TA05 03-002

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Date: March 6, 2003
Refer to: RRES-GPP-03-033

Mr. John Young, Corrective Action Project Leader
Permits Management Program
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2905 Rodeo Park Drive East
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Santa Fe, NM 87505-6303

MAR 2003

SUBJECT: LOS ALAMOS NATIONAL LABORATORY (LANL) WELL COMPLETION REPORT FORMAT

Dear Mr. Young:

In response to your letter of January 23 2003, regarding "Review of Well Completion Reports Los Alamos National Laboratory, NM0890010515", we are in substantial agreement with your review of the Well Completion Reports submitted to date. This letter describes how the streamlined well completion report format comports with your comments. Additionally, the preliminary draft well completion report for well R-13 is included as an attachment to this letter to provide New Mexico Environment Department (NMED) a chance to work with LANL on refining the final product. Upon completion of your review of the preliminary draft R-13 well completion report, we would welcome the opportunity to meet with you and discuss your observations and comments before finalizing the report.

The following table describes where the information requested in your letter can be found in the new format for the well completion reports:

Information Requested	Well Completion Report Section
Description of Activities Completed	3.0 Summary of Drilling Activities
Summaries of all data collected during drilling	4.0 Sampling and Analysis of Core, Drill Cuttings and Groundwater Appendix C: Lithology Log
Cross-Referenced Table of planned work vs actual work accomplished, noting any and all variations, including rationale for any changes made to the scope of work.	Appendix A: Activities Planned Compared to Work Performed
Hydraulic property tests, water levels, all occurrences of groundwater	6.0 Lithology and Hydrogeology 8.2 Hydrologic Testing
Geophysical logs and interpretations	5.0 Borehole Geophysics

2832

Information Requested	Well Completion Report Section
	Appendix D: Schlumberger Geophysical Report/Montage
Borehole logs	Appendix C: Lithology Log
Core analyses, groundwater chemistry	4.0 Sampling and Analysis of Core, Drill Cuttings and Groundwater
Brief descriptions of stratigraphy and lithology	6.0 Lithology and Hydrogeology Appendix C: Lithology Log
Well completion problems or irregularities; potential impacts to the integrity of the well and methods to assess impacts	8.0 Well Development and Log Hydrogeologic ~~Setting~~
Installation or plans for installation of transducers	8.3 Dedicated Pump Installation
Geologic samples, matric potentials, moisture measurements included in borehole logs	Appendix C: Lithology
Borehole video log	Appendix E: Borehole video (DVD on inside back cover sleeve

Other data-related points raised in your letter that were not addressed in the previous table are:

- Uncertainties or percent error for all measurements, including slug and straddle packer testing data
- Detailed information that is relevant for determining fate and transport of contaminants or for use in developing the 3-D conceptual model

Both of these points regard information that is established by the analysis of the data collected. The new format of the Well Completion Reports is streamlined by reporting what data are collected and how the data are collected and does not include data analysis or interpretation. The uncertainty associated with well test data is difficult to quantify, and is best treated in the context of the interpretation of the test. For example, instrument error is relatively easy to quantify, and we will provide this information in our well completion reports, based on the specification of the instrument. On the other hand, the uncertainty of the estimated value of hydraulic conductivity determined from a slug test is a complex function of measurement errors and conceptual model uncertainties (since simplified models are usually assumed for reducing data). This type of error is best left to the comprehensive report that presents hydrologic testing data interpretations, rather than including this analysis in the well completion report. Similarly, information that is relevant to determining fate and transport of contaminants is derived from analyzing and interpreting data, and thus will be an important component of interpretative reports.

With respect to the required schedule for submitting well completion reports and fact sheets, we would like to reiterate a point made at the Hydrogeologic Characterization Quarterly Meeting on January 22, 2003, that our definition of when the wells are

considered complete is when the well head is surveyed, so that all of the data necessary to develop the fact sheet and well completion report are available. For many of the wells drilled in calendar year 2002 (R-16, R-20, R-23, and R-32), the surveyed data were delivered on January 9, 2003. The fact sheets for wells R-14, R-16, R-20, R-23, and R-32 were submitted to NMED on February 18, 2003. The anticipated submittal date for the fact sheet for well R-21 is by March 14, 2003. Drafts of the well completion reports for the 2002 wells are largely complete, but we appreciate the opportunity to discuss the draft R-13 well completion report with you before finalizing the reports. We look forward to working with you on refining the final well completion report product.

If you have any questions, please contact either Charlie Nylander (505) 665-4681 or Mat Johansen (505) 665-5046.

Sincerely,

for

Charles Nylander, Program Manager
Groundwater Protection Program
Los Alamos National Laboratory

Sincerely,

for

Mat Johansen, Project Manager
Program Compliance Manager
National Nuclear Security Admin.
Office of Los Alamos Site Operations

CN/MJ/th

Enclosure: Characterization Well R-13 Completion Report

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DRAFT

LA-UR-XXXXX
GPP-03-023
ER2003-0160
March 2003

Characterization Well R-13 Completion Report

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Produced by the Risk Reduction and Environmental Stewardship

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List of Acronyms and Abbreviations

AITH	array induction tool, version H
ASTM	American Society for Testing and Materials
bgs	below ground surface
BMP	best management practices
CNTG	compensated neutron tool, model G
DH	down hole
DR	dual rotary
DTH	down-the-hole
ECS	elemental capture spectroscopy
ER	Environmental Restoration (Project)
ESH	Environmental, Safety, and Health
FIP	Field Implementation Plan
FMI	formation microimager
FMU	Facility Management Unit
FSF	Field Support Facility
GIT	Groundwater Investigations Team
gal.	gallon
gpm	gallons per minute
GPS	global positioning system
hp	horse power
ID	inner diameter
LANL	Los Alamos National Laboratory
NGS	natural gamma spectroscopy
NTU	nephelometric turbidity unit
OD	outer diameter
psi	pounds per square inch
PVC	polyvinyl chloride
RC	reverse circulation
RRES	Risk Reduction and Environmental Stewardship Division
SSHASP	Site-Specific Health and Safety Plan
TA	technical area
TD	total depth
TLDM	triple detector lithodensity
UR-DTH	under-reaming down-the-hole-hammer
WGII	Washington Group International, Inc.
WCSF	waste characterization strategy form

CHARACTERIZATION WELL R-13 COMPLETION REPORT

by

Rick Lawrence, Paula Schuh, Curtis Schultz, Dan Thompson, Eric Tow

ABSTRACT

Characterization well R-13 was installed under implementation of the "Hydrogeologic Workplan" (LANL 1998, 59599). This well was funded by the Nuclear Weapons Infrastructure, Facilities, and Construction Program. The R-13 project was directed by the Environmental Restoration (ER) Project in accordance with the Mortandad Canyon Work Plan (LANL 1997, 56835). Management of the drilling program was carried out by Washington Group International, Inc. (WGII) under a subcontract to the Laboratory. The well is located in Mortandad Canyon, in the east-central portion of the Los Alamos National Laboratory (LANL or the Laboratory). Well R-13 is primarily designed to determine whether Laboratory releases and treatment plant effluents may be present in or near the Mortandad Canyon watershed and, if so, the extent to which contaminants have affected groundwater quality.

Well R-13 was designed to provide hydrogeologic and water-quality data on the regional aquifer downgradient of contaminant release sites in Mortandad and Ten Site Canyons. According to the Risk Reduction and Environmental Stewardship Division, specific sources of concern include the waste water treatment plant at Technical Area (TA) - 50 and a former waste water treatment facility at TA-35 that have historically released effluent.

Hydrologic, geologic, geochemical, and geophysical information obtained during completion and subsequent sampling of these wells will provide data for the LANL three-dimensional hydrologic and geologic conceptual models and contribute to implementing a Laboratory-wide groundwater monitoring system. Monitoring of this network of wells supports the Laboratory's "Groundwater Protection Management Program Plan" (LANL 1996, 70215).

The R-13 borehole was drilled to a total depth (TD) of 1133 ft below ground surface (bgs) using air-rotary drilling methods. Well installation was completed on February 25, 2002, with a single screen in the regional aquifer and equipped with a dedicated submersible pump.

Geologic strata encountered during drilling operations at R-13 included the following, in descending order: alluvial sediments, the Tshirege Member of the Bandelier Tuff, the Cerro Toledo interval, the Otowi Member of the Bandelier Tuff, the Guaje Pumice Bed, upper Puye Formation sediments, Cerros del Rio Basalt, and a sedimentary sequence making up the lower section of Puye Formation. No core drilling was conducted at R-13. Samples of drill cuttings were collected at regular intervals for stratigraphic, petrographic, and geochemical analysis.

No perched water was encountered at R-13. The regional zone of groundwater saturation was encountered at a depth of 834 ft bgs in the Puye Formation. Groundwater samples were collected from the regional aquifer for analysis of selected organic and inorganic constituents and radiochemical compounds.

1.0 INTRODUCTION

This completion report summarizes the site preparation, drilling, well construction, well development, and related activities conducted for the R-13 site from August 14, 2001 to February 25, 2002 for characterization well R-13. The well is located on the floor of Mortandad Canyon approximately 5890 ft east-southeast of well R-15 and 250 ft north of the Los Alamos National Laboratory (LANL or the Laboratory), as shown in Figure 1.0-1.

The information presented in this report was compiled from field reports and activity summaries generated by LANL and subcontractor personnel. Geophysical data provided by Schlumberger, Inc. (Schlumberger) and geodetic survey results are also included. Results of these activities are discussed briefly and shown in tables and figures contained in this report. Detailed analysis and interpretation of geologic, geochemical, geophysical, and hydrologic data will be included in separate technical documents prepared by the Laboratory.

Well R-13 was funded by the Nuclear Weapons Infrastructure, Facilities, and Construction Program and installed by the Laboratory's Environmental Restoration (ER) Project, now called the Risk Reduction and Environmental Stewardship Division (RRES). Washington Group International, Inc. (WGII), under contract to the Laboratory, was responsible for overseeing and executing the drilling activities.

This characterization well will function primarily to investigate the nature and extent of impacts to regional groundwater resulting from Laboratory activities in the Mortandad Canyon watershed. Water quality, geochemical, hydrologic, and geologic information gathered during completion will augment knowledge of regional subsurface characteristics and distribution of any contaminants downgradient of TA-35, a potential source for groundwater contamination. Well R-13 is designed to provide water-quality and water-level monitoring data from the regional aquifer. Data from R-13 will be used to update the evolving sitewide hydrologic and geologic conceptual models for the Laboratory.

Figure 3.0-1 Well Summary Data Sheet for R-13

Location: TA-5, Mortandad Canyon

Survey coordinates (brass marker in NW corner of R-13 cement pad):
x = 1640992 E y = 1766994 N (NAD 83)
z = 6659.7 ft asl (NGVD 29)

Drilling: fluid-assist air rotary reverse circulation with casing advance
Start date: 8/21/01
End date: 9/20/01

Borehole drilled to 1133 ft. total depth (TD)

Data collection:
Hydrologic properties: Field Hydraulic Test: Draw-down Pumping Test
Cores/cuttings submitted for geochemical and contaminant characterization: (0)
Groundwater samples submitted for geochemical and contaminant characterization: (1)
Geologic properties: Mineralogy, petrography, and chemistry: (12)
Borehole logs:
Lithologic: 0-1133 ft.
Video (LANL tool): 760-828 ft
Natural gamma (LANL tool): 0-760 ft (cased), 760-830 ft (open hole) ; 0-850 ft (cased), 850-1053 ft (open hole); 0-1126 ft (cased)
Schlumberger Logs: 0-850 ft (cased), 850-1058 ft (open hole): Compensated neutron, array induction, litho-density, electron capture, natural gamma, formation micro-imager.

Contaminants Detected in Borehole Samples:
Regional groundwater: none

Well construction:
Drilling Completed: 9/20/01
Contract Geophysics: 9/24/01
Well Constructed: 9/26/01-10/6/01
Well Developed: 10/11/01-10/30/01
Dedicated Pump Installed: 02/20/02

Casing: 4.5-in ID, 5.0-in OD stainless steel with external couplings

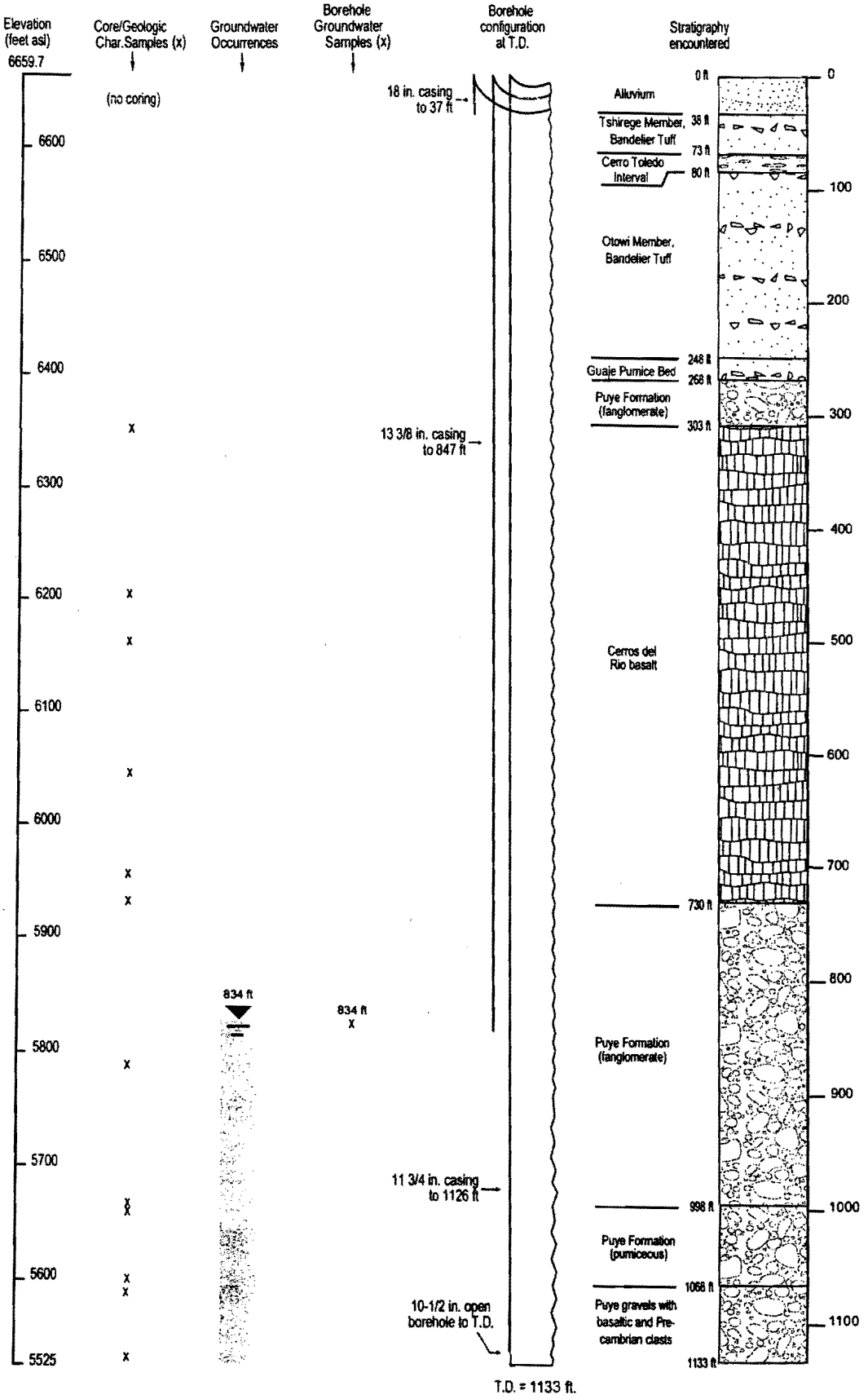
Number of Screens: 1
4.5-in ID, 5.563-in OD pipe based, s.s. wire-wrapped; 0.010-in slot

Screen (perforated pipe interval):
Screen #1 - 958.3 - 1018.7 ft

Well development consisted of brushing, bailing, and pumping.

Groundwater occurrence was determined by recognition of first water produced while drilling. Static water levels were determined after the borehole was rested.

Preliminary geologic contacts determined by examination of cuttings and interpretation of geophysical logs.



3.1 Drilling Activities

Drilling activities at R-13 were conducted from August 21 through September 21, 2001 (Table 3.1-1 and Appendix B).

Table 3.1-1
Borehole R-13 Drill Shift Information

Activity	Dates	Number of shifts[a]
Site preparation	August 14 – August 17, 2001	4
Rig mobilization/drilling/ demobilization	August 21 – September 21, 2001	43
Geophysics/well design	September 23 – September 24, 2001	6
Well installation/annular backfilling	September 26 – October 6, 2001	18
Well development/hydrologic testing	October 10, 2001 – October 31, 2001	22
Well completion tasks	November 01 – December 05, 2001	8
Dedicated pump installation	February 20 – February 25, 2002	4
Total shifts	August 14, 2001 – February 25, 2002	105

[a] Shifts are defined as 12 hours in duration. Work performed for any portion of a shift is recorded as one shift in this table.

On August 21, 2001, Dynatec mobilized the DR-24 drill rig and support equipment to the site and commenced R-13 drilling operations. Dynatec initially advanced 18-in. steel conductor casing by reaming with the assistance of a 16-in. tricone long-tooth carbide button bit from ground surface to the contact between alluvium and the underlying Tshirege Member of the Bandelier Tuff. The conductor casing was landed at 37 ft bgs and cemented in place on August 22, 2001. Open hole drilling continued with a 12 1/4-in. tricone bit from 37 ft bgs through the Bandelier Tuff, Cerro Toledo interval, and Puye Formation sediments. The top of the Cerros del Rio basalt was encountered at approximately 303 ft bgs.

To offset slow drilling conditions in the basalt, Dynatec switched to a 16-in. DTH bit and stabilizer. Drilling progressed to 325 ft bgs before losing circulation in the open borehole. The stabilizer was then removed from the drill string and open hole drilling continued from 325 to 410 ft.

On August 25, 2001, the annular seal outside of the 18-in. conductor casing began leaking, and cuttings were circulating out along the outside of the casing rather than through the discharge line. To solve this problem, Dynatec elected to advance 13 3/8-in. casing using a 14 1/2-in. under-reaming down-the-hole-hammer (UR-DTH) bit and began casing advance drilling until a suitable depth was reached to land the casing. Drilling progressed through basalt from 410 ft to 705 ft bgs. Operations were then shut down for the Labor Day holiday.

Drilling operations resumed on September 5, 2001. Casing advance drilling continued from 705 ft to 760 ft bgs where the 13 3/8-in. casing was landed in the Puye Formation, approximately 30 ft below the base of the Cerros del Rio basalt. Dynatec then changed to a 12 1/4-in. tricone bit and drilled open hole from 760 ft to 832 ft bgs.

Problems developed at R-13 on September 7, 2001, when hydraulic oil was discovered in a cuttings sample collected from the 827 to 832 ft interval. It was determined that a small leak had developed in a mixing tank pump and hydraulic oil was inadvertently pumped into the borehole. On September 8 and 9, 2001, Dynatec undertook procedures as approved by Laboratory and ER Project management to remediate and decontaminate the borehole and drilling equipment. The drill string and down hole (DH) tools were tripped out and decontaminated. The open-hole portion of the borehole was then flushed and pumped out five times using a total of 3700 gal. of hot water mixed with Liquinox® and Quick Foam®, followed by a rinse with 200 gal. of potable water. Oil residue was then cleaned from the mixing tank, and the borehole was flushed three more times with 2400 gal. of hot water mixed with Liquinox® and Quick Foam®. All fluids involved in the decontamination procedure were pumped into 3000-gal. polyethylene tanks for temporary storage.

On September 10, 2001, the borehole was purged of 300 gal. of water by circulating air through the drill stem. A sample was collected for analysis to determine if contamination was still present in the borehole. Dynatec performed waste management activities for the remainder of the day, as directed by LANL waste management representatives.

As a result of events that took place in New York City and Washington, D.C., site activities were temporarily suspended on September 11, 2001, when LANL implemented security measures that shut down all nonessential operations.

On September 12, 2001, the DH video camera and natural gamma-logging tool were used to assess the condition of the borehole. Dynatec constructed a temporary storage area for drill cuttings while the original containment area was remediated.

Dynatec resumed drilling operations on September 13, 2001. Casing advance using a 14 1/2-in. UR-DTH bit and 13-3/8-in. drill casing proceeded from 760 to 849 ft bgs to seal off the zone where the hydraulic oil leak had occurred. The DTH bit was then exchanged for a 12 1/4-in. mill-tooth drill bit. The borehole was advanced open hole in Puye sediments from 849 to 963 ft bgs. Groundwater was detected at a depth of 834.0 ft bgs, and a sample was collected for analysis.

On September 15, 2001, the borehole was advanced to 1083 ft bgs. Sloughing conditions rendered open-hole drilling ineffective. The decision was made by LANL ER management to advance 11 3/4-in. drill casing in an attempt to seal off flowing sands encountered in the Puye Formation. Dynatec completed tripping in of the drill casing on September 17, 2001, and continued casing advance drilling using a 10 5/8-in. tricone drill bit from 1030 to 1094 ft bgs. Subsequent open hole drilling advanced to a depth of 1133 ft bgs. Continued sloughing prevented further advancement of the borehole; as a result, the 10 5/8-in. tricone drill bit was tripped out.

Upon LANL's direction, casing advance with a 12 3/4-in. UR-DTH bit and 11 3/4-in. casing resumed in an attempt to deepen the borehole. Flowing sand and gravel conditions prohibited advancement of the borehole beyond 1133 ft bgs. The drill string and 11 3/4-in. casing were then tripped out in order to proceed with borehole geophysical logging operations. R-13 drilling activities were completed on September 21, 2001.

4.0 SAMPLING AND ANALYSIS OF CORE, DRILL CUTTINGS, AND GROUNDWATER

During drilling operations at R-13, drill cuttings were collected according to the R-13 FIP. As drilling conditions permitted, a sufficient quantity of borehole material was collected via RC at 5-ft intervals. A portion of the cuttings was sieved (at >#10 and >#35 mesh) and placed in chip-tray bins along with an

unsieved portion. These chip trays were studied to determine lithological characteristics and used to assist the preparation of lithologic logs. The remaining cuttings were sealed in zip lock bags and set in core boxes for curation. No cuttings samples were submitted for contaminant analysis. Prior to curation of the chip trays and cuttings, 12 sample were removed for mineralogic, petrographic, and geochemical analysis.

During drilling operations, perched groundwater zones were not encountered. Regional groundwater was encountered at 834 ft bgs. One sampling event for groundwater contaminant analysis took place at this depth. The list of analytes for this sampling event can be found in Appendix A. Analytical results from the R-13 sample submittals will be presented in a separate Laboratory report.

5.0 BOREHOLE GEOPHYSICS

WGII (using LANL tools) and Schlumberger performed borehole geophysical logging operations at well R-13. Table 5.0-1 lists the surveys performed.

Table 5.0-1
Borehole and Well Logging Surveys Conducted in R-13

Surveyor	Date	Method	Cased Footage	Open-hole Interval (ft bgs)	Remarks
WGII/LANL	September 12, 2001	Video, Natural gamma	0 – 760	760 – 832	To evaluate borehole conditions after down-hole discharge and subsequent cleaning of hydraulic fluid
WGII/LANL	September 15, 2001	Video, Natural gamma	0 – 850	850 –1053	To evaluate unstable open borehole conditions
WGII/LANL	September 20, 2001	Natural gamma	0 – 1126	0	Conducted before retracting 11 3/4-in. drill casing
Schlumberger	September 24, 2001	Logging suite[a]	0 – 826	826 –1058	Schlumberger borehole logging conducted at TD prior to well installation
WGII/LANL	October 12, 2001	Video	0 –1029	0	Filmed to 832 ft (water level) to evaluate bentonite in the well casing
WGII/LANL	October 15, 2001	Video	0 – 1029	0	Filmed to 1020 ft (sump) to evaluate the condition of well casing interior during development
WGII/LANL	October 19, 2001	Video	0 – 1029	0	Filmed to 833 ft (water level) to evaluate condition of the well casing interior

[a] Schlumberger suite of borehole logging surveys included triple detector lithodensity, array induction imager, epithermal compensated neutron log, elemental capture sonde, full-bore formation microimager, and natural gamma ray spectrometry.

5.1 LANL-Supported Geophysical Logging

Between September 12 and October 19, 2001, natural gamma and video camera logs were performed in borehole R-13 using down-hole tools provided by LANL. A series of down-hole surveys were conducted in the R-13 borehole and the installed well. The gamma logs were collected to provide lithologic and stratigraphic information that complemented data gathered from cuttings. The video logs were used to troubleshoot drilling-related problems and to observe interior well conditions. Table 5.0-1 summarizes the borehole and well logs conducted in R-13.

Three natural gamma logs were run. Natural gamma logs have proven successful in discriminating between geologic units that contain varying concentrations of uranium, thorium, and potassium. The first gamma log was carried out from 0 to 832 ft bgs. At that time, the borehole contained an 18-in. surface casing from ground surface to 37 ft bgs and a 13 3/8-in. drill casing from ground surface to 760 ft bgs. Open borehole conditions extended from 760 to 832 ft bgs. This logging run was conducted shortly after the borehole was flushed to remove hydraulic fluid that had circulated into the borehole. The second gamma log run was inside the 13 3/8-in. drill casing from surface to 760 ft bgs, with the 18-in. surface casing still in place to 37 ft bgs. The borehole was open from 760 to 1053 ft bgs. The third gamma log run was inside 11 3/4-in. drill casing from surface to 1126 ft bgs, 13 3/8-in. casing from surface to 850 ft bgs, and the surface casing still in place. Measurements of natural gamma activity were obtained every 0.1 ft as the logging tool was raised upward from the bottom of the borehole at a rate of about 15 ft/min.

Several video camera logs were run to evaluate the condition of the borehole after hydraulic fluid decontamination operations. One run was made to assess the stability of the borehole prior to deploying the natural gamma tool. A video log was also performed to view the condition of the well interior after it was discovered that a slug of bentonite had fallen into the well during construction. A final camera run was conducted as a quality control procedure to inspect the condition of the stainless steel well casing and screens installed at R-13. The video log of the open borehole was digitized to a DVD and included as Appendix D (see the inside back cover of this report).

5.2 Schlumberger Geophysical Logging

Schlumberger conducted geophysical logging in the R-13 borehole on September 24, 2001. A suite of logging surveys was performed after retracting the 11 3/4-in. drill casing from 1126 ft to 826 ft bgs. At that time, an 18-in. surface casing extended from ground surface to 37 ft bgs, a 13 3/8-in. drill casing extended from ground surface to 850 ft bgs, and a 11 3/4-in. drill casing extended from ground surface to 826 ft bgs. The remaining interval of the borehole between 850 and 1058 ft bgs was open.

The primary purpose of the Schlumberger logging was to characterize the conditions in the hydrogeologic units penetrated by the R-13 borehole with emphasis on gathering data on moisture distribution, assessing groundwater in the regional aquifer, measuring capacity for flow, and obtaining lithologic/stratigraphic data. Secondary objectives included evaluating borehole geometry and assessing the degree of drilling fluid invasion along the borehole wall.

Schlumberger ran a suite of geophysical logging tools in the cased borehole including the following:

- The Array Induction Tool, Version H, (AITH™) measures formation electrical resistivity and borehole fluid resistivity, thus evaluating the drilling fluid invasion into the formation, the presence of moist zones away from the borehole wall, and the presence of clay-rich zones;
- The Triple detector Litho-Density (TLDM™) measures formation bulk density related to porosity, photoelectric effect related to lithology, and borehole diameter using a single-arm caliper;

- Natural Gamma Spectroscopy (NGS™) measures spectral and overall natural gamma ray activity, including potassium, thorium, and uranium concentrations, thus evaluating geology and lithology, particularly the amount of clay in open- and cased-hole conditions;
- Elemental Capture Sonde (ECS™) measures concentrations of hydrogen, silicon, calcium, sulfur, iron, potassium, titanium, and gadolinium to characterize mineralogy, lithology and water content of the formation;
- Compensated Neutron Tool, Model G (CNTG™) measures volumetric water content beyond the casing to evaluate formation moisture content and porosity; and
- Formation Micro-Imager (FMI™) measures electrical conductivity images of the borehole wall and the borehole diameter with a two-axis caliper, to evaluate geologic bedding and fracturing, including strike and dip of these features, fracture apertures and rock textures.

Additionally, a calibrated natural gamma tool was used to record gross natural gamma-ray activity with every logging method (except the NGS™ run) to correlate depth runs between each of the surveys conducted.

The Schlumberger logging report and the geophysical logs compiled as a montage can be found in Appendix E, which is stored on a CD (see the inside back cover of this report).

6.0 LITHOLOGY AND HYDROGEOLOGY

A preliminary assessment of the hydrogeologic features encountered during drilling operations at R-13 is present below. Included is a brief description of the geologic units identified during characterization of cuttings. Groundwater occurrences are discussed based on drilling evidence, open-hole video logging, and geophysical logging data.

6.1 Stratigraphy and Lithologic Logging

Rock units and stratigraphic relations, interpreted primarily from visual examination of drill cuttings samples and interpretation of geophysical data, are briefly discussed in order of younger to older occurrence. Such interpretations may be revised upon further analysis of petrographic, geochemical, mineralogical, and geophysical logging. A lithologic log for the R-13 borehole is provided in Appendix C.

Alluvium (0 to 38 ft bgs)

Cuttings samples indicated unconsolidated alluvium in R-13 from ground surface to approximately 38 ft bgs that represent abandoned stream channels of Mortandad Canyon. These Quaternary deposits contain tuffaceous silty sands and gravels derived from the Bandelier Tuff.

Bandelier Tuff (38 to 268 ft bgs)

The Quaternary Bandelier Tuff intersected by borehole R-13 include the Tshirege Member, (Unit 1g), the Cerro Toledo interval, the Otowi Member, and the Guaje Pumice Bed.

Tshirege Member of the Bandelier Tuff, Unit 1g (38 to 73 ft bgs)

Unit Qbt 1g of the Tshirege Member of the Bandelier Tuff was encountered from 38 and 73 ft bgs. This interval represents the basal part of the Tshirege Member that is made up of nonwelded to poorly welded rhyolite ash-flow tuff. Drill cuttings indicate abundant (up to 80% by volume) vitric pumice; hence, the unit is identified as 1g (*g* representing glassy). Cuttings contain 20% or more intermediate to felsic volcanic lithic fragments and lesser amounts of quartz and sanidine crystals.

The Cerro Toledo Interval (73 to 80 ft bgs)

The brief interval from 73 to 80 ft bgs is interpreted to represent tephra and volcaniclastic sediments of the Cerro Toledo interval underlying the Tshirege Member. Texturally, this unit is made up of silt to very coarse sands and gravels. Pebble-size clasts are subrounded and typically composed of dacite and rhyodacite volcanics in a matrix of white vitric pumice, quartz, and sanidine crystals.

Ash-flows of the Otowi Member of the Bandelier Tuff (80 to 248 ft bgs)

R-13 penetrated 168 ft of nonwelded to poorly welded rhyolite ash-flow tuff representing the Otowi Member of the Bandelier Tuff. The upper part of this sequence contains abundant fibrous, vitric pumice fragments that are orange-tan in color. The Otowi Member is lithic-rich and typically contains up to 80% dacitic and andesitic xenolithic fragments and 10% or less quartz and sanidine phenocrysts. Whole rock chip samples frequently exhibited ground vitric ash that indicates the nonwelded character of the tuff matrix.

Guaje Pumice Bed (248 to 268 ft bgs)

The interval from 248 to 268 ft bgs is interpreted to represent the Guaje Pumice Bed that forms the basal unit of the Bandelier Tuff. Drill cuttings indicate that this pumiceous unit is predominantly light pinkish-gray tephra. Pumice fragments, volumetrically as much as 90%, are vitric to locally clay-altered. The remainder is made up of dacitic lithic fragments and quartz and sanidine crystals.

Upper Puye Formation (268 to 303 ft bgs)

The 37-ft-thick interval from 268 to 303 ft bgs in R-13 is made up of generally fine clastic sediments interpreted to represent an upper facies of the Tertiary-age Puye Formation. Cuttings in this interval are predominantly made up of indurated clay-cemented tuffaceous sandstone and siltstone with less than 10% clasts by volume of mixed volcanic lithologies, including dacite, andesite, basalt, pumice, and minor amounts of quartz and sanidine crystals.

Cerros del Rio Basalt (303 to 730 ft bgs)

R-13 intersected a series of basalt flows and scoriaceous breccias from 303 to 703 ft bgs that make up the Tertiary Cerros del Rio basalt. Basalt flows in this section are generally porhyritic with phenocrysts of olivine, pyroxene, and minor plagioclase in an aphanitic groundmass. Flows exhibit a wide range of vesicularity and are locally scoriaceous. The interval from 460 to 483 ft bgs contains abundant scoria that is reddish with iron-oxide staining, suggesting that this interval is an interflow breccia separating distinct flow events in the sequence. Evidence of local hydrothermal alteration in these rocks also includes sericitization of groundmass minerals, iddingsite replacement of olivine phenocrysts, amygdaloidal clays, and clay or calcite coatings on fracture surfaces. Clay-coated, rounded basalt clasts in chip samples from 595 to 605 ft bgs suggest this interval may represent a sedimentary interflow deposit between basalt flows.

Lower Puye Formation (730 to 1133 ft bgs)

Stratigraphically, below the Cerros del Rio basalt R-13 encountered a sequence of clastic sediments from 730 ft bgs to the bottom of the borehole at 1133 ft bgs. This clastic sediment interval is the lower section of the Puye alluvial-fan deposits. A wide range of textures, from silty sands to coarse gravels, is present in this interval, and there is a predominance of volcaniclastic materials evident throughout the chip samples. From 730 to 998 ft bgs, the Puye Formation is dominantly composed of dacitic and basaltic clasts (up to 98% by volume) and typically contains up to 15% fine-grained tuffaceous sandstone and siltstone fragments. Trace amounts of glassy scoria, pumice, and quartz are locally present. The interval from 998 to 1068 ft bgs is notably rich in pumice (generally 50% or more pumice) with moderate amounts of dacite, silicified dacite, rhyodacite, fine-grained volcanic sandstone, and minor basalt scoria.

The lowermost interval of the Puye Formation from, 1068 to 1133 ft bgs, exhibits a 5 to 20% by volume component of Precambrian quartzite and metamorphosed granitic rocks. Quartzite-bearing gravel horizons interlayered within Puye sediments appear to be common in the study area. Dethier (1997) referred to the Totavi Lentil as a distinct gravel subunit containing 80% or more clasts of quartzite and other Precambrian crystalline rocks. The presence of quartzite in the above-mentioned interval suggests a depositional environment that resulted in the local mixing of volcaniclastic Puye alluvial-fan sediments with axial gravels of the ancestral Rio Grande.

6.2 Groundwater Occurrence and Characteristics

Perched groundwater saturation above the regional aquifer was not predicted in the planned drilling of R-13. As anticipated, no intermediate perched water-bearing zones were identified. The regional water table was intersected during borehole advancement at approximately 834 ft bgs.

Water in borehole R-13 was first observed in alluvium after installing 18-in. surface casing to 37 ft bgs, 1 ft above the contact with the Tshirege Member of the Bandelier Tuff. Chemical analysis of a collected sample ruled out the presence of naturally occurring groundwater. Water was measured and sampled again in the borehole at 672.5 ft bgs after drilling operations were shut down for several days. Visual inspection showed that this water contained drilling fluids and was not naturally occurring groundwater.

Water in the regional aquifer was encountered while drilling in the Puye Formation and drilling was halted at 903 ft and again at 943 ft bgs to circulate fluids within the borehole in an attempt to observe increased water production, which did not occur. At a depth of 963 ft, drilling was again halted and a water level was measured at 832.7 ft bgs. The water level eventually stabilized at 834 ft bgs. At the time these water-level measurements were collected, the bottom of the drill casing was at 850 ft bgs and the borehole was open to 963 ft bgs. After R-13 well installation and development activities were completed, and prior to installation of a dedicated pump, the water level was measured at 833.7 ft bgs.

Schlumberger geophysical logs showed a moisture zone boundary at 835 ft bgs. Below 835 ft the formation appeared to be saturated to TD, as would be expected at the regional groundwater table. Above 835 ft, data indicated a sharp, large decrease in water saturation (percentage of pore space occupied by water) and the water saturation remained below 40%, except for a few sharp peaks. Below this depth, water saturation was consistently more than 65% and predominantly more than 80%. Water-filled porosity above the 835-ft level averaged approximately 10% by volume. Results of geophysical logging are presented in Appendix E.

7.0 WELL DESIGN AND CONSTRUCTION

Well R-13 was installed as part of the implementation of the Mortandad Canyon Work Plan (LANL 1997, 56835) and the Hydrogeologic Workplan (LANL 1998, 59599). Sections 8.1 and 8.2 describe the R-13 well design and construction, respectively.

7.1 Well Design

The Laboratory and WGII produced the well design for R-13. Information gathered from geophysical logs, video logs, borehole geologic samples, water-level data, field water-quality data, and drillers' observations was analyzed by the Groundwater Investigations Team (GIT) to plan screen placement intervals for the well. The final well design specified a single screen equipped with a dedicated pump to monitor water levels and potential contaminant concentrations in the regional aquifer. No intermediate perched zones were identified; therefore, no screens were placed above the regional aquifer. The planned and actual screen location is given in Table 7.1-1.

Table 7.1-1
Summary of Well Screen Information for R-13

Screen #	Planned Depth * (ft)	Actual Depth * (ft)	Geologic/hydrologic Setting
1	959.1 – 1020.0	958.3 – 1018.7	Regional zone of saturation in the Puye Formation

* These intervals represent the perforated area of the screen

7.2 Well Construction

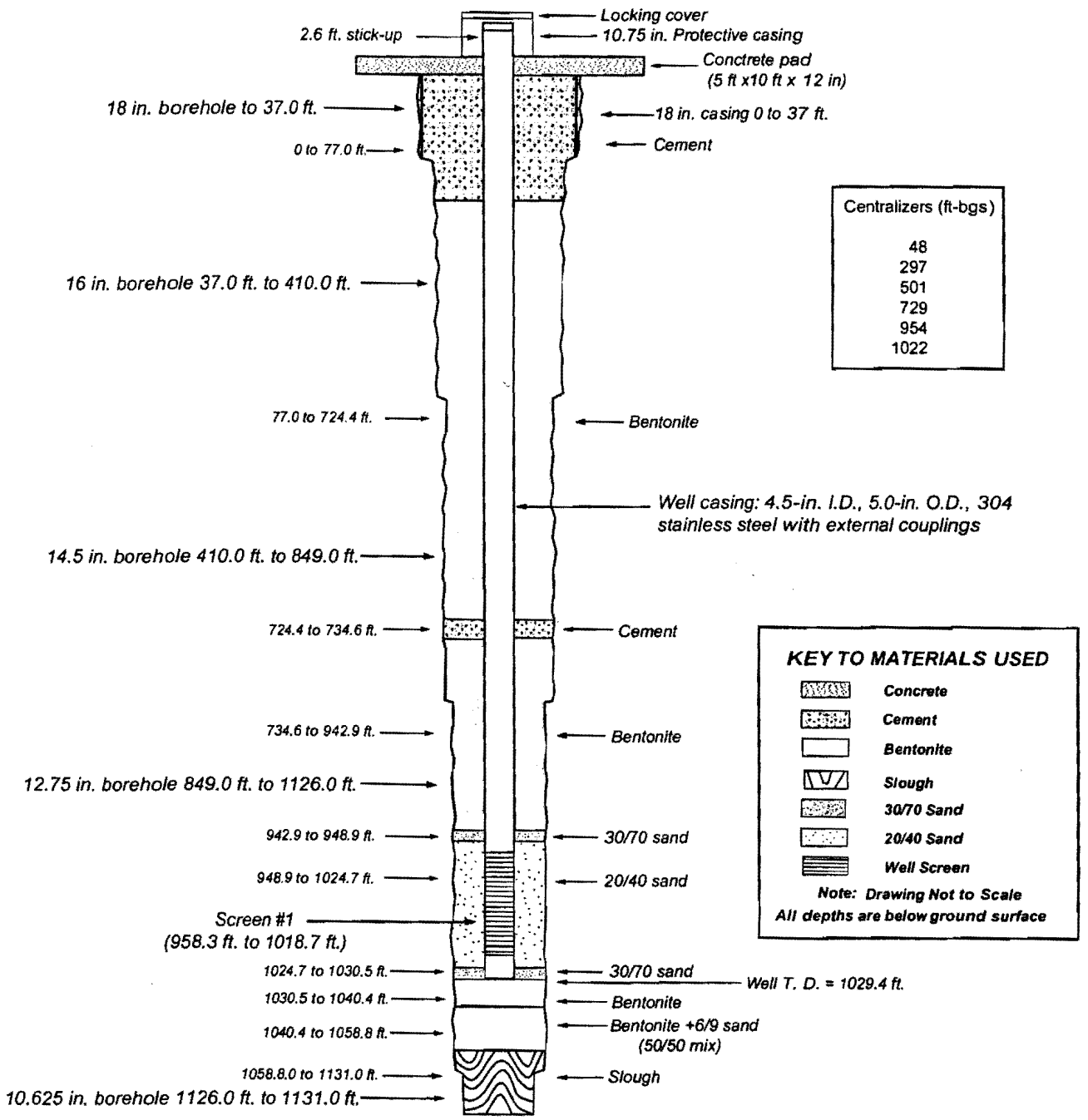
Well R-13 casing and pipe-based screens were manufactured using 4.5-in. inner diameter (ID)/5.0-in. outer diameter (OD), type 304 stainless steel fabricated to American Society for Testing and Materials (ASTM) A554 standards. External couplings were also type 304 stainless steel fabricated to ASTM standard A312 and A511, both of which exceed the tensile strength of the threaded casing ends. The pipe-based screens were modified from 10-ft sections of blank well casing by drilling 0.375-in.-diameter holes and then welding a stainless steel wire-wrap (with 0.010-in. spacing) over the perforated interval. The final OD of the screened sections was 5.56-in.

All stainless steel well components were cleaned at the well site using a steam cleaner and scrub brushes. All backfill materials were placed in the casing/borehole annulus through a tremie pipe. Well construction activities were completed in 18 shifts from September 26 to October 6, 2001 (Table 3.1-1).

7.2.1 Steel Installation

Well steel installation consisted of connecting joints of stainless steel well casing and screen sections by means of threaded couplings. The bottom of the well was set at 1029.4 ft bgs. Stainless steel centralizers were installed above and below each screen and in several locations above the zone of regional saturation to enhance positional stability during and after backfill placement operations. Dynatec installed the R-13 well casing and screen from September 26 to 27, 2001. Figure 7.2-1 shows the as-built well casing configuration and indicates the depths of the various well components from ground surface.

Figure 7.2-1 As-built R-13 Well Configuration Diagram



Note: 1. The screen interval lists the footage of the pipe perforations, not the top and bottom of screen joints.

2. Pipe-based screen: 4.5-in. I.D., 5.563-in. O.D., 304 stainless steel with s.s. wire wrap; 0.010-in slot

3. The interval of slough at the base of the borehole consists of Santa Fe Group sands.

4. Dedicated pump location not shown.

7.2.2 Annular Fill Placement

Placement of annular fill consisted of using a 1- 13/16-in. steel tremie pipe to deliver annular materials to the specified depths (Figure 7.2-1). The bottom of the borehole was measured prior to placement of backfill materials. Filter pack across the screened interval consisted of silica sand materials mixed with municipal water and placed in the annulus as a fluid slurry. Bentonite materials and sand were placed below and above the screened interval to seal the annular space and isolate the water-bearing zone. Bentonite was delivered using EZ-MUD® polymer mixed with municipal water as a fluid slurry. Portland cement (mixed at a ratio of 5 gal. of water to each bag of cement) was used to provide a foundation for annular fill above the regional aquifer and to protect the annular space around the wellhead in the upper 77 ft of the borehole. Approximately 20,630 gal. of municipal water were used during placement of backfill material.

Dynatec performed backfilling activities from September 27 to October 6, 2001. Table 7.2-1 summarizes the annular fill materials installed. The final configuration of annular materials is illustrated in Figure 7.2-1.

Table 7.2-1
Annular Fill Materials, Characterization Well R-13

Material	Amount	Unit[h]
20/40 sand[a]	151	bags
30/70 sand[b]	23	bags
6/9 sand[c]	334	bags
Benseal® bentonite [d]	5.5	bags
Holeplug® bentonite chips[e]	545	bags
Pelplug® bentonite pellets[f]	899	buckets
Portland® cement[g]	159	bags

[a] 20/40 sand is medium grained and used to pack screened intervals.

[b] 30/70 sand is fine grained and used to separate screen packs from bentonite or cement from bentonite.

[c] 6/9 and 8/12 sands are coarse and used to plug formation fractures and matrix pores.

[d] Benseal® is granular bentonite that produces a slurry when mixed with water.

[e] Holeplug® bentonite is 3/8-in. angular and unrefined bentonite chips.

[f] Pelplug® bentonite is 1/4-in. by 3/8-in. refined elliptical pellets.

[g] Portland® cement was mixed with municipal water at a ratio of 5 gal. water for each bag of cement.

[h] Sand bag = 45 pounds ea., bentonite bags/buckets = 50 pounds ea., cement bags = 90 pounds ea.

8.0 WELL DEVELOPMENT AND HYDROGEOLOGIC TESTING

Well development and hydrologic testing activities at R-13 were conducted in 22 shifts from October 10 to 31, 2001 (Table 3.1-1). Well development procedures included wire brushing, well screen swabbing and surging, bailing, and pumping. Development activities were followed by hydraulic slug tests conducted across the screened interval.

8.1 Well Development

Well development at R-13 was performed in two stages. The initial stage consisted of scouring the well interior, swabbing and surging the screened interval to draw fine sediment from the constructed filter pack, and bailing to remove solid materials from the well. In the second stage, a submersible pump was lowered to the screened interval where on/off-cyclic pumping was performed to remove any remaining fines from the filter pack and adjacent formation.

Criteria for well development were based on field water-quality parameters (turbidity, specific conductance, pH, and temperature). To monitor progress during each development stage, samples of groundwater were periodically collected and parameter measurements were recorded. One objective of well development was to remove suspended sediment from the water until turbidity, measured in nephelometric turbidity units (NTU), was less than 5 NTU for three consecutive samples. Similarly, other measured parameters were required to stabilize before terminating development procedures. The well was declared sufficiently developed when the above criteria were met or could not be improved with continued pumping. Table 8.1-1 presents water quality parameter data measured at the beginning and end of each stage of well development.

Table 8.1-1
Development of R-13

Method	Water Produced (gal)	Range of Parameters[a]			
		pH	Temperature (°C)	Specific Conductance (µS/cm)[b]	Turbidity (NTU)
Bailing screen 1	458	NA	NA–19.5	0.298–0.312	317–249
Bail/jetting	741	NA	20.0–20.5	0.391–0.182	>1000
Bail/swab screen 1	1448	NA–8	19.9–19.1	0.18–0.170	1000–214
Pumping screen 1	22,063	7.48–7.8	21.3–20.3	0.192–0.139	494–2.74

[a] Parameters presented as value at beginning followed by value at end of development method.
[b] Specific conductance in reported microsiemens per centimeter.
[c] NA = not measured.

Preliminary bailing from the R-13 screened interval and sump was initially performed to remove bentonite materials that had been introduced into the well during construction. An attempt to scour the interior of the well casing and screen using a wire brush was impeded when the brush became clogged with bentonite. A subsequent video camera survey showed that the casing and couplings were coated with bentonite.

Bailing procedures were initiated by the drillers, using a 12-gal.-capacity steel bailer to remove debris and sediment from the sump. Additional wire brushing was resumed, and jetting procedures were employed to dislodge the remaining bentonite from the well interior. Bailing procedures continued until all foreign matter was removed. Water turbidity was not reduced significantly and remained greater than 1000 NTU after approximately 700 gal. had been withdrawn from the well.

Bailing was followed by surging and swabbing techniques that focus on filter pack development. In surging the well, a wire-line-controlled surge block with a weighted pipe attached was used to make rapid upward-downward strokes across the screen and to facilitate changing to a wire line bailer. Next, a swabbing tool was lowered in the well and drawn repeatedly across the screen interval while municipal

water was injected at a rate of 20 gallons per minute (gpm). Water turbidity exceeded 1000 NTU at the beginning and declined to 214 NTU at the end of the surging, swabbing, and bailing operation. Prior to this point in well development, no pH measurements had been taken because bentonite in the bailed water was expected to increase pH levels (Table 7.1-1).

Pump development procedures were applied to the screened interval (958.3 to 1018.7 ft bgs) using a 10-horse power (hp) submersible pump. The pump intake was lowered to the bottom of the screen and the pump was cycled on at a nominal rate of 20 gpm while water samples were collected at regular intervals for parameter measurements. The pump was then cycled off for a minimum 15-min period to allow water level recovery. Next, the pump was raised approximately 2 ft and the process repeated until the entire screen interval was traversed. Approximately 22,000 gal. of water were withdrawn from the well at the end of 14 pumping cycles. Turbidity levels declined from 494 to 2.74 NTU throughout the pump development stage (Table 8.1-1).

Figure 8.1-1 illustrates the effects of pump development on measured field parameters. The graph shows that specific conductance, pH, and temperature were stable during the latter period of pumping and that turbidity values had declined consistently to less than 5 NTU when R-13 was declared fully developed.

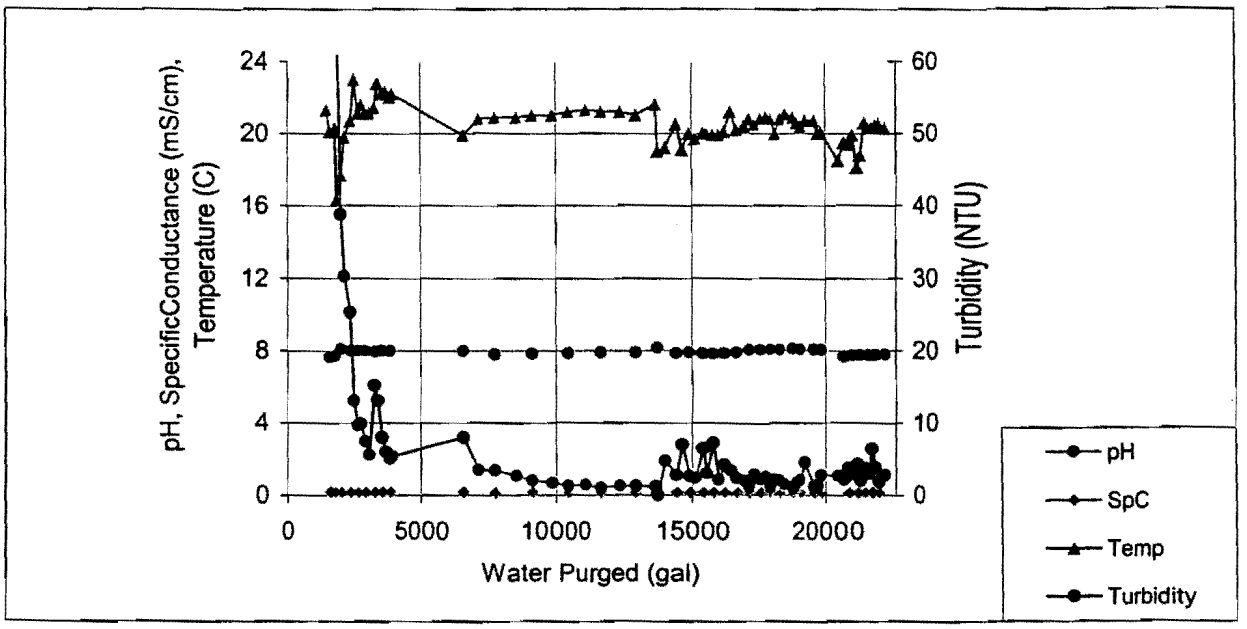


Figure 8.1-1 Effects of pump development on water quality parameters (screen 1) R-13

8.2 Hydrologic Testing

Hydrologic tests conducted in well R-13 consisted of a draw-down pumping test that was performed on October 13, 2001, after well development was completed. The pumping test procedure involved lowering the 10 hp-submersible pump intake 931 ft, approximately 27 ft above the top of the well screen. An In-Situ, Inc. transducer, model PXD-261 water-level sensor probe, was placed 10 ft above the pump intake at 921 ft bgs. The pump was turned on and run at an average continuous rate of 18.7 gpm for 22 min. The water level dropped 3 ft in the first minute before stabilizing for the remainder of the test. The test was repeated to verify the initial results. These hydrogeologic tests indicate that the formation is capable of yielding up to 19 gpm.

8.3 Dedicated Pump Installation

On February 20, 2002, a dedicated pump for groundwater monitoring was installed inside the well casing. The pump is a 4-in. diameter, submersible, Grunfos™ Model 10S50-48DS, with a 5-hp, 460-volt motor, rated for 11 gpm at 933 ft. The pump will be used to collect groundwater samples for water quality monitoring. The dedicated pump assembly, riser pipe, and other components were installed with a Smeal work-over rig, provided and operated by Rio Grande Well Supply.

The riser pipe consisted of 1-1/4-in., Schedule 40S, type 304/TP 304L stainless steel connected with 3000-pound F304/F304l stainless steel couplers. The thread compound used was Loctite® 567. A 1-in. Schedule 40 polyvinyl chloride (PVC) flush-thread transducer access pipe was set at the top of the pump to allow unobstructed access for water-level measurements. The pump control leads and PVC transducer pipe were secured to the riser pipe, 5 ft above the pump, and every 60 ft thereafter, with stainless steel bands. In addition, the leads and PVC pipe were secured to the riser pipe every 10 ft with cold-weather vinyl cable and pipe tape that is both water and corrosion resistant. The length of the pump assembly, riser joints, and couplers were measured and assembled to ensure installation of the pump intake at 935.4 ft bgs.

The pump installation was completed and tested on February 25, 2002. The pump yielded a discharge rate of approximately 10 gpm over a 10-min period.

9.0 WELLHEAD COMPLETION AND SITE RESTORATION

After completion of the pump installation, finish work commenced on the wellhead area. Well components were surveyed, and the site underwent final clean up and restoration.

9.1 Wellhead Completion

The surface completion for well R-13 involved pouring a reinforced (5000 psi) concrete pad, 7-ft wide by 12-ft long by 12-in. thick, around the well casing to ensure long-term structural integrity of the well. The concrete pad was poured on December 5, 2001. A 3-in. galvanized-steel conduit was embedded vertically through the pad and connected to the protective casing to allow for future wiring of a solar power energy supply. A brass survey pin was installed in the northwest corner of the pad. A 10 3/4-in. steel casing with locking lid protects the well riser. Four 4-in.-diameter steel bollards were placed next to each side of the pad. The bollard next to the west side of the pad is removable to facilitate access to the well for sampling and maintenance. The pad was designed to be slightly elevated with base course graded up around the pad to allow drainage.

9.2 Geodetic Survey

The location of well R-13 was determined by geodetic survey on January 29, 2002, using a Topcon GTS 302 total station having 3 in. positional accuracy. Control points used for this survey were well MCO-13 (brass cap) and location MO-10009. Prior measurements were provided by Merrick and Co., LANL permanent monument records. Local control was also set by the surveyor based on the above monuments. Field measurements were reduced using Plus 3 Terra Model software V-6.7.

This survey located the brass cap monument at well R-13 in the concrete pad as well as the four pad corners, the PVC riser and 10 in. casing. Table 9.2-2 summarizes the results of readings conducted for

various components of the completed wellhead. The coordinates shown are in New Mexico State Plane Grid Coordinates, Central Zone (North American Datum, 1983 [NAD 83]) expressed in U.S. feet. Elevation is expressed in feet above mean sea level relative to the National Geodetic Vertical Datum of 1929.

Table 9.2-2 Geodetic Data for Well R-13

Description	East	North	Elevation
Brass cap in R-13 pad	1640991.66	1766994.17	6673.05
PVC riser	1640992.71	1766993.14	6673.91
Concrete well pad corner	1640991.61	1766995.46	6672.97
Concrete well pad corner	1640995.16	1766992.07	6673.01
Concrete well pad corner	1640988.40	1766984.84	6673.01
Concrete well pad corner	1640984.85	1766988.31	6673.00
10 in. casing top	1640988.36	1766988.39	6676.23

The Facility for Information Management, Analysis and Display (FIMAD) location identification number for the R-13 well is MO-10097.

9.3 Site Restoration

The R-13 site area was recontoured to match the surrounding topography. Prior to recontouring, the cuttings containment area was excavated and the plastic lining removed. The containment area was then backfilled with dirt that had been bermed up during construction of the pad. Base-course gravel was regraded and compacted across the site to form a smaller pad. In addition, the site was cleared of the brush piles created by tree removal during drill pad construction.

The straw wattles and silt fences that are part of the R-13 site best management practices (BMP) installations will remain in place as needed after the post-operational reclamation process. The site was re-seeded with a LANL-provided blend of native grasses mixed with straw mulch to facilitate re-introduction of ground cover.

10.0 ACKNOWLEDGEMENTS

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D. Hill of WGII was the site safety officer for drilling activities. E. Trujillo of ESH-5 provided Laboratory oversight for health and safety.

R. Bohn provided oversight for waste management, and R. Evans provided support for waste management.

K. Greene and J. Skalski provided contract field support, sample management and analytical support.

D. Counce of LANLwas the analyst for water chemistry analyses used for screening of groundwater collected from saturated zones and for leachate analyses of core and cuttings.

C. Nylander of ESH-18 of the Groundwater Integration Team for participating, planning and making decisions regarding drilling methods, well design, and evaluation of data collection.

D. Broxton of LANL provided field support and oversight of data collection activities.

S. Pearson and J. McCann of LANL provided field oversight of drilling activities.

T. Whitacre of the Department of Energy (DOE), Los Alamos Area Office, provided DOE oversight.

J. Young of the New Mexico Environmental Department (NMED) provided regulatory oversight during drilling operations and acted as liaison with the regulators.

D. Steven was a compositor/editor. G. Stoopes provided technical support.

M. Sachdeva of LANL served as an editor.

R. Bohn, D. Broxton, B. Enz, E. Louderbough, J. McCann, S. Pearson, and D. Vaniman reviewed this report.

P. Longmire of LANL provided analytical and geochemical oversight during drilling activities.

The geodetic survey was performed by Southwest Mountain Services under the direction of Mitch Noonan.

T. Herrera and N. Germain provided administrative support.

W. Stone provided hydrologic oversight during drilling activities and hydrological testing on finished wells.

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Appendix A

Activities Planned for R-13 Compared with Work Performed

Appendix A
Activities Planned for R-13 Compared with Work Performed

Activity	Hydrogeologic Workplan	Hydrogeologic Work Plan for Mortandad Canyon	R-13 Field Implementation Plan	R-13 Actual Work
Planned Depth	100 to 500 ft into the regional aquifer	R-13 proposed depth of 1330 ft	Approximately 1700 ft	Total drill depth 1133 ft
Drilling Method	Methods may include, but are not limited to hollow-stem auger (HSA), air-rotary/Odex/Stratex, air-rotary/Barber rig, and mud-rotary drilling	Methods may include, but are not limited to HSA, air-rotary/Odex/Stratex, air-rotary/Barber rig, and mud-rotary drilling	Fluid-assisted, open-hole, air-rotary drilling	Same as FIP
Amount of Core	10% of the borehole	Approximately 10%	No core planned	No core attempted
Lithologic Log	Log to be prepared from core, cutting, and drilling performance.	Log to be prepared from core, cutting, and drilling performance data.	Log to be prepared from cuttings, geophysical logs, and drilling performance.	Same as FIP
Number of Water Samples Collected for Contaminant Analysis	A water sample may be collected from each saturated zone, five zones assumed. The number of sampling events after well completion is not specified.	For planning and conceptual design purposes, it has been assumed that four water-bearing zones will be encountered. Groundwater samples will be collected from each water-bearing zone.	Up to three borehole groundwater screening samples will be collected during drilling. These samples will target groundwater in the perched zone(s) and in the regional aquifer. The number of sampling events after well completion is not specified.	One groundwater sample was obtained at the top of the regional water table at 903 ft bgs.
Water Sample Analysis	Initial sampling: Radiochemistry I, II, and III, ^{3}H, general inorganics, stable isotopes, VOCs, and metals Saturated Zones: radionuclides (tritium, ^{90}Sr, ^{137}Cs, ^{241}Am, plutonium isotopes, uranium isotopes, gamma spectrometry, and gross alpha, beta, and gamma), stable isotopes (hydrogen, oxygen, and in special cases nitrogen), major ions (cations and anions), trace metals, and trace elements	Analytical suite for intermediate perched zone and regional aquifer groundwater samples: major and minor ions, trace elements, organic compounds, dissolved organic carbon, total suspended solids, total dissolved solids, neutral species (SiO_2), hardness, cyanide, stable and radiogenic isotopes, and radionuclides	Metals (dissolved), anions (dissolved), gamma spectrometry, ^{241}Am, ^{137}Cs, ^{238}Pu, $^{239,240}Pu$, ^{234}U, ^{235}U, ^{238}U, ^{90}Sr (total), stable isotopes: $^{18}O/^{16}O$, D/H, $^{15}N/^{14}N$, tritium, tritium (low level or direct counting), RVgross-alpha, beta plus RVgross-gamma, TUICPMS, TKN, CLO_4^-	Same as FIP
Water Sample Field Measurements	Alkalinity, pH, specific conductance, temperature, turbidity	Alkalinity, pH, specific conductance, temperature, dissolved oxygen, turbidity	pH, specific conductance, temperature, turbidity	Same as FIP

Activity	Hydrogeologic Workplan	Hydrogeologic Work Plan for Mortandad Canyon	R-13 Field Implementation Plan	R-13 Actual Work
Number of Core/Cuttings Samples Collected for Contaminant Analysis	Twenty samples of core or cuttings to be analyzed for potential contaminant identification in each borehole.	Sample locations are based on predicted formation depths.	Up to 5 core/cuttings samples will be collected for geochemical and contaminant characterization within water-bearing zones encountered during drilling. Approximately 52 sidewall core samples will be collected every 20 ft from the level of the canyon floor to the top of the regional saturated zone.	No core or sidewall core samples were collected. No cuttings samples were submitted for contaminant analysis.
Core/Cuttings Sample Analytes	Uppermost sample to be analyzed for a full range of compounds: deeper samples will be analyzed for the presence of radiochemistry I, II, and III analytes, tritium (low- and high-detection levels), and metals. Four samples to be analyzed for VOCs.	Analytical suite for borehole core samples includes anions, trace elements, organic compounds, total organic carbon, cyanide, and radionuclides.	Testing of core/cutting samples may include radionuclides, metals, and anions. Sidewall core samples will be analyzed for anion, stable isotope, and tritium profiles.	No core or sidewall core samples were collected. No cuttings samples were submitted for contaminant analysis.
Laboratory Hydraulic-Property Tests	Physical properties analyses will be conducted on 5 core samples and will typically include moisture content, porosity, particle density, bulk density, saturated hydraulic conductivity, and water retention characteristics.	Physical properties analyses will be conducted on core samples and will typically include moisture content, moisture potential, and saturated hydraulic conductivity.	Not specified in plan	No samples submitted
Geology	Ten samples of core or cuttings will be collected for petrographic, X-ray fluorescence (XRF) and X-ray diffraction (XRD) analyses.	Selected samples of core or cuttings will be collected for petrographic, X-ray fluorescence (XRF), X-ray diffraction (XRD) and K/Ar or $^{39}Ar/^{40}Ar$ isotopic dating analyses.	The geology task leader will determine the number of samples for characterization of mineralogy, petrography, and rock chemistry based on geologic and hydrologic conditions encountered during drilling.	Twelve samples were characterized for mineralogy, petrography, and rock chemistry.

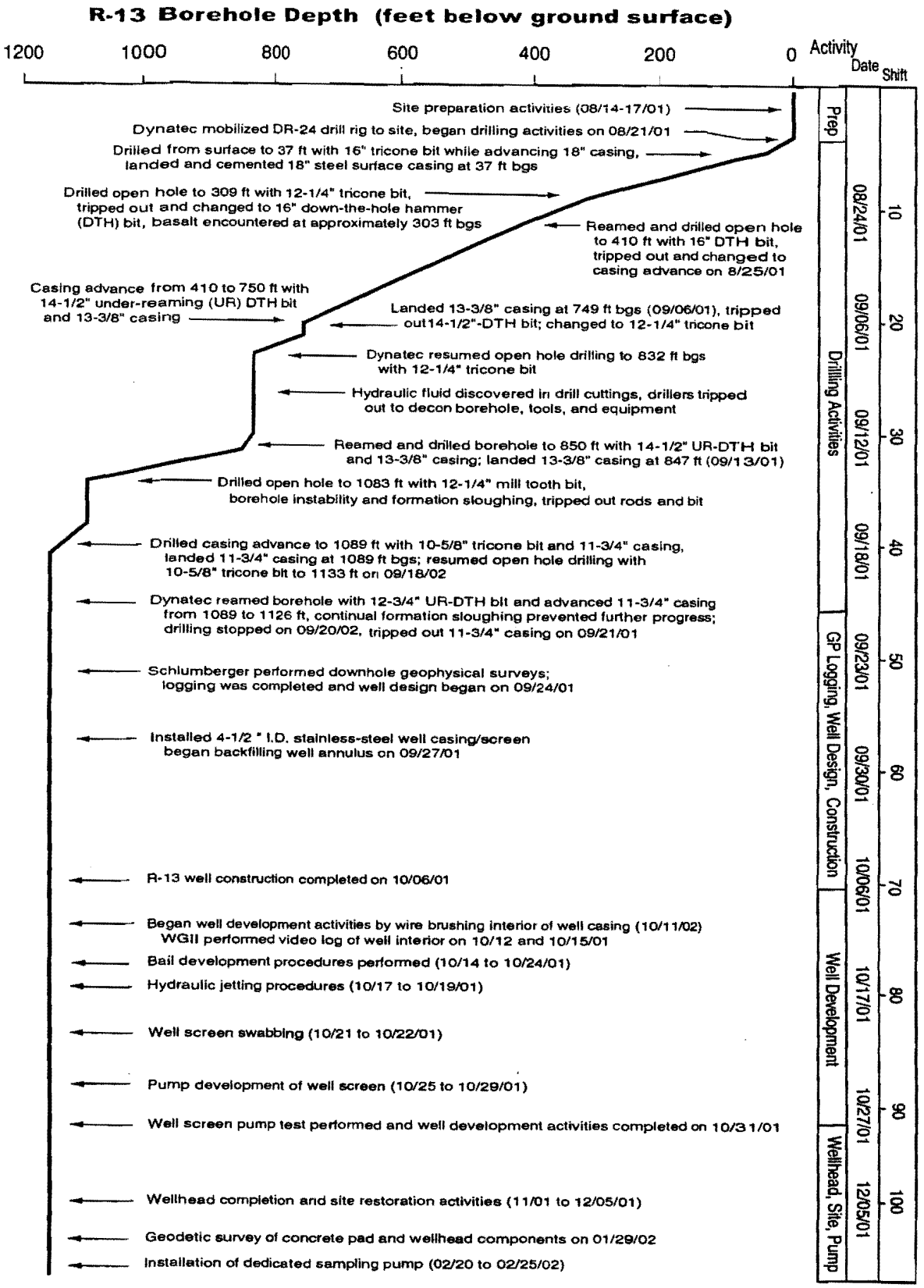
Activity	Hydrogeologic Workplan	Hydrogeologic Work Plan for Mortandad Canyon	R-13 Field Implementation Plan	R-13 Actual Work
Geophysics	In general, open-hole geophysics includes caliper, electromagnetic induction, natural gamma, magnetic susceptibility, borehole color videotape (axial and sidescan), fluid temperature (saturated), single-point resistivity (saturated), and spontaneous potential (saturated). In general, cased-hole geophysics includes gamma-gamma density, natural gamma, and thermal neutron.	Geophysical logs will be run in the boreholes, and compact neutron moisture logs may be run in shallower portions of the boreholes. Natural gamma, neutron moisture, and density logs may be run in shallower portions of the boreholes. Natural gamma, neutron moisture, and density logs may be run if the drilling method and borehole stability permit. Other geophysical logs may be considered if, in the opinion of the technical team, they will satisfy a technical need. In general, open-hole geophysics includes caliper, electromagnetic induction, magnetic susceptibility, borehole color videotape (axial and sidescan), fluid temperature (saturated), single-point resistivity (saturated), and spontaneous potential (saturated). In general, cased-hole geophysics includes gamma-gamma density, natural gamma, and thermal neutron.	Typical wire-line logging service as planned: open-hole geophysics includes array induction imager, triple lithodensity, combinable magnetic resonance, natural gamma, natural gamma spectrometry, epithermal compensated neutron log, caliper, fullbore formation micro imager, elemental capture spectrometer, and borehole videotape. In general, cased-hole geophysics includes triple lithodensity, natural gamma, natural gamma spectrometry, epithermal compensated neutron log and elemental capture spectrometer	Video (LANL tool): 760-828 ft, natural gamma (LANL tool): 0–830 ft (cased 0–760), 0–1053 ft (cased 0–850) and 0–1125 ft bgs (cased 0–1126) Schlumberger geophysics 0–1058 ft (cased 0–850 ft): compensated neutron, array induction, litho-density, electron capture, natural gamma, formation micro-imager
Water-Level Measurements	Procedures and methods not specified in Hydrogeologic Workplan	Procedures and methods not specified in Hydrogeologic Workplan	Water levels will be determined for each saturated zone by water-level meter or by pressure transducer.	Water-level meter used to measure the regional water table
Field Hydraulic-Property Tests	Not specified in Hydrogeologic Workplan	Not specified in Hydrogeologic Workplan	Slug or pumping tests may be conducted in saturated intervals once the well is completed.	No hydraulic property tests performed
Surface Casing	Approximately 20-in. OD extends from land surface to 10-ft depth in underlying competent layer and grouted in place	Approximately 20-in. OD extends from land surface to 10-ft depth in underlying competent layer and grouted in place.	18-in. OD schedule 40, low carbon steel casing will be installed as deep as possible below ground level (nominally 35-40 ft) and will extend approximately 3 ft above the ground surface and cemented in place.	18-in. OD steel casing set at 37 ft bgs and cemented in place

Activity	Hydrogeologic Workplan	Hydrogeologic Work Plan for Mortandad Canyon	R-13 Field Implementation Plan	R-13 Actual Work
Minimum Well Casing Size	6-5/8-in. OD	6-5/8-in. OD	5-in OD x 4.5-in. ID	5-in OD (4.5-in ID) stainless steel casing w/ external couplings
Well Screen	Machine-slotted (0.01-in.), stainless steel screens with flush-jointed threads; number and length of screens to be determined on a site-specific basis and proposed to NMED.	Machine-slotted (0.01-in.), stainless steel screens with flush-jointed threads; number and length of screens to be determined on a site-specific basis and proposed to NMED.	Well screen shall be constructed with multiple sections of 5.56-in. OD, pipe-based stainless-steel screen with a 0.01 in. slot size.	Same as FIP
Filter Material	>90% silica sand, properly sized for the 0.010-in. slot size of the well screen; extends 2 ft above and below the well screen	>90% silica sand, properly sized for the 0.010-in. slot size of the well screen; extends 2 ft above and below the well screen	Primary filter pack shall consist of round, clean, washed and resieved silica sand with a uniformity coefficient of 2.0 or less, placed 10 ft above and 5 ft below the well screen. The size of the filter pack shall be selected based on the characteristics of the formation to be screened. Secondary filter pack is finer silica sand placed 2 ft above and below the primary pack.	Primary filter pack constructed of 20/40 silica sand placed 6 ft below and 10 ft above the screen. Secondary filter pack constructed of 30/70 silica sand placed in a 6-ft-thick layer above and below the primary filter pack.
Backfill Material (exclusive of filter materials)	Uncontaminated drill cuttings below sump and bentonite above sump	Uncontaminated drill cuttings below sump and bentonite above sump	Bentonite, gravel, silica sand, and/or cement in borehole below well; fine sand in transition zone; 50% bentonite and 50% gravel or sand above transition zone to bottom of surface casing; cement grout between surface casing and borehole wall and between surface casing and well casing.	Sand and bentonite in borehole below well casing; bentonite seal below filter pack; bentonite above filter pack. One cement grout plug 724.4 to 734.6 and cement from surface to 77 ft bgs.
Sump	Stainless steel casing with an end cap	Stainless steel casing with an end cap	5-in diameter stainless-steel casing, 30 ft long	5-in diameter stainless steel casing, 10 ft long
Bottom Seal	Bentonite	Bentonite	Bentonite	Same as FIP

Appendix B

Operations Chronology Graph

Appendix B



Well R-13 Operations Chronology Graph

Appendix C

Lithologic Descriptions of Drill Cuttings from Borehole R-13

Appendix C - Lithologic Descriptions of Drill Cuttings from Borehole R-13			
Geologic Unit	**Lithologic Description**	**Sample Interval (ft)**	**Elevation Range (ft above msl)**
Qal, alluvium	No sample collected.	0–23	6780.5–6757.5
	Unconsolidated sediments, silt (SM), grayish orange (10YR 7/4), composed of nonwelded vitric pumice. +35F (i.e., plus No. 35 sieve sample fraction): 20% quartz and sanidine crystals, 80% ash. +60F (i.e., plus No. 60 sieve sample fraction): predominantly ash.	23–28	6757.5–6752.5
	Unconsolidated sediments, silty gavel with sand (GM), grayish orange (10YR 7/4), composed of nonwelded vitric tuff, lithic poor. +35F: predominantly quartz and sanidine crystals.	28–33	6752.5–6747.5
	No sample recovery.	33–38	6747.5–6742.5
Qbt 1g, Unit 1g, Tshirege Member of the Bandelier Tuff	Rhyolite tuff, pale brown (5YR 5/2), pumice-rich, poorly welded. +10F: (i.e., plus No. 10 sieve sample fraction) 60–70% subrounded vitric pumice fragments; 15–20% intermediate to felsic volcanic lithics; 10% quartz and sanidine phenocrysts; 5% clasts that are weakly cemented with clay and Fe-oxide.	38–43	6742.5–6737.5
	Rhyolite tuff, light brown (5YR 5/2), pumice-rich, poorly welded. +10F: 80% vitric pumice clasts, subrounded; 20% intermediate to felsic volcanic clasts, minor quartz and sanidine crystals (locally, clasts and crystals are weakly cemented with clay). +35F: dominantly quartz and sanidine crystals with lesser amounts of pumice and volcanic lithics.	43–53	6737.5–6727.5
	Rhyloite tuff, pale yellowish brown (5YR 6/2), pumice- and lithic-rich, poorly welded. +10F: 50% vitric pumice clasts; 50% intermediate to felsic volcanic clasts, subrounded. +35F: composed of pumice, quartz and sanidine crystals, and minor lithics.	53–58	6727.5–6722.5
	Rhyolite tuff, grayish orange (10YR 7/4), pumice-rich, nonwelded. +10F: 50% glassy pumice fragments, subrounded; 50% intermediate to felsic volcanic clasts. +35F: 60% pumice, 30% volcanic lithics, 10% quartz and sanidine crystals.	58–63	6722.5–6717.5
	Rhyolite tuff, very light gray (N8), lithic-rich, poorly welded. +10F: 70–100% dacite fragments (up to 5 mm), subangular; 10–30% quartz and sanidine crystals; minor pumice. Volcanic clasts commonly silicified, with clay rims.	63–73	6717.5–6707.5
Qct, Cerro Toledo Interval	Tephra deposit /tuffaceous sediments, silty sand with gravel (SM), light pinkish gray (5YR 8/1), silt to very coarse sand and pebbles. +10F: 60–70% gray to light brown hornblende dacite and rhyodacite lithics, clasts (up to 1.0 cm) are broken to subrounded; 30–40% white vitric pumice. +35F: 70–80% pumice, 5–10% quartz and sanidine crystals, 15–25% dacite lithics.	73–78	6707.5–6702.5
	Tephra deposit/tuffaceous sediments, sand with gravel (SW), pale orange gray (10YR 8/2), silt to very coarse sand, gravel clasts (up to 8 mm) angular to subrounded +10F: 60–70% gray to pinkish dacite, 30–40% brown to orange tan vitric pumice. +35F: 10% pumice, 30% volcanic lithics, 60% quartz and sanidine crystals. Note: sudden increase in free crystals and appearance of oxidized pumice fragments suggest the stratigraphic top of Qbo, estimated at 80 ft bgs.	73–83	6702.5–6697.5

Appendix C - Lithologic Descriptions of Drill Cuttings from Borehole R-13			
Geologic Unit	**Lithologic Description**	**Sample Interval (ft)**	**Elevation Range (ft above msl)**
Qbo, Otowi Member of the Bandelier Tuff	Rhyolite tuff, light pinkish gray (5YR 8/1), poorly welded. +10F: 30–40% pinkish gray and reddish dacite; 60–70% fibrous porphyritic vitric pumice, pale orange, vitric luster (up to 1.8 cm). +35F: 20–30% pumice, 30–40% lithic, 30–40% quartz and sanidine crystals.	83–88	6697.5–6868.5
	Rhyolite tuff, pinkish gray (5YR 8/1), poorly to nonwelded. +10F: 60–70% dacite and andesite lithic fragments, 10–30% white to light orange tan pumice (up to 1.0 cm).	88–103	6868.5–6677.5
	Rhyolite tuff, pinkish gray (5YR 8/1), poorly welded. +10F: 80–90% pumice fragments, large (up to 1.5 cm), fibrous textured; 10–20% dacite lithics.	103–113	6677.5–6667.5
	Rhyolite tuff, pinkish gray (5YR 8/1), poorly to nonwelded. +10F: 50–60% dacite and latite lithic fragments, 40–50% white and tan pumice (up to 1.0 cm) pumice. +35F: 10–20% pumice, 20–30% lithics, 30–40% quartz and sanidine crystals. WR (i.e., unsieved whole rock) sample has ashy matrix.	113–128	6667.5–6652.5
	Rhyolite tuff, pinkish gray (5YR 8/1), lithic-rich, poorly welded. +10F: 90–95% dacite lithic fragments (0.5 to 1.5 cm), 5–10% quartz and sanidine crystals, 5–10% pumice. +35F: 3–5% pumice; 20–30% volcanic lithics; 65–75% pumice.	128–143	6652.5–6637.5
	Rhyolite tuff, grayish orange pink (5YR 7/2), lithic-rich, poorly welded. +10F: 60–70% dacite lithic (up to 2.0 cm), 30–40% vitric pumice fragments, 5–10% quartz and sanidine crystals. +35F: 15–25% pumice, 30–40% volcanic lithics, 30–40% quartz and sanidine crystals. WR sample has ashy matrix.	143–148	6637.5–6632.5
	Rhyolite tuff, pale yellowish brown (10YR 6/2), poorly welded. +10F: 70–80% dacite and latite fragments (up to 2.0 cm); 15–25% fibrous textured pumice, 5–10% quartz and sanidine crystals. +35F: 5–10% pumice, 30–40% lithics, 40–50% quartz and sanidine crystals.	148–153	6632.5–6627.5
	Rhyolite tuff, pale yellowish brown (10YR 6/2), moderately welded. +10F: 65–75% dacite and latite fragments, 10–20% fibrous textured pumice (up to 2.0 cm), 5–10% quartz and sanidine crystals, 10–20% fragments of indurated tuff; spotty Mn-oxide coatings on some pumices. +35F: 10–30% pumice, 20–40% lithics, 50–70% quartz and sanidine crystals. WR sample contains abundant ash.	153–168	6627.5–6612.5
	Rhyolite tuff, very pale orange (10YR 8/2), nonwelded. +10F: 80–90% dacite and latite fragments (up to 1.0 cm), 5–10% quartz and sanidine crystals, 5–10 pumice. +35F: 35–45% white and brown pumice, 20–30% lithics, 30–40% quartz and sanidine crystals. WR sample has ashy matrix.	168–183	6612.5–6597.5
	Rhyolite tuff, grayish orange pink (5YR 7/2), ash-rich, nonwelded. +10F:60–70% dacite fragments, 5–10% quartz and sanidine crystals, 15–25% pale tan vitric pumice (up to 1.0 cm), pumices commonly exhibit spotty Mn-oxide coatings. +35F: 20–30% pumice, 30–40% lithics, 30–40% quartz and sanidine crystals. WR sample has ashy matrix.	183–188	6597.5–6592.5

Appendix C - Lithologic Descriptions of Drill Cuttings from Borehole R-13			
Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
	Rhyolite tuff, grayish orange pink (5YR 7/2), nonwelded. +10F: 60–70% dacite and latite fragments, 20–30%% vitric pumice fragments (up to 3 mm) with local Mn-oxide coatings10% coarse quartz and sanidine crystals (up to 3 mm). +35F: 30–40% pumice, 20–30% lithics, 40–50% sanidine-sanidine crystals. WR sample has ashy matrix.	188–193	6592.5–6587.5
	Rhyolite tuff, pinkish gray (5YR 8/1), pumice- and lithic-rich, nonwelded. +10F: 65–75% dacite and andesite fragments (up to 2.0 cm), 10–15% pumice, 5–10% quartz and sanidine crystals. +35F: 10–15% pumice, 20–30% lithics, 60–70% quartz and sanidine crystals. WR sample has ashy matrix.	193–203	6587.5–6577.5
	Rhyolite tuff, light pinkish gray (5YR 8/1), lithic-rich, poorly welded. +10F: 70–80% dacite and andesite fragments (up to 2.0 cm) commonly coated with clay, 10–15% vitric pumice (up to 1.8 cm), 5–10% quartz and sanidine crystals. +35F: 10–30% pumice, 20–30% lithics, 50–70% quartz and sanidine crystals. WR sample has ashy matrix.	203–213	6577.5–6567.5
	Rhyolite tuff, pinkish gray (5YR 8/1), nonwelded. +10F: 60–70% dacite and latite fragments, 25–30% white vitric pumice fragments (coarse, up to 2.3 cm) with local Mn-oxide coatings, 5–10% quartz and sanidine crystals. +35F: 15–25% pumice, 15–20% lithics, 60–70% quartz and sanidine crystals. WR sample has ashy matrix.	213–223	6567.5–6557.5
	Rhyolite tuff, light gray (N7), nonwelded. +10F: 65–75% reddish brown to gray dacite and latite fragments, 20–30% white to pale tan pumice fragments (up to 1.0 cm) with local Mn-oxide coatings, 3–5% quartz and sanidine crystals. +35F: 40–50% pumice, 25–30% lithics, 15–20% quartz and sanidine crystals. WR sample has ashy matrix.	223–233	6557.5–6547.5
	Rhyolite tuff, very light gray (N8), pumice-rich, nonwelded. +10F: 15–20% dacite and latite fragments, 60–70% vitric pumice fragments (up to 1.5 cm), 3–5% quartz and sanidine crystals.	233–238	6547.5–6542.5
	Rhyolite tuff, very light (N8), pumice-rich, poorly welded +10F: 20–25% reddish to dark gray dacite lithic fragments (up to 1.2 cm), 70–75% vitric pumice (up to 1.5 cm),5–10% quartz and sanidine crystals. +35F: 20–30% pumice, 20–30% lithics, 40–60% quartz and sanidine crystals.	238–248	6542.5–6532.5
Qbog, Guaje Pumice Bed	Tephra deposit/tuffaceous sediments, light pinkish gray (5YR 6/1), vitric, pumice-rich, nonwelded. +10F: 80–90% pumice fragments (0.5 to 2.0 cm), 2–10% dacite lithics, 5–10% quartz and sanidine crystals. Note: 50% of pumices altered to brown clay in 263 to 268 ft interval. The presence of clay-cemented tuffaceous sandstone indicates the basal portion of the Qb0g and the proximity to the Puye formation contact at 268 ft.	248–268	6532.5–6512.5
Tpf, Puye Formation	Clastic sediments, silty sand with gravel (SM), light brown (5YR 6//4), pebbles (up to 1.0 cm) are subangular to subrounded. WR/+10F: composed of indurated clay-cemented tuffaceous sandstone, various volcanic (andesite, rhyodacite, basalt) rocks, lesser quartz and sanidine crystals (frosted crystal faces), minor pumice.	268–283	6512.5–6497.5
	Clastic sediments, clayey sand with gravel (SC), light pinkish tan (5YR 7/2), pebbles (up to 1.0 cm) are subangular to subrounded. WR/+10F: 85–95% indurated tuffaceous sandstone and siltstone, 5–15% various volcanic (andesite, basalt, pumice) rocks that are locally clay coated.	283–303	6497.5–6477.5

Appendix C - Lithologic Descriptions of Drill Cuttings from Borehole R-13			
Geologic Unit	**Lithologic Description**	**Sample Interval (ft)**	**Elevation Range (ft above msl)**
Tb, Cerros del Rio Basalt	Transitional Tpf/Tb interval, light brown (5YR 7/2), weathered basalt fragments. WR/+10F: 90% broken basalt fragments (up to 0.5 cm), 10% clay. Basal Tpf contact with underlying basalt estimated at 305 ft bgs.	303–308	6477.5–6472.5
	Basalt, medium gray (N5), weakly porphyritic with aphanitic groundmass, highly vesicular to scoriaceous. WR/+10F: 95–98% olivine basalt; 2–5% other volcanic rocks (andesite, pumice), quartz and sanidine crystals, and tuffaceous sandstone. Clasts are angular to subangular.	308–325	6472.5–6455.5
	Basalt, medium gray (N4), porphyritic with aphanitic groundmass, vesicular . WR/+10F: pale green olivine phenocrysts (10% of volume), euhedral crystals (1–2 mm) locally replaced by iddingsite; fracture and vesicle coated surfaces by white clay.	325–340	6455.5–6440.5
	Basalt, medium gray (N5), porphyritic with aphanitic groundmass, vesicular. WR/+10F: pale green olivine phenocrysts, commonly euhedral (up to 5 mm), less abundant euhedral plagioclase; minor clay lining vesicles.	340–360	6440.5–6420.5
	Basalt, medium gray (N5), slightly porphyritic with aphanitic groundmass, vesicular. WR/+10F: pale green to amber-colored minor olivine phenocrysts, locally altered to iddingsite, white laths of plagioclase; vesicles commonly lined with light brown to white clay.	360–385	6420.5–6395.5
	Basalt, medium gray (N5), slightly porphyritic with aphanitic groundmass, vesicular, basalt fragments show some degree of roundness. +35F: contains 10–20% tuffaceous siltstone clasts possibly indicating volcaniclastic sedimentary interlayer occurring within this interval. WR sample is very clayey.	385–390	6395.5–6390.5
	Basalt, medium gray (N5), porphyritic with aphanitic groundmass, vesicular. WR/+10F: pale green olivine phenocrysts (10% volume), mostly euhedral (up to 3 mm), commonly altered to reddish iddingsite. Groundmass locally sericitized; local clay lining vesicles.	390–405	6390.5–6375.5
	Basalt, medium gray (N5), weakly porphyritic with aphanitic groundmass, highly vesicular to massive. WR/+10F: pale green euhedral (up to 3 mm) olivine phenocrysts. Amygdaloidal clay, locally limonitic, very common.	405–430	6375.5–6350.5
	Basalt, light gray (N6), slightly porphyritic with aphanitic groundmass, massive. WR/+10F: olivine phenocrysts mostly replaced by iddingsite. Groundmass is partially hydrothermally altered and sericitized.	430–445	6350.5–6335.5
	Basalt, light gray (N7), porphyritic with aphanitic groundmass, massive to partly scoriaceous. WR/+10F: coarse (up to 5 mm) olivine phenocrysts entirely replaced by iddingsite. Interval is distinctive for its strong sericite alteration of groundmass feldspars, resulting in a pitted surface texture and generally bleached coloration. The interval 460–465 ft contains 40–50% reddish brown Fe-oxide-stained scoriaceous basalt fragments.	445–465	6335.5–6315.5
	Basalt/scoria, dusky red (5YR 3/4), slightly porphyritic with aphanitic groundmass, scoriaceous. WR/+10F: olivine phenocrysts entirely replaced by iddingsite, intense Fe-oxide staining throughout, amygdaloidal clay common. The interval 480–485 ft has 40–50% massive, less vesicular basalt mixed with scoria. Basal contact of scoriaceous basalt estimated at 483 ft bgs.	465–485	6315.5–6295.5

Appendix C - Lithologic Descriptions of Drill Cuttings from Borehole R-13			
Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Tb, Cerros del Rio Basalt	Basalt, light gray (N6), porphyritic with aphanitic groundmass, vesicular to massive. WR/+10F: olivine phenocrysts entirely replaced by dark red iddingsite. Groundmass has local Fe-oxide staining, moderately sericitized.	485–495	6295.5–6285.5
	Basalt, very light gray (N7), porphyritic with aphanitic groundmass, massive. WR/10F: olivine phenocrysts rimmed or totally replaced by iddingsite; groundmass almost completely sericitized. Selected fragments are distinctly rounded, possibly the result of abrasion due to drilling process.	495–510	6285.5–6270.5
	Basalt, light gray (N6), porphyritic with aphanitic groundmass, massive. WR/+10F: olivine phenocrysts rimmed or entirely replaced by dark red iddingsite; groundmass almost completely sericitized and bleached. Selected fragments are well rounded, suggesting they were milled during drilling.	510–540	6270.5–6240.5
	Basalt, light gray (N6), porphyritic with aphanitic groundmass, massive. WR/+10F: olivine phenocrysts replaced by iddingsite. Groundmass sericitized.	540–545	6240.5–6235.5
	Basalt, medium gray (N5), porphyritic with aphanitic groundmass, massive. WR/+10F: olivine phenocrysts locally replaced (iddingsite), traces of clay and Mn-oxide.	545–555	6235.5–6225.5
	Basalt, medium gray (N5), porphyritic with aphanitic groundmass, massive. WR/+10F: olivine phenocrysts locally rimmed or replaced by iddingsite, minor clay present.	555–565	6225.5–6215.5
	Basalt, medium gray (N5), porphyritic with aphanitic groundmass, massive. WR/+10F: olivine phenocrysts rimmed or replaced by iddingsite, local clay present in lower 10 ft of interval.	565–585	6215.5–6195.5
	Basalt, light olive gray (5Y 6/1), porphyritic with aphanitic groundmass, massive. WR/+10F: olivine phenocrysts unaltered to rimmed or replaced by iddingsite, minor plagioclase phenocrysts.	585–595	6195.5–6185.5
	Basalt, medium gray (N6), porphyritic with aphanitic groundmass, massive. WR/+10F: olivine phenocrysts mostly altered to iddingsite; locally rounded clasts.	595–600	6185.5–6180.5
	Basalt, light olive gray (5Y 6/1), porphyritic with aphanitic groundmass, massive. WR/+10F: olivine phenocrysts show advanced alteration to iddingsite. Numerous rounded basalt clasts with clay coatings suggest possible sedimentary interflow deposit.	600–605	6180.5–6175.5
	Basalt, light olive gray (5Y 6/1), porphyritic with aphanitic groundmass, massive. WR/+10F: olivine phenocrysts fresh to locally rimmed or replaced by iddingsite, rare plagioclase phenocrysts; clay lining fractures in interval 615–620 ft.	605–625	6175.5–6155.5
	Basalt, light olive gray (5Y 6/1), porphyritic with aphanitic groundmass, massive to partly vesicular. WR/+10F: olivine phenocrysts show varying states of iddingsite alteration; clay amygdules present. Some clasts partly rounded.	625–635	6155.5–6145.5
	Basalt, light olive gray (5Y 6/1), porphyritic with aphanitic groundmass, massive. WR/+10F: olivine phenocrysts fresh to locally rimmed or replaced by iddingsite, rare pyroxene phenocrysts.	635–650	6145.5–6130.5

Appendix C - Lithologic Descriptions of Drill Cuttings from Borehole R-13			
Geologic Unit	**Lithologic Description**	**Sample Interval (ft)**	**Elevation Range (ft above msl)**
Tb, Cerros del Rio Basalt	Basalt, light olive gray (5Y 6/1), porphyritic, groundmass aphanitic to microcrystalline, massive. WR/+10F: phenocrysts of olivine, pyroxene, plagioclase, olivines unaltered to slightly altered (iddingsite), pyroxenes prismatic crystals giving rock a speckled appearance; groundmass microcrystalline with laths of plagioclase visible.	650–685	6130.5–6095.5
	Basalt, light olive gray (5Y 6/1), porphyritic, groundmass microcrystalline, massive. WR/+10F: phenocrysts of olivine (up to 2 mm) and plagioclase, olivines unaltered to locally rimmed or replaced by iddingsite.	685–705	6095.5–6075.5
	Basalt, light olive gray (5Y 6/1), porphyritic with aphanitic groundmass, massive. WR/+10F: phenocrysts of olivine, pyroxene, and plagioclase; olivines fresh to locally altered (iddingsite), prismatic pyroxenes impart a speckled texture to rock; clasts locally rounded.	705–710	6075.5–6070.5
	Basalt, dark olive gray to black (5Y 2/1), porphyritic with aphanitic groundmass, vesicular. WR/+10F: olivine phenocrysts of varying stages of iddingsite replacement; rock locally has cinder or glassy appearance; cinders commonly coated with clay, calcite, or zeolite.	710–715	6070.5–6065.5
	Basalt, medium gray (N5), porphyritic with aphanitic groundmass, vesicular. WR/+10F: phenocrysts of olivine, plagioclase, and pyroxene; olivines partly altered or replaced (iddingsite).	715–725	6065.5–6055.5
	Basalt, medium to dark gray (N4), porphyritic with aphanitic groundmass, vesicular. WR/+10F: phenocrysts of olivine and plagioclase, olivines partly replaced or rimmed by iddingsite, fragments have cinder appearance, cinders coated with clay, calcite, or zeolite.	725–730	6055.5–6050.5
Tpf, Puye Formation	Volcaniclastic sediments, clayey gravel (GC), pale yellowish brown (10YR 6/2), pebbles (up to 3.0 cm) mostly angular. WR/+10F: 100% lithic clasts made up of dacite, basalt, and pink siltstone.	730–735	6050.5–6045.5
	Volcaniclastic sediments, gravel with silt and sand (GW), grayish orange pink (5YR 7/2), pebbles (up to 2.7 cm) are angular to subangular. WR/+10F: 98% lithic clasts made up of dacite and vesicular basalt, 2% pale orange quartz.	735–740	6045.5–6040.5
	Volcaniclastic sediments, clayey gravel (GC), medium orange pink (10R 7/4), clasts angular to subrounded. WR/+10F: 90% lithic clasts made up of laminated siltstone and sandstone, 10% basalt with iddingsite alteration and intermediate volcanics (dacite). Interval may represent a clay interlayer.	740–745	6040.5–6035.5
	Volcaniclastic sediments, gravel with sand and clay (GW), light olive gray (5Y 6/1), sand and pebbles (up to 5.0 mm), clasts subangular to subrounded. WR/+10F: lithic clasts made up of 70% basalt, 20% dacite, and 10% sandstone/siltstone.	745–750	6035.5–6030.5
	Volcaniclastic sediments, gravelly sand (SW), light gray (N6), clasts (up to 1.o cm) angular to subrounded. WR/+10F: lithic clasts composed of 40–50% glassy basaltic scoria, 50–60% porphyritic dacite. **Note:** glassy basaltic scoria common in the interval 750–787 ft.	750–757	6030.5–6023.5
	Volcaniclastic sediments, gravel with silt and sand (GW), light olive gray (5Y 6/1), pebble gravel with silty matrix, clasts (up to 5.0 mm) angular to subrounded. WR/+10F: lithic clasts composed of 70–80% porphyritic dacite, 20–30% glassy basaltic scoria.	757–762	6023.5–6018.5

Appendix C - Lithologic Descriptions of Drill Cuttings from Borehole R-13			
Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Tpf, Puye Formation	Volcaniclastic sediments, gravel (GP), light gray (N6) to varicolored, pebbles (up to 1.5 cm) are subangular to subrounded. WR/+10F: lithic clasts composed of 80% silicified porphyritic dacite, 20% basaltic scoria.	762–767	6018.5–6013.5
	Volcaniclastic sediments, gravel with sand and silt (GW), grayish orange (10YR 7/4), pebbles (up to 1.7 cm) in matrix of sandy silt, clasts subangular to subrounded. WR/+10F: lithic clasts composed of 30–50% silicified dacite, 10–30% tuffaceous siltstone, and 10–20% basaltic scoria.	767–777	6013.5–6003.5
	Volcaniclastic sediments, gravel with sand (GW), light gray (N6) to varicolored, clasts (up to 1.0 cm) subangular to subrounded. WR/+10F: lithic clasts composed of 70–80% dacite and andesite, 10–20% basaltic scoria, and 10–15% tuffaceous siltstone.	777–787	6003.5–5993.5
	Volcaniclastic sediments, gravel with sand and clay (GW), light olive gray (5Y 6/1), clasts (up to 3.0 cm) subrounded to rounded. WR/+10F: lithic clasts composed of 70–80% dacite, 5–10% basalt, and 5% tuffaceous siltstone.	787–792	5993.5–5988.5
	Volcaniclastic sediments, sand with gravel and clay (SW), light brownish gray (5YR 6/1), pebbles (up to 1.2 cm) are subangular to subrounded. WR/+10F: lithic clasts composed of 90–95% dacite, 5% tuffaceous siltstone, and minor basaltic scoria.	792–812	5988.5–5968.5
	Volcaniclastic sediments, sand with gravel (SW), light brownish gray (5YR 6/1), medium to very coarse sand, pebbles (up to 1.0 cm) are subangular to subrounded. WR/+10F: lithic clasts composed of 85–95% dacite and andesite, 5–7% dacitic pumice fragments, and minor basaltic scoria.	812–827	5968.5–5953.5
	Volcaniclastic sediments, sand with gravel and silt (SW), grayish orange pink (5YR 7/2), clasts (up to 1.3 cm) subangular to rounded. WR/+10F: lithic clasts composed of 95–98% dacite and lesser andesite.	827–832	5953.5–5948.5
	Volcaniclastic sediments, gravel with sand (GW), light gray (N6) to varicolored, clasts (up to 2.0 cm) subangular to rounded. WR/+10F: lithic clasts composed of dacite, andesite, basalt scoria, and tuffaceous siltstone.	832–837	5948.5–5943.5
	Volcaniclastic sediments, gravel with sand (GW), light brownish gray (5YR 6/1), clasts (up to 3.0 cm) subangular to subrounded. WR/+10F: composed of 99% dacite to rhyodacite clasts. Note: coarse gravel interval.	837–847	5943.5–5933.5
	Volcaniclastic sediments, gravel with sand (GW), light brownish gray (5YR 6/1), clasts (up to 1.3 cm) subrounded to rounded. WR/+10F: clasts composed of 98% dacite, rhyodacite, and minor basalt.	847–854	5933.5–5926.5
	Volcaniclastic sediments, clayey sand with gravel (SC), grayish pink (%YR 7/2), clasts (up to 5 mm) are subangular to rounded. +10F: clasts composed of 90–95% dacite and rhyodacite, 5–10% vesicular basalt. WR samples have clayey matrix.	854–868	5926.5–5912.5
	Volcaniclastic sediments, gravel with clay and sand (GW), grayish pink (5YR 7/2), clasts (up to 2.2 cm) are subangular to rounded. WR/+10F: clasts composed of 95–98% dacite and rhyodacite; 3–5% tuffaceous sandstone, trace quartzite	868–888	5912.5–5892.5

Appendix C - Lithologic Descriptions of Drill Cuttings from Borehole R-13			
Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Tpf, Puye Formation	Volcaniclastic sediments, sand with gravel (SW), light brownish gray (5YR 6/1), medium to very coarse sand with pebbles (up to 1.7 cm), subangular to subrounded. WR/+10F: clasts composed of 99% dacite and rhyodacite.	888–908	5892.5–5872.5
	Volcaniclastic sediments, clayey gravel with sand (GC), grayish pink (5YR 7/2), clasts (up to 1.0 cm) are subangular to subrounded. +10F: clasts composed of 95–98% dacite and rhyodacite; 3–5% tuffaceous sandstone. +35F: contains 50–60% brown tuffaceous siltstone/sandstone. WR sample is clay rich.	908–918	5872.5–5862.5
	Volcaniclastic sediments, sand with gravel and silt (SW), grayish pink (5YR 7/2), clasts (up to 1.2 cm) are subangular to subrounded. WR/+10F: clasts composed of 98% dacite and rhyodacite, minor volcanic siltstone to fine-grained sandstone, minor pumice.	918–933	5862.5–5847.5
	Volcaniclastic sediments, silty sand with gravel (SM), light pinkish gray (5YR 7/2), clasts (up to 1.8 cm), subangular to subrounded. WR/+10F: clasts composed of 95–98% porphyritic dacite, 3–5% fine-grained tuffaceous sandstone. +35F: limonite-cemented grains, crystals very common.	933–938	5847.5–5842.5
	Volcaniclastic sediments, gravel with sand (GW), light gray (N6) to pinkish gray, clasts (up to 1.5 cm) are subangular to rounded. WR/+10F: clasts composed of 99% dacite and rhyodacite.	938–943	5842.5–5837.5
	Volcaniclastic sediments, gravelly sand with silt (SW), light pinkish gray (5YR 7/2), clasts (up to 1.0 cm) are subangular to rounded; many clasts broken, suggesting coarse gravel. WR/+10F: clasts composed of 99% dacite and rhyodacite, trace pumice.	943–963	5837.5–5817.5
	Volcaniclastic sediments, gravel with sand (GW), light brownish gray (5YR 6/1), clasts (up to 1.5 cm) are subrounded to subangular. WR/+10F: clasts composed of 100% dacite, rhyodacite, and andesite, trace pumice. +35F: contains 90% volcanic lithics, 10% free quartz and sanidine crystals. Upper 5 ft of the interval has clayey matrix.	963–973	5817.5–5807.5
	Volcaniclastic sediments, sand (SP), light brownish gray (5YR 6/1), medium to very coarse sand and granules (up to 0.5 mm), subangular to rounded. WR/+10F: composed of porphyritic dacite, rhyodacite, and andesite. +35F: contains 5% free quartz and sanidine crystals.	973–983	5807.5–5797.5
	Volcaniclastic sediments, sand (SW), yellowish brown (10YR 5/4), very fine to very coarse sand and granules (up to 0.3 mm), subrounded to subangular. +10F: composed of porphyrtic dacite and rhyodacite (less than 10% of the entire sample retained by the No. 10 sieve). Note: fine clastic interval.	983–998	5797.5–5782.5
	Volcaniclastic sediments, sand with gravel (SW), light brown (5YR 6/4), subrounded to rounded grains (up to 1.0 cm). +10F: 98% white aphyric pumice, minor basalt scoria and dacite. +30F: 80–90% volcanic lithics, 10% quartz and sanidine crystals. Note: pumice-rich interval 998–1068 ft.	998–1003	5782.5–5777.5
	Volcaniclastic sediments, gravel with sand (GW), light gray (N6), to varicolored, clasts (up to 1.2 cm), subrounded to rounded. WR/+10F: 90% silicified dacite porphyry, 10% pumice.	1003–1008	5777.5–5772.5

Appendix C - Lithologic Descriptions of Drill Cuttings from Borehole R-13			
Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Tpf, Puye Formation	Volcaniclastic sediments, gravel with sand (GW), light gray (N6), clasts subangular to subrounded. WR/+10F:40–60% aphyric pumice, 40–60% dacitic volcanic lithics, 5–10% tuffaceous sandstone.	1008–1018	5772.5–5762.5
	Volcaniclastic sediments, sand with gravel (SP), varicolored, white (N9), to light gray (N6), medium to coarse sand with pebbles (up to 1.0 cm) subrounded to rounded. WR/+10F: 50–75% aphyric pumice, 25–30% dacite, rhyodacite, and andesite; 2–5% siltstone.	1018–1033	5762.5–5747.5
	Volcaniclastic sediments, sand with gravel (SW), varicolored, white (N9) to dark gray (N6), clasts (up to 1.0 cm) subrounded to rounded. WR/+10F: 60–80% white and gray pumice, 10–20% dacite and basaltic scoria, and intermediate to felsic volcanics, 5–10% volcanic sandstone.	1033–1043	5747.5–5737.5
	Volcaniclastic sediments, gravel with sand (GW), varicolored, white (N9) to light gray (N6), clasts (up to 2.0 cm) subangular to subrounded. WR/+10F: 60–80% white and gray pumice, 20–30% dacite and silicified dacite, 10–20% tuffaceous sandstone.	1043–1058	5737.5–5722.5
	Volcaniclastic sediments, gravel with sand (GW), varicolored, white (N9) to light tan, clasts (up to 1.0 cm) subangular to subrounded. WR/+10F: 75–80% white and gray pumice, 15% silicified dacite, 5% fine-grained volcanic sandstone, 1–2% quartz and sanidine crystals.	1058–1063	5722.5–5717.5
	Volcaniclastic sediments, gravel with sand (GW), varicolored, white (N9) to light gray (N6), clasts (up to 1.5 cm) subangular to subrounded. WR/+10F: 85% white pumice, 10–15% silicified dacite, 10–15% fine-grained volcanic sandstone. +35F: 10–20% pumice, 70–75% lithics, 3–5% quartz and sanidine crystals, 10–15% volcanic sandstone, minor quartzite.	1063–1068	5717.5–5712.5
	Clastic sediments, sand with gravel (SW), varicolored, white (N9) to light gray (N6), clasts (up to 5 mm) subangular to subrounded. WR/+10F: 75–80% flow-banded rhyodacite and dacite, 3–5% pumice, 10–15% volcanic sandstone, 3–5% quartzite. Note: first interval with significant Precambrian lithic components indicates river gravel deposits within the Puye Formation from 1068 to 1133 ft bgs.	1068–1073	5712.5–5707.5
	Clastic sediments, gravel with sand (GW), varicolored, white (N9) to light gray (N6), clasts (up to 1.5 cm) subrounded to rounded. WR/+10F: 75–85% volcanic lithics (andesite, dacite, rhyodacite), 5–10% fine-grained volcanic sandstone, 5–10% white to pinkish quartzite, trace granitic rocks, 1–2% quartz and sanidine crystals.	1073–1083	5707.5–5697.5
	Clastic sediments, gravel with sand (GW), light brownish gray (5YR 6/1), clasts (up to 1.5 cm) subrounded to rounded. WR/+10F: 60–80% rhyodacite and dacite, 20–40% quartzite, 5–10% granitic rocks.	1083–1093	5697.5–5687.5
	Clastic sediments, gravel with sand (GW), varicolored, white (N9) to light gray (N6), clasts (up to 1.5 cm) subrounded to rounded. WR/+10F: 70–80% volcanic lithics (andesite, dacite, rhyodacite), 10–30% quartzite.	1093–1103	5687.5–5677.5
	Clastic sediments, sand with gravel (SW), pale yellowish brownish gray (5YR 6/2), fine to medium sand with pebbles (up to 1.5 cm), subrounded to rounded. WR/+10F: 80–90% porphyritic dacite, 5–10% vesicular basalt, 2–5% quartzite.	1103–1108	5677.5–5672.5

Appendix C - Lithologic Descriptions of Drill Cuttings from Borehole R-13			
Geologic Unit	Lithologic Description	Sample Interval (ft)	Elevation Range (ft above msl)
Tpf, Puye Formation	Clastic sediments, gravelly sand (SW), medium brown (5YR 5/4), fine to medium sand with pebbles (up to 1.0 cm), subrounded to rounded. WR/+10F: 60–80% andesite and dacite, 10–30% vesicular basalt, 5–10% quartzite, minor tuffaceous sandstone.	1108–1118	5672.5–5662.5
	Clastic sediments, sand with gravel and clay (SW), pale brownish gray (5YR 7/2), fine to coarse sand with pebbles (up to 1.5 cm), subangular to rounded. WR/+10F: 10–60% basalt, 30–50% rhyodacite and dacite, 5–10% quartzite.	1118–1128	5662.5–5652.5
	Clastic sediments, gravel with sand (GW), light brownish gray (5YR 6/1) to varicolored, clasts (up to 2.0 cm), subangular to subrounded. WR/+10F: 70–80% rhyodacite and dacite, 10–20% basalt, 5–10% quartzite, minor granitic rocks, trace micaceous quartzite schist.	1128–1133	5652.5–5647.5
	TOTAL DEPTH = 1133 FT BGS.		

Note: American Society for Testing Materials (ASTM) standards were used in describing the texture of drill chip samples for sedimentary rocks such as alluvium and the Puye Formation. ASTM method D 2488-90 incorporates the Unified Soil Classification System (USCS) as a standard for field examination and description of soils. The following is a glossary of standard USCS symbols used in the R-13 lithlog.

SW = Well-graded sand GM = Silty Gravel

GW = Well graded gravel GC = Clayey gravel

GP = Poorly graded gravel

REFERENCE

ASTM D 2488-90. Standard Practice and Identification of Soils (Visual-Manual Procedure)

Note: Cuttings were collected at nominal 5-ft intervals and divided into three sample splits: (1) unsieved, or whole rock (WR) sample; (2) +10F sieved fraction (No. 10 sieve equivalent to 2.0 mm); and (3) +35F sieved fraction (No. 35 sieve equivalent to 0.50 mm).

Note: The term "percent," as used in the above descriptions, refers to percent by volume for a given sample component.

Note: Color designations (hue, value, and chroma, i.e., 5YR 5/2) are from "The Geological Society of America Rock-Color Chart."