rate was 0.77 gpm for 1440 min with a drawdown of 6.38 ft, making the specific capacity 0.12 gpm/ft. In addition to specific capacity and pumping time, other input values used in the calculations included a range of storage coefficient values from 0.01 to 0.1 and a borehole radius of 0.59 ft (inferred from the volume of filter pack required to backfill the screen zone obtained from the construction log). Fully penetrating conditions were assumed for the purposes of these calculations as described earlier.

Iterating these inputs yielded lower-bound transmissivity values shown on Figure C-8.3-1. Depending on the storage coefficient value, the lower-bound transmissivity ranged from about 90 to 130 gpd/ft, consistent with the pumping test results.

C-9.0 SUMMARY

Constant-rate pumping tests were conducted on TW-2Ar. The tests were performed to gain an understanding of the hydraulic characteristics of the shallow perched Puye sediments in which TW-2Ar is screened. Several observations and conclusions were drawn for the tests as summarized below.

A comparison of barometric pressure and TW-2Ar water level data suggested a barometric efficiency near 100%.

The perched zone was saturated from 97.9 ft to 112 ft bgs (14.1 ft thick), resting on tight silt identified at 112 to 115 ft bgs.

The most reliable transmissivity value determined from the test pumping was 124 gpd/ft. Based on the saturated thickness of 14.1 ft, this implied an *average* hydraulic conductivity of 8.8 gpd/ft^2, or 1.2 ft/d. However, visual observations made during drilling showed a large water contribution from about 107.5 ft bgs. Thus, the gravel seam at that depth provided a disproportionate contribution to the well yield and transmissivity.

TW-2Ar produced 0.77 gpm with 6.38 ft of drawdown after 1440 min of pumping, resulting in a specific capacity of 0.12 gpm/ft. The corresponding computed lower-bound transmissivity values ranged from about 90 to 130 gpd/ft, consistent with the pumping test results.

The saturated perched zone appeared to be laterally extensive, as the data showed no obvious indication of boundary conditions.

C-10.0 REFERENCES

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

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

Bradbury, K.R., and E.R. Rothschild, March-April 1985. "A Computerized Technique for Estimating the Hydraulic Conductivity of Aquifers from Specific Capacity Data," *Ground Water,* Vol. 23, No. 2, pp. 240-246. (Bradbury and Rothschild 1985, 098234)

Brons, F., and V.E. Marting, 1961. "The Effect of Restricted Fluid Entry on Well Productivity," *Journal of Petroleum Technology,* Vol. 13, No. 2, pp. 172-174. (Brons and Marting 1961, 098235)

Cooper, H.H., Jr., and C.E. Jacob, August 1946. "A Generalized Graphical Method for Evaluating Formation Constants and Summarizing Well-Field History," *American Geophysical Union Transactions,* Vol. 27, No. 4, pp. 526-534. (Cooper and Jacob 1946, 098236)

Driscoll, F.G., 1986. Excerpted pages from *Groundwater and Wells*, 2nd Ed., Johnson Filtration Systems Inc., St. Paul, Minnesota. (Driscoll 1986, 104226)

Gringarten, A.C. and P.A. Witherspoon, 1972. A Method of Analyzing Pump Test Data From Fractured Aquifers, Int. Soc. Rock Mechanics and Int. Assoc. Eng. Geol., Proc. Symp. Rock Mechanics, Stuttgart, vol. 3-B, pp. 1-9

Hantush, M.S., July 1961. “Drawdown around a Partially Penetrating Well,” *Journal of the Hydraulics Division, Proceedings of the American Society of Civil Engineers,* Vol. 87, No. HY 4, pp. 83-98. (Hantush 1961, 098237)

Hantush, M.S., September 1961. “Aquifer Tests on Partially Penetrating Wells,” Journal of the Hydraulics Division, Proceedings of the American Society of Civil Engineers, pp. 171–195. (Hantush 1961, 106003)

Kruseman, G. P. and N. A. de Ridder, 1991. “Analysis and Evaluation of Pumping Test Data” International Institute for Land Reclamation and Improvement, The Netherlands.

Schafer, D.C., January-February 1978. "Casing Storage Can Affect Pumping Test Data," *The Johnson Drillers Journal,* pp. 1-6, Johnson Division, UOP, Inc., St. Paul, Minnesota. (Schafer 1978, 098240)

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

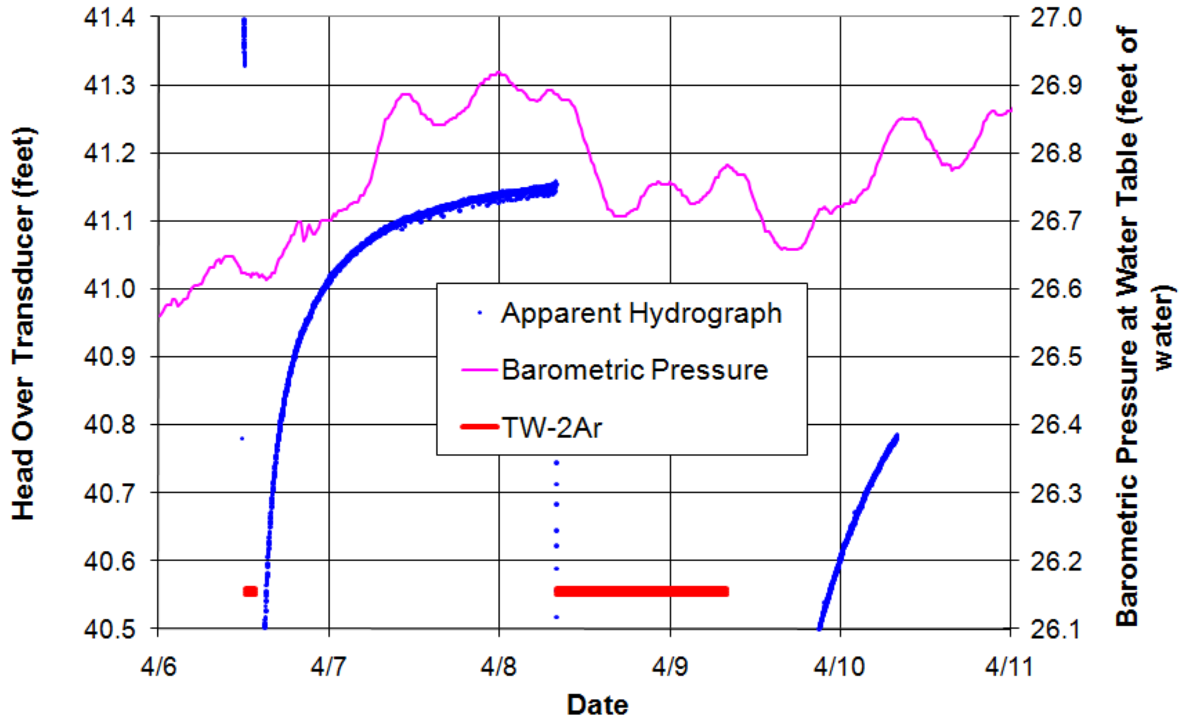

Figure C-7.0-1 Well TW-2Ar apparent hydrograph

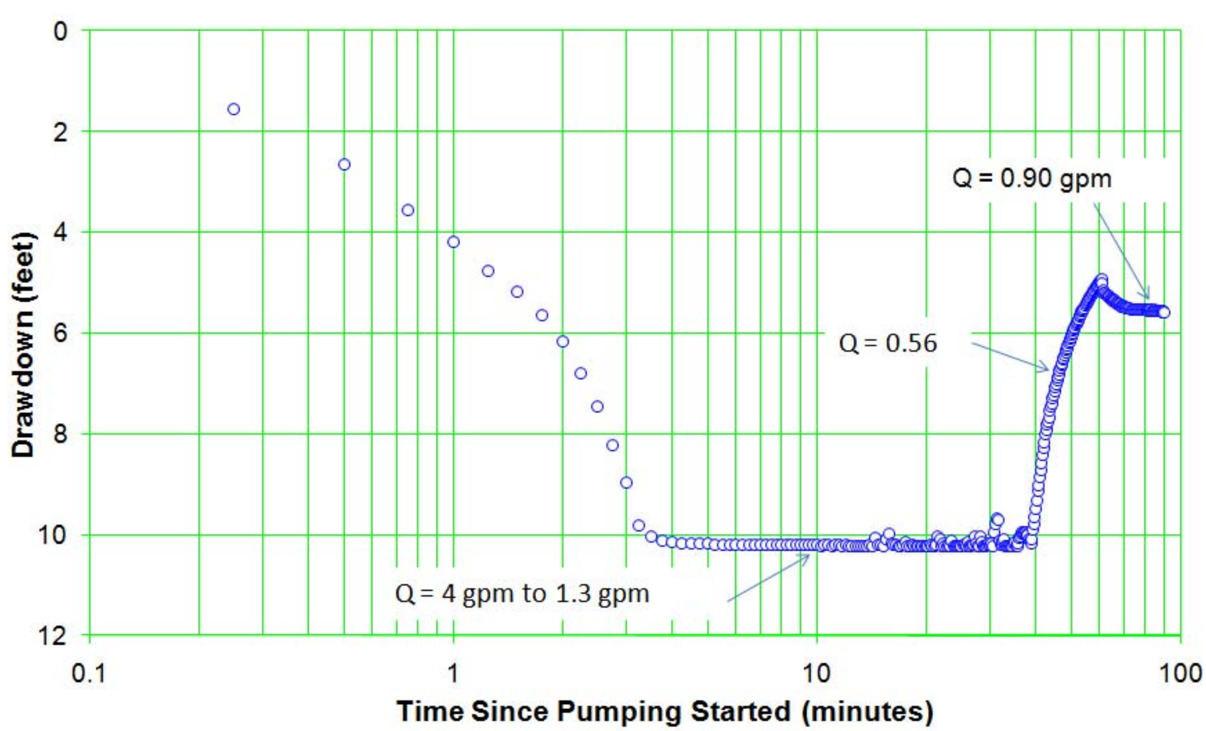

Figure C-8.1-1 Well TW-2Ar step-drawdown test response

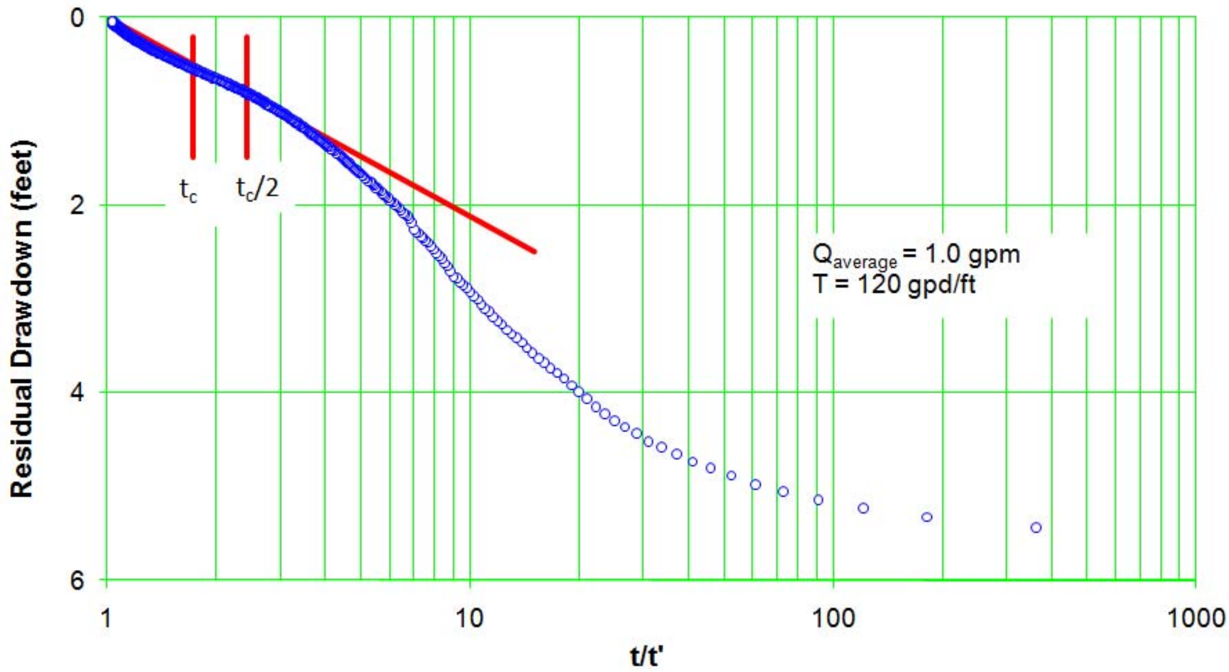

Figure C-8.1-2 Well TW-2Ar step-drawdown test recovery

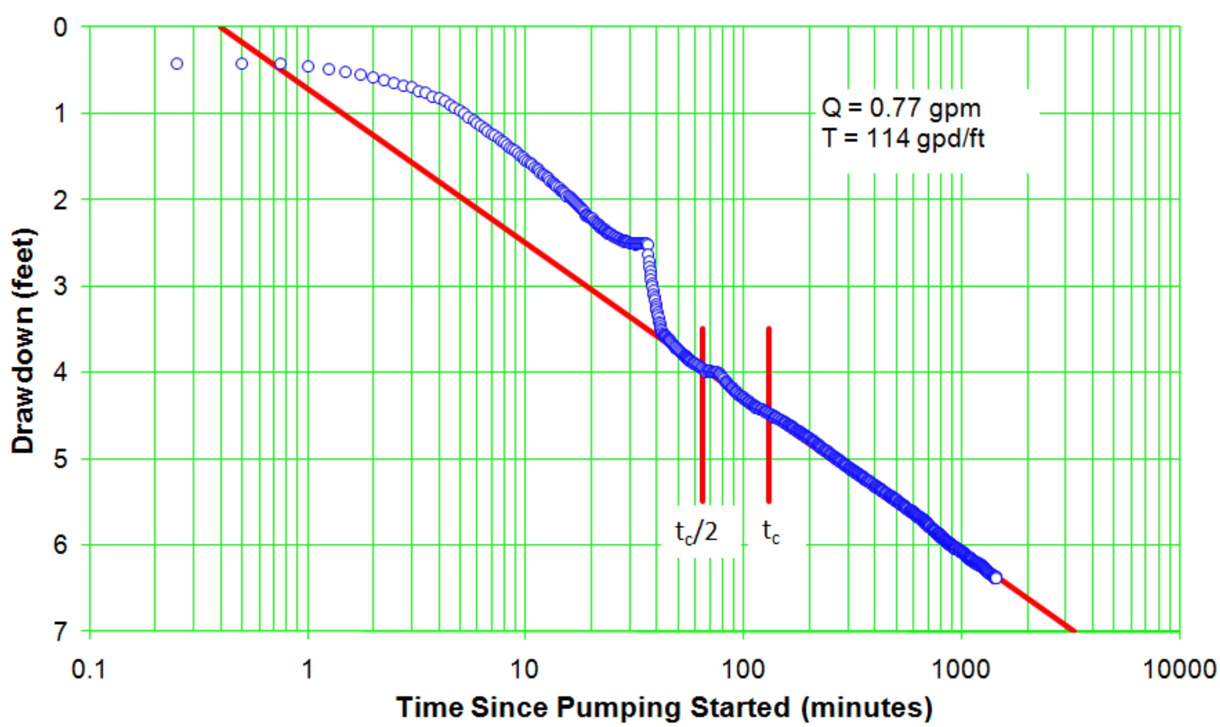

Figure C-8.2-1 Well TW-2Ar drawdown

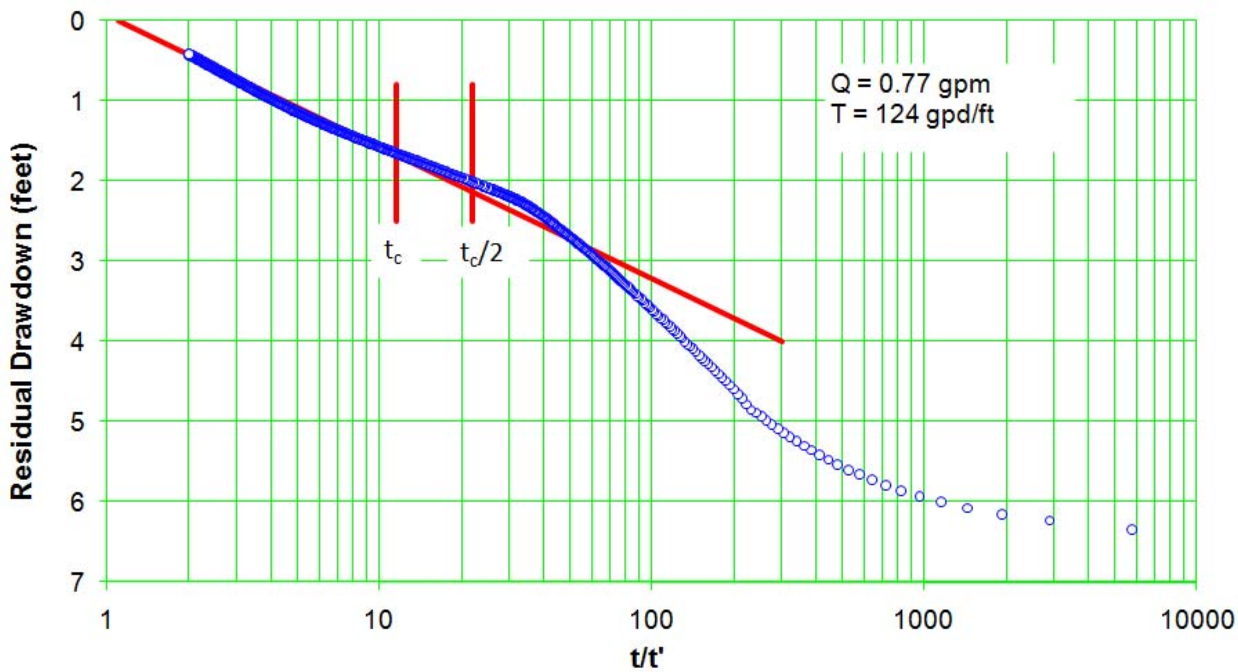

Figure C-8.2-2 Well TW-2Ar recovery

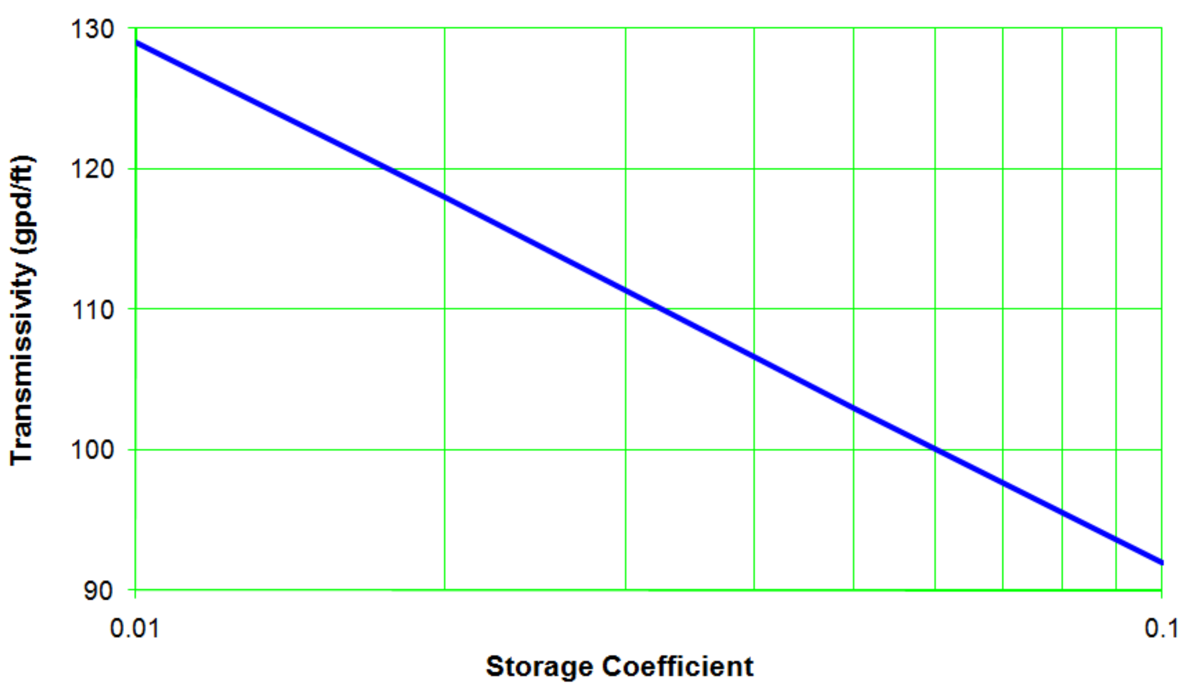

Figure C-8.3-1 Well TW-2Ar lower-bound transmissivity

Appendix D

Geophysical Logging
(on CD included with this document)