ERID-208721

LA-UR-11-6712
December 2011
EP2011-0334

Completion Report for Regional Aquifer Well R-64

Los Alamos
NATIONAL LABORATORY
EST. 1943

Prepared by the Environmental Programs Directorate

EP2011-0334

Completion Report for Regional Aquifer Well R-64

December 2011

Responsible project manager:

Ted Ball	Theodore J. Ball	Project Manager	Environmental Programs	28 NOV 11
Printed Name	Signature	Title	Organization	Date

Responsible LANS representative:

Michael J. Graham	MJ Graham	Associate Director	Environmental Programs	28 Nov 11
Printed Name	Signature	Title	Organization	Date

Responsible DOE representative:

George J. Rael		Manager	DOE-LASO	12-1-2011
Printed Name	Signature	Title	Organization	Date

EXECUTIVE SUMMARY

This well completion report describes the drilling, well construction, development, aquifer testing, and dedicated sampling system installation for regional aquifer groundwater well R-64, located on the north edge of DP Mesa within Los Alamos National Laboratory Technical Area 21 (TA-21) in Los Alamos County, New Mexico. The R-64 monitoring well is intended to monitor water quality in the regional aquifer downgradient of potential release sites at TA-21 consistent with the New Mexico Environment Department– (NMED-) approved drilling work plan.

The R-64 monitoring well borehole was drilled using dual-rotary air-drilling methods. Fluid additives used included potable water and foam. Foam-assisted drilling was used only to a depth of 1145 ft below ground surface (bgs), approximately 100 ft above the top of the regional aquifer.

The following geologic formations were encountered at R-64: Tshirege Member of the Bandelier Tuff, Cerro Toledo interval, Otowi Member of the Bandelier Tuff, Guaje Pumice Bed of the Otowi Member, Puye Formation, and Miocene pumiceous sediments. R-64 was drilled to a total depth of 1380 ft bgs.

Well R-64 was completed as a single-screen well allowing evaluation of water quality and water levels within the regional aquifer. The screened interval is set between 1285 and 1305.5 ft bgs within Miocene pumiceous sediments. The static depth to water after well installation was 1269.1 ft bgs.

The well was completed in accordance with an NMED-approved well design. The well was developed and the regional aquifer groundwater met target water-quality parameters. Aquifer testing indicates that regional aquifer monitoring well R-64 is productive and will perform effectively to meet the planned objectives. A sampling system and transducer have been placed in the screened interval, and groundwater sampling at R-64 will be performed as part of the annual Interim Facility-Wide Groundwater Monitoring Plan.

CONTENTS

Figures

Tables

Appendixes

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 (LANL group)
Eh	oxidation-reduction potential
EP	Environmental Programs
F	filtered
FD	field duplicate
FTB	field trip blank
gpd	gallon per day
gpm	gallons per minute
hp	horsepower
I.D.	inside diameter
LANL	Los Alamos National Laboratory
NAD	North American Datum
NMED	New Mexico Environment Department
NTU	nephelometric turbidity unit
O.D.	outside diameter
ORP	oxidation-reduction potential
PVC	polyvinyl chloride
Qbo	Otowi Member of the Bandelier Tuff
Qbog	Guaje Pumice Bed of the Otowi Member of the Bandelier Tuff
Qbt	Tshirege Member of the Bandelier Tuff
Qct	Cerro Toledo Interval
RPF	Records Processing Facility
TA	technical area
TD	total depth
Tjfp	Tertiary Jemez Fanglomerate Pumiceous (called Miocene pumiceous sediments in this report)
TOC	total organic carbon

Tpf	Puye Formation
UF	unfiltered
VOC	volatile organic compound
WCSF	waste characterization strategy form
WES-EDA	Waste and Environmental Services Division–Environmental Data and Analysis (LANL group)

1.0 INTRODUCTION

This completion report summarizes borehole drilling, well construction, well development, aquifer testing, and dedicated sampling system installation for regional aquifer monitoring well R-64. The report is written in accordance with the requirements in Section IV.A.3.e.iv of the March 1, 2005 (revised 2008), Compliance Order on Consent (the Consent Order). The R-64 monitoring well borehole was drilled from April 16 to May 22, 2011, and completed from May 29 to July 11, 2011, at Los Alamos National Laboratory (LANL or the Laboratory) for the Laboratory's Environmental Programs (EP) Directorate.

Well R-64 is located on the north edge of DP Mesa within the Laboratory's Technical Area 21 (TA-21) in Los Alamos County, New Mexico (Figure 1.0-1). Well R-64 was installed to monitor water quality in the regional aquifer downgradient of potential release sites at TA-21. Secondary objectives were to establish water levels in the regional aquifer, identify potential perched aquifers, and to collect drill-cuttings samples.

The R-64 borehole was drilled to a total depth (TD) of 1380 ft below ground surface (bgs). During drilling, cuttings samples were collected at 5-ft intervals in the borehole from ground surface to TD. A monitoring well was installed with a screened interval between 1285 and 1305.5 ft bgs within Miocene pumiceous sediments. The depth to water (DTW) of 1269.1 ft bgs was recorded on July 14, 2011, after well installation.

Postinstallation activities included well development, aquifer testing, surface completion, conducting a geodetic survey, and sampling system installation. Future activities will 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 associated with the R-64 project.

2.0 ADMINISTRATIVE PLANNING

The following documents were prepared to guide activities associated with the drilling, installation, and development of regional aquifer well R-64:

- "Drilling Work Plan for Regional Aquifer Wells MW-14 (R-64) and MW-10 (R-65)" (LANL 2011, 111604);
- "Drilling Plan for Regional Aquifer Well R-64" (TerranearPMC 2011, 205994);
- "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 Installation of Regional Well R-64 (MW-14) at TA-21" (LANL 2011, 204890).

3.0 DRILLING ACTIVITIES

This section describes the drilling approach and provides a chronological summary of field activities conducted at monitoring well R-64.

3.1 Drilling Approach

The drilling methodology, equipment, and drill-casing sizes for the R-64 monitoring well were selected to retain the ability to investigate and case off any perched groundwater encountered above the regional aquifer. Further, the drilling approach ensured that a sufficiently sized drill casing was used to meet the required 2-in. minimum annular thickness of the filter pack around a 5.88-in.–outside diameter (O.D.) well screen.

Dual-rotary air-drilling methods using a Foremost DR-24HD drill rig were employed to drill the R-64 borehole. Dual-rotary drilling has the advantage of simultaneously advancing and casing the borehole. The Foremost DR-24HD drill rig was equipped with conventional drilling rods, tricone bits, downhole hammer bits, a deck-mounted air compressor, and general drilling equipment. Auxiliary equipment included two Ingersoll Rand trailer-mounted air compressors. Three sizes of A53 grade B flush-welded mild carbon-steel casing (20-in. and 16-in. O.D. and 12-in. inside diameter [I.D.]) were used for the R-64 project.

The dual-rotary technique at R-64 used filtered compressed air and fluid-assisted air to evacuate cuttings from the borehole during drilling. Drilling fluids, other than air, used in the borehole (all within the vadose zone) included potable water and a mixture of potable water with Baroid AQF-2 foaming agent. The fluids were used to cool the bit and help lift cuttings from the borehole. Use of the foaming agent was terminated at 1145 ft bgs, roughly 100 ft above the expected top of the regional aquifer. No additives other than potable water were used for drilling below 1145 ft bgs. Total amounts of drilling fluids introduced into the borehole are presented in Table 3.1-1.

3.2 Chronological Drilling Activities for the R-64 Well

Drilling equipment and supplies were mobilized to the R-64 drill site on April 14 and 15, 2011. Decontamination of the equipment and tooling was performed before mobilization to the site. On April 16, following on-site equipment inspections, the monitoring well borehole was initiated at 1320 h using dual-rotary methods with 20-in. drill casing and an 18.5-in. tricone bit. The 20-in. casing was set at 32.2 ft bgs in Unit 3 of the Tshirege Member of the Bandelier Tuff.

On April 17, open-hole drilling commenced using a 17.5-in. tricone bit. Drilling proceeded through the Tshirege Member, the Cerro Toledo interval, the Otowi Member, the Guaje Pumice Bed of the Otowi Member, and the top of the Puye Formation to 660 ft bgs before drilling operations were suspended between April 20 and 26 for the Easter holiday break.

On April 27, operations resumed and starting on April 28, 16-in. casing was installed in the open borehole to a depth of 630 ft bgs. On May 2, a 15-in. tricone bit was used to advance the 16-in. casing through volcaniclastic sediments to 956 ft bgs.

Between May 11 and 16, 12-in. casing was installed to 955 ft bgs. The 12-in. casing string and an underreaming hammer bit were advanced through the remaining Puye Formation and into the Miocene pumiceous sediments to 1205 ft bgs. On May 20, a 12-in. tricone bit was used to advance the borehole and 12-in. casing string through the remaining portion of the Miocene pumiceous sediments. Water was encountered at approximately 1270 ft bgs on May 21. Casing advance drilling proceeded to the TD at 1380 ft bgs on May 22, 2011.

The 16-in. casing shoe was cut on May 8 at 940 ft bgs before installing the 12-in. casing string. The 12-in. casing shoe was cut on May 23 at 1370 ft bgs.

During drilling, field crews worked 12-h shifts, 7 d/wk. Operations were suspended between April 20 and 26 for the Easter holiday break. All associated activities proceeded normally without incident or delay.

4.0 SAMPLING ACTIVITIES

This section describes the cuttings and groundwater sampling activities for monitoring well R-64. All sampling activities were conducted in accordance with applicable quality procedures.

4.1 Cuttings Sampling

Cuttings samples were collected from the R-64 monitoring well borehole at 5-ft intervals from ground surface to the TD of 1380 ft bgs. At each interval, approximately 500 mL of bulk cuttings was collected by the site geologist from the drilling discharge cyclone, placed in resealable plastic bags, labeled, and archived in core boxes. Whole rock and +35 and +10 sieve size fractions were also processed, placed in chip trays, and archived for each 5-ft interval. Radiation control technicians screened the cuttings before removal from the site. All screening measurements were within the range of background values. The cuttings samples were delivered to the Laboratory’s archive at the conclusion of drilling activities.

R-64 stratigraphy is summarized in section 5.1 and a detailed lithologic log is presented in Appendix A.

4.2 Water Sampling

Four groundwater-screening samples were collected during development, and five groundwater-screening samples were collected during aquifer testing from the pump’s discharge line for total organic carbon (TOC) analysis (Table 4.2-1). The TOC results are presented in Appendix B.

Groundwater characterization samples will be collected from the completed well in accordance with the Consent Order. For the first year, the samples will be analyzed for the full suite of constituents including radioactive elements; anions/cations; general inorganic chemicals; volatile and semivolatile organic compounds; and stable isotopes of hydrogen, nitrogen, and oxygen. The analytical results will be included in the appropriate periodic monitoring report issued by the Laboratory. After the first year, the analytical suite and sample frequency at R-64 will be evaluated and presented in the annual “Interim Facility-Wide Groundwater Monitoring Plan.”

5.0 GEOLOGY AND HYDROGEOLOGY

A brief description of the geologic and hydrogeologic features encountered at R-64 is presented below. The Laboratory’s geology task leader and project site geologist examined cuttings to determine geologic contacts and hydrogeologic conditions. Drilling observations and water level measurements were used to characterize groundwater encountered at R-64.

5.1 Stratigraphy

Rock units for the R-64 borehole are presented below in order of youngest to oldest in stratigraphic occurrence. Lithologic descriptions are based on binocular microscope analysis of drill cuttings collected from the discharge hose. Figure 5.1-1 illustrates the stratigraphy at R-64. A detailed lithologic log for R-64 is presented in Appendix A.

Unit 3, Tshirege Member of the Bandelier Tuff, Qbt 3 (0–90 ft bgs)

Unit 3 of the Tshirege Member of the Bandelier Tuff was encountered from 0 to 90 ft bgs. Unit 3 is a poorly to moderately welded devitrified ash-flow tuff (i.e., ignimbrite) that is crystal rich, slightly pumiceous and lithic poor, and exhibits a matrix of fine ash.

Unit 2, Tshirege Member of the Bandelier Tuff, Qbt 2 (90–155 ft bgs)

Unit 2 of the Tshirege Member of the Bandelier Tuff was intersected from 90 to 155 ft bgs. Unit 2 represents a moderately to strongly welded devitrified rhyolitic ash-flow tuff (i.e., ignimbrite) that is composed of abundant (up to 40% by volume) quartz and sanidine crystals. Cuttings typically contain abundant fragments of indurated tuff and numerous free quartz and sanidine crystals.

Unit 1v, Tshirege Member of the Bandelier Tuff, Qbt 1v (155–222 ft bgs)

Unit 1v of the Tshirege Member of the Bandelier Tuff occurs from 155 to 222 ft bgs. Unit 1v is a poorly to moderately welded devitrified rhyolitic ash-flow tuff that is pumiceous, generally lithic poor, and crystal bearing to locally crystal rich. Abundant ash matrix is rarely preserved in cuttings. Cuttings commonly contain numerous fragments of indurated crystal-rich tuff with compressed, devitrified pumice lapilli. Abundant free quartz and sanidine crystals dominate cuttings in many intervals, and minor small (generally less than 10 mm in diameter) volcanic lithic inclusions also occur in cuttings.

Unit 1g, Tshirege Member of the Bandelier Tuff, Qbt 1g (222–305 ft bgs)

Unit 1g of the Tshirege Member of the Bandelier Tuff was encountered from 222 to 305 ft bgs. Unit 1g is a poorly welded vitric rhyolitic ash-flow tuff that is poorly to moderately indurated, strongly pumiceous, and crystal bearing. White to pale-orange, lustrous, glassy pumice lapilli, which are both quartz and sanidine phyric, are characteristic of Unit 1g. Cuttings contain minor fragments of abundant free quartz and sanidine crystals and minor small (up to 10 mm) volcanic (predominantly dacitic) lithic inclusions.

Cerro Toledo Interval, Qct (305–355 ft bgs)

The Cerro Toledo interval was encountered from 305 to 355 ft bgs. The Cerro Toledo interval is a sequence of poorly consolidated tuffaceous and volcaniclastic sediments that occurs regionally between the Tshirege and Otowi Members of the Bandelier Tuff. The Cerro Toledo interval at R-64 contains grayish-orange to white, poorly sorted, pebble gravels with silty, fine to coarse sands composed of volcanic and tuffaceous debris. Commonly subrounded detrital clasts are composed of dacites, rhyolite, abundant vitric pumices, and quartz and sanidine crystals.

Otowi Member of the Bandelier Tuff, Qbo (355–630 ft bgs)

The Otowi Member of the Bandelier Tuff was encountered from 355 to 630 ft bgs. The Otowi Member is composed of poorly welded vitric rhyolitic ash-flow tuffs that are pumiceous, crystal bearing, and lithic bearing. Drill cuttings contain pale-orange, glassy pumices, volcanic lithic clasts (up to 10 mm), and quartz and sanidine crystals. Lithic fragments are commonly subangular to subrounded and generally of intermediate volcanic composition, including porphyritic dacites.

Guaje Pumice Bed of the Otowi Member of the Bandelier Tuff, Qbog (630–650 ft bgs)

The Guaje Pumice Bed represents an air-fall tephra deposit of rhyolitic pumice that forms the base of the Otowi Member. The Guaje deposit was encountered from 630 to 650 ft bgs. Drill cuttings in this interval contain abundant (up to 70% by volume), lustrous, vitric pumice lapilli (up to 15 mm in diameter) with trace occurrences of small volcanic lithic fragments. The deposit is poorly unconsolidated.

Puye Formation, Tpf (650–1060 ft bgs)

Puye Formation volcaniclastic sediments were encountered from 650 to 1060 ft bgs. Cuttings from this interval consist of white to pale-orange fine-grained lithic gravels and sandstones. Sand-sized pumice and volcanic clasts are typically subangular to subrounded, and fine quartz grains are subrounded. These deposits likely contain intervals with cobbles and boulders, but these larger clasts are pulverized during drilling.

Miocene Pumiceous Sediments, Tjfp (1060–1380 ft bgs)

A pumice-rich volcaniclastic section was intersected from 1060 ft to the bottom of the R-64 borehole at 1380 ft bgs. These sediments are composed of fine to medium gravels with fine to coarse sand that are moderately to poorly sorted, weakly cemented, and contain detrital vitric pumices making up 30% or more (locally as much as 80%) by volume.

5.2 Groundwater

Drilling at R-64 proceeded without any groundwater indications until 1270 ft bgs as noted by the drilling crew. After drilling to 1337 ft bgs, water production was estimated at 15 gallons per minute (gpm). The borehole was then advanced to the TD of 1380 ft bgs. The water level was 1269.2 ft bgs on May 29, before well installation. The DTW in the completed well was 1269.1 ft bgs on July 14. During development, the average sustainable pumping rate was approximately 2 gpm.

5.2.1 Regional Aquifer Groundwater Elevations

The regional aquifer water level elevation for R-64 was 5852.47 ft above mean sea level (amsl) on July 14. This elevation conforms reasonably well with the surrounding regional aquifer water level elevations as shown in Figure 5.2-1. The level at R-64 will continue to be monitored and incorporated into the Laboratory's regional aquifer water level map.

6.0 BOREHOLE LOGGING

Natural gamma ray and conductivity logs were run on April 26, 2011. A natural gamma ray log was recorded on May 23, 2011, inside the 12-in. casing after the borehole TD of 1380 ft bgs was reached. Logging was conducted with Laboratory logging equipment and staff. The natural gamma ray log is included as Appendix D (on CD included with this document).

7.0 WELL INSTALLATION

The R-64 well was installed between May 29 and July 11, 2011.

7.1 Well Design

The R-64 well was designed in accordance with the Consent Order, and NMED approved the final well design before installation (Appendix E). The well was designed with a screened interval between 1285 and 1305.5 ft bgs to monitor the groundwater quality near the top of the regional aquifer within the Miocene pumiceous sediments.

7.2 Well Construction

Decontamination of the stainless-steel well casing, screens, and tremie pipe, along with mobilization of the Pulstar workover rig and initial well construction materials, took place from May 27 to 29.

The R-64 monitoring well was constructed of 5.0-in.-I.D./5.56-in.-O.D., type A304 passivated stainless-steel threaded casing fabricated to American Society for Testing and Materials (ASTM) A312 standards. The screened section used two 10-ft lengths of 5.0-in.-I.D. rod-based 0.020-in. wire-wrapped screens to make up the 20-ft-long screen interval. Compatible external stainless-steel couplings (also type A304 stainless steel fabricated to ASTM A312 standards) were used to join the individual casing sections. The coupled unions between threaded sections were approximately 0.5 ft long. A 2-in. steel tremie pipe was used to deliver backfill and annular fill materials downhole during well construction. Short lengths of 16-in. (15.6-ft-long section of casing and shoe, from 940 to 955.6 ft bgs) and 12-in. drill casing (10.0-ft-long section of casing and shoe, from 1370 to 1380 ft bgs) remain in the borehole. The 16-in. casing stub was encased in the upper bentonite seal, and the 12-in. casing stub was encased in the slough during well completion.

A 10.6-ft-long stainless-steel sump was placed below the bottom of the well screen. The well casing was started into the borehole on May 29 at 0925 h. The well casing was hung by wireline with the bottom at 1316.1 ft bgs. Stainless-steel centralizers (two sets of four) were welded to the well casing approximately 2.0 ft above and below the screened interval. Figure 7.2-1 presents an as-built schematic showing construction details for the completed well.

The installation of annular materials, which are listed in Table 7.2-1, began on June 2 after the bottom of the borehole was measured at 1369.1 ft bgs (approximately 10.9 ft of slough had accumulated in the borehole). The lower bentonite seal was installed between June 2 and 5 from 1310.8 to 1369.1 ft bgs using 51.6 ft^3 of 3/8-in. bentonite chips.

The filter pack was installed between June 5 and 6 from 1278.7 to 1310.8 ft bgs using 41 ft^3 of 10/20 silica sand. The actual volume of filter pack sand was 81% greater than the calculated volume, which is likely due to an oversized borehole caused by sloughing in the unconsolidated Miocene pumiceous sediments. The filter pack was surged to promote compaction. The fine sand collar was installed above the filter pack from 1275.8 to 1278.7 ft bgs using 1.5 ft^3 of 20/40 silica sand.

From June 6 to 24, the upper bentonite seal was installed from 56.6 to 1275.8 ft bgs using 1575.8 ft^3 of 3/8-in. bentonite chips. On July 11, a cement seal was installed from 3.0 to 56.6 ft bgs. The cement seal used 133.6 ft^3 of Portland Type I/II/V cement. This volume exceeded the calculated volume of 106.7 ft^3 by 25%, which is likely due to cement loss to the near-surface formations.

Operationally, well construction proceeded smoothly, 12 h/d, 7 d/wk, from May 29 through June 25. A wildfire started in the Jemez Mountains of the Santa Fe National Forest west of Los Alamos on June 26. Well construction was suspended from June 26 through July 10 and was completed on July 11, 2011.

8.0 POSTINSTALLATION ACTIVITIES

Following well installation at R-64, the well was developed and aquifer pumping tests were 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.

8.1 Well Development

The well was developed between July 13 and 21, 2011. Initially, the screened interval was bailed and swabbed to remove formation fines in the filter pack and well sump. Bailing continued until water clarity visibly improved. Final development was then performed with a submersible pump.

The swabbing tool employed was a 4.5-in.-O.D., 1-in.-thick nylon disc attached to a weighted steel rod. The wireline-conveyed tool was drawn repeatedly across the screened interval, causing a surging action across the screen and filter pack. The bailing tool was a 4.0-in.-O.D. by 21.0-ft-long carbon steel bailer with a total capacity of 12 gal. The tool was repeatedly lowered by wireline, filled with water, withdrawn from the well, and emptied into the cuttings pit. Approximately 324 gal. of groundwater was removed during bailing activities.

After bailing, a 5-horsepower (hp), 4-in. Berkeley submersible pump was installed in the well for the final stage of well development. On July 15, the screened interval was pumped from bottom to top in 2-ft increments. The pump was then used to purge the well sump. On July 18, the pump intake was set at 1305 ft bgs for the remainder of purging. Approximately 5090 gal. of groundwater was purged with the submersible pump during well development.

Total Volumes of Introduced and Purged Water

During drilling, approximately 2565 gal. of potable water was added below the surface of the regional aquifer at approximately 1270 ft bgs. An additional 5992 gal. was added during installation of the screened-interval filter pack. In total, approximately 8557 gal. of potable water was introduced to the borehole within the regional aquifer during project activities.

Approximately 5414 gal. of groundwater was purged at R-64 during well development activities. Another 2979 gal. was purged during aquifer testing. After aquifer testing, an additional 267 gal. was purged. Total groundwater purged during postinstallation activities was 8660 gal.

8.1.1 Well Development Field Parameters

During the pumping stage of well development, turbidity, temperature, pH, dissolved oxygen (DO), oxidation-reduction potential (ORP), and specific conductance were measured. The required TOC and turbidity values for adequate well development are less than 2.0 ppm and less than 5 nephelometric turbidity units (NTU), respectively.

Field parameters were measured by collecting aliquots of groundwater from the discharge pipe with the use of a flow-through cell. The final parameters at the end of well development were pH of 7.85, temperature of 22.27°C, specific conductance of 148 μS/cm, and turbidity of 8.3 NTU. Table B-2.2-1 in Appendix B shows field parameters and purge volumes measured during well development.

During the 24-h aquifer test, turbidity values decreased to the final recorded value of 5.8 NTU, near the target turbidity of 5 NTU.

8.2 Aquifer Testing

Aquifer pumping tests were conducted at R-64 between August 1 and 5, 2011. Several short-duration tests with short-duration recovery periods were performed on the first three days of testing. A 24-h pump test followed by a 24-h recovery period completed the testing of the screened interval. The average sustainable pumping rate for the 24-h test was 2 gpm.

A 5-hp pump was used for the aquifer tests. A total of approximately 2979 gal. of groundwater was purged during aquifer testing. Turbidity, temperature, pH, DO, ORP, and specific conductance were measured during the 24-h test. Measured parameters are presented in Appendix B. The R-64 aquifer test results and analysis are presented in Appendix C.

8.3 Dedicated Sampling System Installation

The dedicated sampling system for R-64 was installed on August 10, 2011. The pumping system uses an environmentally retrofitted 4-in. 5-hp Grundfos submersible pump set near the bottom of the screened interval. Due to insufficient head above the screen, the pump was set within the screened interval in a stainless-steel pump shroud. The pump column is constructed of 1-in. threaded/coupled passivated stainless-steel pipe. A weep valve was installed at the bottom of the uppermost pipe joint to protect the pump column from freezing. To measure water levels in the well, two 1-in.-I.D. schedule 80 polyvinyl chloride (PVC) pipes are installed to sufficient depth to set a dedicated transducer and to provide access for manual water level measurements. The PVC transducer tubes are equipped with 9-in. sections of 0.010-in. slot screen with a threaded end cap on the bottom of each tube. An In-Situ Level Troll 500 30-psig transducer is installed in one of the PVC tubes to monitor the water level in the well's screened interval.

Sampling system details for R-64 are presented in Figure 8.3-1a. Figure 8.3-1b presents technical notes for the well, and Figure 8.3-1c shows the environmentally retrofitted Grundfos pump performance curve.

8.4 Wellhead Completion

A reinforced concrete surface pad, 10 ft × 10 ft × 6 in. thick, was installed at the R-64 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, were set at the outside edges of the pad to protect the well from traffic. All four bollards are easily removable 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 August 17, 2011 (Table 8.5-1). The survey data conform to Laboratory Information Architecture project standards IA-CB02, "GIS Horizontal Spatial Reference System," and IA-D802, "Geospatial Positioning Accuracy Standard for A/E/C and Facility Management." All coordinates are expressed relative to the New Mexico State Plane Coordinate System Central Zone (North American Datum [NAD] 83); elevation is expressed in feet amsl using the National Geodetic Vertical Datum of 1929. Survey points include ground surface elevation near the concrete pad, the top of the brass pin in the concrete pad, the top of the well casing, and the top of the protective casing for the R-64 monitoring well.

8.6 Waste Management and Site Restoration

Waste generated from the R-64 project included drilling fluids, purged groundwater, drill cuttings, decontamination water, and contact waste. A summary of the waste characterization samples collected during drilling, well construction, and development of the R-64 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 Intermediate Well R-64 (MW-14) at TA-21" (LANL 2011, 204890).

Fluids produced during drilling, well development, and aquifer testing are expected to be land-applied after a review of associated analytical results per the waste characterization strategy form (WCSF) and ENV-RCRA-QP-010.2, Land Application of Groundwater. If it is determined the drilling fluids are nonhazardous but cannot meet the criteria for land application, they will be evaluated for treatment and disposal at one of the Laboratory's 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-QP-011.2, 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 pit and managing the fluids and cuttings as described above, removing the polyethylene liner, removing the containment area berms, and backfilling and regrading the containment area, as appropriate.

9.0 DEVIATIONS FROM PLANNED ACTIVITIES

Drilling, sampling, and well construction at R-64 were performed as specified in "Drilling Plan for Regional Aquifer Well R-64" (TerranearPMC 2011, 205994).

10.0 ACKNOWLEDGMENTS

Boart Longyear drilled and installed the R-64 monitoring well.

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

TerranearPMC provided oversight on all preparatory and field-related activities.

11.0 REFERENCES AND MAP DATA SOURCES

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

Copies of the master reference set are maintained at the NMED Hazardous Waste Bureau; the U.S. Department of Energy–Los Alamos Site Office; U.S. Environmental Protection Agency, Region 6; 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.

11.1 References

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

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

LANL (Los Alamos National Laboratory), January 2011. “Drilling Work Plan for Regional Aquifer Wells MW-14 (R-64) and MW-10 (R-65),” Los Alamos National Laboratory document LA-UR-11-0186, Los Alamos, New Mexico. (LANL 2011, 111604)

LANL (Los Alamos National Laboratory), March 31, 2011. “Waste Characterization Strategy Form for Installation of Regional Aquifer Well R-64 (MW-14) at TA-21,” EP2011-0125, Los Alamos National Laboratory, Los Alamos, New Mexico. (LANL 2011, 204890)

TerranearPMC, April 2011. “Drilling Plan for Regional Aquifer Well R-64,” plan prepared for Los Alamos National Laboratory, Los Alamos, New Mexico. (TerranearPMC 2011, 205994)

11.2 Map Data Sources

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

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

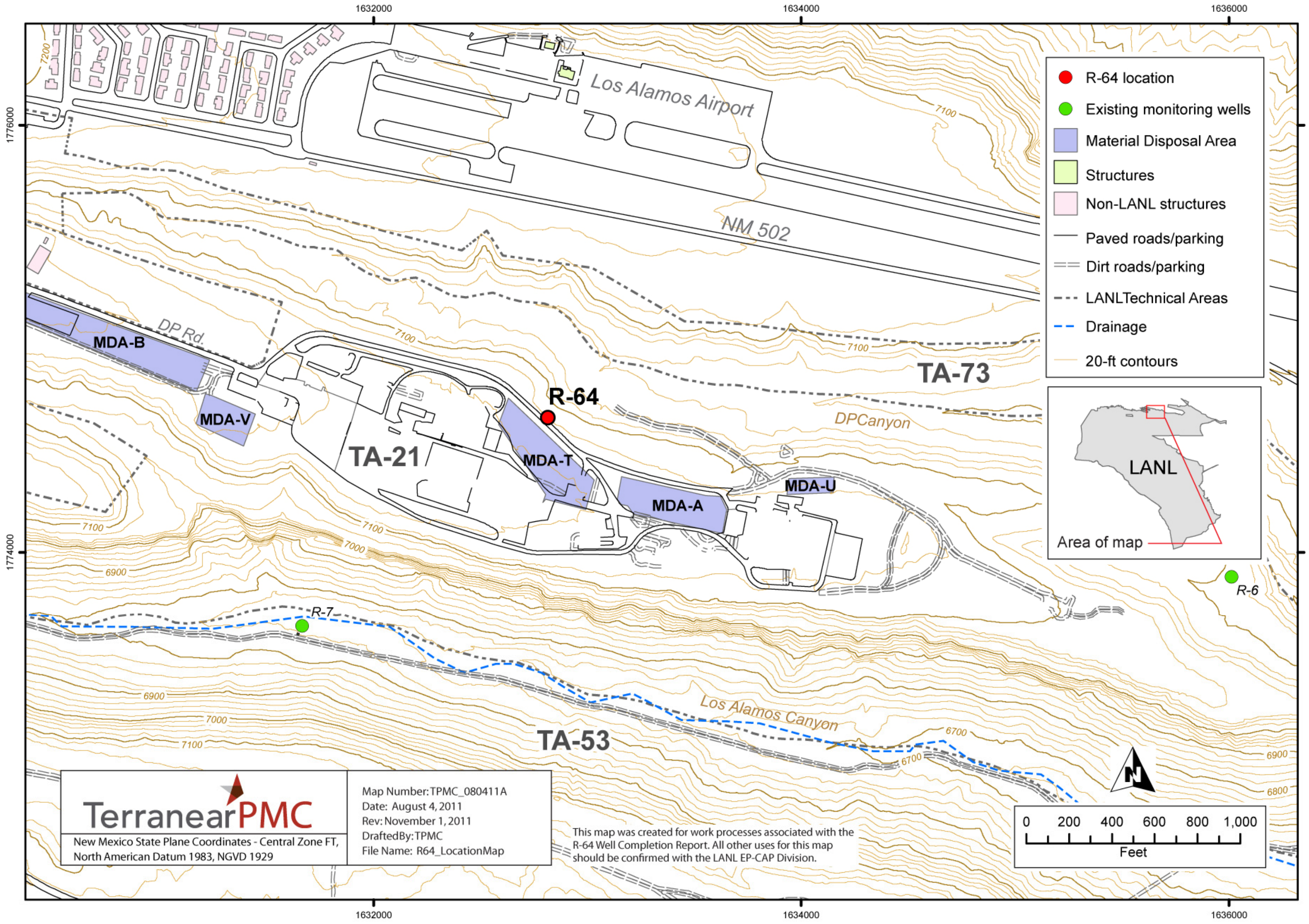
Surface Drainages, 1991; Los Alamos National Laboratory, ENV Environmental Remediation and Surveillance Program, ER2002-0591; 1:24,000 Scale Data; Unknown publication date.

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

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

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

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

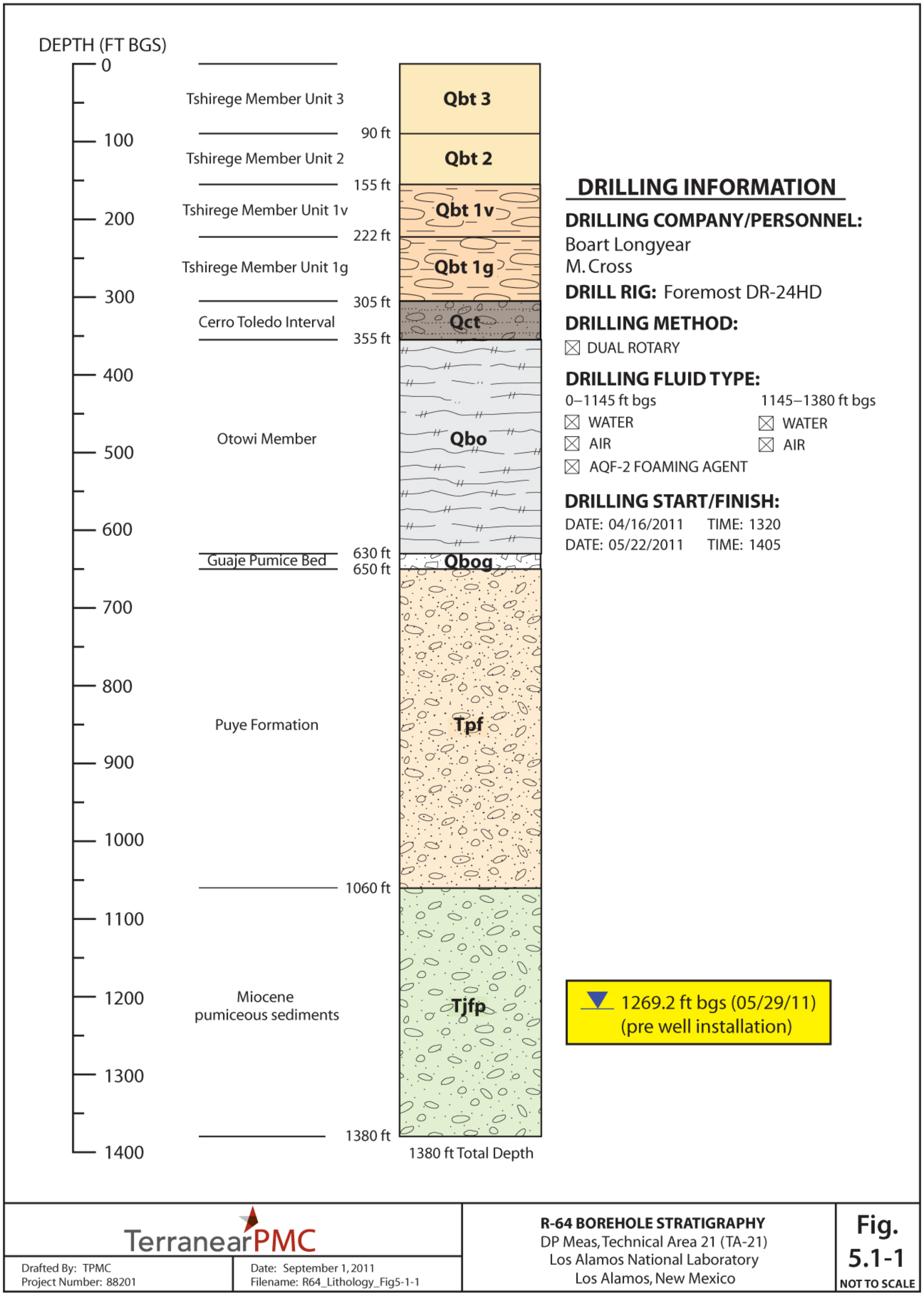


New Mexico State Plane Coordinates - Central Zone FT,
North American Datum 1983, NGVD 1929

Map Number: TPMC_080411A
Date: August 4, 2011
Rev: November 1, 2011
DraftedBy: TPMC
File Name: R64_LocationMap

This map was created for work processes associated with the R-64 Well Completion Report. All other uses for this map should be confirmed with the LANL EP-CAP Division.

Figure 1.0-1 Location of monitoring well R-64



DRILLING INFORMATION

DRILLING COMPANY/PERSONNEL:
Boart Longyear
M. Cross

DRILL RIG: Foremost DR-24HD

DRILLING METHOD:
☒ DUAL ROTARY

DRILLING FLUID TYPE:

0–1145 ft bgs	1145–1380 ft bgs
☒ WATER	☒ WATER
☒ AIR	☒ AIR
☒ AQF-2 FOAMING AGENT	

DRILLING START/FINISH:
DATE: 04/16/2011 TIME: 1320
DATE: 05/22/2011 TIME: 1405

▼ 1269.2 ft bgs (05/29/11)
(pre well installation)

TerranearPMC
Drafted By: TPMC
Project Number: 88201
Date: September 1, 2011
Filename: R64_Lithology_Fig5-1-1

R-64 BOREHOLE STRATIGRAPHY
DP Meas, Technical Area 21 (TA-21)
Los Alamos National Laboratory
Los Alamos, New Mexico

Fig.
5.1-1
NOT TO SCALE

Figure 5.1-1 Monitoring well R-64 borehole stratigraphy

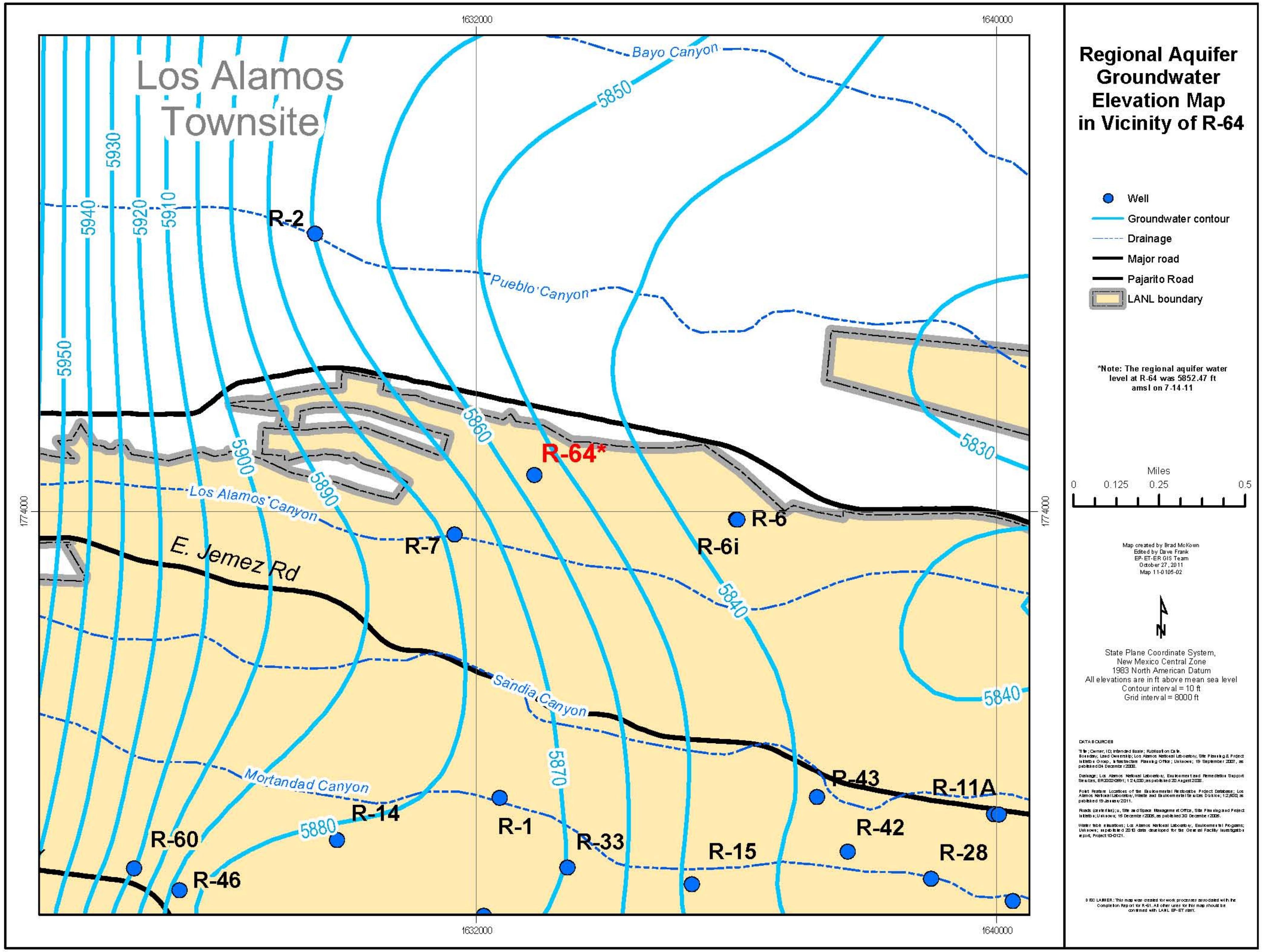
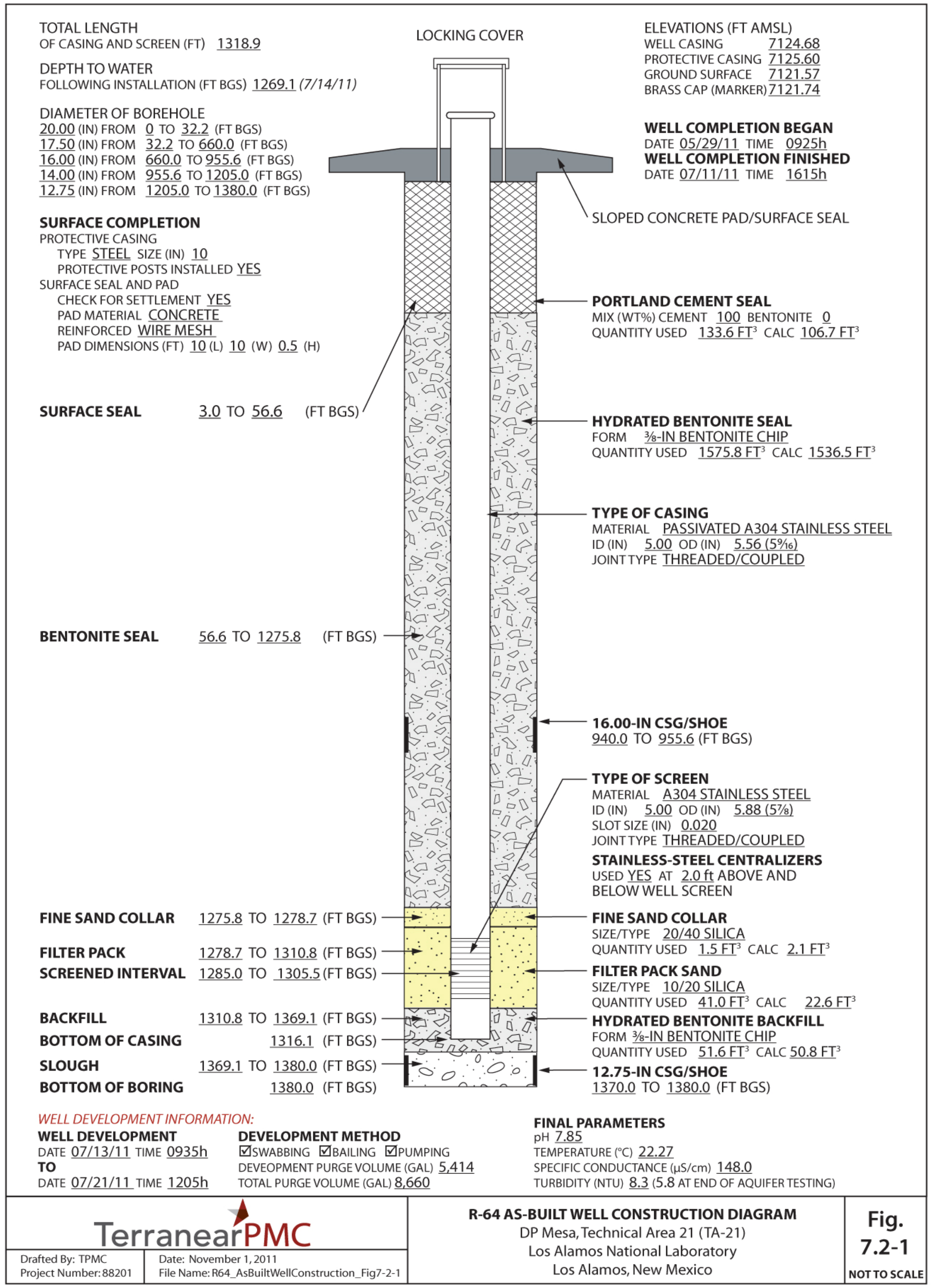


Figure 5.2-1 Regional aquifer groundwater elevations



TOTAL LENGTH
OF CASING AND SCREEN (FT) 1318.9

DEPTH TO WATER
FOLLOWING INSTALLATION (FT BGS) 1269.1 *(7/14/11)*

DIAMETER OF BOREHOLE
20.00 (IN) FROM 0 TO 32.2 (FT BGS)
17.50 (IN) FROM 32.2 TO 660.0 (FT BGS)
16.00 (IN) FROM 660.0 TO 955.6 (FT BGS)
14.00 (IN) FROM 955.6 TO 1205.0 (FT BGS)
12.75 (IN) FROM 1205.0 TO 1380.0 (FT BGS)

SURFACE COMPLETION
PROTECTIVE CASING
TYPE STEEL SIZE (IN) 10
PROTECTIVE POSTS INSTALLED YES
SURFACE SEAL AND PAD
CHECK FOR SETTLEMENT YES
PAD MATERIAL CONCRETE
REINFORCED WIRE MESH
PAD DIMENSIONS (FT) 10 (L) 10 (W) 0.5 (H)

SURFACE SEAL 3.0 TO 56.6 (FT BGS)

BENTONITE SEAL 56.6 TO 1275.8 (FT BGS)

FINE SAND COLLAR 1275.8 TO 1278.7 (FT BGS)

FILTER PACK 1278.7 TO 1310.8 (FT BGS)
SCREENED INTERVAL 1285.0 TO 1305.5 (FT BGS)

BACKFILL 1310.8 TO 1369.1 (FT BGS)
BOTTOM OF CASING 1316.1 (FT BGS)
SLOUGH 1369.1 TO 1380.0 (FT BGS)
BOTTOM OF BORING 1380.0 (FT BGS)

ELEVATIONS (FT AMSL)
WELL CASING 7124.68
PROTECTIVE CASING 7125.60
GROUND SURFACE 7121.57
BRASS CAP (MARKER) 7121.74

WELL COMPLETION BEGAN
DATE 05/29/11 TIME 0925h
WELL COMPLETION FINISHED
DATE 07/11/11 TIME 1615h

PORTLAND CEMENT SEAL
MIX (WT%) CEMENT 100 BENTONITE 0
QUANTITY USED 133.6 FT^3 CALC 106.7 FT^3

HYDRATED BENTONITE SEAL
FORM ⅜-IN BENTONITE CHIP
QUANTITY USED 1575.8 FT^3 CALC 1536.5 FT^3

TYPE OF CASING
MATERIAL PASSIVATED A304 STAINLESS STEEL
ID (IN) 5.00 OD (IN) 5.56 (5$\frac{9}{16}$)
JOINT TYPE THREADED/COUPLED

16.00-IN CSG/SHOE
940.0 TO 955.6 (FT BGS)

TYPE OF SCREEN
MATERIAL A304 STAINLESS STEEL
ID (IN) 5.00 OD (IN) 5.88 (5⅞)
SLOT SIZE (IN) 0.020
JOINT TYPE THREADED/COUPLED

STAINLESS-STEEL CENTRALIZERS
USED YES AT 2.0 ft ABOVE AND BELOW WELL SCREEN

FINE SAND COLLAR
SIZE/TYPE 20/40 SILICA
QUANTITY USED 1.5 FT^3 CALC 2.1 FT^3

FILTER PACK SAND
SIZE/TYPE 10/20 SILICA
QUANTITY USED 41.0 FT^3 CALC 22.6 FT^3

HYDRATED BENTONITE BACKFILL
FORM ⅜-IN BENTONITE CHIP
QUANTITY USED 51.6 FT^3 CALC 50.8 FT^3

12.75-IN CSG/SHOE
1370.0 TO 1380.0 (FT BGS)

WELL DEVELOPMENT INFORMATION:

WELL DEVELOPMENT
DATE 07/13/11 TIME 0935h
TO
DATE 07/21/11 TIME 1205h

DEVELOPMENT METHOD
☑SWABBING ☑BAILING ☑PUMPING
DEVEOPMENT PURGE VOLUME (GAL) 5,414
TOTAL PURGE VOLUME (GAL) 8,660

FINAL PARAMETERS
pH 7.85
TEMPERATURE (°C) 22.27
SPECIFIC CONDUCTANCE (µS/cm) 148.0
TURBIDITY (NTU) 8.3 (5.8 AT END OF AQUIFER TESTING)

TerranearPMC
Drafted By: TPMC
Project Number: 88201
Date: November 1, 2011
File Name: R64_AsBuiltWellConstruction_Fig7-2-1

R-64 AS-BUILT WELL CONSTRUCTION DIAGRAM
DP Mesa, Technical Area 21 (TA-21)
Los Alamos National Laboratory
Los Alamos, New Mexico

Fig. 7.2-1
NOT TO SCALE

Figure 7.2-1 Monitoring well R-64 as-built well construction diagram

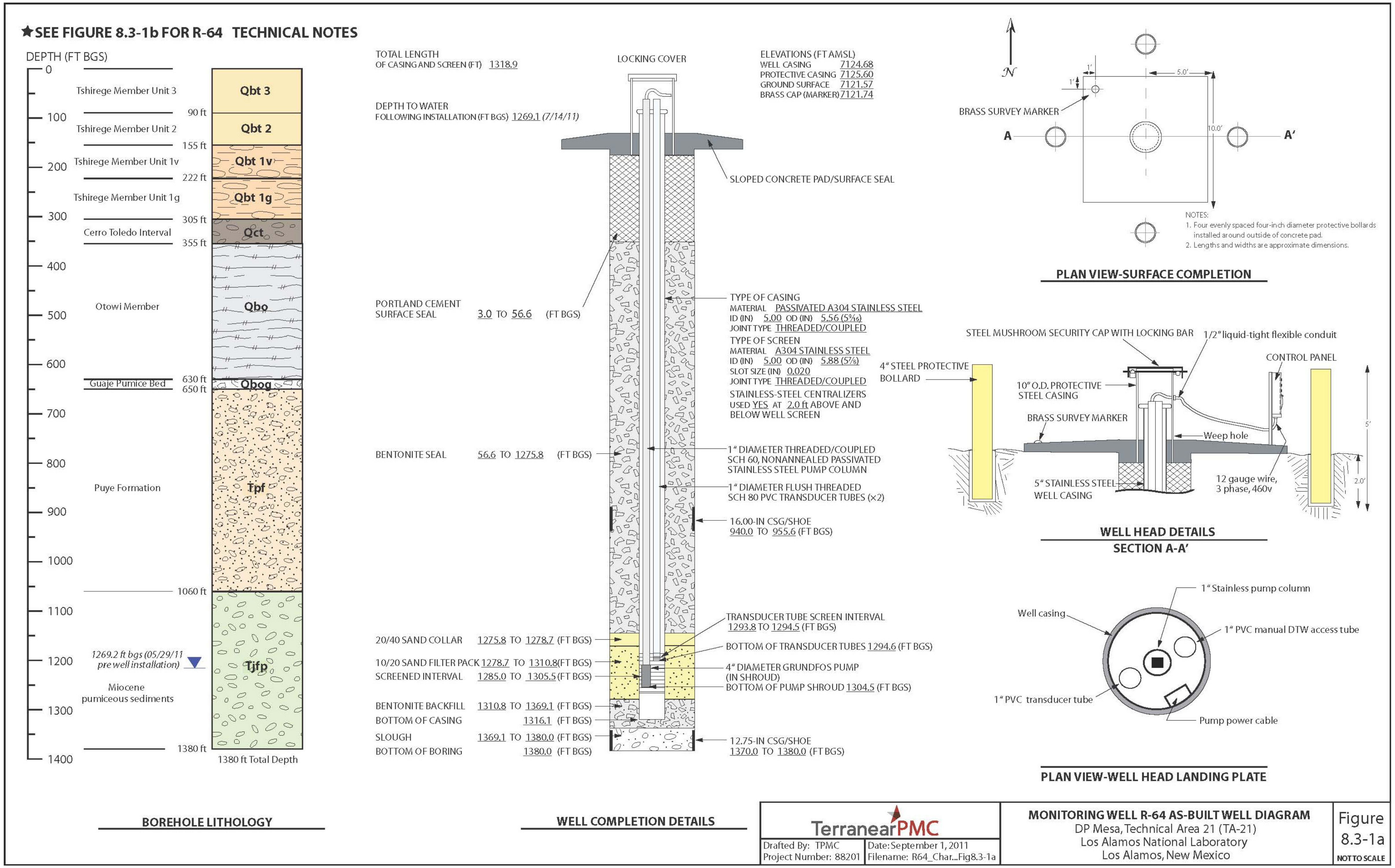
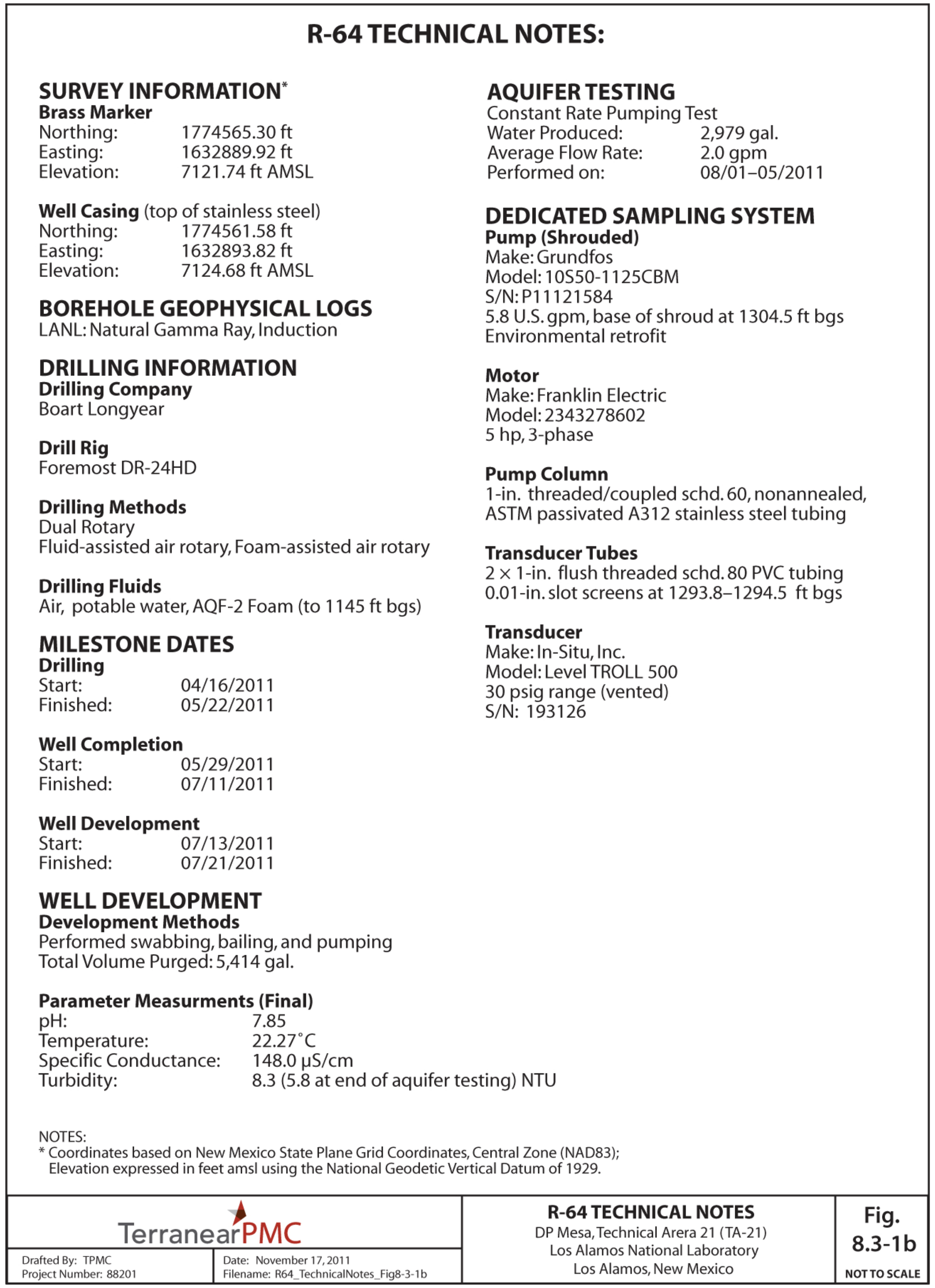


Figure 8.3-1a Monitoring well R-64 as-built diagram with borehole lithology and technical well completion details



R-64 TECHNICAL NOTES:

SURVEY INFORMATION*

Brass Marker
Northing: 1774565.30 ft
Easting: 1632889.92 ft
Elevation: 7121.74 ft AMSL

Well Casing (top of stainless steel)
Northing: 1774561.58 ft
Easting: 1632893.82 ft
Elevation: 7124.68 ft AMSL

BOREHOLE GEOPHYSICAL LOGS

LANL: Natural Gamma Ray, Induction

DRILLING INFORMATION

Drilling Company
Boart Longyear

Drill Rig
Foremost DR-24HD

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

Drilling Fluids
Air, potable water, AQF-2 Foam (to 1145 ft bgs)

MILESTONE DATES

Drilling
Start: 04/16/2011
Finished: 05/22/2011

Well Completion
Start: 05/29/2011
Finished: 07/11/2011

Well Development
Start: 07/13/2011
Finished: 07/21/2011

WELL DEVELOPMENT

Development Methods
Performed swabbing, bailing, and pumping
Total Volume Purged: 5,414 gal.

Parameter Measurments (Final)
pH: 7.85
Temperature: 22.27˚C
Specific Conductance: 148.0 μS/cm
Turbidity: 8.3 (5.8 at end of aquifer testing) NTU

AQUIFER TESTING

Constant Rate Pumping Test
Water Produced: 2,979 gal.
Average Flow Rate: 2.0 gpm
Performed on: 08/01–05/2011

DEDICATED SAMPLING SYSTEM

Pump (Shrouded)
Make: Grundfos
Model: 10S50-1125CBM
S/N: P11121584
5.8 U.S. gpm, base of shroud at 1304.5 ft bgs
Environmental retrofit

Motor
Make: Franklin Electric
Model: 2343278602
5 hp, 3-phase

Pump Column
1-in. threaded/coupled schd. 60, nonannealed,
ASTM passivated A312 stainless steel tubing

Transducer Tubes
2 × 1-in. flush threaded schd. 80 PVC tubing
0.01-in. slot screens at 1293.8–1294.5 ft bgs

Transducer
Make: In-Situ, Inc.
Model: Level TROLL 500
30 psig range (vented)
S/N: 193126

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

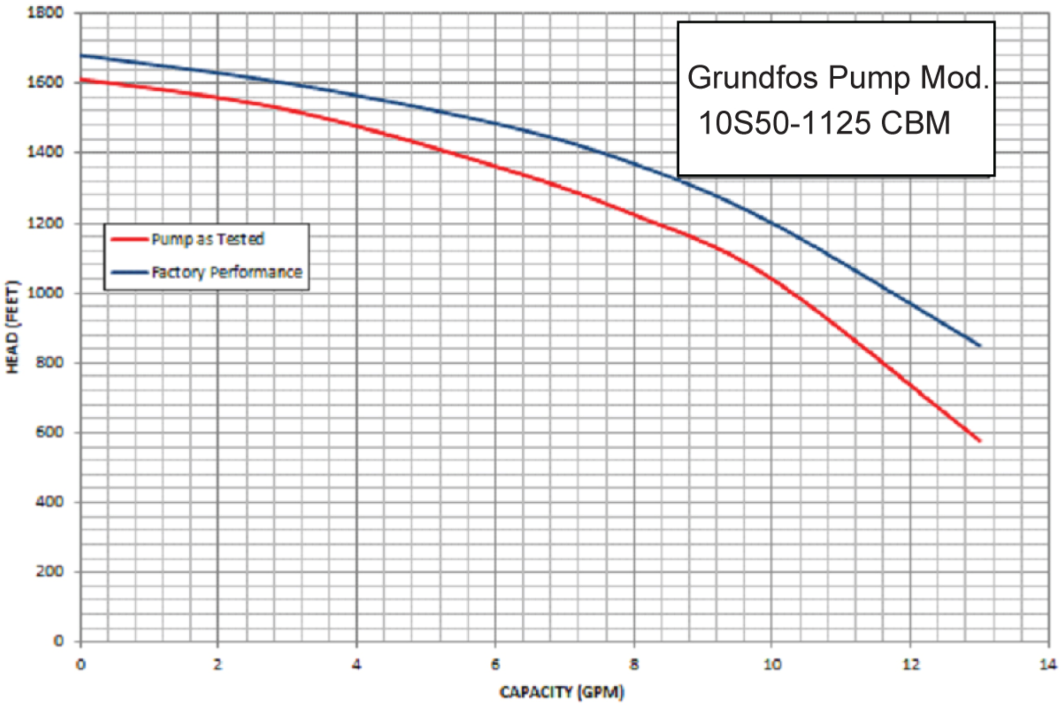
TerranearPMC
Drafted By: TPMC
Project Number: 88201
Date: November 17, 2011
Filename: R64_TechnicalNotes_Fig8-3-1b

R-64 TECHNICAL NOTES
DP Mesa, Technical Arera 21 (TA-21)
Los Alamos National Laboratory
Los Alamos, New Mexico

Fig. 8.3-1b
NOT TO SCALE

Figure 8.3-1b As-built technical notes for monitoring well R-64

R-64 PUMP CURVE:



Dedicated Retofitted Pump As Tested

GPM	HEAD (FT)
12	730
9	1140
6	1360
3	1520
0	1610

Stock (Non-retrofitted) Catalog Performance

GPM	HEAD (FT)
12	965
9	1290
6	1485
3	1600
0	1680

TerranearPMC

Drafted By: TPMC
Project Number: 88201

Date: November 1, 2011
Filename: R64_PumpCurves_Fig8-3-1c

R-64 DEDICATED PUMP PERFORMANCE CURVE
DP Mesa, Technical Arera 21 (TA-21)
Los Alamos National Laboratory
Los Alamos, New Mexico

Fig. 8.3-1c
NOT TO SCALE

Figure 8.3-1c Dedicated pump performance curve for monitoring well R-64

Table 3.1-1
Fluid Quantities Used during R-64 Drilling and Well Construction

Date	Depth Interval (ft bgs)	Water (gal.)	Cumulative Water (gal.)	AQF-2 Foam (gal.)	Cumulative AQF-2 Foam (gal.)
Drilling					
04/16/11	0–35	250	250	2	2
04/17/11	35–122	2000	2250	5	7
04/18/11	122–400	4000	6250	20	27
04/19/11	400–660	2500	8750	34	61
05/03/11	660–691	1000	9750	10	71
05/04/11	691–750	3000	12,750	10	81
05/05/11	750–847	5000	17,750	10	91
05/06/11	847–897	3000	20,750	10	101
05/07/11	897–935	3000	23,750	15	116
05/08/11	935–956	1500	25,250	10	126
05/17/11	956–993	1000	26,250	5	131
05/18/11	993–1080	3000	29,250	8	139
05/19/11	1080–1205	3000	32,250	5 (above 1145 ft bgs)	144
05/20/11	1205–1227	1000	33,250	0	144
05/21/11	1227–1315	3000	36,250	0	144
05/22/11	1315–1380	1000	37,250	0	144
Well Construction					
06/02/11	1369–1357	1000	1000	n/a*	n/a
06/04/11	1357–1320	2000	3000	n/a	n/a
06/05/11	1320–1280	2000	5000	n/a	n/a
06/06/11	1280–1258	2000	7000	n/a	n/a
06/07/11	1258–1192	2000	9000	n/a	n/a
06/08/11	1192–1125	2000	11,000	n/a	n/a
06/14/11	1125–975	4000	15,000	n/a	n/a
06/20/11	975–848	1000	16,000	n/a	n/a
06/21/11	848–597	2000	18,000	n/a	n/a
06/22/11	597–416	1750	19,750	n/a	n/a
06/23/11	416–220	2000	21,750	n/a	n/a
06/24/11	220–57	1750	23,500	n/a	n/a
07/11/11	57–3	500	24,000	n/a	n/a
Total Water Volume (gal.)					
R-64	61,250				

*n/a = Not applicable. Foam use terminated at 1145 ft bgs during drilling; none used during well construction.

Table 4.2-1
Summary of Groundwater Screening Samples Collected during Well Development and Aquifer Testing of Well R-64

Location ID	Sample ID	Date Collected	Collection Depth (ft bgs)	Sample Type	Analysis
Well Development					
R-64	WST64-11-23937	07/15/11; 1800 h	1305	Groundwater, pumped	TOC
R-64	WST64-11-23938	07/18/11; 1800 h	1305	Groundwater, pumped	TOC
R-64	WST64-11-23939	07/19/11; 1800 h	1305	Groundwater, pumped	TOC
R-64	WST64-11-23940	07/20/11; 1800 h	1305	Groundwater, pumped	TOC
Aquifer Testing					
R-64	WST64-11-23944	08/04/11; 1156 h	1295	Groundwater, pumped	TOC
R-64	WST64-11-23945	08/04/11; 1600 h	1295	Groundwater, pumped	TOC
R-64	WST64-11-23946	08/04/11; 2000 h	1295	Groundwater, pumped	TOC
R-64	WST64-11-23948	08/05/11; 0400 h	1295	Groundwater, pumped	TOC
R-64	WST64-11-23949	08/05/11; 0800 h	1295	Groundwater, pumped	TOC

Table 7.2-1
R-64 Monitoring Well Annular Fill Materials

Material	Volume
Upper surface seal: cement slurry	133.6 ft^3
Upper bentonite seal: bentonite chips	1575.8 ft^3
Fine sand collar: 20/40 silica sand	1.5 ft^3
Filter pack: 10/20 silica sand	41.0 ft^3
Backfill: bentonite chips	51.6 ft^3

Table 8.5-1
R-64 Survey Coordinates

Identification	Northing	Easting	Elevation
R-64 brass cap embedded in pad	1774565.30	1632889.92	7121.74
R-64 ground surface near pad	1774566.90	1632889.54	7121.57
R-64 top of stainless-steel well casing	1774561.58	1632893.82	7124.68
R-64 top of 10-in. protective casing	1774561.81	1632893.45	7125.60

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, Development, and Sampling System Installation at R-64

Location ID	Sample ID	Date Collected	Description	Sample Type
R-64	WST64-11-9634	04/18/11	Drill cuttings—1st VOC[a] sample	Solids
R-64	WST64-11-9637(FTB[b])	04/18/11	Drill cuttings—1st VOC sample	Solids
R-64	WST64-11-9635	05/04/11	Drill cuttings—2nd VOC sample	Solids
R-64	WST64-11-9638(FTB)	05/04/11	Drill cuttings—2nd VOC sample	Solids
R-64	WST64-11-9636	05/23/11	Drill cuttings—3rd VOC sample	Solids
R-64	WST64-11-9639(FTB)	05/23/11	Drill cuttings—3rd VOC sample	Solids
R-64	WST64-11-9841	05/25/11	Drill cuttings suite	Solids
R-64	WST64-11-9764(UF[c])	06/01/11	Decon well casing not previously used at the Laboratory	Liquid
R-64	WST64-11-9757(F[d])	06/01/11	Decon well casing not previously used at the Laboratory	Liquid
R-64	WST64-11-9771(FD[e])	06/01/11	Decon well casing not previously used at the Laboratory	Liquid
R-64	WST64-11-9778(FTB)	06/01/11	Decon well casing not previously used at the Laboratory	Liquid
R-64	WST64-11-9763(UF)	06/06/11	Decon drill rig	Liquid
R-64	WST64-11-9756(F)	06/06/11	Decon drill rig	Liquid
R-64	WST64-11-9770(FD)	06/06/11	Decon drill rig	Liquid
R-64	WST64-11-9777(FTB)	06/06/11	Decon drill rig	Liquid
R-64	WST64-11-14106(UF)	06/13/11	R-64 drill fluids—pit # 2 (East Pit)	Liquid
R-64	WST64-11-14107(FD)	06/13/11	R-64 drill fluids—pit # 2 (East Pit)	Liquid
R-64	WST64-11-14105(F)	06/13/11	R-64 drill fluids—pit # 2 (East Pit)	Liquid
R-64	WST64-11-14108(FTB)	06/13/11	R-64 drill fluids—pit # 2 (East Pit)	Liquid
R-64	WST64-11-12194 (UF)	07/25/11	Development water	Liquid
R-64	WST64-11- 12193(F)	07/25/11	Development water	Liquid
R-64	WST64-11-12195(FD)	07/25/11	Development water	Liquid
R-64	WST64-11-12196(FTB)	07/25/11	Development water	Liquid
R-64	WST64-11-10091(F)	07/26/11	R-64 drill fluids—pit # 1 (West Pit)	Liquid
R-64	WST64-11-10092(UF)	07/26/11	R-64 drill fluids—pit # 1 (West Pit)	Liquid
R-64	WST64-11-10093(FD)	07/26/11	R-64 drill fluids—pit # 1 (West Pit)	Liquid
R-64	WST64-11-10094(FTB)	07/26/11	R-64 drill fluids—pit # 1 (West Pit)	Liquid

Table 8.6-1 (continued)

Location ID	Sample ID	Date Collected	Description	Sample Type
R-64	WST64-11-9765(UF)	08/11/11	R-64 Decon: downhole equipment (pump and pipe used for dev. and aquifer test)	Liquid
R-64	WST64-11-9758(F)	08/11/11	R-64 Decon: downhole equipment (pump and pipe used for dev. and aquifer test)	Liquid
R-64	WST64-11-9772(FD)	08/11/11	R-64 Decon: downhole equipment (pump and pipe used for dev. and aquifer test)	Liquid
R-64	WST64-11-9779(FTB)	08/11/11	R-64 Decon: downhole equipment (pump and pipe used for dev. and aquifer test)	Liquid
R-64	WST64-11-9766(UF)	08/16/11	R-64 Decon: permanent sampling system	Liquid
R-64	WST64-11-9759(F)	08/16/11	R-64 Decon: permanent sampling system	Liquid
R-64	WST64-11-9773(FD)	08/16/11	R-64 Decon: permanent sampling system	Liquid
R-64	WST64-11-9780(FTB)	08/16/11	R-64 Decon: permanent sampling system	Liquid

[a] VOC = Volatile organic compound.

[b] FTB = Field trip blank.

[c] UF = Unfiltered.

[d] F = Filtered.

[e] FD = Field duplicate.

Appendix A

Borehole R-64 Lithologic Log

Borehole Identification (ID): R-64	**Technical Area (TA):** 21	**Page :** 1 of 12
Drilling Company: Boart Longyear Company	**Start Date/Time:** 4/16/11; 1320	**End Date/Time:** 5/22/11; 1405
Drilling Method : Dual Rotary	**Machine:** Foremost DR24 HD	**Sampling Method OD:** Grab
Ground Elevation: 7121.57 ft amsl		**Total Depth:** 1380 ft
Drillers: M. Cross	**Site Geologists:** Travis Naibert, Ryan McGuill, Andy Miller	

Depth (ft bgs)	**Lithologic Description**	**Lithologic Symbol**	**Notes**
0–10	**UNIT 3 OF THE TSHIREGE MEMBER OF THE BANDELIER TUFF:** Tuffaceous clasts—pale-orange/gray (10YR 8/2), crystal-bearing, lithic-bearing tuff clasts and rounded clasts (quartzite, dacite) in well-pad base course. 0'–10' WR: 80–90% pale-orange (10YR 8/2), crystal-rich tuff clasts; 10–20% subrounded to subangular clasts of quartzite imported as base-course gravels for drill-pad construction. +35F: 95–100% quartz and sanidine crystals; <5% tuff fragments.	Qbt 3	Note: Drill cuttings for descriptive analysis were collected at 5-ft intervals from ground surface to borehole TD at 1380 ft bgs. Unit 3 of the Tshirege Member of the Bandelier Tuff (Qbt 3), encountered from 0 to 90 ft bgs, is 90 ft thick.
10–35	Rhyolitic tuff—pale-orange (10YR 8/2) to white (N9) tuff fragments, strongly welded, moderately indurated, crystal rich, lithic poor. 10'–35' WR: 20–40% powdered ash-flow tuff (i.e., ignimbrite); 30–50% quartz and sanidine crystals; 10–30% devitrified tuff fragments; trace lithic clasts. +10F: 75–95% crystal-rich, lithic-poor ash-flow tuff fragments; 5–25% quartz and sanidine crystals. +35F: 95–100% quartz and sanidine crystals; <5% tuff fragments; trace dacite lithic clasts.	Qbt 3	
35–90	Rhyolitic tuff—pale-orange (10YR 8/2) to white (N9) tuff fragments, moderately welded grading downwards to poorly welded, moderately indurated, very crystal rich, lithic poor. 35'– 90' WR: 20–40% powdered ash-flow tuff (i.e., ignimbrite); 30–70% quartz and sanidine crystals; 10–20% devitrified tuff fragments; trace lithic clasts. +10F: 90–95% quartz and sanidine crystals; 5–10% crystal-rich, lithic-poor ash-flow tuff fragments; trace lithic clasts. +35F: 95–100% quartz and sanidine crystals; <5% tuff fragments; trace dacite lithic clasts.	Qbt 3	The Qbt 3/Qbt 2 contact, estimated at 90 ft bgs, is based on examination of drill cuttings.
90–110	**UNIT 2 OF THE TSHIREGE MEMBER OF THE BANDELIER TUFF:** Rhyolitic tuff—brownish-gray (5YR 4/1) to gray (N8 to N6) tuff fragments, strongly welded, crystal rich, lithic poor. 90'–110' WR/+10F/+35F: 60–80% strongly welded, crystal-rich, lithic-poor, devitrified ash-flow tuff fragments; 20-40% quartz and sanidine crystals (more abundant from 100 to 105 ft bgs); trace dacite lithics.	Qbt 2	Unit 2 of the Tshirege Member of the Bandelier Tuff (Qbt 2), encountered from 90 to 155 ft bgs, is estimated to be 65 ft thick.

Borehole Identification (ID): R-64	**Technical Area (TA):** 21	**Page :** 2 of 12
Drilling Company: Boart Longyear Company	**Start Date/Time:** 4/16/11; 1320	**End Date/Time:** 5/22/11; 1405
Drilling Method : Dual Rotary	**Machine:** Foremost DR24 HD	**Sampling Method OD:** Grab
Ground Elevation: 7121.57 ft amsl		**Total Depth:** 1380 ft
Drillers: M. Cross	**Site Geologists:** Travis Naibert, Ryan McGuill, Andy Miller	

Depth (ft bgs)	**Lithologic Description**	**Lithologic Symbol**	**Notes**
110–145	Rhyolitic tuff—very light- to medium-gray (N8 to N6) tuff fragments, strongly welded, crystal rich, lithic poor. 110'–145' WR/+10F: 60–80% crystal-rich ash-flow tuff fragments and powdered tuff; 20–40% quartz and sanidine crystals; <5% rhyolite and dacite lithic clasts. +35F: 75–95% quartz and sanidine crystals; 5–25% ash-flow tuff clasts; trace lithic clasts.	Qbt 2	
145–150	Rhyolitic tuff—very light- to medium-gray (N8 to N6) tuff fragments, crystal rich, lithic poor. 145'–150' WR: 70-80% powdered ash flow tuff; 20-30% quartz and sanidine crystals. +35F >99% quartz and sanidine crystals; trace lithic fragments; trace devitrified ash-flow tuff fragments.	Qbt 2	Note: +10F size fraction was not collected for 145 to 150 ft bgs.
150–155	Rhyolitic tuff—white to light-gray (N9 to N7) tuff fragments, moderately welded, crystal rich. 150'–155' WR/+10F: 70–80% crystal-rich ash-flow tuff fragments and powdered tuff; 20–25% quartz and sanidine crystals; 5–10% rhyolite and dacite lithic clasts. +35F: 75–85% quartz and sanidine crystals; 15–25% ash-flow tuff clasts; trace lithic clasts.	Qbt 2	The Qbt 2/Qbt 1v contact, estimated at 155 ft bgs, is based on the natural gamma geophysical log and examination of drill cuttings.
155–165	**UNIT 1V OF THE TSHIREGE MEMBER OF THE BANDELIER TUFF:** Rhyolitic tuff—light-gray (N8 to N7) tuff fragments, moderately to poorly welded. 155'–165' WR/+10F: 40–60% light-gray ash-flow tuff fragments; 30–60% rhyolitic and dacitic lithic clasts; <10% quartz and sanidine crystals. +35F: 80–90% quartz and sanidine crystals; 10–15% devitrified ash-flow tuff clasts; 5% lithic clasts.	Qbt 1v	Unit 1v of the Tshirege Member of the Bandelier Tuff (Qbt 1v), encountered from 155 to 222 ft bgs, is 67 ft thick.
165–195	Rhyolitic tuff—light-gray (N8 to N7) tuff fragments, poorly welded, crystal rich. 165'–195' +10F: 10–30% light-gray ash-flow tuff fragments; 20–30% rhyolitic and dacitic lithic clasts; 40–70% quartz and sanidine crystals. +35F: 80–90% quartz and sanidine crystals; 5–20% lithic clasts; <5% ash-flow tuff clasts.	Qbt 1v	

Borehole Identification (ID): R-64	**Technical Area (TA):** 21	**Page :** 3 of 12
Drilling Company: Boart Longyear Company	**Start Date/Time:** 4/16/11; 1320	**End Date/Time:** 5/22/11; 1405
Drilling Method : Dual Rotary	**Machine:** Foremost DR24 HD	**Sampling Method OD:** Grab
Ground Elevation: 7121.57 ft amsl		**Total Depth:** 1380 ft
Drillers: M. Cross	**Site Geologists:** Travis Naibert, Ryan McGuill, Andy Miller	

Depth (ft bgs)	**Lithologic Description**	**Lithologic Symbol**	**Notes**
195–200	Rhyolitic tuff—light-gray (N7) and pinkish-gray (5YR 8/1) tuff fragments, poorly welded, crystal rich. 195'–200' +10F: 10–20% light-gray ash-flow tuff fragments; 80–90% rhyolitic and dacitic lithic clasts. +35F: 90–95% quartz and sanidine crystals; <5% devitrified ash-flow tuff clasts; trace pumice and lithic fragments.	Qbt 1v	
200–222	Rhyolitic tuff—pinkish gray (5YR 8/1), poorly welded, crystal rich, moderately pumiceous. 200'–222' +10F: 75–85% light pinkish-gray, pumiceous, crystal-bearing ash-flow tuff fragments; 15–25% rhyolitic and dacitic lithic clasts. +35F: 40–60% quartz and sanidine crystals; 40–50% pumiceous ash-flow tuff clasts; 5–15% lithic fragments.	Qbt 1v	The Qbt 1v/Qbt 1g contact, estimated at 222 ft bgs, is based on natural gamma geophysical log and vitric pumices in drill cuttings.
222–240	**UNIT 1G OF THE TSHIREGE MEMBER OF THE BANDELIER TUFF:** Rhyolitic tuff—grayish orange (7.5YR 8/2), poorly welded, pumiceous, crystal rich. 222'–240' +10F: 60–65% orange-gray, pumiceous, crystal-bearing ash-flow tuff fragments; 20–30% glassy pumices; 5–20% lithic clasts. +35F: 70–80% pumiceous ash-flow tuff clasts; 10–20% quartz and sanidine crystals; 10–20% lithic fragments.	Qbt 1g	Unit 1g of the Tshirege Member of the Bandelier Tuff (Qbt 1g), encountered from 222 to 305 ft bgs, is 83 ft thick.
240–260	Rhyolitic tuff—grayish orange (7.5YR 8/2), poorly welded, pumiceous, crystal rich. 240'–260' +10F: 90–100% orange glassy pumices; 0–10% lithic clasts. +35F: 70–80% quartz and sanidine crystals; 20–30% glassy pumice fragments; trace lithic clasts.	Qbt 1g	
260–305	Rhyolitic tuff—grayish orange (7.5YR 8/2) to white (N9), poorly welded, pumiceous, crystal rich. 260'–305' +10F: 90–100% glassy pumices; 0–10% lithic clasts. +35F: 50–70% quartz and sanidine crystals; 30–50% glassy pumice fragments; trace lithic clasts.	Qbt 1g	The Qbt 1g/Qct contact, estimated at 305 ft bgs, is based on natural gamma geophysical log.

Borehole Identification (ID): R-64	**Technical Area (TA):** 21	**Page :** 4 of 12
Drilling Company: Boart Longyear Company	**Start Date/Time:** 4/16/11; 1320	**End Date/Time:** 5/22/11; 1405
Drilling Method : Dual Rotary	**Machine:** Foremost DR24 HD	**Sampling Method OD:** Grab
Ground Elevation: 7121.57 ft amsl		**Total Depth:** 1380 ft
Drillers: M. Cross	**Site Geologists:** Travis Naibert, Ryan McGuill, Andy Miller	

Depth (ft bgs)	Lithologic Description	Lithologic Symbol	Notes
305–320	**CERRO TOLEDO INTERVAL:** Pumice clasts—grayish orange (7.5YR 8/2) to white (N9). 305'–320' +10F: 100% glassy pumices. +35F: 40–50% quartz and sanidine crystals; 50–60% glassy pumice fragments; trace lithic clasts.	Qct	The Cerro Toledo interval (Qct), encountered from 305 to 355 ft bgs, is 50 ft thick.
320–350	Pumice clasts and rounded volcaniclastic sediments—grayish-orange (7.5YR 8/2) to white (N9) pumices and subrounded or broken clasts of dacite and rhyolite. 320'–350' +10F: 70–90% glassy pumices; 10–30% gray dacite and red and gray rhyolite clasts. +35F: 30–40% quartz and sanidine crystals; 40–60% glassy pumice fragments; 20–30% lithic clasts.	Qct	
350–355	Pumice clasts—grayish orange (7.5YR 8/2) to white (N9). 350'–355' +10F: 100% glassy pumices. +35F: 99% glassy pumice fragments; 1% volcaniclastic sediments.	Qct	The Qct/Qbo contact, estimated at 355 ft bgs, is based on natural gamma geophysical log and examination of drill cuttings.
355–365	**OTOWI MEMBER OF THE BANDELIER TUFF:** Pumiceous tuff—pale-orange (10YR 8/2), glassy, pumice clasts containing abundant red, altered pyroxenes (?). 355'–365' +10F: 100% orange, glassy, crystal-bearing pumices; trace dacite fragments. +35F: 70–90% glassy pumice fragments; 10–30% quartz and sanidine crystals; trace lithic fragments.	Qbo	The Otowi Member of the Bandelier Tuff (Qbo), encountered from 355 to 630 ft bgs, is 275 ft thick.
365–385	Pumiceous tuff—pale-orange (10YR 8/2), glassy, pumice clasts containing abundant red, altered pyroxenes (?). 365–385' +10F: 100% orange, glassy, crystal-bearing pumices; trace dacite fragments. +35F: 50–60% glassy pumice fragments; 40–50% quartz and sanidine crystals; 1–2% lithic fragments.	Qbo	
385–400	Pumiceous tuff—pale-orange (10YR 8/2), glassy, pumice clasts containing abundant red, altered pyroxenes (?). 385'–400' +10F: 100% orange, glassy, crystal-bearing pumices; trace dacite fragments. +35F: 40–60% glassy pumice fragments; 40–55% quartz and sanidine crystals; 5% lithic fragments.	Qbo	

Borehole Identification (ID): R-64	**Technical Area (TA):** 21	**Page :** 5 of 12
Drilling Company: Boart Longyear Company	**Start Date/Time:** 4/16/11; 1320	**End Date/Time:** 5/22/11; 1405
Drilling Method : Dual Rotary	**Machine:** Foremost DR24 HD	**Sampling Method OD:** Grab
Ground Elevation: 7121.57 ft amsl		**Total Depth:** 1380 ft
Drillers: M. Cross	**Site Geologists:** Travis Naibert, Ryan McGuill, Andy Miller	

Depth (ft bgs)	**Lithologic Description**	**Lithologic Symbol**	**Notes**
400–415	Ash-flow tuff—pale-orange (10YR 8/2), crystal-rich powdered tuff. 385'–400' WR: 60% powdered tuff; 40% quartz and sanidine crystals. +10F: few to no returns, including few pumice clasts. +35F: 70–80% quartz and sanidine crystals; 20–30% pumice fragments.	Qbo	
415–440	Pumiceous tuff—pale-orange (10YR 8/2), glassy, pumice clasts containing abundant red, altered pyroxenes (?). 415'–440' +10F: 100% rounded, orange, glassy, crystal-bearing pumices. +35F: 50–60% glassy pumice fragments; 30–45% quartz and sanidine crystals; 5–10% lithic fragments.	Qbo	
440–470	Pumiceous tuff—pale-orange (10YR 8/2), crystal-rich powdered tuff with abundant pumice clasts. 440'–470' WR: 50% powdered tuff; 30% quartz and sanidine crystals; 20% pumice clasts. +10F: 80–90% pumice clasts; 5–15% volcanic lithic clasts; <5% quartz crystals. +35F: 60–80% quartz and sanidine crystals; 15–30% pumice fragments; 5–10% volcanic lithic clasts.	Qbo	
470–535	Pumiceous tuff—pale-orange (10YR 8/2), glassy, pumice clasts and dacite lithic fragments. 470'–535' +10F: 40–60% rounded, orange, glassy, crystal-bearing pumices; 40–60% gray or reddish-gray dacite lithic clasts. +35F: 60–70% quartz and sanidine crystals; 20–35% glassy pumice fragments; 5–10% lithic fragments.	Qbo	
535–575	Pumiceous tuff—pale orange (10YR 8/2), glassy, pumice clasts and dacite lithic fragments. 535'– 575' +10F: 20-50% orange, glassy, crystal-bearing pumices; 50-80% gray or reddish gray dacite lithic clasts. +35F: 60-70% quartz and sanidine crystals; 20-35% glassy pumice fragments; 5-10% lithic fragments.	Qbo	

Borehole Identification (ID): R-64	**Technical Area (TA):** 21	**Page :** 6 of 12
Drilling Company: Boart Longyear Company	**Start Date/Time:** 4/16/11; 1320	**End Date/Time:** 5/22/11; 1405
Drilling Method : Dual Rotary	**Machine:** Foremost DR24 HD	**Sampling Method OD:** Grab
Ground Elevation: 7121.57 ft amsl		**Total Depth:** 1380 ft
Drillers: M. Cross	**Site Geologists:** Travis Naibert, Ryan McGuill, Andy Miller	

Depth (ft bgs)	Lithologic Description	Lithologic Symbol	Notes
575–585	Pumiceous tuff—pale-orange (10YR 8/2), glassy, pumice clasts and dacite lithic fragments. 575'–585' +10F: 40–60% orange, glassy, crystal-bearing pumices; 40–60% gray or reddish-gray dacite lithic clasts. +35F: 50–60% quartz and sanidine crystals; 30–45% glassy pumice fragments; 5–10% lithic fragments.	Qbo	
585–630	Pumiceous tuff—white (N9), glassy, pumice clasts and gray (N6) to reddish-gray (5YR 4/1) dacite lithic fragments. 585'–630' +10F: 40–70% white, glassy, crystal-bearing pumices; 30–60% varicolored dacite lithic clasts. +35F: 45–55% quartz and sanidine crystals; 30–45% glassy pumice fragments; 10–15% lithic fragments.	Qbo	The Qbo/Qbog contact, estimated at 630 ft bgs, is based on natural gamma geophysical log.
630–650	**GUAJE PUMICE BED OF THE OTOWI MEMBER OF THE BANDELIER TUFF:** Pumiceous tuff—white (N9), glassy, pumice clasts and gray (N6) lithic fragments. 630'–650' +10F: 40–70% white, glassy, crystal-bearing pumices; 30–60% varicolored dacite lithic clasts. +35F: 40–50% quartz and sanidine crystals; 50–60% white pumice fragments; <5% lithic fragments.	Qbog	The Guaje Pumice Bed of the Otowi Member of the Bandelier Tuff (Qbog), encountered from 630 to 650 ft bgs, is 20 ft thick. The Qbog/Tpf contact, estimated at 650 ft bgs, is based on natural gamma geophysical log.
650–670	**PUYE FORMATION:** Pumice and dacite clasts—white (N9) to pale-orange pumice clasts and gray (N6) to reddish-gray (5YR 4/1) dacite lithic clasts. 650'–670' +10F: 50–70% pumice clasts; 30–50% dacite clasts; <5% angular quartz and sanidine grains. +35F: 30–50% pumice clasts; 20–40% dacite clasts; 10–40% quartz and feldspar grains.	Tpf	The Puye Formation (Tpf), encountered from 650 to 1060 ft bgs, is 510 ft thick. Note: larger clast sizes and more returns collected between 665 and 670 ft bgs.
670–700	Volcaniclastic sediments—varicolored grains of dacite and rhyolite with minor glassy pumice clasts. 670'–700' +10F: 85–90% subangular grains (up to 20 mm) of dacite and rhyolite; 10–15% subrounded pumice clasts; trace quartz grains. +35F: 80–90% dacite grains; 10–15% pumice clasts; 5–10% quartz and feldspar grains.	Tpf	Note: grains become more rounded below 690 ft bgs.

Borehole Identification (ID): R-64	**Technical Area (TA):** 21	**Page :** 7 of 12
Drilling Company: Boart Longyear Company	**Start Date/Time:** 4/16/11; 1320	**End Date/Time:** 5/22/11; 1405
Drilling Method : Dual Rotary	**Machine:** Foremost DR24 HD	**Sampling Method OD:** Grab
Ground Elevation: 7121.57 ft amsl		**Total Depth:** 1380 ft
Drillers: M. Cross	**Site Geologists:** Travis Naibert, Ryan McGuill, Andy Miller	

Depth (ft bgs)	**Lithologic Description**	**Lithologic Symbol**	**Notes**
700–720	Volcaniclastic sediments—varicolored grains of dacite and rhyolite with minor glassy pumice clasts. 700'–720' +10F: 90–95% subrounded to rounded grains (up to 5 mm) of dacite and rhyolite; 5–10% subrounded pumice clasts; trace quartz grains. +35F: 80–90% dacite grains; 10–15% pumice clasts; 5–10% quartz and feldspar grains.	Tpf	
720–735	Volcaniclastic sediments—varicolored grains of dacite and rhyolite. 720'–735' +10F: 95–100% subrounded to rounded grains (5 to 10 mm) of dacite and rhyolite; <5% quartz grains. +35F: 90–95% dacite grains; 5–10% quartz and feldspar grains.	Tpf	
735–750	Volcaniclastic sediments—varicolored grains of dacite and rhyolite. 735'–750' +10F: 95–100% subrounded to rounded grains (up to 20 mm) of dacite and rhyolite; <5% quartz grains. +35F: 90–95% dacite grains; 5–10% quartz and feldspar grains.	Tpf	
750–770	Volcaniclastic sediments—varicolored grains of dacite and rhyolite. 750'–770' +10F: 90–95% subrounded to rounded grains (mostly coarse-sand size) of dacite and rhyolite; 5–10% well-cemented sandstone clasts; trace quartz and biotite grains. +35F: 80–90% dacite grains; 10–15% pumice clasts; 5–10% quartz and feldspar grains.	Tpf	
770–785	Volcaniclastic sediments—varicolored grains of dacite and rhyolite. 770'–785' +10F: 90–95% subrounded to rounded grains (more gravel than above) of dacite and rhyolite; 5–10% well-cemented sandstone clasts; trace quartz and biotite grains. +35F: 80–90% dacite grains; 10–15% pumice clasts; 5–10% quartz and feldspar grains.	Tpf	

Borehole Identification (ID): R-64	**Technical Area (TA):** 21	**Page :** 8 of 12
Drilling Company: Boart Longyear Company	**Start Date/Time:** 4/16/11; 1320	**End Date/Time:** 5/22/11; 1405
Drilling Method : Dual Rotary	**Machine:** Foremost DR24 HD	**Sampling Method OD:** Grab
Ground Elevation: 7121.57 ft amsl		**Total Depth:** 1380 ft
Drillers: M. Cross	**Site Geologists:** Travis Naibert, Ryan McGuill, Andy Miller	

Depth (ft bgs)	**Lithologic Description**	**Lithologic Symbol**	**Notes**
785–845	Volcaniclastic sediments—varicolored grains of dacite and rhyolite. 785’–845’ +10F: 90–95% subrounded to subangular grains (mainly gravel up to 5 mm) of dacite and rhyolite; 5–10% well-cemented sandstone clasts; trace quartz and biotite grains. +35F: 80–90% dacite grains; 10–15% pumice clasts; 5–10% quartz and feldspar grains.	Tpf	
845–855	Volcaniclastic sediments—varicolored grains of dacite and rhyolite. 845’–855’ +10F: 60–75% subangular grains (mainly gravel up to 5 mm) of dacite and rhyolite; 25–40% well-cemented sandstone clasts; trace quartz and biotite grains. +35F: 70–80% dacite grains; 5% pumice clasts; 20–25% quartz and feldspar grains.	Tpf	
855–920	Volcaniclastic sediments—varicolored grains of dacite and rhyolite. 855’–920’ +10F: 95–100% subangular grains (gravel up to 10 mm) of dacite and rhyolite; 5–10% well-cemented sandstone clasts; trace quartz and biotite grains. +35F: 95–100% dacite grains; <5% quartz and feldspar grains.	Tpf	Note: The interval 895 to 910 ft bgs contains more sand-sized grains.
920–935	Volcaniclastic sediments—varicolored grains of dacite and rhyolite. 920’–935’ +10F: 80–90% subangular grains (sand dominated) of dacite and rhyolite; 10–20% well-cemented sandstone clasts; trace quartz and biotite grains. +35F: 95–100% dacite grains; <5% quartz and feldspar grains.	Tpf	
935–950	Volcaniclastic sediments—varicolored grains of dacite and rhyolite. 935’–950’ +10F: 98–100% subangular grains (sand dominated) of dacite and rhyolite; <2% well-cemented sandstone clasts; trace quartz grains. +35F: 95–100% dacite grains; <5% quartz and feldspar grains.	Tpf	

Borehole Identification (ID): R-64	**Technical Area (TA):** 21	**Page :** 9 of 12
Drilling Company: Boart Longyear Company	**Start Date/Time:** 4/16/11; 1320	**End Date/Time:** 5/22/11; 1405
Drilling Method : Dual Rotary	**Machine:** Foremost DR24 HD	**Sampling Method OD:** Grab
Ground Elevation: 7121.57 ft amsl		**Total Depth:** 1380 ft
Drillers: M. Cross	**Site Geologists:** Travis Naibert, Ryan McGuill, Andy Miller	

Depth (ft bgs)	**Lithologic Description**	**Lithologic Symbol**	**Notes**
950–995	Volcaniclastic sediments—varicolored grains of dacite and rhyolite. 950’–995’ +10F: 98–100% subangular grains (dominated by 2–5 mm gravel) of dacite and rhyolite; <2% well-cemented sandstone clasts; trace quartz grains. +35F: 95–100% dacite grains; <5% quartz and feldspar grains; trace cemented sandstone clasts.	Tpf	
995–1000	Volcaniclastic sediments—varicolored grains of dacite and rhyolite, and a few well-rounded pumice clasts. 995’–1000’ +10F: 95–98% subangular grains (dominated by 2–5 mm gravel) of dacite and rhyolite; 2–5% well-rounded, quartz- and biotite-bearing pumice clasts; trace quartz grains. +35F: 95–100% dacite grains; <5% quartz and feldspar grains.	Tpf	
1000–1035	Volcaniclastic sediments—varicolored grains of dacite and rhyolite. Gravel-dominated interval with less sand than above. 1000’–1035’ +10F: 98–100% subangular grains (gravel up to 25 mm) of dacite and rhyolite; <2% well-cemented sandstone clasts; trace quartz grains. +35F: 95–100% dacite grains; <5% quartz and feldspar grains.	Tpf	
1035–1060	Volcaniclastic sediments—varicolored grains of dacite and rhyolite. Mixed sand and large gravel. 1035’–1060’ +10F: 98–100% angular to subangular grains (gravel up to 25 mm) of dacite and rhyolite; <2% well-cemented sandstone clasts; trace quartz and biotite grains. +35F: 85–95% dacite grains; 5–15% quartz and feldspar grains.	Tpf	The Tpf/Tjfp contact, estimated at 1060 ft bgs, is based on first significant appearance of vitric rhyolitic pumice clasts below Tpf in drill cuttings.
1090–1115	Volcaniclastic sediments—White quartz-rich, biotite-bearing vitric pumice clasts and varicolored grains of dacite and rhyolite. Coarse sand and granules. 1090’–1115’ WR/+10F: 75–90% white quartz-rich vitric pumice clasts; 10–25% gray to reddish-gray dacite and rhyolite clasts. +35F: 60–90% vitric pumice clasts; 5–30% quartz and feldspar grains; 5–20% dacite grains.	Tjfp	

Borehole Identification (ID): R-64	**Technical Area (TA):** 21	**Page :** 10 of 12
Drilling Company: Boart Longyear Company	**Start Date/Time:** 4/16/11; 1320	**End Date/Time:** 5/22/11; 1405
Drilling Method : Dual Rotary	**Machine:** Foremost DR24 HD	**Sampling Method OD:** Grab
Ground Elevation: 7121.57 ft amsl		**Total Depth:** 1380 ft
Drillers: M. Cross	**Site Geologists:** Travis Naibert, Ryan McGuill, Andy Miller	

Depth (ft bgs)	**Lithologic Description**	**Lithologic Symbol**	**Notes**
1115–1155	Volcaniclastic sediments—White to pale-orange quartz-rich, biotite-bearing vitric pumice clasts and varicolored grains of dacite and rhyolite. Fine sand to gravel. 1115'–1155' WR/+10F: 70-95% white to pale-orange quartz-rich pumice or perlite clasts; 5–30% gray to reddish-gray dacite and rhyolite clasts. +35F: 60–80% vitric pumice clasts; 10–20% quartz and feldspar grains; 10–20% dacite grains.	Tjfp	
1155–1190	Volcaniclastic sediments—White to pale-orange quartz-rich, biotite-bearing vitric pumice clasts and varicolored grains of dacite and rhyolite. Fine sand to gravel, dominated by coarse sand. 1155'–1190' WR/+10F: 70–95% white to pale-orange quartz-rich pumice or perlite clasts; 5–30% gray to reddish-gray dacite and rhyolite clasts. +35F: 50–70% vitric pumice clasts; 10–20% quartz and feldspar grains; 20–30% dacite grains.	Tjfp	
1190–1205	Volcaniclastic sediments—White vitric pumice clasts and varicolored grains of dacite, rhyolite, and vesicular andesite. Fine sand to gravel. 1190'–1205' WR/+10F: 60–85% white vitric pumice clasts; 5–30% gray to reddish-gray dacite clasts; trace andesite clasts. +35F: 40–70% vitric pumice clasts; 10–20% quartz and feldspar grains; 20–40% dacite grains.	Tjfp	
1240–1260	Volcaniclastic sediments—White vitric pumice clasts and varicolored grains of dacite and rhyolite. Fine sand to gravel with minor silt. 1240'–1260' WR/+10F: 50–75% white vitric pumice clasts; 25–50% gray to reddish-gray dacite clasts; trace andesite clasts. +35F: 40–70% vitric pumice clasts; 10–20% quartz and feldspar grains; 20–40% dacite grains.	Tjfp	

Borehole Identification (ID): R-64	**Technical Area (TA):** 21	**Page :** 11 of 12
Drilling Company: Boart Longyear Company	**Start Date/Time:** 4/16/11; 1320	**End Date/Time:** 5/22/11; 1405
Drilling Method : Dual Rotary	**Machine:** Foremost DR24 HD	**Sampling Method OD:** Grab
Ground Elevation: 7121.57 ft amsl		**Total Depth:** 1380 ft
Drillers: M. Cross	**Site Geologists:** Travis Naibert, Ryan McGuill, Andy Miller	

Depth (ft bgs)	**Lithologic Description**	**Lithologic Symbol**	**Notes**
1260–1275	Volcaniclastic sediments—White to pale-orange vitric pumice clasts and varicolored grains of dacite and rhyolite. Fine sand to gravel with minor silt. 1260'–1275' WR/+10F: 70–85% white to pale-orange vitric pumice clasts; 15–30% gray to reddish-gray dacite clasts; trace andesite clasts. +35F: 60–80% vitric pumice clasts; 10–20% quartz and feldspar grains; 10–20% dacite grains.	Tjfp	
1275–1300	Volcaniclastic sediments—White to pale-orange vitric pumice clasts and varicolored grains of dacite. Medium to coarse sand to gravel with few fines. 1275'–1300' WR/+10F: 60–75% white to pale-orange vitric pumice clasts; 25–40% gray to reddish-gray dacite clasts; trace andesite clasts. +35F: 60–80% vitric pumice clasts; 20–40% dacite grains.	Tjfp	
1300–1310	Volcaniclastic sediments—White to pale-orange vitric pumice clasts and varicolored grains of dacite. Medium sand and gravel. 1300'–1310' WR/+10F: 20–40% white to pale-orange vitric pumice clasts; 60–80% gray to reddish-gray dacite clasts; trace andesite clasts. +35F: 30–80% pumice clasts; 20–70% dacite grains.	Tjfp	
1310–1320	Volcaniclastic sediments—White to pale-orange vitric pumice clasts and varicolored grains of dacite. Medium sand and gravel up to 25 mm. 1310'–1320' WR/+10F: 50–60% white to pale-orange vitric pumice clasts; 40–50% gray dacite clasts. +35F: 60–90% pumice clasts; 10–40% dacite grains.	Tjfp	
1320–1350	Volcaniclastic sediments—White to pale-orange vitric pumice clasts and varicolored grains of dacite. Fine sand to gravel up to 5 mm. 1320'–1350' WR/+10F: 70–85% white to pale-orange vitric pumice clasts; 15–30% gray to reddish-gray dacite clasts; trace andesite clasts. +35F: 80–90% vitric pumice clasts; 10–20% dacite grains.	Tjfp	

Borehole Identification (ID): R-64	**Technical Area (TA):** 21		**Page :** 12 of 12	
Drilling Company: Boart Longyear Company	**Start Date/Time:** 4/16/11; 1320		**End Date/Time:** 5/22/11; 1405	
Drilling Method : Dual Rotary	**Machine:** Foremost DR24 HD		**Sampling Method OD:** Grab	
Ground Elevation: 7121.57 ft amsl			**Total Depth:** 1380 ft	
Drillers: M. Cross	**Site Geologists:** Travis Naibert, Ryan McGuill, Andy Miller			

Depth (ft bgs)	Lithologic Description	Lithologic Symbol	Notes
1350–1380	Volcaniclastic sediments—White to pale-orange vitric pumice clasts and varicolored grains of dacite. Fine sand to gravel up to 15 mm with decreasing sand downsection. 1350'–1380' WR/+10F: 20–40% white to pale-orange vitric pumice clasts; 60–80% gray to reddish-gray dacite clasts. +35F: 60–80% vitric pumice clasts; 10–40% dacite grains; 10–20% quartz crystals.	Tjfp	Note: drilling at R-64 was concluded at a total depth of 1380 ft bgs.

Abbreviations

5YR 8/4 (example) = 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

Qbt 3 = Unit 3 of the Tshirege Member of the Bandelier Tuff

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

Qbt 1v = Unit 1v (vapor-phase) of the Tshirege Member of the Bandelier Tuff

Qbt 1g = Unit 1g (glassy) of the Tshirege Member of the Bandelier Tuff

Qct = Cerro Toledo interval

Qbo = Otowi Member of Bandelier Tuff

Qbog = Guaje Pumice Bed

Tpf = Puye Formation

Tjfp = Tertiary Jemez Fanglomerate Pumiceous (called Miocene pumiceous sediments herein)

+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

Screening Groundwater Analytical Results

B-1.0 SCREENING GROUNDWATER ANALYSES AT R-64

R-64 is a regional aquifer monitoring well with one screened interval from 1285 to 1305.5 ft below ground surface (bgs) in the Miocene pumiceous sediments. This appendix presents screening analytical results for samples collected during well development and aquifer testing at R-64.

Laboratory analyses

Four groundwater samples were collected during development and five groundwater samples were collected during aquifer testing for total organic carbon (TOC) analysis. Los Alamos National Laboratory's (LANL's or the Laboratory's) Earth and Environmental Sciences Group 14 (EES-14) conducted the analyses. Table B-1.0-1 lists the samples submitted for TOC analyses from R-64.

Field analyses

Additionally, groundwater samples were collected from a flow-through cell at regular intervals during well development and aquifer testing and measured for pH, conductivity, temperature, dissolved oxygen (DO), oxidation-reduction potential (ORP), and turbidity.

B-2.0 SCREENING ANALYTICAL RESULTS

This section presents the TOC concentrations and field parameters measured during well development and aquifer testing.

B-2.1 Total organic carbon

TOC was not detected (<0.2 mgC/L) in the nine groundwater samples collected during well development and aquifer testing at well R-64 (Table B-2.1-1).

B-2.2 Field parameters

Field parameters measured during well development and aquifer testing are presented in Table B-2.2-1 and summarized below.

During well development, pH varied from 5.90 to 8.20 and temperature ranged from 20.23°C to 24.50°C. DO concentrations varied from 3.84 to 5.72 mg/L. Specific conductance ranged from 144 to 231 μS/cm, and turbidity values varied from 65.2 to 8 nephelometric turbidity units (NTU). Corrected Eh values, determined from field ORP measurements, varied from 294.1 to 452.1 mV. Two temperature-dependent correction factors were used to calculate Eh values from field ORP measurements: 203.9 and 198.5 mV at 20ºC and 25ºC, respectively.

During aquifer testing, pH varied from 6.69 to 7.76 and temperature ranged from 19.07°C to 25.74°C. DO concentrations varied from 2.08 to 5.34 mg/L. Specific conductance ranged from 89 to 205 μS/cm, and turbidity values varied from 112.8 to 5.8 NTU. Corrected Eh values, determined from field ORP measurements, varied from 298.1 to 314.9 mV. The same correction factors listed above were used to convert ORP values to Eh.

The final parameters measured at the end of well development were pH of 7.85, temperature of 22.27ºC, DO of 5.12 mg/L, specific conductance of 148 μS/cm, and turbidity of 8.3 NTU. At the end of aquifer testing, the turbidity had dropped to 5.8 NTU. Figure B-2.2-1 shows the field parameters measured over the course of well development and aquifer testing.

B-3.0 SUMMARY OF SCREENING ANALYTICAL RESULTS

TOC was not detected in the nine samples collected during well development and aquifer testing. Turbidity was 5.8 NTU at the end of aquifer testing. R-64 will be sampled quarterly for 1 yr, and then data will be assessed and incorporated into the Interim Facility-Wide Groundwater Monitoring Plan. Data from ongoing sampling at R-64 will be analyzed and presented in the appropriate Laboratory periodic monitoring report.

Table B-1.0-1
Summary of Groundwater Screening Samples Collected during Well Development and Aquifer Testing at Well R-64

Location ID	Sample ID	Date Collected	Collection Depth (ft bgs)	Sample Type	Analysis
Well Development					
R-64	WST64-11-23937	07/15/11; 1800 h	1305	Groundwater, pumped	TOC
R-64	WST64-11-23938	07/18/11; 1800 h	1305	Groundwater, pumped	TOC
R-64	WST64-11-23939	07/19/11; 1800 h	1305	Groundwater, pumped	TOC
R-64	WST64-11-23940	07/20/11; 1800 h	1305	Groundwater, pumped	TOC
Aquifer Testing					
R-64	WST64-11-23944	08/04/11; 1156 h	1295	Groundwater, pumped	TOC
R-64	WST64-11-23945	08/04/11; 1600 h	1295	Groundwater, pumped	TOC
R-64	WST64-11-23946	08/04/11; 2000 h	1295	Groundwater, pumped	TOC
R-64	WST64-11-23948	08/05/11; 0400 h	1295	Groundwater, pumped	TOC
R-64	WST64-11-23949	08/05/11; 0800 h	1295	Groundwater, pumped	TOC

Table B-2.1-1
TOC Results

Sample ID	EPA Method	TOC Concentration (mgC/L)
WST64-11-23937	415.1	Not detected (<0.20)
WST64-11-23938	415.1	Not detected (<0.20)
WST64-11-23939	415.1	Not detected (<0.20)
WST64-11-23940	415.1	Not detected (<0.20)
WST64-11-23944	415.1	Not detected (<0.20)
WST64-11-23945	415.1	Not detected (<0.20)
WST64-11-23946	415.1	Not detected (<0.20)
WST64-11-23948	415.1	Not detected (<0.20)
WST64-11-23949	415.1	Not detected (<0.20)

Table B-2.2-1
Purge Volumes and Field Parameters during Well Development and Aquifer Testing at R-64

Date	pH	Temp (°C)	DO (mg/L)	ORP (mV)	Eh (mV)	Specific Conductivity (µS/cm)	Turbidity (NTU)	Purge Volume Between Samples (gal.)	Cumulative Purge Volume (gal.)
Well Development									
07/13/11	n/r*; bailing							324	324
07/15/11	n/r; pumping while swabbing screen							124	448
07/18/11	6.18	22.71	3.84	158.9	357.4	231	65.2	306	754
	7.61	22.87	4.20	115.1	313.6	178	49.8	45	799
	8.14	22.00	4.12	175.0	378.9	177	41.3	45	844
	8.20	23.31	4.43	127.1	325.6	169	38.9	45	889
	8.17	23.09	4.55	115.8	314.3	166	33.5	57	946
	8.08	23.72	4.16	228.5	427.0	165	29.0	60	1006
	8.08	24.23	4.40	144.3	342.8	164	29.4	60	1066
	8.04	24.00	4.57	123.1	321.6	165	25.4	120	1186
	8.03	24.50	4.78	128.9	327.4	164	23.7	57	1243
	8.01	23.57	5.05	159.2	357.7	162	21.9	60	1303
	8.02	23.53	4.53	124.1	322.6	160	18.1	57	1360
	7.99	22.29	5.10	127.2	331.1	160	18.0	63	1423
	8.01	23.81	5.01	105.7	304.2	159	18.6	60	1483
	8.01	23.49	5.21	109.4	307.9	160	17.9	63	1546
	7.96	22.94	4.81	115.0	313.5	158	15.0	60	1606
	7.99	22.83	5.12	174.2	372.7	156	15.6	60	1666
07/19/11	5.90	21.83	4.55	157.7	361.6	205	21.5	336	2002
	7.39	22.31	4.65	136.9	340.8	158	17.3	63	2065
	7.89	22.36	4.83	126.6	330.5	157	17.6	63	2128
	7.96	22.16	5.07	125.3	329.2	156	16.9	63	2191
	7.88	22.58	5.17	115.7	314.2	156	13.0	63	2254
	7.92	22.51	5.28	203.5	402.0	156	13.4	63	2317
	7.91	23.22	5.06	129.8	328.3	156	13.6	126	2443
	7.89	22.63	5.35	120.7	319.2	155	10.5	60	2503
	7.89	22.12	5.45	131.3	335.2	154	10.1	63	2566
	7.88	21.93	5.51	116.6	320.5	154	10.5	60	2626
	7.89	22.03	5.02	116.5	320.4	154	10.0	63	2689
	7.87	23.00	5.04	114.9	313.4	153	14.0	63	2752
	7.73	23.78	5.39	126.9	325.4	155	10.9	63	2815
	7.71	22.99	5.25	133.6	332.1	153	12.3	60	2875
	7.81	23.27	5.30	124.0	322.5	153	10.3	60	2935
	7.83	23.00	5.24	115.7	314.2	152	9.1	60	2995
	7.84	21.79	5.38	248.2	452.1	157	8.4	63	3058
	7.87	22.17	5.38	170.2	374.1	151	8.2	63	3121
	7.90	22.13	5.40	149.3	353.2	153	8.3	63	3184

Table B-2.2-1 (continued)

Date	pH	Temp (°C)	DO (mg/L)	ORP (mV)	Eh (mV)	Specific Conductivity (µS/cm)	Turbidity (NTU)	Purge Volume Between Samples (gal.)	Cumulative Purge Volume (gal.)
Well Development									
07/20/11	7.35	22.39	4.31	110.6	314.5	161	17.9	398	3582
	7.83	21.88	5.13	103.0	306.9	150	16.6	64	3646
	8.04	22.23	5.26	105.4	309.3	149	14.8	64	3710
	8.05	22.34	5.29	108.3	312.2	149	14.8	63	3773
	8.03	22.62	5.26	108.5	307.0	148	13.5	63	3836
	8.03	22.64	5.25	104.1	302.6	148	12.0	62	3898
	7.97	23.09	5.15	96.8	295.3	148	16.9	124	4022
	7.96	23.55	5.10	106.7	305.2	148	13.3	64	4086
	7.96	23.40	5.28	113.8	312.3	148	12.2	44	4130
	7.96	22.14	5.24	113.9	317.8	147	12.7	125	4255
07/20/11	7.98	21.14	5.34	117.3	321.2	146	9.2	61	4316
	8.01	20.93	5.36	107.6	311.5	145	9.0	72	4388
	8.02	20.74	5.51	107.0	310.9	145	8.9	54	4442
	8.04	20.23	5.72	105.6	309.5	145	8.0	75	4517
	8.04	20.78	5.49	101.6	305.5	144	9.4	62	4579
	8.04	21.39	5.48	99.1	303.0	145	9.2	62	4641
	8.03	21.60	5.48	97.6	301.5	145	8.2	50	4691
07/21/11	7.87	20.89	4.54	90.2	294.1	150	17.0	346	5037
	8.01	22.30	4.89	95.6	299.5	149	11.9	65	5102
	7.91	22.77	4.98	105.4	303.9	148	9.8	61	5163
	7.87	22.11	5.02	111.8	315.7	148	9.2	73	5236
	7.85	22.27	5.12	98.6	302.5	148	8.3	178	5414
Aquifer Pump Test									
08/01/11	n/r; pumping, mini-tests							34	34
08/02/11	n/r; pumping, mini-tests							93	127
08/03/11	n/r; pumping, mini-tests							77	204
08/04/11 to 08/05/11	6.84	24.15	2.08	104.1	302.6	205	112.8	221	425
	7.76	25.74	3.39	103.8	302.3	89	28.4	110	535
	7.65	21.54	4.57	101.4	305.3	158	22.5	102	637
	7.51	20.39	4.48	96.3	300.2	147	20.4	121	758
	7.59	20.35	4.63	98.5	302.4	137	18.2	115	873
	7.61	20.36	4.70	99.2	303.1	142	12.1	233	1106
	7.62	19.82	4.30	102.9	306.8	140	13.1	113	1219
	7.67	20.41	5.34	101.8	305.7	140	11.2	119	1338

Table B-2.2-1 (continued)

Date	pH	Temp (°C)	DO (mg/L)	ORP (mV)	Eh (mV)	Specific Conductivity (µS/cm)	Turbidity (NTU)	Purge Volume Between Samples (gal.)	Cumulative Purge Volume (gal.)
08/04/11 to 08/05/11	7.67	20.48	5.00	104.9	308.8	139	10.3	119	1457
	7.65	20.01	4.92	107.6	311.5	139	9.2	112	1569
	7.71	19.87	4.79	104.1	308.0	138	8.6	115	1684
	6.69	19.79	4.82	104.8	308.7	137	8.5	117	1801
	7.66	19.67	5.03	107.5	311.4	137	8.3	117	1918
	7.70	19.62	4.89	108.5	312.4	137	7.6	117	2035
	7.71	19.63	4.82	111.0	314.9	136	7.1	118	2153
	7.70	19.74	4.95	110.4	314.3	136	7.6	118	2271
	7.62	19.49	4.97	110.9	314.8	135	7.0	118	2389
	7.75	19.52	4.69	103.8	307.7	136	6.6	118	2507
	7.75	19.07	4.58	102.9	306.8	136	6.3	118	2625
	7.76	19.57	4.56	104.6	308.5	135	6.3	116	2741
	7.75	19.46	4.83	100.2	304.1	135	6.5	120	2861
	7.73	22.35	4.27	94.2	298.1	138	5.8	118	2979
Post Aquifer Test Pumping									
08/24/11	5.62	19.05	5.10	164.0	367.9	245	64.6	79	79
	7.23	23.40	6.42	132.6	331.1	161	77.6	30	109
	7.46	20.24	7.48	175.9	379.8	152	63.1	30	139
	7.59	21.97	7.30	158.0	361.9	148	46.8	30	169
	7.62	21.44	7.37	179.2	383.1	147	35.6	30	199
	7.56	21.35	7.59	163.5	367.4	145	31.4	30	229
	7.48	21.90	7.71	168.0	371.9	145	27.5	38	267

Note: ORP-to-Eh value correction factors were 203.9 µS/cm at 20°C; 198.5 µS/cm at 25°C.

*n/r = Not recorded.

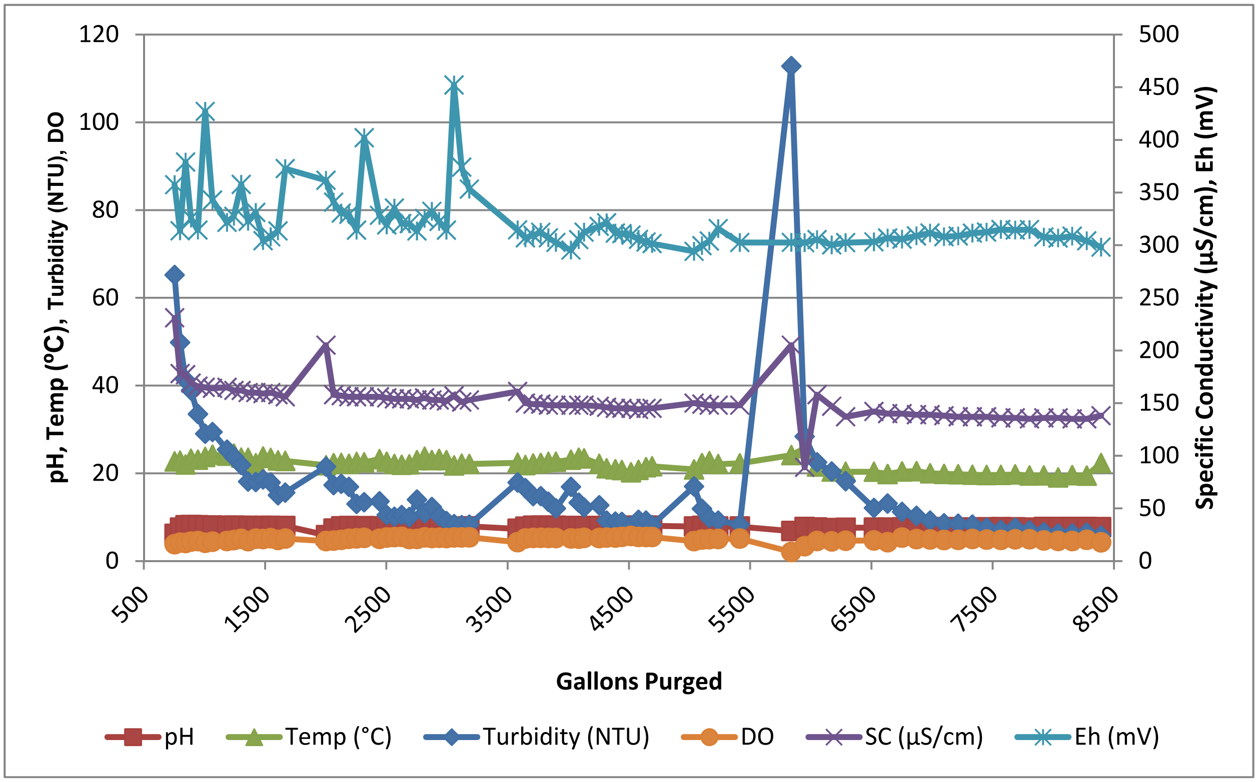


Figure B-2.2-1 **Field parameters vs volume purged during R-64 well development and aquifer testing**

Appendix C

Aquifer Testing Report

C-1.0 INTRODUCTION

This appendix describes the hydraulic analysis of pumping tests conducted during August 2011 at R-64, a single-screened regional aquifer well located above DP Canyon at Technical Area 21 (TA-21). The tests on R-64 were conducted to characterize the saturated materials and quantify the hydraulic properties of the screened interval. Testing consisted of brief trial pumping, background water level data collection, and a 24-h constant-rate pumping test.

As in most of the regional well pumping tests conducted on the plateau, an inflatable packer system was installed initially in R-64 to try to eliminate casing storage effects on the test data. However, due to the low yield of the screened interval at R-64, the water level dropped below the top of the screen during well development and initial test pumping, causing water to drain from the filter pack behind the blank casing above the screen. During subsequent water level recovery, air became trapped in that area. The trapped air caused a storage-like effect on the pumping test data by expanding and compressing during pumping and recovery. As a result, data from the trial tests revealed storage effects in spite of using an inflatable packer system.

During trial testing, the production rate obtained from the well during testing was below the expected pumping rate, suggesting a pump or pipe failure of some kind. To investigate, following trial testing, the pump was pulled and replaced. The decision was made to run the replacement pump without an inflatable packer because of the fact that storage effects were inevitable, with or without a packer. When the original pump was examined, it was discovered that a fatigue crack in the body of the check valve above the pump was allowing leakage of water back into the well, reducing the net flow to the surface.

Conceptual Hydrogeology

The screened interval for R-64 is set within unconsolidated Miocene pumiceous deposits. The well screen is 20.5 ft long, extending from 1285 to 1305.5 ft below ground surface (bgs). The static water level measured on August 1, 2011, before testing was 1269.33 ft bgs. The ground-surface elevation at the well was estimated at 7122 ft above mean sea level (amsl), making the estimated water level elevation 5852.67 ft amsl.

The well screen penetrates only a thin portion of the pumiceous deposits. During drilling, the borehole was advanced to 1380 ft and was still in pumiceous sediments at that depth, more than 110 ft below the water table.

R-64 Testing

R-64 was tested from August 1 to 5, 2011, and recovery data were collected through the morning of August 6. On August 1, the pump was installed and operated long enough to fill the drop pipe. Testing began with brief trial pumping on August 2. As stated above, trial testing showed that it was not possible to obtain adequate yield, so the pump was pulled and replaced. After collecting background data, the constant-rate pumping test was begun on August 4, continuing for 24 h until August 5. Following constant-rate testing, recovery data were recorded for 24 h until August 6.

Trial testing of R-64 began at 8:30 a.m. on August 2 at a discharge rate of 1.4 gallons per minute (gpm) and continued for 30 min. Even though it was known that R-64 could produce a greater flow (e.g., 2 gpm based on well-development pumping rates), it was not possible to adjust the discharge rate any higher than 1.4 gpm. During trial 1, the rate actually declined slightly to 1.2 gpm by the end of the test. Following shutdown, recovery data were recorded for 60 min until 10:00 a.m. when trial 2 pumping began at a discharge rate of 0.86 gpm—the maximum yield obtainable at that time. As pumping continued, the discharge rate declined further, eventually reaching just a trickle. Following pump shutoff at 11:00 a.m., the pump was pulled from the well and replaced. Inspection of the original pump revealed a crack in the check valve above the pump, accounting for the inability to obtain the expected production rate.

With the replacement pump installed, the 24-h pumping test was begun at 8:00 a.m. on August 4, with an average discharge rate during the test of nearly 2.0 gpm. Pumping continued until 8:00 a.m. on August 5. Following shutdown, recovery data were recorded for 24 h until 8:00 a.m. on August 6 when the pump was pulled from the well.

C-2.0 BACKGROUND DATA

The background water level data collected before the pumping tests help distinguish the naturally occurring water level fluctuations from those caused by the pumping test. Background water level fluctuations have several causes, among them barometric pressure changes, operation of other wells in the aquifer, Earth tides, and long-term trends related to weather patterns. The background data hydrographs from the monitored wells were compared with barometric pressure data from the area to determine if a correlation existed.

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

Subsequent pumping tests, including R-64, have used nonvented transducers. These devices simply record the total pressure on the transducer, that is, the sum of the water height plus the barometric pressure. This results in an attenuated “apparent” hydrograph in a barometrically efficient well. Take as an example a 90% barometrically efficient well. When monitored using a vented transducer, an increase in barometric pressure of 1 unit causes a decrease in recorded downhole pressure of 0.9 unit because the water level is forced downward 0.9 unit by the barometric pressure change. However, using a nonvented transducer, the total measured pressure increases by 0.1 unit (the combination of the barometric pressure increase and the water level decrease). Thus, the resulting apparent hydrograph changes by a factor of 100 minus the barometric efficiency, and in the same direction as the barometric pressure change, rather than in the opposite direction.

Barometric pressure data were obtained from TA-54 tower site from the Waste and Environmental Services Division–Environmental Data and Analysis (WES-EDA). The TA-54 measurement location is at an elevation of 6548 ft amsl, whereas the wellhead elevation is at roughly 7122 ft amsl. The static water level in R-64 was 1269.33 ft below land surface, making the water-table elevation approximately 5852.67 ft amsl. Therefore, the measured barometric pressure data from TA-54 had to be adjusted to reflect the pressure at the elevation of the water table within R-64.

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

$$P_{WT} = P_{TA54} \exp\left[-\frac{g}{3.281R} \left(\frac{E_{R-64} - E_{TA54}}{T_{TA54}} + \frac{E_{WT} - E_{R-64}}{T_{WELL}} \right) \right]$$

Equation C-1

where P_{WT} = barometric pressure at the water table inside R-64

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

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

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

$E_{R\text{-}64}$ = land surface elevation at R-64 site, in feet (approximately 7122 ft)

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

E_{WT} = elevation of the water level in R-64, in feet (approximately 5852.67 ft)

T_{TA54} = air temperature near TA-54, in kelvin (assigned a value of 70.8ºF, or 294.7 K)

T_{WELL} = air column temperature inside R-64, in kelvin (assigned a value of 62.3ºF, or 290.0 K)

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

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

C-3.0 IMPORTANCE OF EARLY DATA

When pumping or recovery first begins, the vertical extent of the cone of depression is limited to approximately the well-screen length, the filter-pack length, or the aquifer thickness in relatively thin permeable strata. For many pumping tests on the Pajarito Plateau, the early pumping period is the only time that the effective height of the cone of depression is known with certainty, because soon after startup, the cone of depression expands vertically through permeable materials above and/or below the screened interval. Thus, the early data often offer the best opportunity to obtain hydraulic conductivity information because conductivity would equal the earliest-time transmissivity divided by the well-screen length.

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

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

Equation C-2

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

D = inside diameter of well casing, in inches

d = outside diameter of column pipe, in inches

Q = discharge rate, in gallons per minute

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

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

For wells screened across the water table or wells in which the filter pack can drain during pumping, there can be an additional storage contribution from the filter pack. The following equation provides an estimate of the storage duration accounting for both casing and filter-pack storage.

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

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

D_B = diameter of borehole, in inches

D_C = outside diameter of well casing, in inches

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

In some instances, it is possible to eliminate casing-storage effects by setting an inflatable packer above the tested screen interval before conducting the test. As described previously, this approach was not successful in the testing performed on R-64, as the data included storage effects associated with trapped air in the filter pack above the screen caused by antecedent dewatering of the screen during well development. Because of inevitable storage effects on the test data, the inflatable packer was left out of the pumping string when the replacement pump was installed for conducting the 24-h test on R-64.

C-4.0 TIME-DRAWDOWN METHODS

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

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

where

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

and

$$u = \frac{1.87r^2S}{Tt}$$ **Equation C-6**

and where s = drawdown, in feet

Q = discharge rate, in gallons per minute

T = transmissivity, in gallons per day per foot

S = storage coefficient (dimensionless)

t = pumping time, in days

r = distance from center of pumpage, in feet

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

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

Equation C-7

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

Equation C-8

where T = transmissivity, in gallons per day per foot

S = storage coefficient

Q = discharge rate, in gallons per minute

$W(u)$ = match-point value

s = match-point value, in feet

u = match-point value

t = match-point value, in minutes

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

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

Equation C-9

The Cooper-Jacob equation is a simplified approximation of the Theis equation and is valid whenever the *u* value is less than about 0.05. For small radius values (e.g., corresponding to borehole radii), *u* is less than 0.05 at very early pumping times and therefore is less than 0.05 for most or all measured drawdown values. Thus, for the pumped well, the Cooper-Jacob equation usually can be considered a valid approximation of the Theis equation. An exception occurs when the transmissivity of the aquifer is very low. In that case, some of the early pumped well drawdown data may not be well approximated by the Cooper-Jacob equation.

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

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

Equation C-10

where T = transmissivity, in gallons per day per foot

Q = discharge rate, in gallons per minute

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

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

Equation C-11

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

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

b = aquifer thickness

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

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

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

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

K_z = vertical hydraulic conductivity

K_r = horizontal hydraulic conductivity

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

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

Equation C-12

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

C-5.0 RECOVERY METHODS

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

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

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

The recovery data are particularly useful 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.

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

C-6.0 SPECIFIC CAPACITY METHOD

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

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

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

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

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

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

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

To apply this procedure, a storage coefficient value must be assigned. Storage coefficient values generally range from 10^{-5} to 10^{-3} for confined aquifers and 0.01 to 0.25 for unconfined aquifers (Driscoll 1986, 104226). Unconfined conditions were assumed for R-64, because of the proximity of the screen to the water table, and a storage coefficient of 0.1 was arbitrarily assigned. The calculation result is not particularly sensitive to the choice of storage coefficient value, so a rough estimate is generally adequate to support the calculations.

The analysis also requires assigning a value for the saturated aquifer thickness, b. For R-64, an arbitrary thickness of double the well-screen length was assigned in the calculations. The assigned thickness does not have a great effect on the calculations, because sediments far above or below the well screen contribute little flow to the well.

C-7.0 BACKGROUND DATA ANALYSIS

Background aquifer pressure data collected during the R-64 tests were plotted along with barometric pressure to determine the barometric effect on water levels.

Figure C-7.0-1 shows aquifer pressure data from R-64 during the test period along with barometric pressure data from TA-54 that have been corrected to equivalent barometric pressure in feet of water at the water table. The R-64 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 test periods for the R-64 pumping tests are included on the figure for reference.

Note that there was a gap in the data during the afternoon and early evening of August 2. This is when the original pump was pulled from the well and replaced because of the defective check valve.

The data shown in Figure C-7.0-1 showed at most a subdued hydrograph response to changes in barometric pressure. This implied a high barometric efficiency for R-64. Future long-term monitoring will permit an exact determination of the barometric efficiency.

The background data showed some anomalies. Note that when the replacement pump was installed late on August 2, the head over the transducer stabilized overnight to about 58.21 ft. Then, on August 3, when the pump was operated briefly to fill the drop pipe, the head over the transducer reequilibrated to a level about 0.05 ft higher. It is likely that this was caused by slight stretching/movement (“settling in”) of the drop pipe in response to the stress induced by filling it with water.

Another oddity was that the data showed apparent “superrecovery” after most pump shutoff events. This was shown on August 1 when the original pump was installed and the drop pipe filled, again on August 3 when the drop pipe was filled using the replacement pump, and finally on August 5 at the conclusion of the 24-h pumping test. In each case, water levels recovered quickly to a position about 0.05 ft above the original static water level and then slowly subsided over the next several hours.

Development pumping that was performed a couple of weeks earlier showed similar response. The development was performed with a pressure transducer installed to observe water levels. A portion of the corresponding data set is shown in Figure C-7.0-2. This figure shows that the response was identical to that from the pumping tests in that there was apparent rapid overrecovery of about 0.05 ft, which then subsided gradually over several hours.

Several theories were considered to explain the observed water levels. A couple of other R-wells at the Laboratory have shown superrecovery response, although the magnitude was much greater—several feet or tens of feet. In those instances, the unusual recovery response was attributed to dynamic effects associated with expansion of abundant gas or air in the formation pores. The water pumped from R-64 did not show obvious signs of gas or air content, however, and thus this possibility was dismissed.

Another possible cause of the water level overrecovery and decay that was considered, particularly in light of the discovery of the cracked check valve in the original pumping string, was the possibility that a portion of the drop-pipe water slowly leaked back into the well, temporarily raising the observed head.

However, there were two additional check valves above the defective one, about 11 ft and 32 ft higher in the string. Assuming that these two check valves did not both fail simultaneously, drop-pipe water would have remained in the string, held there by suction, even with a defective (cracked) lower check valve. Thus, the defective valve did not cause the observed effect. Furthermore, after the defective valve was replaced, the same anomalous water level response was observed (on August 5).

Of significance was that the apparent superrecovery effect was not observed on August 2 at the conclusion of the trial 1 pumping test. This test was conducted with the packer inflated, effectively sealing off the pumped zone from overlying portions of the drop pipe. The most likely explanation for the water level rise and decline following the other pumping events was that a leaky coupling joint or possibly several leaky coupling joints in the drop pipe somewhere above the packer allowed slow release of water from the drop pipe, both during pumping and after pumping stopped. Following trial 1, the intervening packer prevented the leaked water from reaching the screen zone. Supporting this idea, as discussed below, deflating the packer following trial testing showed a buildup of water above the packer—presumably water that had leaked from the drop pipe.

The leakage of water in this manner would release a finite volume of water after the pump was shut off, the magnitude of which would depend on the location of the leaky joint. Suction forming inside the drop pipe would suspend water one atmosphere (about 27 ft) above the leaky joint, at which point leakage would cease. This would account for the consistent, finite-duration head buildup pattern observed after each pump shutoff event. The head buildup would be caused by water already in transit down the well that had been leaking during pumping plus the fixed volume of drop pipe that drains once pumping stops. Thus, the conclusion was that a defective coupling joint or joints allowed drainage of a fixed volume of water from the drop pipe each time the pump was shut off. In tests conducted with the packer deflated (or no packer at all), the drainage of water into the well caused the observed rise and decay in level. In the trial testing, which was conducted with the packer inflated, this effect was absent because the leaked water remained trapped above the packer until the packer was unseated.

C-8.0 WELL R-64 DATA ANALYSIS

This section presents the data obtained from the R-64 pumping tests and the results of the analytical interpretations. Data are presented for trial 1, trial 2, and the 24-h constant-rate test.

C-8.1 Well R-64 Trial 1 Test

Figure C-8.1-1 shows a semilog plot of the drawdown data collected from the trial 1 test on R-64 at an initial discharge rate of 1.4 gpm. As shown in the figure, there was exaggerated drawdown for about the first 15 s of pumping as previously drained drop pipe refilled. As discussed above, a leaky coupling joint or joints in the drop-pipe string likely allowed a small volume of water to drain from the pipe during and for a time following each pumping event.

Data recorded immediately following the refilling of the drop pipe likely continue to show storage effects, gradually transitioning from steep to flat during the first few minutes of pumping. Then, after several minutes of pumping, water levels began to rise slightly in response to a gradually decreasing discharge rate as the leak through the defective check valve worsened.

The narrow window of data between storage effects and discharge-rate reduction revealed an estimated transmissivity of 1140 gallon per day (gpd)/ft. This value is considered only an approximation because of the minimal portion of the data set used to compute it and the unknown duration of storage effects associated with the expansion of the trapped air in the upper reaches of the filter pack.

The effective thickness of hydraulically contiguous sediments corresponding to the computed transmissivity is not known. However, as discussed below, data from the 24-h test suggest minimal hydraulic connection between the shallow sediments and deeper sediments within the regional aquifer at this location. This is typical of observations at other well sites where the uppermost saturated sediments are essentially hydraulically isolated from deeper zones by tight intervening layers (e.g., R-35a and R-35b). If one assigned an arbitrary thickness of twice the well-screen length (41 ft), the corresponding contiguous saturated thickness would extend from the static water level to a few feet beneath the bottom of the well screen. For this hypothetical thickness, the computed hydraulic conductivity would be 1140/41 = 28 gpd/ft^2, or 3.7 ft/d. This is only an order of magnitude estimate of the hydraulic conductivity, as the true effective thickness of the zone reflected in the computed transmissivity is unknown.

Figure C-8.1-2 shows the recovery data collected following shutdown of the trial 1 pumping test. Note that this was the only shutdown event that occurred with the packer inflated and, thus, did not show the anomalous overrecovery that was seen following all other pump shutoff events.

The early recovery data show storage effects associated with compression of trapped air in the filter pack above the well screen. Subsequent data reveal a steady, continuous slope change and premature recovery, i.e., well before a t/t' value of 1.0, likely an indication of hysteretic effects. In unconfined aquifers, the early rate of recovery can be more rapid than that of drawdown because of a smaller effective storage coefficient during recovery. During pumping the capillary fringe above the water table increases in thickness, while during recovery it gets thinner (Bevan 2005). If the rate of thinning during recovery exceeds the rate of growth during pumping, the effective storage coefficient during recovery will be less than that during pumping, resulting in a more rapid initial recovery rate than drawdown rate, followed by a corresponding slowing of the recovery rate at late time. Additionally, as the water table rebounds during recovery, air is trapped in the previously dewatered pore spaces, further decreasing the effective recovery storage coefficient. Because of these probable effects, the data do not support a calculation of transmissivity.

C-8.2 Well R-64 Trial 2 Test

Figure C-8.2-1 shows a semilog plot of the drawdown data collected from the trial 2 test on R-64 at an initial discharge rate of 0.86 gpm. The early data show a storage effect, indicated by the slope transition from steep to flat. The transmissivity computed from a brief window of data following the cessation of storage effects is 760 gpd/ft.

Assuming a saturated thickness of hydraulically contiguous sediments of 41 ft (twice the well screen length), the hydraulic conductivity computes to 19 gpd/ft^2, or 2.5 ft/d. The actual effective saturated thickness of the tested interval is unknown, but this calculation provides a rough order of magnitude estimate of the expected hydraulic conductivity.

After just a few minutes of pumping, the discharge rate began changing erratically, primarily declining—likely an artifact of a variable leakage rate through the crack in the defective check valve above the pump. In some previous regional-well pumping tests, erratic and declining pumping rates were shown to be caused by gas/air buildup beneath the inflatable packer pushing the pumping water level down to the pump intake. Although this proved not to be the case with R-64, the possibility had not yet been ruled out, so as a precaution, the packer was deflated to liberate any air that might be trapped beneath it. When this was done, the water level immediately rose several feet above the static level. This was caused by water that had accumulated above the packer moving down into the pumped zone and flowing into the aquifer. This response showed that in addition to leakage through the cracked check valve above the pump (and below the packer), water was leaking from a defective coupling joint above the packer.

After the packer was deflated, the discharge rate continued to decline, reaching just a trickle for the last several minutes of pumping. Because of this, the trial 2 test was terminated to allow the pump to be pulled and replaced.

C-8.3 Well R-64 24-Hour Constant-Rate Test

Figure C-8.3-1 shows a semilog plot of the drawdown data collected from the 24-h constant-rate pumping test conducted at an average discharge rate near 2.0 gpm. The relevant casing-storage times are shown on the graph for reference.

The data show some indication of discharge rate variations that is borne out by flow-rate measurements made during the test. It is possible that the leakage rate through the defective threaded joint in the drop pipe varied, accounting for the changes in observed flow rate.

The rate settled in at about 2.0 gpm over the final 20 h of pumping. This is reflected in the relatively stable drawdown plot over this period. Note that the largely stable slope during the bulk of the pumping test suggests that the pumped interval was not well connected hydraulically to underlying sediments; if it was, the drawdown slope would be steadily flatter over time, consistent with vertical expansion of the cone of depression. The relative stability of the observed drawdown slope over nearly 20 h of pumping suggests a fairly limited thickness of hydraulically contiguous sediments penetrated by the screen. This implies the presence of a tight layer separating the lower aquifer from the uppermost saturated zone.

The transmissivity determined from the line of fit shown in Figure C-8.3-1 is 1000 gpd/ft. Assuming a saturated thickness of hydraulically contiguous sediments of 41 ft (twice the well-screen length), the hydraulic conductivity computes to 24 gpd/ft^2, or 3.3 ft/d. The actual effective saturated thickness of the tested interval is unknown, but this calculation provides a rough order of magnitude estimate of the expected hydraulic conductivity.

Figure C-8.3-2 shows the recovery data collected following shutdown of the 24-h constant-rate pumping test. The casing-storage times are shown on the graph for reference. By the time casing-storage effects had subsided, the water level had already overrecovered above the original static level. This effect was due to the influx of water that had leaked from the defective threaded joint in the drop pipe—including both water that was already flowing down the outside of the drop pipe at the time of pump shutoff plus whatever additional volume drained from the drop pipe once pumping stopped. The recovery curve is not able to be analyzed as a result of both casing-storage effects and drop-pipe drainage.

C-8.4 Well R-64 Specific Capacity Data

Specific capacity data were used along with well geometry to estimate a lower-bound hydraulic-conductivity value for the permeable zone penetrated by R-64. This was done to provide a frame of reference for evaluating the foregoing analyses.

At the end of the 24-h pumping test, the discharge rate was 2.0 gpm with a resulting drawdown of 4.44 ft for a specific capacity of 0.45 gpm/ft. In addition to specific capacity and pumping time, other input values used in the calculations included a storage coefficient value of 0.10, a borehole radius of 0.68 ft (inferred from the volume of filter pack required to backfill the screen zone), a screen length of 20.5 ft, and an assigned saturated thickness of 41 ft (arbitrarily double the screen length).

Applying the Brons and Marting method to these inputs yields a lower-bound hydraulic conductivity value of 17 gpd/ft^2, or 2.3 ft/d. The average hydraulic conductivity value approximated from the foregoing pumping test analyses is around 3 ft/d, which while considered only a rough approximation, is reasonably consistent with the lower-bound value.

C-9.0 SUMMARY

Constant-rate pumping tests were conducted on R-64 to gain an understanding of the hydraulic characteristics of the screened interval near the top of the regional aquifer in Miocene pumiceous sediments.

A comparison of barometric pressure and R-64 water level data show a highly barometrically efficient screen zone.

Defective equipment affected the tests in two ways. First, a cracked check valve above the pump allowed variable leakage of water back into the well during pumping, limiting the maximum rate that could be obtained from the pump and allowing the rate to vary over time. Second, a leaky threaded joint in the drop pipe string allowed leakage of water back into the screen zone during the tests. The original pump and check valve were pulled and replaced, eliminating the leaky check valve. However, the drop-pipe leak persisted.

Storage effects were inevitable because the well screen and filter back had been dewatered during previous well development pumping and initial testing. Dewatering the well screen allowed drainage of the portion of the filter pack above the well screen, behind the blank casing, which then trapped air during water level recovery. Expansion and compression of the trapped air during test pumping and recovery caused storage-like effects. An inflatable packer was used initially during the trial tests in an attempt to eliminate storage effects, to no avail. When the replacement pump was installed, the packer was left out of the pumping string.

Recovery data from trial testing show hysteretic effects typical of many unconfined aquifers. These effects generally render the recovery data unusable because of rapid initial recovery followed by a leveling off in the data slope.

The persistent leaky threaded joint in the drop pipe string allowed water to flow back into the well following pump shutoff. This caused “superrecovery” of the water levels, also making the recovery data unusable. It is likely that hysteretic effects alone would have negated the value of the recovery data if pipe leakage had not occurred.

The test analyses suggest a formation transmissivity on the order of 1000 gpd/ft. The saturated thickness corresponding to the transmissivity value is not known. However, the stable drawdown curve observed during most of the 24-h test implies that the tested interval is not hydraulically connected to the vast saturated thickness of the underlying sediments deeper in the regional aquifer. This suggests a relatively thin, hydraulically isolated upper zone of saturation. For example, assigning a saturated thickness equal to twice the well screen length (2 × 20.5 = 41 ft) yields a hydraulic conductivity of around 3 ft/d. The actual thickness of hydraulically contiguous sediments is not known, so this conductivity value is only an order of magnitude estimate.

R-64 produced 2.0 gpm for 1440 min with 4.44 ft of drawdown for a specific capacity of 0.45 gpm/ft. The lower-bound hydraulic conductivity computed from this information is 2.3 ft/d, consistent with the order of magnitude pumping test value.

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)

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)

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)

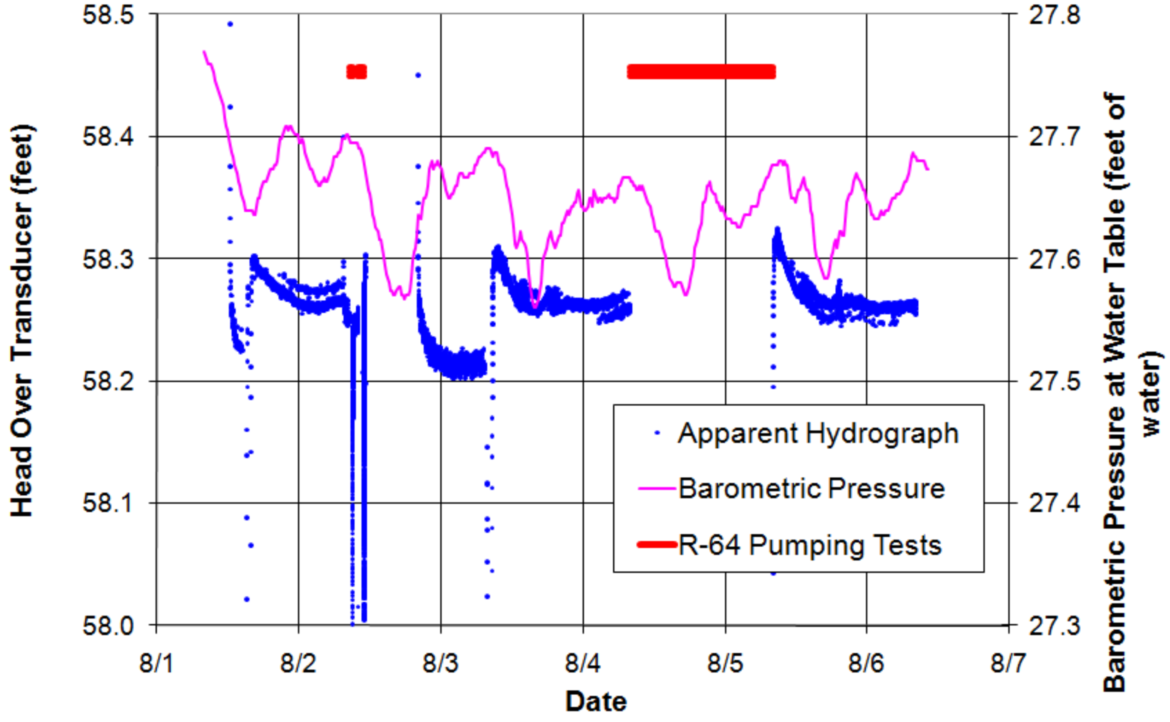


Figure C-7.0-1 Well R-64 apparent hydrograph

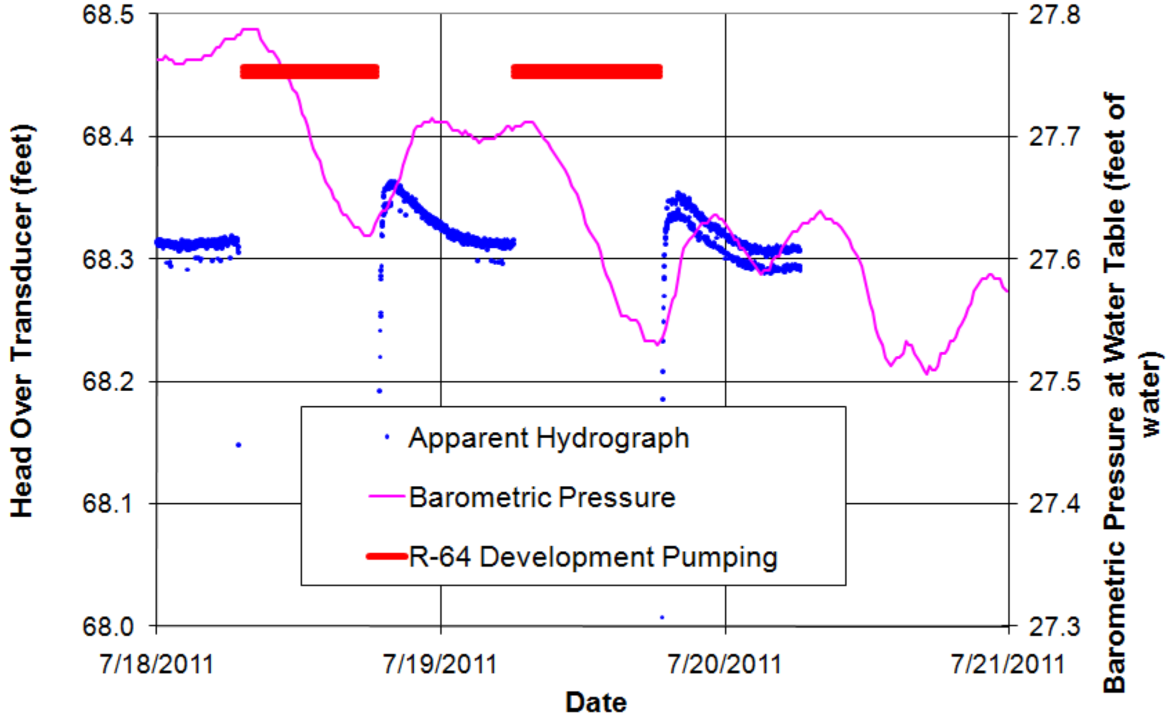


Figure C-7.0-2 Well R-64 development pumping

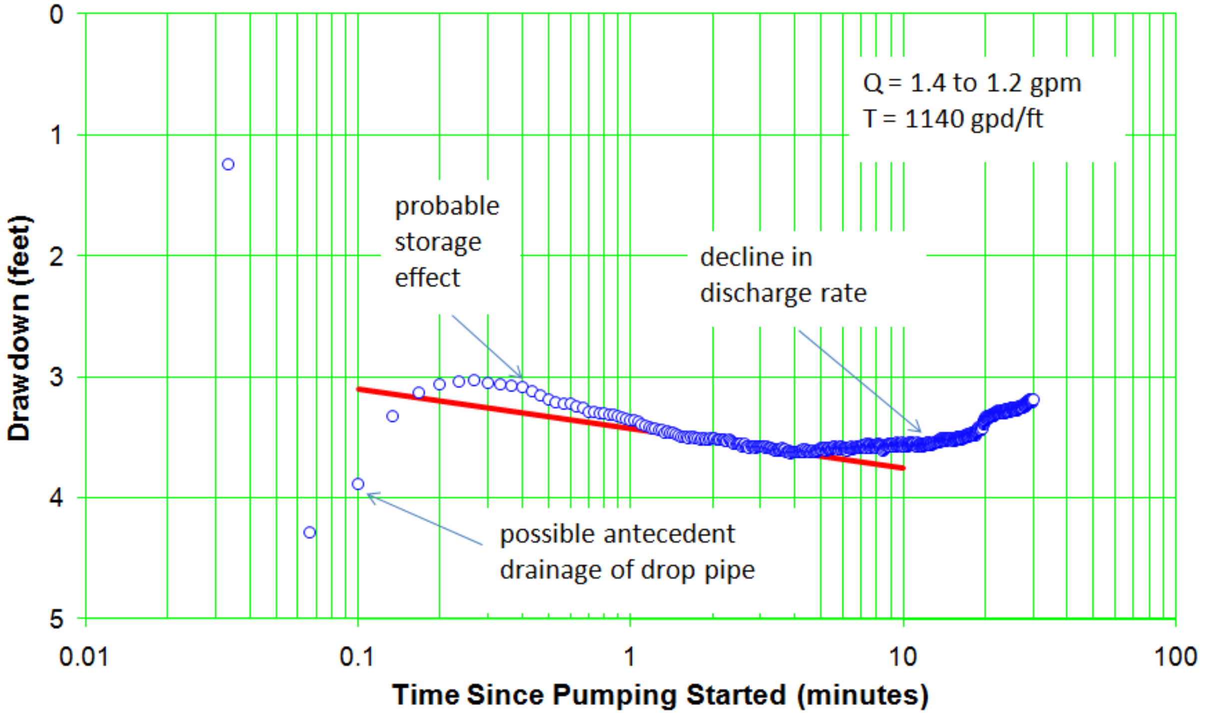


Figure C-8.1-1 Well R-64 trial 1 drawdown

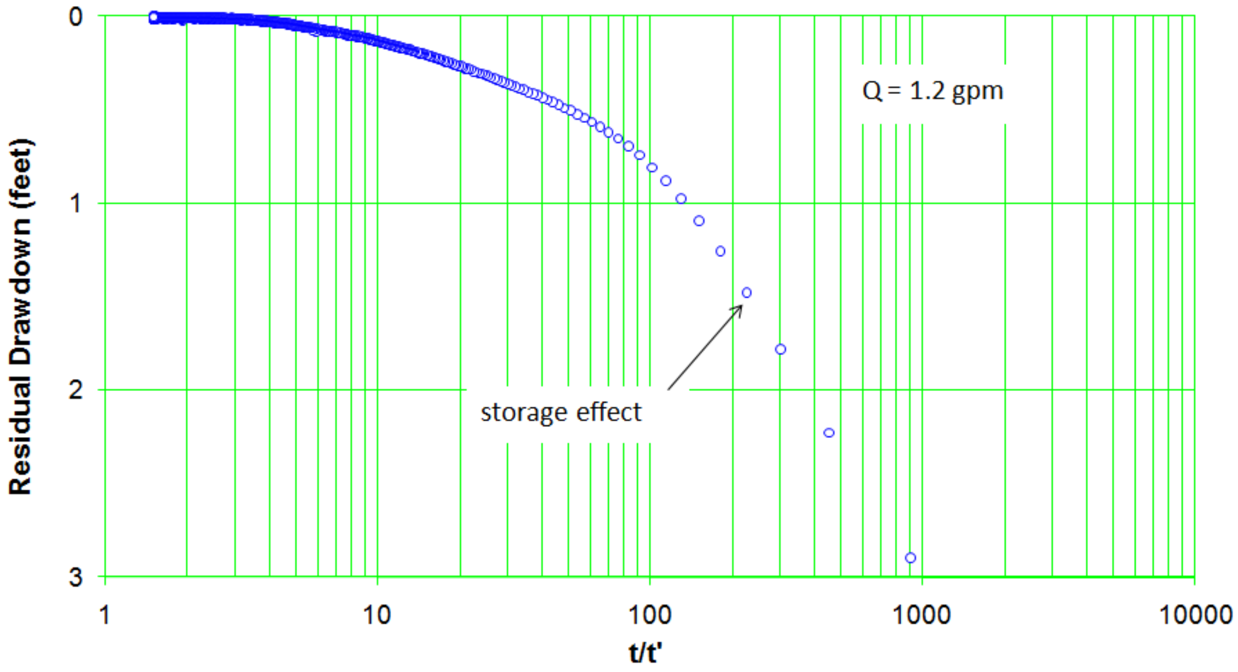


Figure C-8.1-2 Well R-64 trial 1 recovery

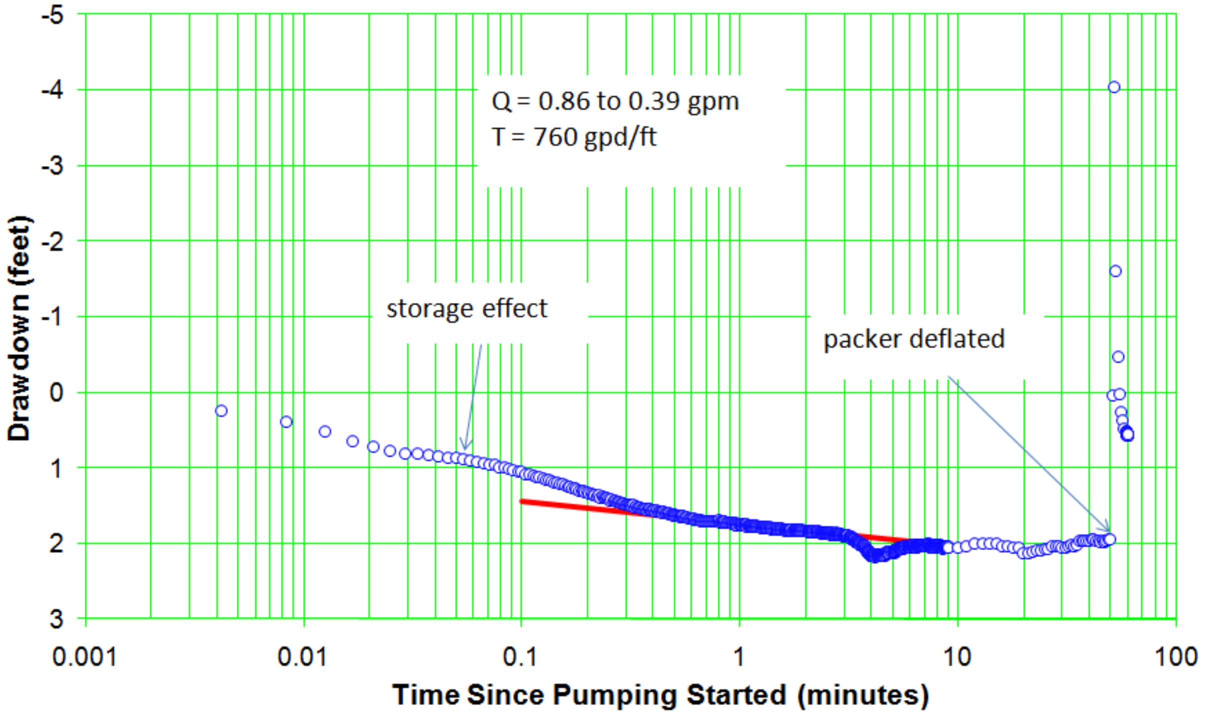


Figure C-8.2-1 Well R-64 trial 2 drawdown

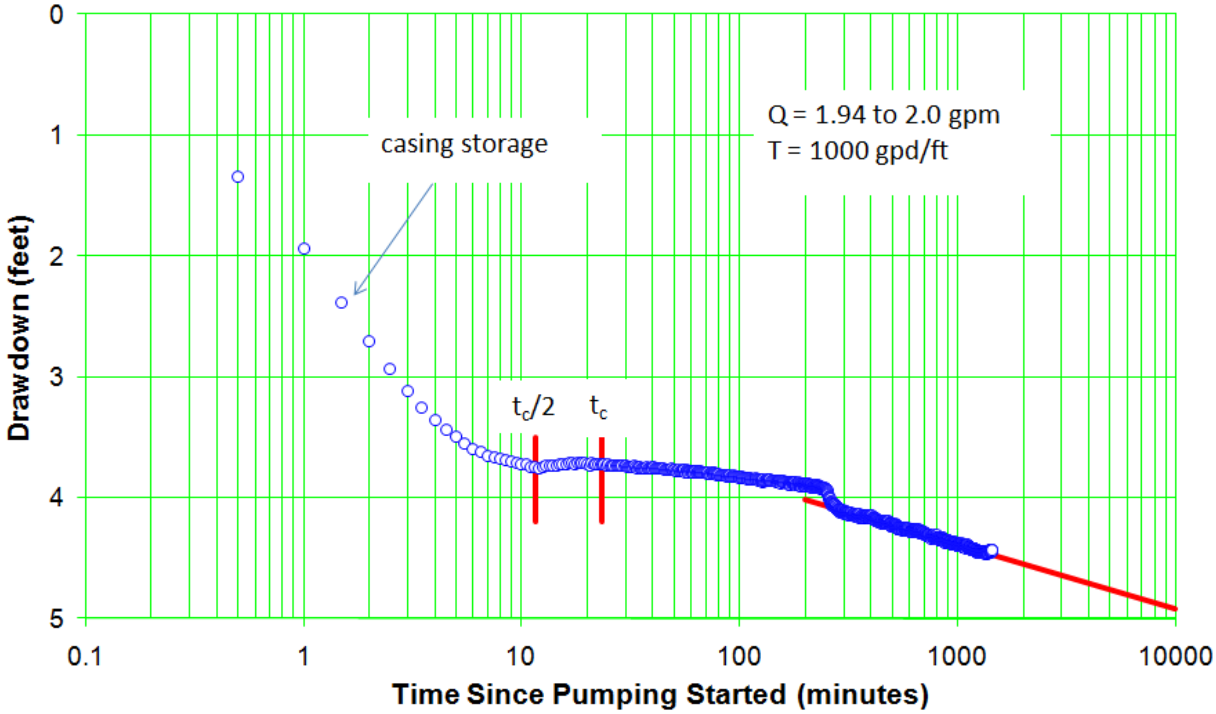


Figure C-8.3-1 Well R-64 drawdown

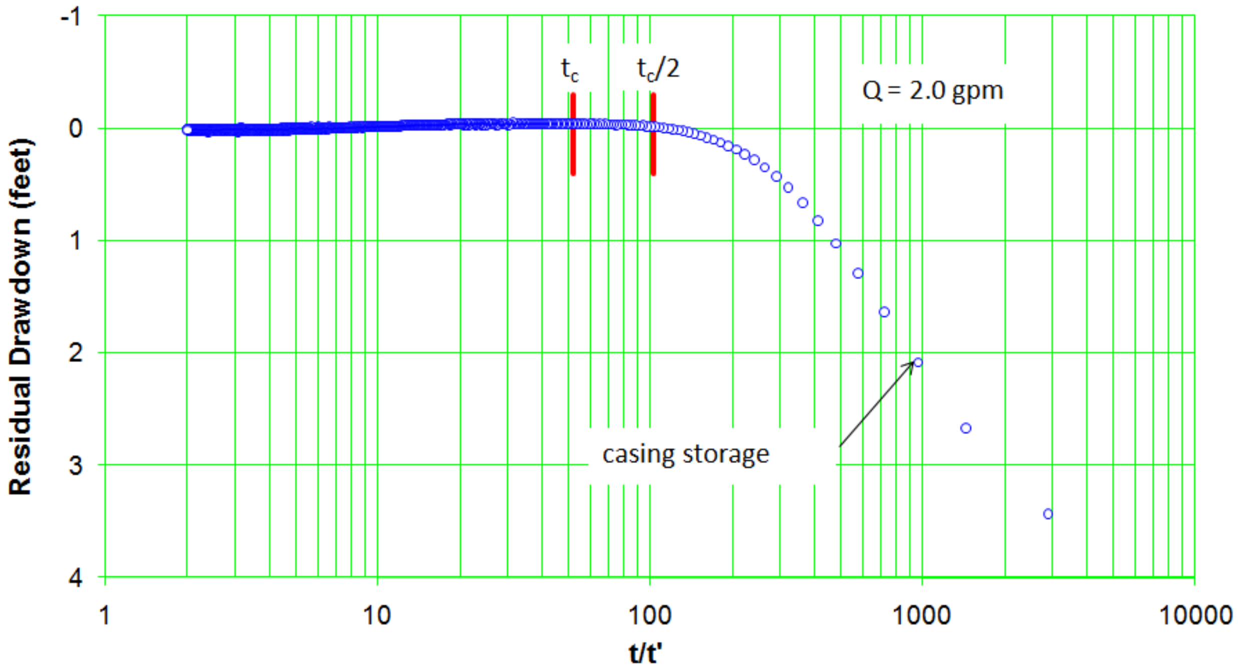


Figure C-8.3-2 Well R-64 recovery

Appendix D

Geophysical Logging
(on CD included with this document)

Appendix E

R-64 Final Well Design and New Mexico Environment Department Approval

Note: The information in the final well design package was developed at the completion of borehole drilling and before development of the final lithologic log. The preliminary information in the well design summary may differ slightly from the final lithologic interpretations or data presented in the well completion report.

R-64 Well: Proposed Well Design

Well Objectives

R-64 is a regional groundwater monitoring well located near the northeast boundary of MDA T at Technical Area (TA-) 21 (Fig. 1). It is being installed to monitor water quality in the regional aquifer down gradient of moderate- to high-priority potential release sites, as described in the TA-21 Groundwater and Vadose Zone Monitoring Well Network Evaluation and Recommendations. Water-level information from R-64 will be used to revise the water table map for the area and may result in moving the R-65 well location to optimize groundwater monitoring down gradient of TA-21 potential release sites.

The drilling work plan for R-64 requires completion of a single-screen monitoring well in the regional aquifer. The well design is based on subsurface information collected during drilling, which includes lithologic types, depth of groundwater, geophysical logs, and drilling information. Because of the well's proximity to potential release sites, the well screen is set near the top of regional saturation to maximize the detection of potential contaminants after they enter the regional aquifer.

Recommended Well Design

It is recommended that R-64 be installed with a single 20-ft rod-based wire-wrapped 20-slot screen 15 ft below the top of the regional groundwater level, which was intersected at about 1270 ft bgs. The primary filter packs will consist of 10/20 sand extending 5 ft above and 5 ft below the well screen. A 2-ft secondary filter pack will be placed above the primary filter pack as shown in Figure 2. The well design is based on the drilling work plan objectives and on subsurface information collected during drilling.

Well Design Considerations

Preliminary lithological contacts from visual examination of cuttings and from gamma logging identified the following geologic contacts in descending stratigraphic order: Bandelier Tuff (0–650 ft), Puye Formation (650-1060 ft), and Miocene pumiceous sands and gravel (1060-1380). No perched groundwater was identified in the R-64 well during drilling and the borehole video (0-647 ft) showed no evidence of perched water. The stratigraphic section below the Bandelier Tuff consists of gravely and sandy layers of the Puye Formation and the Miocene pumiceous sands and gravels. Siltstones and claystones are uncommon in these units at the R-64 site.

Regional groundwater depth was predicted at approximately 1259 ft based on the water table map for the area. The drillers noted the first indication of water at 1300 ft bgs, and as drilling continued, the borehole produced water at variable rates of approximately 10 to 30 gal/minute. An electronic sounder was used to measure a stable groundwater level of 1270 ft bgs after the cased borehole reached the total depth of 1380 ft. The static water level was 1269.5' bgs after cutting the casing at 1370' and pulling it up to 1365'. Based on these measurements, a 1270-ft water level was used to determine the well-screen placement in the proposed well design.

Regional groundwater is within the Miocene pumiceous sand and gravel deposit that consists of pebbly to silty fractions of rounded white pumice with sparse biotite phenocrysts and multiple types of rounded dacite fragments. The well-screen interval (1285 to 1305 ft) is within a poorly sorted coarse to gravely sand with minor component of silty material. Placement of the well screen within a depth range of 1355 to 1380 ft in gravely deposits made up of dacite fragments with reduced amounts of pumice was also considered; however this interval is too deep to meet the goal of sampling groundwater near the water table.

Other Design Considerations

The top of the well screen is placed at least 15 ft below the groundwater level to ensure the well screen and filter pack remain submerged during pumping and aquifer testing. A 20-ft screen was recommended over a 10-ft screen because the >1000-ft depth to groundwater in this well requires installation of a high-capacity pump to lift water to the surface. Experience with existing monitoring wells at LANL has shown that it is often difficult to minimize turbidity during purging and sampling for short screens located near the water table in deep wells, largely because the high-capacity pumps draw the pumping level down into the filter pack. Increasing the screen length to 20 ft accommodates drawdown during pumping events within the screen interval, allowing the well screen to be placed close to the water table.

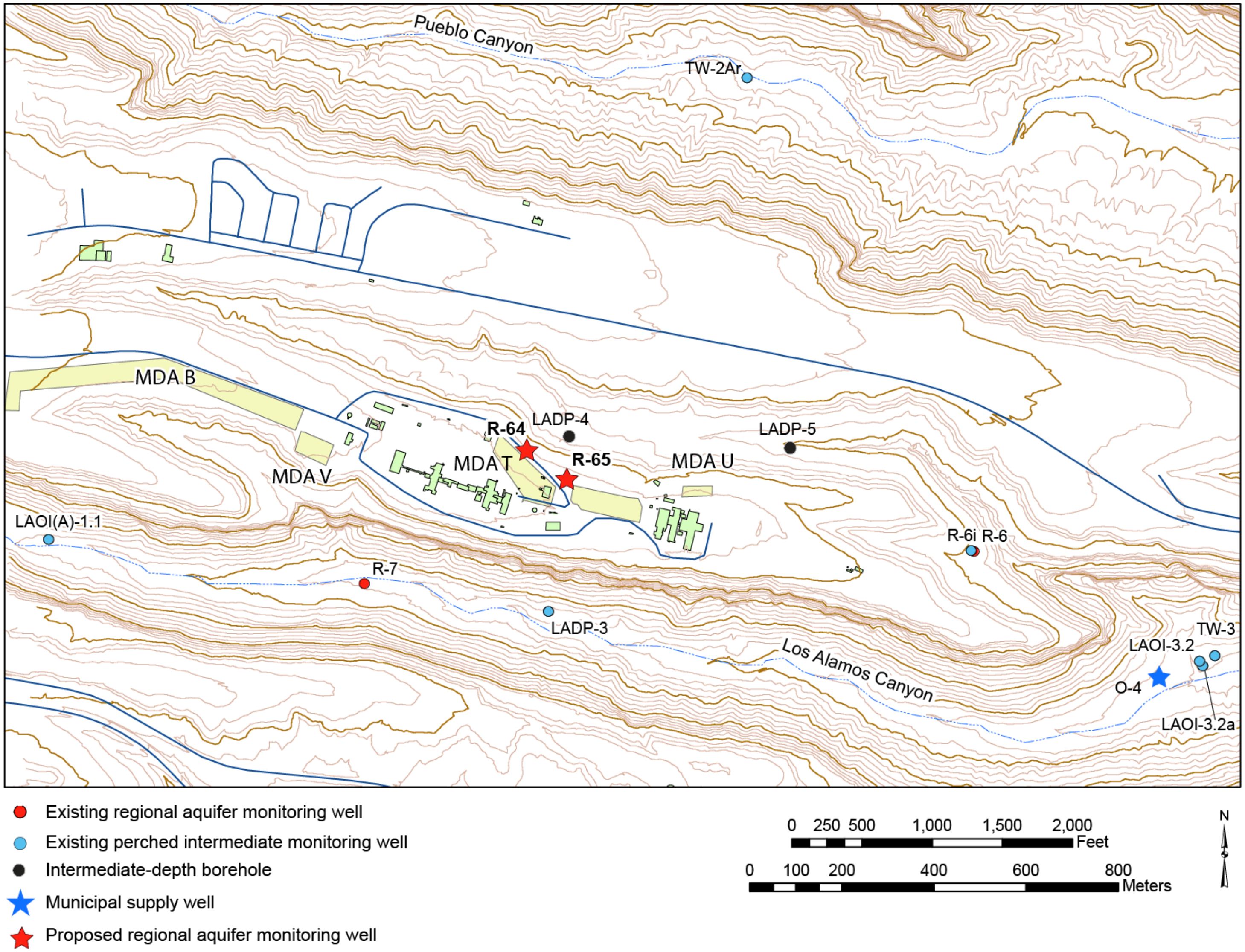


Figure 1 The map shows the location of the R-64 well at Technical Area 21.

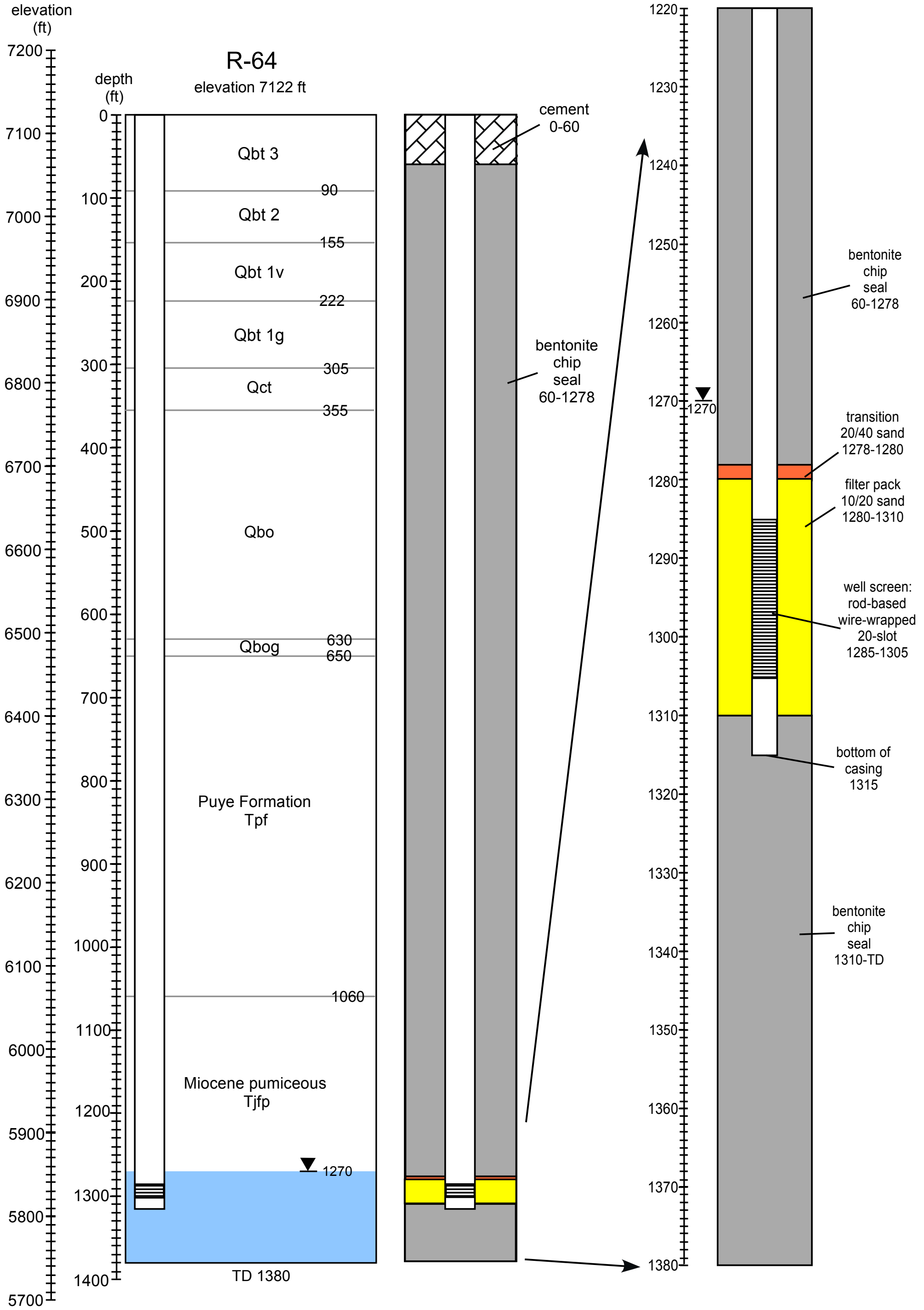


Figure 2 The stratigraphic sequence, lithologic types, and contacts are shown for the R-64 well. The 20-ft well screen design is shown to the right of the stratigraphic section.

From: Dale, Michael, NMENV
To: Everett, Mark C
Cc: Shen, Hai; Woodworth, Lance A; Ball, Theodore T; Wedgeworth, Bruce S; Morley, Richard A; Cobrain, Dave, NMENV; Kulis, Jerzy, NMENV
Subject: RE: R-64 proposed well design
Date: Wednesday, May 25, 2011 3:49:07 PM

Mark,

This e-mail serves as NMED approval for the installation of regional aquifer well R-64 as proposed in the document attached to the original e-mail received by NMED today (May 25, 2011 at 12:58 PM). This approval is based on the information available to NMED at the time of the approval. NMED understands that LANL will provide the results of preliminary sampling, any modifications to the well design proposed in the above-mentioned e-mail, and any additional information related to the installation of well R-64 as soon as such information becomes available. In addition, LANL shall notify NMED within three days of water-quality sampling at the conclusion of the aquifer-testing period at R-64. LANL shall give notice of this installation to the New Mexico Office of the State Engineer as soon as possible. Thank you.

Michael Dale

Hazardous Waste Bureau
New Mexico Environment Department
2905, Rodeo Park Drive East, Building 1
Santa Fe, NM 87505
Phone (505) 476-6046 / Fax (505) 476-6030
Main HWB Phone (505) 476-6000
Los Alamos Phone (505) 661-2673 / Cell 660-1679

From: Everett, Mark C [meverett@lanl.gov]
Sent: Wednesday, May 25, 2011 12:58 PM
To: Dale, Michael, NMENV; Cobrain, Dave, NMENV; Kulis, Jerzy, NMENV
Cc: Shen, Hai; Woodworth, Lance A; Ball, Theodore T; Wedgeworth, Bruce S; M=rley, Richard A
Subject: R-64 proposed well design

Michael,

Here is LANL's proposed well design for R-64. Please contact me with any questions or comments. If you find our proposal acceptable, please respond to this e-mail with your concurrence.

Thanks,

Mark Everett, PG
ADEP ET-EI
Los Alamos National Laboratory
(505) 667-5931