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FINAL
COMPLETION REPORT
INTERMEDIATE WELL R-23i
LOS ALAMOS NATIONAL LABORATORY
LOS ALAMOS, NEW MEXICO
PROJECT NO. 49436

Prepared for:

The US Department of Energy and the
National Nuclear Security Administration through the
US Army Corps of Engineers
Sacramento District

Prepared by:

KLEINFELDER
8300 Jefferson NE, Suite B
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March 2006

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LIST OF ACRONYMS AND ABBREVIATIONS

amsl	above mean sea level
ARCH	air-rotary casing hammer
bgs	below ground surface
BMPs	best management practices
DOE	US Department of Energy
DTW	depth to water
EES-6	Earth and Environmental Sciences Division, Group 6
ft	foot/feet
ft^3	cubic feet
gal.	gallon/gallons
HE	high explosives
ID	inner diameter
in.	inch/inches
Kleinfelder	Kleinfelder, Inc.
LANL	Los Alamos National Laboratory
µS/cm	microSiemens per centimeter
NM	not measured
NMED	New Mexico Environment Department
NTUs	nephelometric turbidity units
OD	outer diameter
pH	percentage of hydrogen ions
ppm	parts per million
Qal	Quaternary Alluvium
Qbo	Otowi Member of the Bandelier Tuff
Qbog	Guaje Pumice Bed of the Otowi Member of the Bandelier Tuff
RCT	radiation control technician
TD	total depth
TOC	total organic carbon
Tb4	Cerros del Rio basalt
WDC	WDC Exploration & Wells

ABSTRACT

Intermediate Well R-23i was installed in accordance with the "Drilling Work Plan for Wells R-16a and R-23i, Final" (Kleinfelder 2005a). Drilling activities were funded and directed by the US Department of Energy. The US Army Corps of Engineers contracted Kleinfelder, Inc., to conduct the drilling, installation and sampling at R-23i. Los Alamos National Laboratory personnel provided technical assistance.

R-23i is located in lower Pajarito Canyon, south of Pajarito Road. The well was drilled and installed to sample perched intermediate groundwater encountered during the drilling of R-23. R-23 was drilled in 2002 as part of the Hydrogeologic Workplan to provide hydrogeologic data and monitor the regional aquifer near potential release sites at Technical Area 54. R-23i is located approximately 25 feet (ft) southwest of R-23.

R-23i was drilled to a total depth of 695 ft below ground surface (bgs). The stratigraphy encountered included, in descending order, Quaternary Alluvium, Otowi Member of the Bandelier Tuff, the Guaje Pumice Bed of the Otowi Member, and Cerros del Rio basalt. Perched intermediate groundwater was encountered within the Cerros del Rio basalt, and a 4.5-inch diameter well was installed with two screened intervals, one between 470.2 and 480.1 ft bgs and the other between 524 and 547 ft bgs. Additionally, a 2-inch diameter well was installed in the R-23i annular space with a screened interval between 400.3 and 420 ft bgs.

The middle and bottom screened intervals in the 4.5-inch well have been developed and sampled. The top screened interval in the 2-inch well has been partially developed by bailing, but has not been sampled. An aquifer test was conducted on the bottom screened interval, but aquifer tests are not planned for the middle and top screened intervals.

Two groundwater samples were collected from the open borehole prior to well installation; additionally, two final samples were collected from the bottom and middle screened intervals after aquifer testing and well development, respectively. The samples were analyzed for anions (including perchlorate), cations and metals; additionally, the sample collected from the bottom screened interval was analyzed for high explosives. Perchlorate was not detected in the four perched intermediate zone samples. Nitrate (as N) was detected in all four samples at concentrations ranging between 0.05 and 0.89 parts per million. High explosive compounds were not detected in the sample from the bottom screened interval.

1.0 INTRODUCTION

This completion report summarizes the site preparation, drilling, well construction, well development, and related activities for Intermediate Well R-23i, drilled in October 2005 at Los Alamos National Laboratory (LANL). Drilling activities were funded and directed by the US Department of Energy (DOE) and contracted by the US Army Corps of Engineers. Kleinfelder, Inc. (Kleinfelder) conducted the drilling, installation, and sampling activities according to the "Drilling Work Plan for Wells R-16a and R-23i, Final" (Kleinfelder 2005a). LANL staff provided technical assistance during field operations.

R-23i is located in lower Pajarito Canyon, south of Pajarito Road, as shown in Figure 1.0-1. The well was drilled and installed to sample perched intermediate groundwater encountered during the drilling of nearby well R-23. R-23 was drilled in 2002 as part of the LANL Hydrogeologic Workplan (LANL 1998) to provide hydrogeologic data and monitor the regional aquifer near potential release sites at Technical Area 54. R-23i is located approximately 25 feet (ft) southwest of R-23.

The drilling work plan specified that R-23i would be drilled to approximately 700 ft below ground surface (bgs) with a proposed completion depth between 580 and 700 ft bgs. R-23i was drilled to a total depth (TD) of 695 ft bgs and perched intermediate groundwater was encountered within the Cerros del Rio basalt. A 4.5-inch (in.) inner diameter (ID) well was installed to 550.7 ft bgs with two screened intervals, one between 470.2 and 480.1 ft bgs and the other between 524 and 547 ft bgs. Additionally, a 2-in. diameter well was installed in the annular space with a screened interval between 400.3 and 420 ft bgs.

For the purposes of this report, the R-23i screened intervals will be referred to as:

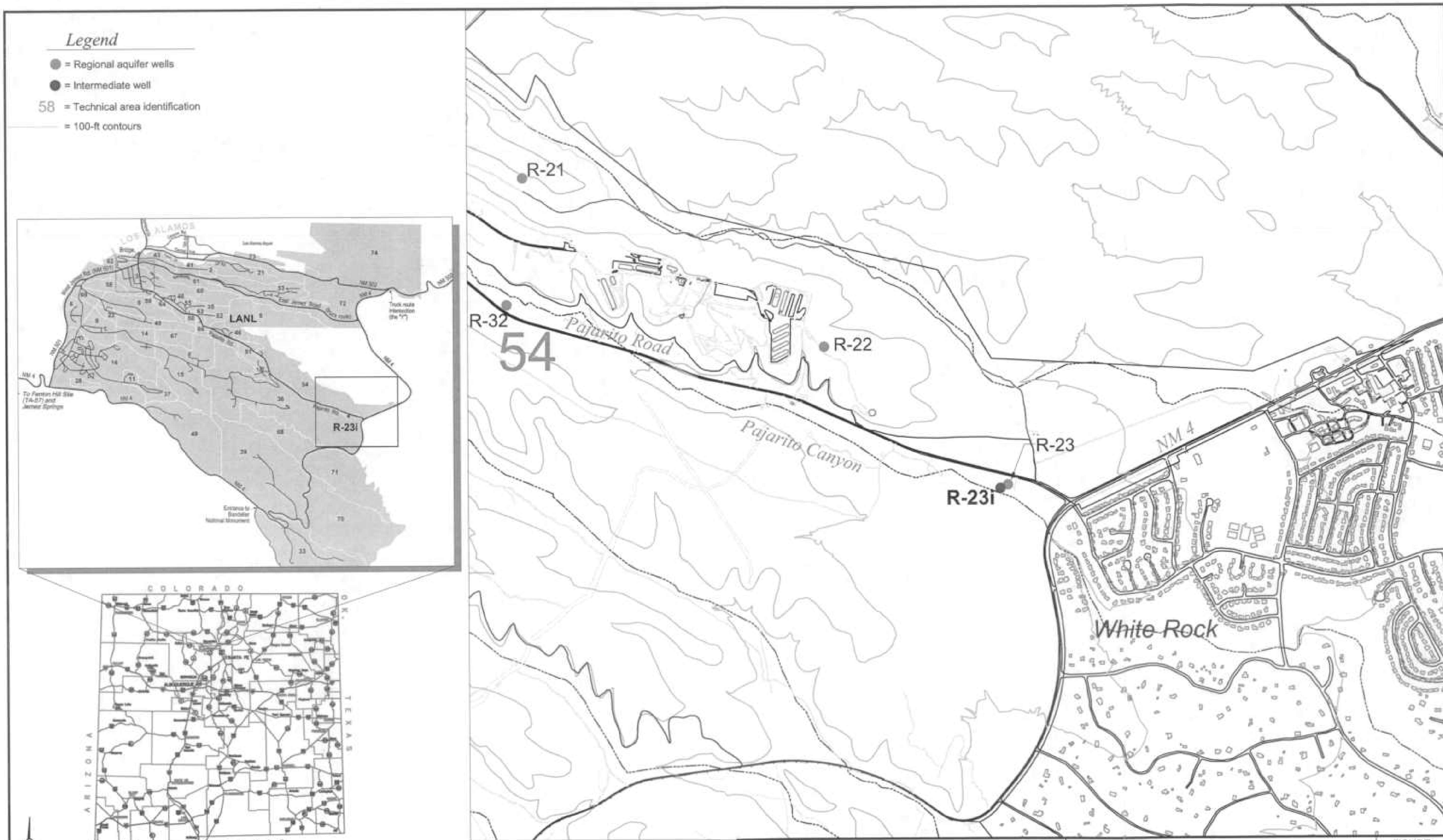
top screened interval (400.3 to 420 ft bgs in the 2-in. well),

middle screened interval (470.2 to 480.1 ft bgs in 4.5-in. well)

bottom screened interval (524 to 547 ft bgs in 4.5-in.well).

The middle and bottom screened intervals have been developed and sampled; the top screened interval has been partially developed by bailing but it has not been sampled to date. An aquifer test was conducted on the bottom screened interval, but aquifer tests are not planned for the middle or top screened intervals.

The information presented in this report was compiled from field reports and activity summaries generated by Kleinfelder, LANL, and subcontractor personnel. Original records, including field reports, field logs, and survey records, are on file in Kleinfelder's Albuquerque office and will be transferred to the LANL Records Processing Facility at the completion of the project. This report contains brief descriptions of all activities associated with R-23i as well as supporting figures, tables, and appendices. Detailed analysis and interpretation of geologic, geochemical, and aquifer data will be included in separate technical documents to be prepared by LANL.



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Drawn By: C. Bhongir	Date: February 2006
Project No.: 49436	Filename: Figure 1.0-1.dwg
Scale: 1" = 1200'	Revision: –

SITE LOCATION MAP
Intermediate Well R-23i
Pajarito Canyon
Los Alamos, New Mexico

FIGURE **1.0-1**

2.0 PRELIMINARY ACTIVITIES

Preliminary activities included preparing administrative planning documents and constructing the drill site.

2.1 Administrative Preparation

Kleinfelder received contractual authorization as a notice to proceed on May 27, 2005. The following documents were prepared to guide the implementation of the scope of work for this well: Drilling Work Plan (Kleinfelder 2005a), Contractor's Quality Management Plan (Kleinfelder 2005b), Site-Specific Health and Safety Plan (Kleinfelder 2005c), and Storm Water Pollution Prevention Plan (Kleinfelder 2005d).

2.2 Site Preparation

Site preparation consisted of installing silt fencing to prevent erosion and runoff from the drill site, setting up the exclusion zone, and constructing the cuttings pit. Best management practices, also known as BMPs, were installed as specified in the Storm Water Pollution Prevention Plan (Kleinfelder 2005d). EnviroWorks, Inc. completed these tasks on August 10, 2005. A radiation control technician (RCT) from LANL's Health, Safety, and Radiation Protection Group-1 screened the site before site preparation activities. A geology trailer, generator, compressor, and safety lighting equipment were moved to the site during the subsequent mobilization of drilling equipment.

3.0 DRILLING ACTIVITIES

WDC Exploration & Wells (WDC) used a Speedstar 50K rig to drill R-23i to a TD of 695 ft bgs between October 11 and 22, 2005. Drilling activities were performed generally in one 12-hour shift per day, 7 days per week, by the drill crew and two site geologists. Depth-to-water (DTW) measurements were taken at the beginning and end of most shifts to check for the presence of groundwater. A chronology of drilling and associated activities for R-23i is presented in Table 3.0-1. Fluids used and recovered during drilling are presented in Table 3.0-2.

On October 11, 2005, WDC began drilling R-23i using the air-rotary casing hammer (ARCH) technique. The crew advanced the borehole to 40 ft bgs using a 12¼-inch (in.) outer diameter (OD) tricone bit. On October 12, they hammered 13⅜-in. conductor casing to 39.5 ft bgs and drilled to 100 ft bgs with intervals of lost circulation. On October 13, 6 ft of slough had accumulated in the borehole. To solve the lost circulation problems, the borehole was cemented with about 4 cubic yards of cement from approximately 94 to 41 ft bgs. The drill crew departed for scheduled days off.

Drilling resumed on October 18 when WDC drilled through the cement plug and then to a total depth of 270 ft bgs using a 12¼-in. hammer bit. On the 19th, the borehole was advanced to 560 ft bgs. On the 20th, water was measured at 454.23 ft bgs and a screening groundwater sample was collected. Video logs were run to identify perched water zones in the open borehole; water was observed to be seeping in at approximately 403.5 and 436 ft bgs. DTW was measured at 449.8 ft bgs after video logging.

On October 21, water was measured at 446.6 ft bgs and the crew was instructed to continue drilling to 695 ft bgs or until the clay content in the cuttings decreased. On the 22nd, WDC began

Table 3.0-1
Chronology of Activities

TASK	R-23I DATES							
	Aug-05	Sep-05	Oct-05	Nov-05	Dec-05	Jan-06	Feb-06	Mar-06
SITE PREPARATION ACTIVITIES	8/10							
BOREHOLE DRILLING/SAMPLING								
Mobilization			10/11					
Air-Rotary Drilling			10/11 - 22					
Groundwater Screening Sampling			10/20 10/31					
BOREHOLE LOGGING								
Geophysical Logging			10/20,21 10/23					
Video Logging			10/20 10/22,23	11/7				
WELL CONSTRUCTION				11/3 - 10				
WELL DEVELOPMENT								
Combined middle/bottom screens				11/13-16				
Bottom screened interval				11/16 -12/5				
Middle screened interval					12/17-20			
Top screened interval							2/8&10	
GROUNDWATER WELL SAMPLING					12/11 12/20			
AQUIFER TESTING					12/8-11			
PUMP INSTALLATION[a]								PENDING
SITE RESTORATION[b]								PENDING

[a]Pumps will be sized and installed in Late Spring of 2006.

[b]Site restoration will begin in Late Spring of 2006 after permission to discharge fluids has been received from the NMED.

drilling through slough from approximately 490 to 560 ft bgs and then advanced the borehole from 560 to 695 ft bgs, the final TD of the borehole. Between approximately 680 and 685 ft bgs, the clay content dropped and the color changed from red to brown. An attempt to run a video log after TD was reached was unsuccessful due to the presence of a bridge at approximately 470 ft bgs.

Table 3.0-2
Introduced and Recovered Fluids

Material		Amount (gallons)
Introduced	QUIK-FOAM®	82
	Defoamer	1
	EZ-MUD®	15
	Potable Water	7,679
	Total Introduced Fluids[a]	7,777
Recovered	Total Recovered Fluids[b]	40,682

[a]Fluids introduced during drilling.
[b]Estimated fluid volume recovered during drilling, well development, and aquifer testing conducted to date.

4.0 SAMPLING ACTIVITIES

This section describes the cuttings and groundwater sampling at R-23i. Sampling activities were generally conducted in accordance with the Drilling Plan (Kleinfelder 2005a).

4.1 Cuttings Sampling

Bulk cuttings were collected in plastic bags from the R-23i borehole at 10-ft intervals from 0 to 400 ft bgs. From 400 to 695 ft bgs, bulk cuttings were collected at 5-ft intervals and processed in the following manner. Approximately 500 to 700 milliliters of bulk cuttings were collected from the discharge hose, sealed in Ziploc® bags, labeled, and transferred to the LANL geology task leader. Beginning at 400 ft bgs, bulk cuttings were also sieved at 5-ft intervals and the sieved fractions (>#10 and >#35 mesh) were placed in chip trays along with unsieved (whole rock) cuttings. The sieved fractions were placed in labeled plastic bags and submitted to LANL. The remaining cuttings were sealed in Ziploc® bags, labeled, and archived in core boxes. LANL RCTs screened all cuttings before they were removed from the site.

4.2 Water Sampling

Two groundwater samples were collected from the open borehole with disposable bailers at R-23i. After the well was installed, with either a packer or bridge plug in place, one sample was collected from the bottom screen at the end of aquifer testing and one sample was colleted from the middle screen after well development. Table 4.2-1 summarizes dates and collection depths for the water samples. The groundwater samples were submitted to the LANL Earth and Environmental Sciences Division, Group 6 (EES-6) for anions, cations, and metals analyses. The sample from the bottom screened interval was also submitted for high explosives (HE) analyses by EES-6.

Table 4.2-1
Groundwater Samples

Sample Number	Date	DTW (ft bgs)	Borehole Depth (ft bgs)	Analyses	Water-bearing Unit
EU0507GR23i01	10/20/05	~500 [a]	560	Anions, cations, metals, ClO_4 [e]	Cerros del Rio basalt
EU0507GR23i02	10/31/05	450-460[a]	496 [d]	Anions, cations, metals, ClO_4	Cerros del Rio basalt
EU0507GR23i03	12/11/05	521.7[b]	550.7	Anions, cations, metals, ClO_4+HE	Cerros del Rio basalt
EU0507GR23i04	12/20/05	505[c]	550.7	Anions, cations, metals, ClO_4	Cerros del Rio basalt

[a] Sample collected with bailer just below water level in open borehole.
[b] Sample collected from completed well from bottom screened interval.
[c] Sample collected from completed well from middle screened interval.
[d] Depth of drill casing prior to cleaning out the borehole after TD was reached.
[e] Perchlorate

5.0 BOREHOLE LOGGING

In the days after October 22, when the TD of 695 ft bgs was reached, multiple attempts were made to run the video camera and geophysical logging tools to TD in order to design the well. However, a bridge developed in the open borehole that prevented logging below approximately 473 to 483 ft bgs.

On October 24, WDC was instructed to run 9⅝-in. casing to approximately 485 ft bgs and then clean out the borehole to the TD of 695 ft bgs so that geophysical and video logs could be run. On the 24th, casing had been installed to 300 ft bgs when the main winch of the drill rig developed mechanical problems. It took several days to get replacement parts for the winch, and then the drill crew left for their scheduled days off.

On October 31, WDC advanced the casing to approximately 500 ft bgs and the DTW was measured at 446.9 ft bgs; a water sample was collected from approximately 450 to 460 ft bgs in the open borehole. On November 1, WDC cleaned out the borehole to 695 ft bgs and tripped the drill string out of the hole to run geophysical logs. However, once again, logging was stopped at 483 ft bgs where a bridge had formed. Therefore, after the TD of 695 ft bgs was reached, induction logs were obtained to depths between 473 and 483 ft bgs, but not to the TD of 695 ft bgs. However, a full suite of Schlumberger geophysical logs was obtained from R-23.

Table 5.0-1 summarizes the dates and types of logging at R-23i. A DVD of the October 20, 2005 video log to a depth of 455 ft bgs is presented in Appendix A; note that the video counter showed water at 476 ft bgs, but DTW after logging was measured at 455 ft bgs. Appendix B on the report CD contains the October 20 gamma log run to 556 ft bgs and the October 23 induction log from 55 to 475 ft bgs.

6.0 HYDROGEOLOGY

This section contains a brief description of the stratigraphy, groundwater, and preliminary hydrochemistry at R-23i. The stratigraphy section is derived from the R-23 well completion report for the interval drilled at R-23i. The groundwater section describes groundwater encountered at R-23i and is based on drilling observations, video logging and water level measurements.

Table 5.0-1
Borehole Logging

Operator	Date	Tools	Cased Footage (ft bgs)	Openhole Interval (ft bgs)	Logged Interval (ft bgs)	Remarks
Kleinfelder	10/20/05	Video	0-39.5	39.5-560	0-455	Water seeping into borehole at 403.5 ft bgs; standing water at 455 ft bgs.
Kleinfelder	10/20/05	Video	0-39.5	39.5-560	0-~455	Standing water was blown out of borehole and a second video log was run in an attempt to see more of the borehole. However, standing water was still present at 455 ft bgs. The video showed water dripping down borehole wall at 436 ft bgs.
Kleinfelder	10/20/05	Gamma	0-39.5	39.5-560	0-556	Successful logging run to 556 ft bgs.
Kleinfelder	10/21/05	Induction	0-39.5	39.5-560	77-469.7	Encountered bridge at 470 ft bgs; log obtained.
Kleinfelder	10/22/05	Video	0-39.5	39.5-695	0-476	Bridge observed at approximately 476 ft bgs; tagged at 468.5 ft bgs after logging run.
Kleinfelder	10/23/05	Video	0-39.5	39.5-603	0-464	Water entering borehole at 403 ft bgs, standing water about 464 ft bgs
Kleinfelder	10/23/05	Induction	0-39.5	39.5-603	55-475	Encountered bridge at ~475 ft bgs; log obtained.
Kleinfelder	10/23/05	Induction	0-39.5	39.5-603	55-473	Encountered bridge at ~473 ft bgs; log obtained.
Kleinfelder	11/1/05	Induction	0-496[a]	496-695	0-483	Encountered bridge at ~483 ft bgs; no log recorded.
LANL	11/7/05	Video	0-400 (tremie in annulus)	400-425 (above backfill)	0-423.5	Three video logs were run in the annulus to design the 2-in well; the lens was obscured ~396 ft bgs in first two logging runs. Third run was successful. No water observed in annulus.

[a]Drill casing was in place to 496 ft bgs.

6.1 Stratigraphy

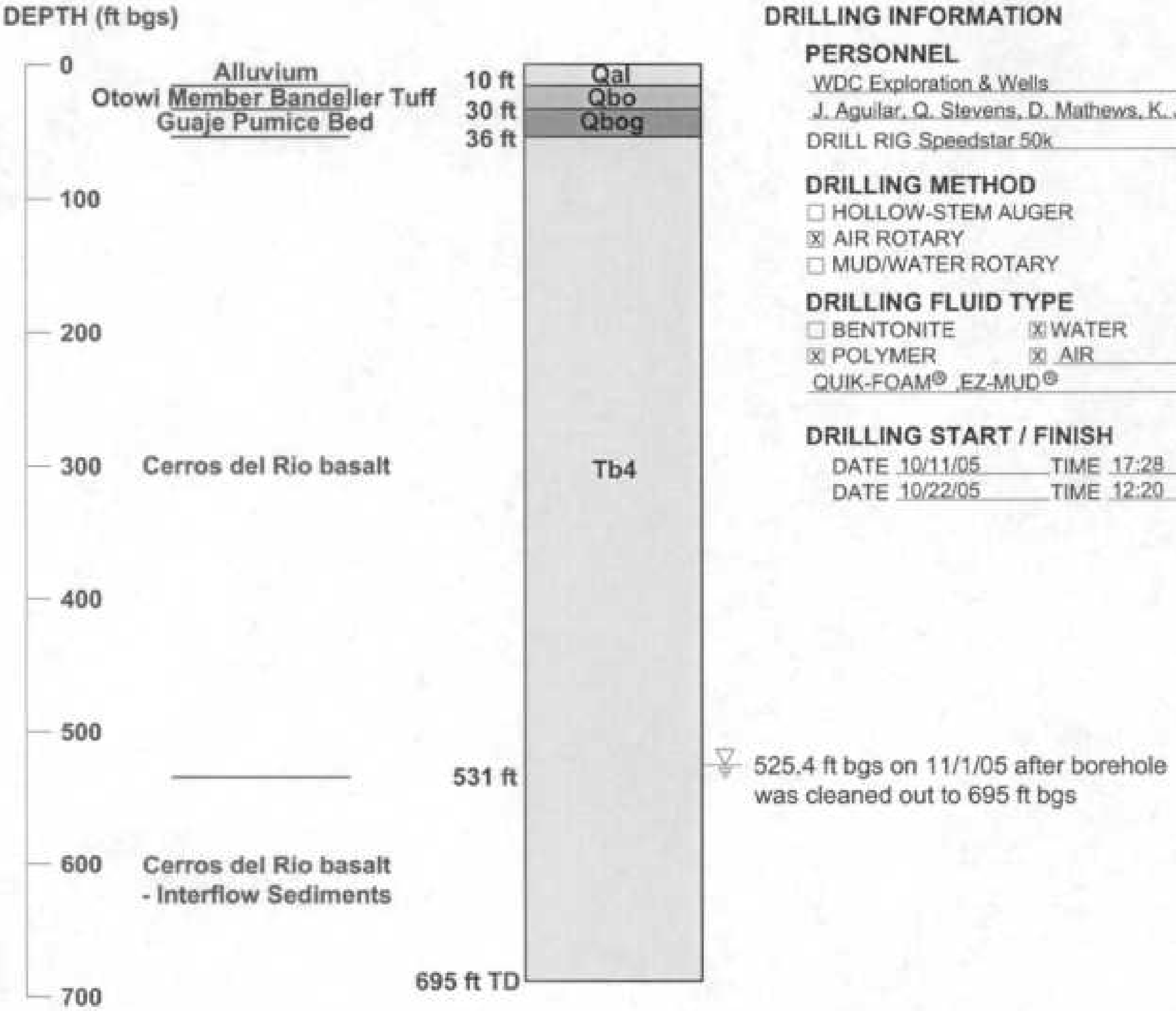
This section presents the stratigraphy from nearby characterization well R-23 to the TD of 695 ft bgs in R-23i (LANL 2003). Figure 6.1-1 summarizes the local stratigraphy and Figure 6.1-2 shows the stratigraphy along with geophysical logs from R-23i. A detailed lithologic log is presented in Appendix C.

Quaternary Alluvium, Qal (0 to 10 ft bgs)

Unconsolidated tuffaceous sands and gravels were noted in the interval from 0 to 10 ft bgs. Alluvial sediments consist primarily of detrital clasts of Bandelier Tuff and Tschicoma dacitic lavas, with mineral grains consisting predominantly of quartz and feldspar. The alluvium is part of the inactive stream channel of Pajarito Canyon.

Otowi Member of the Bandelier Tuff, Qbo (10 to 30 ft bgs)

The Otowi Member of the Bandelier Tuff is made up of rhyolitic ash-flow tuffs that contain ash, vitric pumice with quartz and sanidine phenocrysts, and volcanic lithics of intermediate composition (i.e., dacite and andesite). The Otowi ash-flow tuffs are nonwelded at the R-23 site.



DRILLING INFORMATION

PERSONNEL

WDC Exploration & Wells

J. Aguilar, Q. Stevens, D. Mathews, K. Jones

DRILL RIG Speedstar 50k

DRILLING METHOD

- ☐ HOLLOW-STEM AUGER
- ☒ AIR ROTARY
- ☐ MUD/WATER ROTARY

DRILLING FLUID TYPE

- ☐ BENTONITE
- ☒ WATER
- ☒ POLYMER
- ☒ AIR

QUIK-FOAM®, EZ-MUD®

DRILLING START / FINISH

DATE 10/11/05 TIME 17:28

DATE 10/22/05 TIME 12:20

Note:
Geologic contacts are derived from nearby well R-23.

▽ Depth to water

KLEINFELDER		BOREHOLE SUMMARY DATA SHEET Intermediate Well R-23i Pajarito Canyon Los Alamos, New Mexico	FIGURE 6.1-1
Drawn By: C. Bhongir	Date: February 2006		
Project No.: 49436	Filename: Figure 6.1-1.dwg		
Scale: not-to-scale	Revision: –		

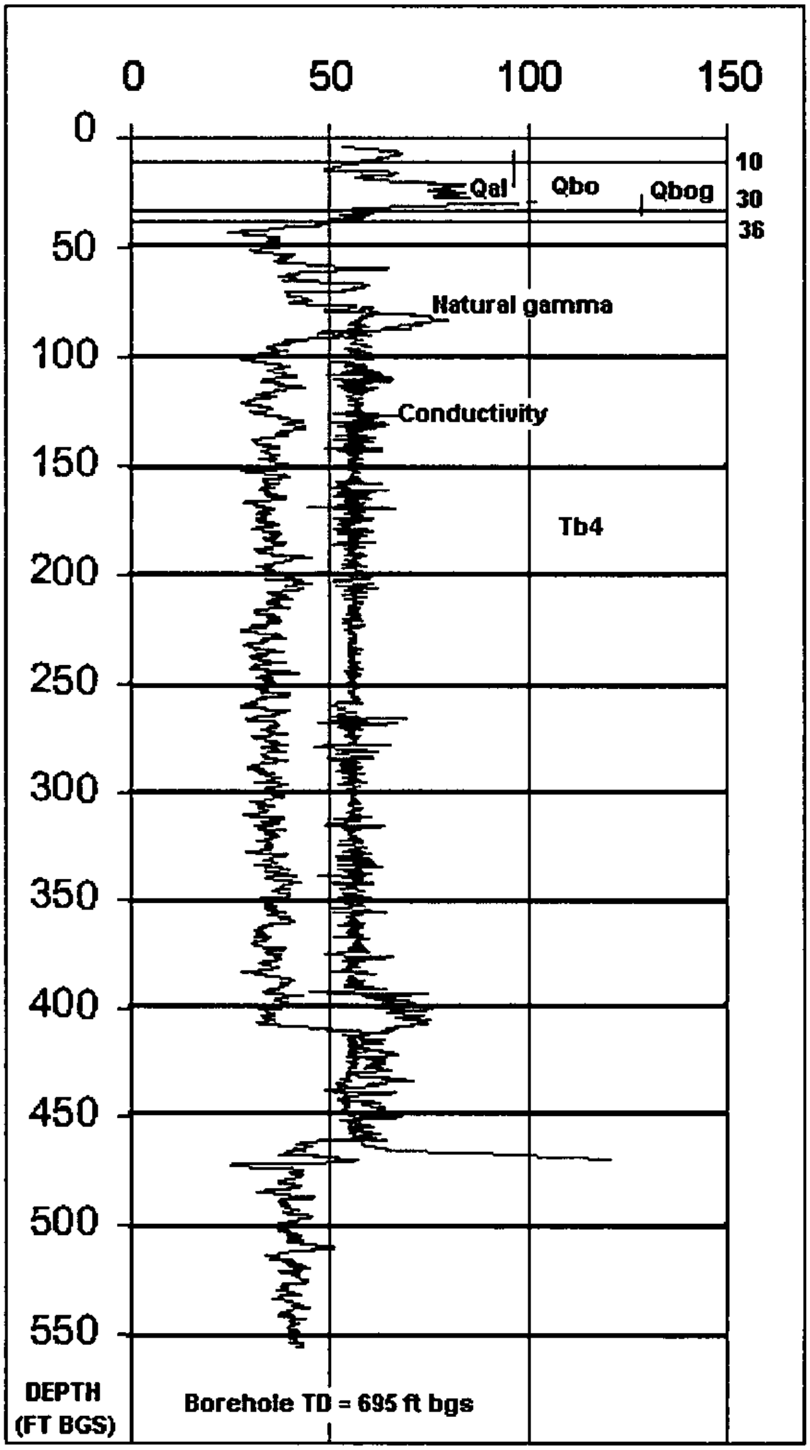


Figure 6.1-2. Geophysical Logs and R-23i Stratigraphy (surface casing installed to 39.5 ft bgs)

Guaje Pumice Bed, Qbog (30 to 36 ft bgs)

The Guaje Pumice Bed is an ash-fall deposit composed of layered rhyolitic pumice and ash that regionally forms the basal unit of the Bandelier Tuff. Drill cuttings from this interval are composed of frothy-textured pumice; finer ash was washed out during drilling.

Cerros del Rio Basalt, Tb4 (36 to 695 ft bgs)

The upper portion of the Cerros del Rio basalt section, from 36 to 411 ft bgs, is made up of a series of basaltic flows separated by layers of scoriaceous breccia. At least four separate lava flows are present in this interval. Flow units in the interval from 36 to 168 ft bgs are slightly porphyritic with sparse olivine and plagioclase phenocrysts in an aphanitic groundmass. Five- to 10-ft-thick layers of oxidized scoriaceous basalt mark the bases of some flows. At least two additional flows are evident in the interval from 168 to 411 ft bgs. These are massive, slightly porphyritic, olivine- and pyroxene-bearing basalts separated by intervals of basaltic scoria. The upper lava flows have weak iron oxidation alteration with local clay development on fractures. The lower flows show generally more intense rock alteration characterized by calcite precipitation and groundmass alteration.

Basaltic lavas and sedimentary interflow deposits are encountered from 411 to 531 ft bgs. Chip samples from throughout this section typically contain slightly porphyritic, olivine-bearing basalt and locally abundant fragments of siltstone and claystone. A 20-ft-thick discrete basalt lava flow is present at the base of this section.

From 531 to 695 ft bgs, the Cerros del Rio basalt is composed of lavas and volcaniclastic interflow sediments. Clayey sand and gravel deposits in the upper 165 ft (531 to 696 ft bgs) contain abundant clastic sedimentary rock fragments, including basaltic sandstone, tuffaceous sandstone, siltstone, and claystone. A significant component of altered basalt chips is present throughout the interval.

6.2 Groundwater

Perched intermediate groundwater was encountered in the Cerros del Rio basalt in R-23i. Standing water was first measured at 454.23 ft bgs in the open borehole with a bottom depth of 560 ft bgs. Video logs were run to identify perched water zones and water was observed to be seeping in at approximately 403.5 and 436 ft bgs. DTW was measured at 449.8 ft bgs after video logging. Video logs could not be obtained below approximately 476 ft bgs due to a bridge that formed in the open borehole, so water-bearing zones below that depth were not observed.

At the completion of drilling to the TD of 695 ft bgs, the DTW also could not be measured because of the bridge at approximately 470 ft bgs. Following well installation, the DTW was 449.1 ft bgs without a packer between the middle and bottom screened intervals. With a packer between the screened intervals, the DTW for the bottom screen was 453.96 ft bgs on December 8, and for the middle screen it was 449.8 ft bgs on December 16. The DTW in the 2-in. well following construction was 405.88 ft bgs on December 8.

6.3 Preliminary Groundwater Analytical Results

Analytical data for the four groundwater samples collected from R-23i are presented and briefly summarized in Appendix D. Perchlorate was not detected in the four perched intermediate zone samples. Nitrate (as N) was detected in all four samples at concentrations ranging between 0.05 and 0.89 parts per million (ppm). HE compounds, with a detection limit of 0.01 ppm, were not detected in the sample from the bottom screened interval.

7.0 WELL INSTALLATION

This section summarizes the well design and well construction activities for the 4.5-in. and 2-in. wells at R-23i.

7.1 Well Design

The well was designed in accordance with LANL Standard Operating Procedure for Well Construction, Revision 3 (LANL 2001). DOE and LANL provided an approved well design to Kleinfelder; the New Mexico Environment Department (NMED) reviewed and concurred with the well design prior to installation. The design called for two screened intervals to monitor intermediate perched zone groundwater quality within the Cerros del Rio basalt. The well was completed with one screened interval from 470.2 to 480.1 ft bgs and another from 524 to 547 ft bgs, with a 3-ft-long sump below the bottom screen. The well casing was 4.5-in. ID/5.0-in. OD, type A304 stainless steel fabricated to American Society for Testing and Materials A312 standards. The well screen for both intervals was 4.5-in. ID, 0.02-in. rod-based, wire-wrapped stainless steel screen.

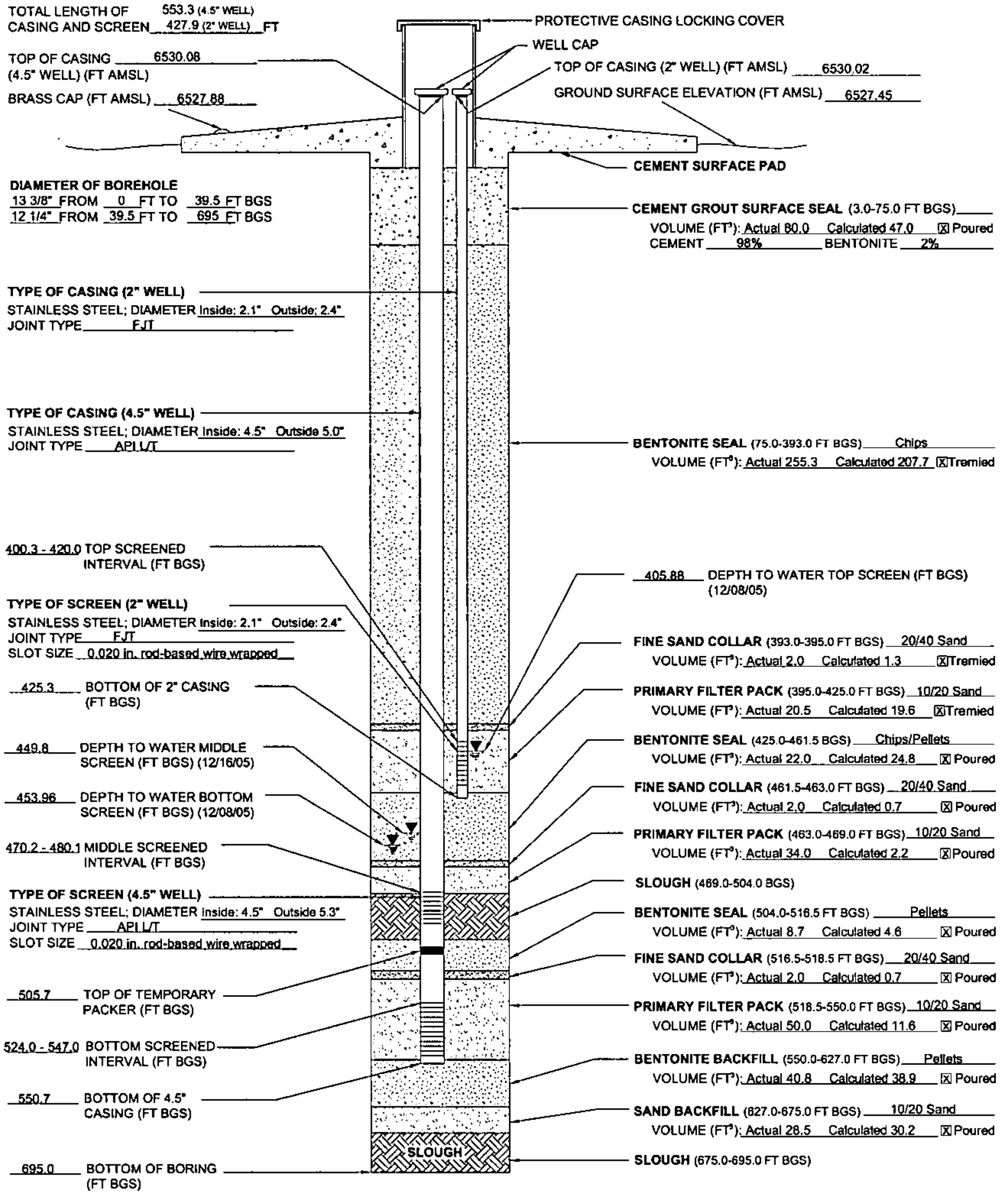
Additionally, a 2-in. stainless steel well was installed in the annular space with a 0.02-in. rod-based, wire-wrapped screen from 400.2 to 420 ft bgs. The casing and screen were factory-cleaned and also steam-cleaned onsite. Figure 7.2-1 is an as-built schematic showing construction details for R-23i.

7.2 Well Construction

The bottom of the borehole was tagged at 675 ft bgs prior to well construction. The 9⅝-in. drill casing was left in place to 656 ft bgs to minimize formation sloughing and bridging during construction. From 675 to 425 ft bgs, annular fill materials were poured through the drill casing; above 425 ft bgs, materials were tremied into place.

The interval from 675 to 627 ft bgs was backfilled with 10/20 silica sand; bentonite pellets were placed from 627 to 550 ft bgs. The well casing and screen were then lowered into the borehole and the annular materials were added between the drill casing and the stainless steel well casing. The bottom of the well casing was placed at 550.7 ft bgs.

The primary filter pack of 10/20 silica sand was installed between 550 and 518.5 ft bgs for the bottom screen. After emplacement of the filter pack, the drillers used a 4-in. rubber disc to swab the screened interval and settle the filter pack. A transition filter pack of 20/40 silica sand was then placed from 518.5 to 516.5 ft bgs. A bentonite seal was installed above the fine sand collar between 516.5 and 504 ft bgs. As the drill casing was removed, formation material sloughed from 504 to 469 ft bgs, covering the majority of the middle screened interval. A thin layer of primary filter pack sand (10/20 silica sand) was installed from 469 to 463 ft bgs, followed by a



FINAL PARAMETERS

	TOP	MIDDLE	BOTTOM
pH	7.99	8.16	8.22
TEMPERATURE (°C)	12.9	18.2	17.7
TURBIDITY (NTUs)	NA	1.7	1-2
SPECIFIC CONDUCTANCE (µS/cm)	331.7	210.0	227.0

TOTAL PURGE VOLUME 32,146 GALLONS

WELL COMPLETION BEGAN
DATE 11/03/05 TIME 09:50
WELL COMPLETION FINISHED
DATE 11/10/05 TIME 15:30

KLEINFELDER

Drawn By: C. Bhongir	Date: February 2006
Project No.: 49436	Filename: Figure 7.2-1.dwg
Scale: not-to-scale	Revision: –

WELL SCHEMATIC
Intermediate Well R-23i
Pajarito Canyon
Los Alamos, New Mexico

FIGURE
7.2-1

1.5-ft thick fine sand collar to 461.5 ft bgs. Bentonite chips and pellets were placed from 461.5 to 425 ft bgs. The 2-in. well was installed in the annulus to 425.3 ft bgs; 10/20 silica sand was installed across the screened interval to 395 ft bgs, followed by a fine sand collar to 393 ft bgs. Bentonite chips were placed from 393 to 75 ft bgs. The cement grout surface seal was emplaced from 75 to 3 ft bgs; it consisted of 98% cement and 2% bentonite. Table 7.2-1 summarizes the volumes of annular fill materials used to complete R-23i. The actual primary filter pack volumes for the bottom and middle screens far exceeded their calculated volumes; it is possible that extra air that was injected in an attempt to break up the bridge at approximately 470 ft bgs may have created large voids in those two areas.

Table 7.2-1
Annular Fill Materials

Material	Volume
Cement grout seal	80 ft^3
Bentonite chips/pellets	326.8 ft^3
20/40 silica sand	6 ft^3
10/20 silica sand	104.5 ft^3
Potable water	632 gallons

ft^3 = cubic ft

8.0 POST-INSTALLATION ACTIVITIES

Following well installation, the well was developed and the wellhead was completed and surveyed. Site restoration activities will commence when NMED permission to discharge fluids has been received.

8.1 Well Development

Initially, all three screens were bailed and swabbed to remove formation fines and filter pack sand across the screened interval. A 4-in. Grundfos submersible pump was used for the final stage of well development in the 4.5-in. well. Turbidity, pH, temperature and specific conductance were measured during the pumping stage of development. Additionally, total organic carbon (TOC) was measured to determine if the levels were below 2.0 ppm, which is an indication that drilling fluids have been removed from the well.

Between November 13 and 16, 2005, 1,999 gallons (gal.) of water were bailed and pumped from the combined screened intervals in the 4.5-in. well at R-23i. A packer was placed in the well between the two screened intervals and they were developed individually by pumping. The bottom screen of R-23i was developed between November 16 and December 5, 2005; the middle screened interval was developed between December 17 and 20, 2005. Subsequent aquifer testing of the bottom screen completed well development for that interval. The top screened interval in the 2-in. well was developed by bailing on February 8 and 10, 2006; due to the low yield of the water-bearing zone at the top screened interval, pumping was not conducted.

Table 8.1-1 shows the volumes of water removed during well development and the resultant water quality parameters and TOC levels. Figures 8.1-1 and 8.1-2 show the water quality parameters measured during the course of well development for the middle and bottom screened intervals, respectively.

Table 8.1-1
Final Water Quality Parameters

Method	Water Removed (gal.)	pH	Temper-ature (°Celsius)	Specific Conductance (µS/cm)	Turbidity (NTUs)	Total Organic Carbon (ppm)
Bailing/Swabbing Bottom and Middle Screens	350	8.4	16.7	235.4	off scale	NM
Pumping Bottom and Middle Screens	1,649	8.3	16.9	157.7	off scale	NM
Pumping Bottom Screen	25,796	8.22	17.7	227	off scale	1.77
Pumping Middle Screen	4,264	8.16	18.2	210	1.7	<0.1
Bailing Top Screen	88	7.99	12.9	331.7	off scale	NM
Aquifer Test Bottom Screen	1,189	NM	NM	NM	~1 - 2	NM

µS/cm = microSiemens per centimeter
NM = not measured
NTUs = nephelometric turbidity units

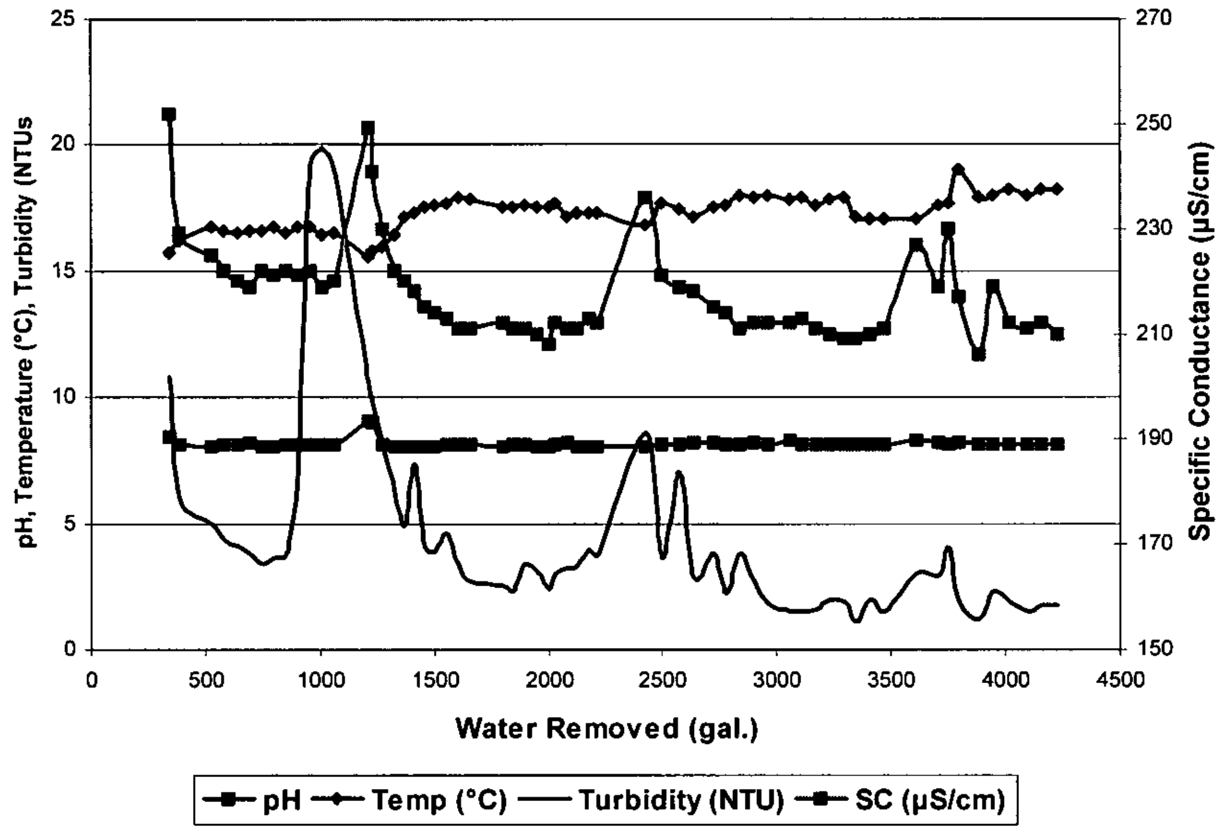


Figure 8.1-1. Water Quality Parameters During Development of the Middle Screen

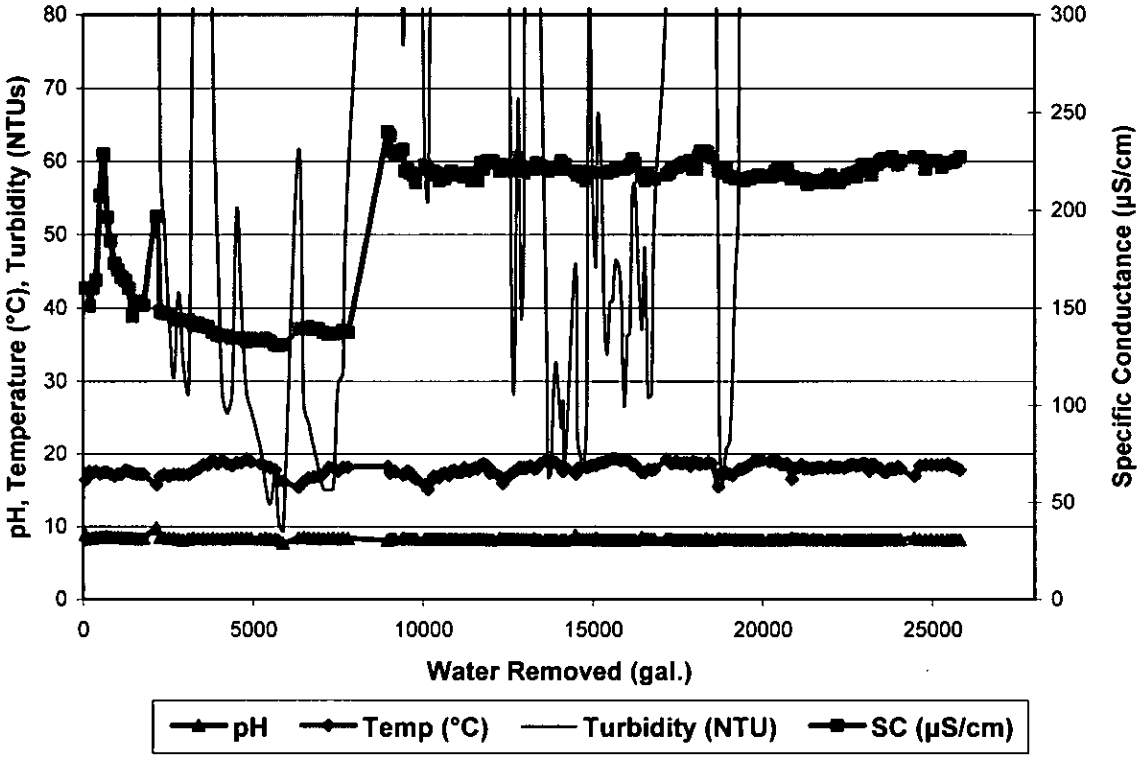


Figure 8.1-2. Water Quality Parameters During Development of the Bottom Screen (NOTE: Aquifer testing completed development of the bottom screen with a final turbidity reading of 1 - 2 NTUs)

8.2 Aquifer Testing

A 24-hour constant rate pumping test was conducted on the bottom screened interval at R-23i; however, testing was not conducted on the middle or top screened intervals. Appendix E contains the complete aquifer testing report for the bottom screened interval. The key points are summarized below:

- The barometric efficiency of the top, middle and bottom screens at R-23i as well as the R-23 screened interval (816 to 873.2 ft bgs) increased with depth, ranging from a low of 31% for the top screen at R-23i to near 100% for R-23.
- The static water level measured in the bottom screen was 10.4 ft lower than that in the middle, indicating a strong downward gradient between them. This suggests a low vertical hydraulic conductivity for the intervening rock. Some of the observed head difference might have been due to bottom screen development pumping that concluded 3 days prior to the aquifer test.
- In response to development pumping of more than 25,000 gallons of water over a 3-week period, the static water level in the bottom screen dropped 4.34 ft.

- The specific capacity produced from the middle screen was about 70% greater than that produced from the bottom screen.
- When pumping from the open well (both middle and bottom screens exposed) the pumping and recovery data were profoundly storage affected. The size of the storage feature coincidentally matched the size of the borehole drilled for the well, suggesting the possibility of an open annulus outside the 4.5-in. well casing at around 465 ft bgs.
- The hydraulic conductivity of the bottom screen porous interflow zone was estimated to be about 0.3 ft per day.
- The hydraulic conductivity of the combined middle and bottom screen porous interflow zones showed one cluster of values averaging 0.42 ft per day and another cluster averaging 0.94 ft per day, for an overall average of 0.68 ft per day.

8.3 Dedicated Sampling System Installation

Dedicated sampling systems have not been installed in the 2-in. or 4.5-in. wells at R-23i. Systems will be selected and installed in late Spring of 2006.

8.4 Wellhead Completion

A reinforced 2,500 pounds per square inch concrete pad, 5 ft by 5 ft by 6 in. thick, was installed around the well casing to provide long-term structural integrity for the well. A brass survey pin was embedded in the northwest corner of the pad. A 10.75-in. OD diameter steel casing with a locking lid was installed to protect the well riser. The concrete pad was elevated slightly above the ground surface, with base-course gravel graded up around the edges.

8.5 Geodetic Survey

Table 8.5-1 presents the geodetic survey data for R-23i. The survey was conducted by ASTS, Inc. of Albuquerque, New Mexico.

Table 8.5-1
Geodetic Data

Description	Northing	Easting	Elevation[a]
Brass cap in R-23i pad	1755148.04	1647898.02	6527.88
4.5-in. Well – Top of stainless steel casing	1755146.40	1647898.85	6530.08
2-in. Well – Top of stainless steel casing	1755146.60	1647898.79	6530.02
Ground surface beside pad	1755149.93	1647897.13	6527.45

[a] Measured in ft above mean sea level relative to the National Geodetic Vertical Datum of 1929.

8.6 Site Restoration

Fluids produced during drilling and development were containerized and sampled in accordance with the July 12, 2005 "Waste Characterization Strategy Form" prepared for the 2005 well drilling program at LANL (Appendix C in Kleinfelder 2005a). Fluid sample results will be compared to the State of New Mexico Water Quality Control Commission Regulation 3103 groundwater standards and applicable Resource Conservation and Recovery Act regulatory limits. Water generated during drilling, development, and aquifer testing will be discharged in accordance with the "Workplan Notice of Intent Decision Tree," revised July 15, 2002, and in coordination with NMED. Site restoration will include removing the silt fencing and reseeding the site.

Waste characterization samples have been collected but some of the results have not been received. Once data have been received and discharge permission has been obtained, a separate memorandum will be issued documenting the results and discharge approval.

9.0 DEVIATIONS FROM PLANNED ACTIVITIES

Appendix F compares the actual drilling and well construction activities at R-23i with the planned activities described in the Drilling Work Plan. In general, drilling, sampling, and well construction were performed as specified in the Drilling Work Plan. The main deviations from planned activities were:

- Cuttings Sampling – The Drilling Work Plan called for cuttings to be collected and sieved at 5-ft intervals beginning at 550 ft bgs; LANL scientists requested that samples be collected at 5-ft intervals beginning at 400 ft bgs and that request was followed.
- Groundwater Analyses – HE analyses were added to the analyte list for the sample collected after well development and aquifer testing from the bottom screened interval.
- Primary Filter Pack, Bottom Screened Interval – The work plan called for 5 ft of primary filter pack sand below each screened interval, but there is 3 ft of sand beneath the bottom screened interval.
- Primary Filter Pack, Middle Screened Interval – During well construction, formation slough accumulated across the majority of the middle screened interval, precluding the installation of the primary filter pack.

10.0 ACKNOWLEDGEMENTS

EnviroWorks, Inc. prepared the drill site.

P. Longmire of LANL evaluated the hydrochemistry.

WDC drilled the R-23i borehole and installed the monitoring well.

11.0 REFERENCES

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Kleinfelder 2005c, Final Site-Specific Health and Safety Plan, Wells Installation R-16a and R-23i, Los Alamos National Laboratory, Los Alamos, New Mexico, July 12, 2005.

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Appendix A

Borehole Video Log

Appendix B

Geophysical Logging Files

Geophysical logging spreadsheets and charts are located on the final report CD.

Appendix C

Lithologic Log

Geologic Unit	Lithologic Description (NOTE: This log is from the June 2003, R-23 Completion Report (LANL 2003))	Sample Interval (ft bgs)	Elevation Range (ft amsl)
Qal, Alluvium	Unconsolidated sediments, moderate yellowish-brown (10YR 5/4), clayey gravel (GC) with sand. +10F: mostly subangular intermediate volcanic clasts (up to 1.0 cm). +35F sample fraction: 60% quartz and sanidine grains; 40% volcanic lithic fragments.	0-5	(R-23 ground surface = 6527.8 R-23i ground surface = 6527.5) 6527.8-6522.8
	Unconsolidated sediments, moderate brown (5YR 4/4), sand (SP), medium-grained, most grains broken, 80% intermediate volcanic clasts, 20% quartz and sanidine grains. Note: None of the sample was retained by the No. 10 sieve; Qal/Qbo contact estimated at 10 ft bgs.	5-10	6522.8-6517.8
Qbo, Otowi Member, Bandelier Tuff	Rhyolitic tuff, mottled, moderate brown (5YR 4/4) to pale yellowish-gray (5YR 8/1). WR (i.e., unsieved whole rock) sample contains 20% pumice; 10% quartz and sanidine phenocrysts; 70% lithic fragments. +10F: 90% subrounded vitric pumice (up to 1.0 cm) with single 1.5 cm andesite lithic fragment.	10-15	6517.8-6512.8
	Rhyolite tuff, pale yellowish-brown (10YR 6/2). WR sample contains 50% pumice; 10% phenocrysts; 40% lithic fragments. +10F: 90-95% subrounded, white frothy pumice (up to 1.0 cm); 5-10% volcanic lithic fragments (up to 5 mm), mostly dacite with some andesite. +35F: 45-50% pumice; 45-50% lithic fragments; 3-5% quartz and sanidine phenocrysts.	15-25	6512.8-6502.8
	No cuttings recovered in this interval. Note: Qbo/Qbog contact estimated at 30 ft bgs.	25-30	6502.8-6497.8
Qbog, Guaje Pumice Bed	Tephra deposit, very pale orange-tan (10YR 8/2), pumiceous. WR sample contains 100% pumice. +10F: 100% subrounded to rounded frothy pumice (up to 1.2 cm).	30-35	6497.8-6492.8
	Tephra deposit, pale yellowish-brown (10YR 6/2), pumiceous. WR sample contains 70-80% pumice; 5-10% phenocrysts; 20-30% lithic fragments. +10F: 80-90% white subrounded vitric pumice (up to 5 mm); 10% dacite and andesite lithic fragments (up to 1.5 cm), minor basalt. Note: Qbog/Tb4 contact estimated at 36 ft bgs based on first basalt returns.	35-40	6492.8-6487.8
Tb4, Cerros del Rio basalt	Basalt, medium-dark gray (N4) with some volcaniclastic sediments. WR/+10F: 70-80% vesicular porphyritic basalt with aphanitic groundmass; 20-30% volcanic lithic fragments of intermediate composition and quartz and sanidine phenocrysts. Note: Tb4 begins at approximately 36 ft bgs.	40-45	6487.8-6482.8
	Basalt, brownish-gray (5YR 4/1), +10F: vesicular porphyritic basalt with aphanitic groundmass, 5-7% phenocrysts of olivine and plagioclase, thin iron oxide coating on fractured surfaces, minor amounts of white clay coating vesicle surfaces.	45-50	6482.8-6477.8
	Basalt, medium-dark gray (N4), porphyritic with aphanitic groundmass, vesicular. +10F: 5-7% phenocrysts of plagioclase and unaltered pale green olivine; trace of white clay lining vesicles from 60-65 ft.	50-65	6477.8-6462.8
	Basalt, medium-dark gray (N4), sparsely porphyritic with aphanitic groundmass, variable vesicularity. +10F: 3-5% phenocrysts of plagioclase and slightly oxidized brown olivine; partial iron oxide coating on fractures and lining vesicles; locally white calcite coats fractures and chips.	65-80	6462.8-6447.8

Geologic Unit	Lithologic Description (NOTE: This log is from the June 2003, R-23 Completion Report (LANL 2003))	Sample Interval (ft bgs)	Elevation Range (ft amsl)
Tb4, Cerros del Rio basalt	Basalt, medium-dark gray (N4), sparsely porphyritic with aphanitic groundmass, vesicular. +10F: phenocrysts of plagioclase and dark colored olivine (up to 1 mm), olivine is oxidized or replaced; trace of light tan clay lining vesicles.	80-90	6447.8-6437.8
	Basalt, medium-dark gray (N4), sparsely porphyritic with phenocrysts of plagioclase and olivine (up to 2 mm); groundmass probably altered.	90-92	6437.8-6435.8
	No cuttings recovered in this interval.	92-97	6435.8-6430.8
	Basalt, brownish-gray (5YR-4/1) to medium-dark gray (N4), vesicular, porphyritic with phenocrysts of olivine (up to 2 mm) and mostly lath-shaped plagioclase (up to 2 mm), some olivine oxidized and iron-stained, some blocky plagioclase crystals; groundmass microcrystalline to aphanitic; some vesicles filled with alteration products or have iron-stained surfaces.	97-103	6430.8-6424.8
	Basalt, medium-dark gray (N4), vesicular to massive, porphyritic with phenocrysts of olivine (up to 2 mm) and lathshaped plagioclase (up to 2 mm), some olivine oxidized and iron-stained; some vesicles have iron-stained surfaces or are in-filled with material. +35F: 2-3% quartz crystals (up to 3 mm).	103-113	6424.8-6414.8
	Basalt, medium gray (N5), mostly vesicular, porphyritic with phenocrysts of olivine (up to 2 mm) and lath-shaped plagioclase (up to 1 mm long); some coating and iron staining of vesicles; some rounded clayey sandstone clasts in +35F.	113-118	6414.8-6409.8
	Basalt, medium gray (N5), mostly massive, porphyritic with phenocrysts of olivine and lath-shaped plagioclase; minor amounts of quartz crystals and one quartz pebble.	118-123	6409.8-6404.8
	Basalt, medium-dark gray (N4) to grayish-red purple (5RP 4/2), abundant vesicles to scoriaceous, porphyritic with phenocrysts of olivine (up to 3 mm) and lath-shaped plagioclase (up to 2 mm long); iron staining common; vesicles filled with clay; quartz crystals comprise 5-10% of the +35F.	123-128	6404.8-6399.8
	Basalt, medium-dark gray (N4), some vesicles, porphyritic with phenocrysts of olivine (up to 2 mm) and blocky to lathshaped plagioclase (up to 2 mm long); groundmass microcrystalline to aphanitic; some vesicles filled with clay; minor iron staining; quartz crystals comprise 5% of +35F.	128-133	6399.8-6394.8
	Basalt, medium-dark gray (N4), sparse vesicles, mostly massive, porphyritic with phenocrysts of olivine (up to 2 mm) and lath-shaped to blocky plagioclase (up to 2 mm); very little iron staining or filling of vesicles.	133-148	6394.8-6379.8
	Basalt, medium gray (N5), very few vesicles, mostly massive, porphyritic with phenocrysts of olivine (up to 2 mm) and lathshaped to blocky plagioclase (up to 2 mm); groundmass microcrystalline; iron staining absent.	148-158	6379.8-6369.8
	Basalt, medium gray (N5) to grayish-red purple (5RP 4/2), abundant vesicles to scoriaceous, porphyritic with generally unaltered phenocrysts of olivine (up to 2 mm) and lathshaped plagioclase (up to 1 mm long). Secondary alteration of groundmass; vesicles lined with secondary alteration minerals, possibly including silica; iron staining common and some calcite evident.	158-168	6369.8-6359.8

Geologic Unit	Lithologic Description (NOTE: This log is from the June 2003, R-23 Completion Report (LANL 2003))	Sample Interval (ft bgs)	Elevation Range (ft amsl)
Tb4, Cerros del Rio basalt	Basalt, grayish-red purple (5RP 4/2), vesicular, porphyritic with phenocrysts of olivine (up to 2 mm) and lath-shaped plagioclase (up to 1 mm long); secondary alteration of groundmass.	168-181	6359.8-6346.8
	Basalt, brownish-gray (5YR 4/1), vesicular, porphyritic with phenocrysts of olivine (up to 2 mm) and lath-shaped plagioclase (up to 1 mm long); secondary alteration of groundmass; blocky calcite crystals evident.	181-191	6346.8-6336.8
	Basalt, brownish-gray (5YR 4/1), sparse vesicles, porphyritic with phenocrysts of olivine (up to 2 mm) and blocky to lathshaped plagioclase (up to 2 mm); secondary alteration of groundmass.	191-196	6336.8-6331.8
	Basalt, grayish-red purple (5RP 4/2), vesicular, porphyritic with phenocrysts of olivine (up to 3 mm) and both blocky and lath-shaped plagioclase (up to 2 mm); secondary alteration of groundmass; shape of vesicles not well defined.	196-206	6331.8-6321.8
	Basalt, medium gray (N5), massive, nonvesicular, porphyritic with phenocrysts of olivine (up to 2 mm) with abundant small (>0.5 mm) scattered olivine in groundmass, lath-shaped plagioclase (up to 2 mm long); secondary calcite crystals common (up to 1 mm); altered microcrystalline groundmass.	206-216	6321.8-6311.8
	Basalt, medium gray (N5), massive, porphyritic with phenocrysts of olivine (up to 2 mm) and abundant small (>0.5 mm) scattered olivine crystals and opaque pyroxene, both blocky and lath-shaped plagioclase (up to 2 mm). Slightly altered microcrystalline groundmass. Alteration less pronounced than basalts above.	216-236	6311.8-6291.8
	No cuttings recovered in this interval.	236-287	6291.8-6240.8
	Basalt, grayish black (N2) to grayish-red purple (5RP 4/2), abundant vesicles to scoriaceous, porphyritic with phenocrysts of olivine (up to 2 mm), no visible plagioclase; microcrystalline groundmass; small, secondary blocky calcite crystals, some silicification evident.	287-297	6240.8-6230.8
	Basalt, grayish black (N2) to grayish-red purple (5RP 4/2), vesicular to scoriaceous, porphyritic with phenocrysts of olivine (up to 2 mm); microcrystalline groundmass, silicification evident; some clay coating on chips.	297-302	6230.8-6225.8
	No cuttings recovered in this interval	302-342	6225.8-6185.8
	Basalt, medium-dark gray (N4) scoriaceous, porphyritic with phenocrysts of olivine (up to 2 mm) and lath-shaped plagioclase (up to 2 mm); some silicification evident; few chips of clay and but clay lines some vesicles; some basalt chips are rounded, indicating probable sedimentary transport.	342-346	6185.8-6181.8
	Basalt, medium light gray (N6) scoriaceous, porphyritic with phenocrysts of olivine (up to 2 mm) and lath-shaped plagioclase (up to 2 mm); some calcite crystals; most chips and vesicles have clay coatings; rare chips of pinkish gray clay.	346-356	6181.8-6171.8
	Basalt, medium gray (N5) vesicular to massive, porphyritic with phenocrysts of olivine (up to 1 mm) and lath-shaped plagioclase (up to 2 mm); some secondary calcite crystals; most vesicles have clay coatings; altered microcrystalline groundmass.	356-361	6171.8-6166.8

Geologic Unit	Lithologic Description (NOTE: This log is from the June 2003, R-23 Completion Report (LANL 2003))	Sample Interval (ft bgs)	Elevation Range (ft amsl)
Tb4, Cerros del Rio basalt	Basalt, light gray (N7), mostly massive with rarely vesicular, porphyritic with phenocrysts of olivine (up to 2 mm) and lathshaped plagioclase (up to 2 mm long); abundant small crystals (<0.5 mm) of olivine, and sparse pyroxene.	361-371	6166.8-6156.8
	Basalt, light gray (N7), mostly massive with minor amount of vesicles, porphyritic with phenocrysts of olivine (up to 2 mm) and blocky to lath-shaped plagioclase (up to 1 mm); abundant small crystals (<0.5 mm) of olivine, sparse pyroxene.	371-386	6156.8-6141.8
	Basalt, medium light gray (N6), massive with rare vesicles. +10F: porphyritic with phenocrysts of olivine (up to 2 mm), blocky to lath-shaped plagioclase (up to 1 mm); abundant small crystals (<0.5 mm) of olivine, sparse pyroxene.	386-411	6141.8-6116.8
	Basaltic sediments, sand (SW) with silt, brownish-gray (5YR 4/1), silt to medium-grained sand, poorly sorted, subangular grains; sand grains are mostly lithic fragments of basalt with some quartz and cemented clay. +10F: basalt, similar to above unit. +35F: basalt and silicified basalt (similar to interval from 287-302 ft bgs); rare chips of pinkish-gray silica-cemented clay.	411-416	6116.8-6111.8
	Basalt, brownish-gray (5YR 4/1). WR sample contains some sand. +10F: basalt chips, mostly massive with rare vesicles, porphyritic with phenocrysts of olivine (up to 1 mm) and plagioclase laths (up to 2 mm long), abundant small crystals (<0.5 mm) of olivine, sparse pyroxene.	416-421	6111.8-6106.8
	Basalt, medium light gray (N6). WR sample contains some sand, +10F: massive basalt, porphyritic with phenocrysts of olivine (up to 1 mm), some very light in color, plagioclase laths (up to 2 mm long); rare pinkish-gray cemented clay chips; groundmass mostly microcrystalline. +35F: contains abundant grayish-brown basalt chips and some cemented clay chips.	421-431	6106.8-6096.8
	Basalt, medium light gray (N6). +10F: massive with some brownish-gray basalt, porphyritic with phenocrysts of olivine (up to 2 mm), with majority very light in color, visible plagioclase crystals are rare; groundmass mostly bleached to white in color; some chips coated with calcite.	431-451	6096.8-6076.8
	Basalt, medium gray (N5). +10F: massive, porphyritic with phenocrysts of olivine (up to 2 mm), some bleached; rare blocky plagioclase crystals, most very small to microcrystalline, abundant small (<0.5 mm) olivine, and some pyroxene; altered microcrystalline groundmass.	451-471	6076.8-6056.8
	Basalt with cemented clay chips, medium gray (N5), poor cuttings returned. +10F: porphyritic basalt with phenocrysts of olivine (up to 2 mm), many bleached; rare, small plagioclase crystals; groundmass microcrystalline. +35F: contains several cemented clay chips.	471-476	6056.8-6051.8
	Basalt and silty sand (SM) (possible interbed), pale yellowish-brown (10YR 6/2). WR sample contains 80% medium gray basalt; 20% sand, very fine to fine-grained, poorly sorted, angular grains, mostly quartz grains with some lithic fragments. +10F: basalt chips with few cemented clay chips. +35F: 80% basalt; 10% brown siltstone; 10% pale orange cemented clay chips.	476-486	6051.8-6041.8

Geologic Unit	Lithologic Description (NOTE: This log is from the June 2003, R-23 Completion Report (LANL 2003))	Sample Interval (ft bgs)	Elevation Range (ft amsl)
Tb4, Cerros del Rio basalt	Basalt and sandy siltstone (possible interbed), medium light gray (N6). WR sample contains mostly basalt with 10% sandy silt. +10F: 97% medium-dark gray basalt, mostly massive with few vesicles, aphanitic to microcrystalline, rare olivine phenocrysts (up to 1 mm), some plagioclase; 3% grayish-orange sandy siltstone. +35F: mostly basalt; 5% sandy siltstone; 2% cemented clay chips.	486-491	6041.8-6036.8
	Basalt and silty sandstone (possible interbed), medium light gray (N6). WR sample contains 95% basalt; 5% silty sand. +10F: mostly massive porphyritic basalt, rare vesicles, olivine phenocrysts (up to 1 mm); minor plagioclase (up to 0.5 mm); groundmass mostly microcrystalline; 1% silty sandstone; one euhedral quartz crystal. +35F: 97% basalt; 3% very fine-grained, silty, sandstone chips.	491-496	6036.8-6031.8
	Basalt and silty sandstone (possible interbed), medium light gray (N6). +10F: mostly massive porphyritic basalt, rare vesicles, olivine phenocrysts (up to 1 mm), plagioclase laths (up to 1 mm); 5% silty sandstone and sandy siltstone; few cemented clay chips and basalt chips with clay coating.	496-506	6031.8-6021.8
	Basalt with siltstone, medium light gray (N6). +10F: mostly massive basalt, sparse olivine and plagioclase phenocrysts (up to 1 mm), groundmass microcrystalline; 3% orange-pink siltstone with very fine-grained sand; rare basalt chips with cemented clay coatings.	506-511	6021.8-6016.8
	Basalt, medium gray (N5). +10F: mostly massive porphyritic basalt with rare vesicles, olivine phenocrysts are nearly clear (bleached), rare plagioclase phenocrysts, groundmass microcrystalline; 2-3% pink tuffaceous siltstone; some basalt chips have white clay coatings.	511-521	6016.8-6006.8
	Basalt, medium gray (N5), porphyritic with aphanitic groundmass, WR: some clay. +10F: 85-90% porphyritic basalt, olivine phenocrysts, both unaltered pale green, and completely replaced by limonite, groundmass mostly unaltered but with 10-15% altered groundmass evident; trace of pink siltstone.	521-526	6006.8-6001.8
	Basalt, light brownish-gray, porphyritic with aphanitic groundmass, WR sample contains abundant clay chips. +10F: 93-95% unaltered to strongly altered basalt; 5-7% white very fine-grained clayey sandstone and siltstone; trace of basalt-rich sandstone. Probable contact between basalt and sediments at 531 ft bgs.	526-531	6001.8-5996.8
Tb4, Cerros del Rio basalt, Interflow Sediments	Basalt/clastic sediments, sandy clay (SC) and basalt, grayish-orange pink (5YR 7/2). WR sample contains 85% sandy clay with 15% basalt chips; highly plastic clay contains some very fine-grained sand and silt. +10 F: mostly basalt, massive, aphanitic, few olivine phenocrysts and some plagioclase; 10% clayey sandstone chips. +35F: mostly basalt with 35% clayey sandstone chips.	531-536	5996.8-5991.8

Geologic Unit	Lithologic Description (NOTE: This log is from the June 2003, R-23 Completion Report (LANL 2003))	Sample Interval (ft bgs)	Elevation Range (ft amsl)
Tb4, Cerros del Rio basalt, Interflow Sediments	Basalt/clastic sediments, sandy silt (SM) and basalt, grayish-orange pink (5YR 7/2). WR sample contains mostly sandy silt with 30% basalt chips; sandy silt contains 20% very fine to fine-grained sand and has some clay content. +10F: 60% silty sand and sandy siltstone; 40% basalt, aphanitic, few olivine and plagioclase phenocrysts. +35F: 50% basalt; 50% sandy siltstone and silty sandstone; few cemented clay chips.	536-541	5991.8-5986.8
	Basalt/clastic sediments, sandy clay (SC), grayish-orange pink (5YR 7/2). WR sample contains 70-75% clay; 20-25% sand; 5-7% basalt chips. +10F: 50% pinkish fine-grained sand and siltstone, sand grains of glassy basalt, feldspar, and possibly olivine; 50% angular, clay-coated basalt chips. +35F: 50% sandy clay; 50% basalt.	541-546	5986.8-5981.8
	Basalt/clastic sediments, sandy clay (SC) and basalt, grayish-orange pink (5YR 7/2). WR sample contains 30-40% clay; 25-35% sand; 15-20% basalt chips. +10F: 35-40% pink tuffaceous siltstone and claystone; 15-20% fine-grained sand, grains of mafic crystals and feldspar, partially iron-stained; 35-40% basalt chips.	546-551	5981.8-5976.8
	Basalt/clastic sediments, clayey gravel (GC) with sand, pale yellow-brown (10YR 6/2), basalt-rich. WR sample contains 70-90% gravel; 10-15% sand; 15-30% fines. +10F: 60-65% angular basalt chips; 7-10% basaltic sandstone, grains of basalt, feldspar, and olivine, iron-stained; 30-35% pinkish siltstone and claystone chips.	551-561	5976.8-5966.8
	Basalt/clastic sediments, clayey gravel (GC) with sand, pale yellowish-brown (10YR 7/2), basalt-rich. WR sample contains 70% gravel; 20% sand; 10-15% fines. +10F: 70-75% unaltered to altered basalt chips; 20-25% fine-grained basaltic sandstone and pinkish claystone and siltstone; trace of calcite. +35F: 95% altered basalt; 5% sandstone and siltstone.	561-566	5966.8-5961.8
	Basalt/clastic sediments, clayey gravel (GC), pale yellowish-brown (10YR 7/2), basalt-rich. WR sample contains 75-80% gravel; 5-10% sand; 20-30% fines. +10F: 80-90% massive to vesicular basalt, aphanitic (lacks olivine), strongly altered, with brown staining; 10-20% volcaniclastic sandstone and pinkish claystone and siltstone. +35F: abundant flakes of clay-altered basalt.	566-576	5961.8-5951.8
	Basalt/clastic sediments, clayey gravel (GC), pale yellowish-brown (10YR .7/2), basalt-rich. WR sample contains 75-80% gravel; 5-10% sand; 20-30% fines. +10F: 85-90% altered basalt or basaltic andesite, aphanitic, abundant flakes of clay-altered basalt; 10-15% volcaniclastic sandstone and siltstone.	576-586	5951.8-5941.8
	Basalt/clastic sediments, siltstone and basaltic sandstone (SW), grayish-orange pink (5YR 7/2) coarse chips (up to 2.5 cm). WR/+10F: 75% pinkish claystone, siltstone and fine-grained sandstone, grains of basalt, feldspar, and mafic crystals; 20-25% coarse subangular, aphyric chips (up to 2.0 cm) of basalt and basaltic andesite.	586-591	5941.8-5936.8
	Basalt/clastic sediments, clay (CH) to clayey sand (SC), grayish-orange pink (5YR 7/2). WR sample contains 10-20% gravel; 40-50% sand; 30-40% fines. +10F: 40-50% altered basalt and basaltic andesite, clayey with flakes of clay common; 40-50% pinkish claystone, siltstone, and tuffaceous sandstone; trace of crystalline calcite.	591-601	5936.8-5926.8

Geologic Unit	Lithologic Description (NOTE: This log is from the June 2003, R-23 Completion Report (LANL 2003)	Sample Interval (ft bgs)	Elevation Range (ft amsl)
Tb4, Cerros del Rio basalt, Interflow Sediments	Basalt/clastic sediments, gravel (GW) with clay and sand, pale yellowish-brown (10YR 6/2). WR sample contains 55-65% gravel; 20-30% sand; 10-15% fines. +10F: 50-55% broken and subangular chips of basalt, partially sericitized; 40-45% pinkish, very fine-grained tuffaceous sandstone and siltstone, minor amounts of orange claystone; sandstone locally contains basalt lithic fragments.	601-611	5926.8-5916.8
	Basalt/clastic sediments, gravel (GW) with clay and sand, pale yellowish-brown (10YR 6/2). WR sample contains 40-50% gravel; 25-35% sand; 10-15% fines. +10F: 80-85% broken and subangular basalt chips, partially altered; 15-20% pinkish-tan tuffaceous siltstone and claystone; 5-7% basalt-rich volcaniclastic sandstone.	611-621	5916.8-5906.8
	Basalt/clastic sediments, clayey sand (SC), pale brown (5YR 5/2). WR sample contains 5-15% gravel; 60-70% sand; 20-25% fines. +10F: only small amount retained; 45-60% broken basalt chips, aphyric and porphyritic with phenocrysts of olivine, groundmass aphanitic, partially altered; 40-55% pinkish tan, very fine-grained tuffaceous sandstone and siltstone.	621-631	5906.8-5896.8
	No cuttings returned in this interval.	631-636	5896.8-5891.8
	Basalt/clastic sediments, clayey sand (SC) to sand (SW) with clay, pale yellowish-brown (10YR 6/2). WR sample contains 5-10% gravel; 55-65% sand; 15-25% fines. +10F: only small amount retained; 5-10% broken basalt chips; 90-95% pinkish very fine-grained sandstone, siltstone, and claystone. +35F: 20-25% basalt; 75-80% siltstone.	636-646	5891.8-5881.8
	Basalt/clastic sediments, clayey sand (SC) to sand (SW) with clay, pale yellowish-brown (10YR 6/2). WR sample contains 5-7% gravel; 65-70% sand; 15-25% fines. +10F: 25-35% broken basalt chips, partially altered; 65-75% pinkish tuffaceous siltstone and claystone. +35F: Similar percentages and composition.	646-661	5881.8-5866.8
	Basalt/clastic sediments, sand (SW) with clay and gravel, grayish orange-pink (5YR 7/2). WR sample contains 10-20% gravel; 65-75% sand; 10-15% fines. +10F: 35-45% broken basalt chips, aphyric, partly scoriaceous, and sericitized or silicified; 55-65% pinkish fine-grained tuffaceous sandstone and siltstone.	661-671	5866.8-5856.8
	Basalt/clastic sediments, gravel (GW) with clay and sand, grayish-orange pink (5YR 7/2). +10F: 55-60% broken basalt chips, massive and scoriaceous, partially clay altered, replacement by opaline silica evident; 40-45% pink to orange very fine-grained tuffaceous sandstone and siltstone.	671-681	5856.8-5846.8
	Basalt/clastic sediments, gravel (GW) with clay and sand, light brown-gray (5YR 6/1). +10F: 65-70% broken basalt chips, both massive and scoriaceous, frequently sericitized and bleached and/or replaced by opaline silica; 30-35% pinkish siltstone and claystone.	681-691	5846.8-5836.8

Geologic Unit	Lithologic Description (NOTE: This log is from the June 2003, R-23 Completion Report (LANL 2003)	Sample Interval (ft bgs)	Elevation Range (ft amsl)
	Basalt/clastic sediments, gravel (GW) with clay and sand, light brown-gray (5YR 6/1), contact with underlying basalt at approximately 692 ft. bgs. WR sample contains 60-70% gravel; 25-30% sand; 10-15% fines. +10F: 80-85% broken basalt chips, scoriaceous, moderately to strongly altered, majority replaced with opaline silica; 15-20% pinkish very fine-grained tuffaceous sandstone and siltstone.	691-696	5836.8-5831.8
	TOTAL DEPTH OF R23i WAS 695 FT BGS.		

Notes: This log was obtained from the R-23 Well Completion Report (LANL 2003) lithologic log with a total depth of 935 ft bgs. Only the portion to 695 ft bgs, the total depth of R-23i, is shown here.

1. American Society for Testing Materials (ASTM) standards (D 2488-90: Standard Practice and Identification of Soils [Visual-Manual Procedure]) were used to describe 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 standard USCS symbols were used in the R-16 lithologic log:

   SW = well-graded sand SC = clayey sand CH = clay, high plasticity

   GC = clayey gravel GW = well-graded gravel SM = silty gravel

2. Cuttings at R-23 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 sieved fraction equivalent to 0.5 mm).
3. The term *percent*, as used in the above descriptions, refers to percent by volume for a given sample component.
4. Color designations such as hue, value, and chroma (e.g., 5YR 5/2) are from the Geological Society of America's Rock Color Chart.

Source of this lithologic log: LANL 2003, Characterization Well R-23 Completion Report, LA-UR-03-2059, ER2003-0235, Los Alamos National Laboratory, Los Alamos, New Mexico, June 2003.

Appendix D

Groundwater Analytical Results

1.0 SAMPLING AND ANALYSIS OF GROUNDWATER AT R-23I

Perched intermediate groundwater was encountered at R-23i. Two screening samples were collected during drilling and two samples were collected from the completed well, one from the bottom screened interval after the aquifer test and one from the middle screened interval after development. The samples were analyzed for anions, perchlorate (ClO_4^-), and metals. The sample from the bottom screened interval was also submitted for high explosives (HE) analyses. During development of the bottom and middle screened intervals, water samples were also submitted for total organic carbon (TOC) analysis.

1.1 Analytical Techniques

Groundwater samples were filtered prior to analysis for metals, trace elements, and major cations and anions. Aliquots of the samples were filtered through 0.45-micrometer Gelman filters. Samples were acidified with analytical grade nitric acid to a pH of 2.0 or less for metal and major cation analyses. Total carbonate alkalinity was measured at Los Alamos National Laboratory's Earth and Environmental Sciences Group 6 (EES-6) using standard titration techniques. Samples collected for TOC analyses were not filtered.

Groundwater samples were analyzed by EES-6 using techniques specified in the US Environmental Protection Agency SW-846 manual. Ion chromatography (IC) was the analytical method for bromide, chloride, fluoride, nitrate, nitrite, oxalate, perchlorate, phosphate, and sulfate. The instrument detection limits (IDLs) for perchlorate analyses were 0.002 and 0.0005 parts per million (ppm). The IDL for HE analyses was 0.01 ppm.

Inductively coupled (argon) plasma optical emission spectroscopy (ICPOES) was used for calcium, magnesium, potassium, silica, and sodium. Aluminum, antimony, arsenic, barium, beryllium, cadmium, cesium, chromium, cobalt, copper, iron, lead, lithium, manganese, mercury, nickel, rubidium, selenium, silver, thallium, thorium, tin, vanadium, uranium, and zinc were analyzed by inductively coupled (argon) plasma mass spectrometry (ICPMS). The precision limits (analytical error) for major ions and trace elements were generally less than ±10% using ICPOES and ICPMS.

1.2 Analytical Results

Analytical results for perched intermediate groundwater samples collected at R-23i are provided in Table 1.2-1. Perchlorate was not detected in the perched intermediate zone samples. Nitrate (as N) was detected in all four samples at concentrations ranging between 0.05 and 0.89 ppm. HE compounds were not detected in the sample from the bottom screened interval at an IDL of 0.01 ppm. TOC was measured in samples from the bottom and middle screened intervals at 1.77 and 0.24 milligrams of carbon per liter, respectively.

Table 1.2-1. Hydrochemistry of Perched Intermediate Zone Groundwater from R-23i (filtered samples)

SAMPLE ID	EU0507GR23i01	EU0507GR23i02	EU0507GR23i03 (bottom screen)	EU0507GR23i04 (middle screen)
SAMPLE TYPE	During drilling	During drilling	After aquifer test	After development
DEPTH (ft bgs)	~500	~450 to 460	521.7 (pump intake)	~505
GEOLOGIC UNIT	Cerros del Rio basalt	Cerros del Rio basalt	Cerros del Rio basalt	Cerros del Rio basalt
DATE	10/20/2005	10/31/2005	12/11/2005	12/20/2005
Charge Balance (%)	+8.05	-0.16	-2.80	-3.91
pH (Lab)	6.91	8.04	7.73	7.80
Ag (ppm)	U [0.001]	U [0.001]	U [0.001]	U [0.001]
Al (ppm)	0.09	0.0056	0.0024	U [0.002]
Alkalinity (ppm $CaCO_3$/L)	89.3	123.0	78.9	87.7
As (ppm)	0.0019	0.0010	0.0023	0.0012
B (ppm)	0.13	0.069	0.014	0.034
Ba (ppm)	0.24	0.28	0.013	0.0058
Be (ppm)	U [0.001]	U [0.001]	U [0.001]	U [0.001]
Br (ppm)	0.08	0.16	0.08	0.07
Ca (ppm)	20.6	18.1	19.2	19.7
Cd (ppm)	U [0.001]	U [0.001]	U [0.001]	U [0.001]
Cl (ppm)	10.6	22.4	10.4	9.47
ClO_4 (ppm)	U [0.005]	U [0.002]	U [0.0005]	U [0.0005]
Co (ppm)	U [0.001]	U [0.001]	U [0.001]	U [0.001]
CO_3 (ppm)	0	7.6	0	0
Cr (ppm)	0.0021	0.0012	U[0.001]	0.0016
Cs (ppm)	U [0.001]	U [0.001]	U [0.001]	U [0.001]
Cu (ppm)	0.0048	0.0026	0.0043	<0.001
F (ppm)	0.32	0.28	0.25	0.25
Fe (ppm)	0.08	<0.01	0.06	<0.01
HCO_3 (ppm)	109	135	96.2	107
Hg (ppm)	0.00012	0.00075	U [0.00005]	U [0.00005]
K (ppm)	2.22	3.48	2.75	2.72
Li (ppm)	0.006	0.014	0.0066	0.0054
Mg (ppm)	5.77	5.84	5.74	5.69
Mn (ppm)	0.0047	0.044	0.0031	<0.001
Mo (ppm)	0.0058	0.041	0.0019	0.0021
Na (ppm)	28.40	61.8	13.3	14.8
Ni (ppm)	0.0012	0.0014	U [0.001]	0.0011
NO_2(as N) (ppm)	0.009	U [0.002]	U [0.002]	U [0.002]
NO_3(as N) (ppm)	0.89	0.050	0.82	0.59
C_2O_4 (ppm)(oxalate)	0.02	0.21	U [0.01]	U [0.01]
Pb (ppm)	U [0.0002]	U [0.0002]	0.0003	U [0.0002]
PO_4 (ppm)	0.06	0.10	U [0.01]	U [0.01]
Rb (ppm)	0.0012	0.0043	0.0037	0.0041
Sb (ppm)	U [0.001]	U [0.001]	U [0.001]	U [0.001]
Se (ppm)	U [0.001]	0.0038	U [0.001]	U [0.001]
SiO_2 (ppm)	39.8	34.5	45.6	44.4
SO_4 (ppm)	10.3	51.2	12.4	12.8
Sn (ppm)	U [0.001]	U [0.001]	U [0.001]	U [0.001]
Sr (ppm)	0.094	0.23	0.088	0.086
Th (ppm)	U [0.001]	U [0.001]	U [0.001]	U [0.001]
Ti (ppm)	0.005	U [0.001]	U [0.002]	U [0.002]
Tl (ppm)	U [0.001]	U [0.001]	U [0.001]	U [0.001]
U (ppm)	0.0011	0.0032	0.0008	0.0009
V (ppm)	0.008	0.002	0.006	0.006
Zn (ppm)	0.02	0.034	0.099	0.13
TDS (calculated)	231.8	341.5	209.8	219.8

Notes: DTW = depth to water; U = Undetected at the IDL shown in brackets.
Bicarbonate (HCO_3) concentrations were calculated from measured total carbonate alkalinity.
Silica was calculated from concentration of silicon.

Appendix E

Aquifer Test Report

TABLE OF CONTENTS

R-23i SCREEN 3 (BOTTOM SCREEN) PUMPING TEST ANALYSIS

INTRODUCTION

This section describes the analysis of constant-rate test pumping conducted in December 2005 on R-23i screen 3 (the bottom screen from 524 to 547 ft bgs), located in lower Pajarito Canyon, adjacent to regional aquifer well R-23. The primary objective of the analysis was to determine the hydraulic properties of the perched zone adjacent to screen 3, as well as the hydraulic interconnection between it and two other shallower screens in R-23i. Consistent with the protocol used in most of the R-well pumping tests, the R-23i testing incorporated an inflatable packer above the pump to try to eliminate the effects of casing storage on the measured data.

R-23i consists of a 4.5-inch (in.) inner diameter (ID) well completed with two screens – screens 2 and 3 (middle and bottom screens, respectively) – and a shallower 2-in. ID well (screen 1, the top screen) placed in the borehole annulus outside the 4.5-in. well casing. The screens are installed in porous interflow zones within the Cerros del Rio basalt. Screen 1 is a 2-in. by 20-foot (ft) long screen and is set between 400.3 and 420 ft below ground surface (bgs). Screen 2 is 10 ft long, installed from 470.2 to 480.1 ft, while screen 3 is 23 ft long, installed from 524 to 547 ft.

On December 8, prior to the onset of testing activities, the static water level in the 2-in. well was 406.00 ft bgs. At that time, the static water level in the R-23i 4.5-in. casing was 454.08 ft bgs with both screens open. The great water level difference between the shallow screened interval and the deeper zones suggested a hydraulic disconnect between the zones, later confirmed by testing.

When the inflatable packer was set between screens 2 and 3, the screen 2 water level rose 3.99 ft, placing it 450.09 ft bgs. Simultaneously, the level in screen 3 dropped 6.43 ft, making it 460.51 ft bgs at the time of testing. The more than 10-foot difference in water levels showed a strong downward gradient, suggesting low average vertical hydraulic conductivity of the intervening basalt between screens 2 and 3. These measurements were made a few days following completion of many days of development pumping on screen 3. Therefore, it was not known whether the extended pumping of screen 3 contributed to the observed head difference between screens 2 and 3, or if it was natural. Nevertheless, the persistence of the observed head difference implied a low vertical conductivity value for the intervening rock.

Testing consisted of brief trial pumping on December 8, followed by a 1-day constant-rate pumping test that was begun on December 10. Two trial tests were conducted. Trial 1 was conducted with the packer deflated, at a discharge rate that varied from more than 10 gallons per minute (gpm) down to 2.1 gpm by the end of the trial. Pumping continued for 60 minutes from 1:00 P.M. until 2:00 P.M. and was followed by 90 minutes of recovery until 3:30 P.M. Leaving the packer deflated permitted obtaining pumping performance data for the combined screen 2 and 3 zones.

Following trial 1, the packer was inflated, hydraulically separating the screen 2 and screen 3 zones. After an equilibration period of 105 minutes, trial 2 was conducted for 105 minutes from 5:15 P.M. until 7:00 P.M. The discharge rate for trial 2 began at 2.6 gpm, but declined to 1.95 gpm by the end of the test. Following shutdown, recovery was monitored for 37.5 hours until

8:30 A.M. on December 10. The extended recovery period was expected to provide background water level data as well.

At 8:30 A.M. on December 10, an attempt was made to initiate the constant-rate pumping test. However, a frozen discharge line forced a shutdown and the test was eventually restarted at 12:00 P.M. Constant-rate pumping was performed for 24 hours until 12:00 P.M. on December11. The discharge rate varied from less than 1 gpm to more than 2 gpm, averaging 1.53 gpm. Following shutdown, recovery/background measurements were recorded for more than 115 hours until 7:15 A.M. on December 16. During testing, water levels were monitored in all three well screen zones.

Discharge Rate Variations

During each pumping event, the discharge rate varied substantially, rather than remaining constant as is desired. In most instances, once the control valve was adjusted to a particular setting, the pumping rate declined steadily over time, requiring periodic readjustment. However, there were also times where the discharge rate increased rather than decreasing. It was believed that mechanical problems involving the pump and/or control valve contributed to this phenomenon. It is also likely that steadily increasing drawdown due to pumping would have contributed in part to the discharge rate reductions by requiring the pump to operate against progressively greater head. However, the changing head condition on the pump was not sufficient to account for the observed discharge rate reductions and certainly couldn't have caused discharge rate increases.

The shallow pumping water levels, combined with the great pressure generated by the pump used for the testing, required valving back the discharge so that about 350 pounds per square inch (psi) was applied across the valve. This was probably greater than the normal operating pressure for the valve and resulted in inconsistent valve operation and fluctuating pressure and discharge. It is also possible that the pump characteristics may have varied because of pump or motor deterioration. The pump used for the R-23i test subsequently survived only one more pumping test before malfunctioning and eventually failing while developing well R-17.

It is not known whether valve instability, or changing pump operating characteristics, or both, contributed to the flow rate variations. Regardless, it was necessary to make corrective adjustments to the control valve periodically, resulting in numerous flow rate changes and rather chaotic water levels. The resulting drawdown data sets were often difficult to analyze, placing an emphasis on use of the recovery data for determining formation properties.

Permeable Zone Thickness

In the analysis below, it was generally assumed that the permeable zone thickness was 100 ft – the distance between the screen 2 static water level at 450 ft and the bottom of the screen 3 porous interflow zone at 550 ft. This dimension was generally used to compute hydraulic conductivity from transmissivity. Note that an alternative interpretation would have been to consider the perched aquifer to extend from the top of the screen 2 porous interflow zone at 470.2 ft (observed at R-23) to the bottom of the screen 3 porous interflow zone at 550 ft, making the assigned thickness 78 ft, rather than 100 ft. This would have resulted in greater computed values of hydraulic conductivity by the ratio 100/78, or 1.28. In practice, the primary permeability is likely concentrated in the two porous interflow zones, with substantially lower conductivity elsewhere. Because the combined porous interflow zone thickness totals 38 ft, if this were used as the permeable zone thickness, then the computed hydraulic conductivities would be increased by the ratio 100/38, or 2.63. In the analyses below, these alternatives were considered; that is, the option was acknowledged that the apparent average conductivity might be 28 percent greater than calculated, and the effective conductivity of the porous interflow zones might be 163 percent greater than the nominal computed average conductivity.

BACKGROUND DATA

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

Background water level fluctuations have several causes, among them barometric pressure changes, operation of other wells in the aquifer, earth tides, and long-term trends related to weather patterns. The background data hydrographs from the R-23i tests, as well as that from adjacent regional aquifer well R-23, were compared to barometric pressure data from the area to determine if a correlation existed.

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

Subsequent pumping tests, including those at R-23i, have utilized non-vented transducers. These devices simply record the total pressure on the transducer, that is, the sum of the water height plus the barometric pressure. This results in an attenuated "apparent" hydrograph in a barometrically efficient well. Take as an example a 90 percent barometrically efficient well. When monitored using a vented transducer, an increase in barometric pressure of 1 unit causes a decrease in recorded down-hole pressure of 0.9 units, because the water level is forced downward 0.9 units by the barometric pressure change. However, using a non-vented transducer, the total measured pressure increases by 0.1 units (the combination of the barometric pressure increase and the water level decrease). Thus, the resulting apparent hydrograph changes by a factor of 100 minus the barometric efficiency, and in the same direction as the barometric pressure change, rather than in the opposite direction.

Barometric pressure data were obtained from the Los Alamos National Laboratory TA-54 tower site from the Environmental Division-Meteorology and Air Quality (ENV-MAQ). The TA-54 measurement location is at an elevation of 6548 ft above mean sea level (amsl), whereas the wellhead elevation is 6528 ft amsl. The static water level in the 4.5-in. casing in R-23i was about 454 ft bgs, making the water table elevation approximately 6074 ft amsl. Therefore, the measured barometric pressure data from TA-54 had to be adjusted to reflect the pressure at the elevation of the water table within R-23i.

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

$$P_{WT} = P_{TA54} \exp\left[-\frac{g}{3.281R}\left(\frac{E_{R23i} - E_{TA54}}{T_{TA54}} + \frac{E_{WT} - E_{R23i}}{T_{WELL}} \right) \right] \tag{1}$$

where,

P_{WT} = barometric pressure at the water table inside R-23i
P_{TA54} = barometric pressure measured at TA-54
g = acceleration of gravity, in m/sec^2 (9.80665 m/sec^2)
R = gas constant, in J/Kg/degree Kelvin (287.04 J/Kg/degree Kelvin)
E_{R23i} = land surface elevation at R-23i, in ft (6528 ft)
E_{TA54} = elevation of barometric pressure measuring point at TA-54, in ft (6548 ft)
E_{WT} = elevation of the water level in R-23i, in ft (approximately 6074 ft)
T_{TA54} = air temperature near TA-54, in degrees Kelvin (assigned a value of 24.9 degrees Fahrenheit, or 269.2 degrees Kelvin)
T_{WELL} = air temperature inside R-23i, in degrees Kelvin (assigned a value of 62 degrees Fahrenheit, or 289.8 degrees Kelvin)

This formula is an adaptation of an equation provided by ENV-MAQ. It can be derived from the ideal gas law and standard physics principles. An inherent assumption in the derivation of the equation is that the air temperature between TA-54 and the well is temporally and spatially constant, and that the temperature of the air column in the well is similarly constant. Similar calculations were made for the data collected from R-23.

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

IMPORTANCE OF EARLY DATA

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

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

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

where,

t_c = duration of casing storage effect, in minutes
D = inside diameter of well casing, in in.
d = outside diameter of column pipe, in in.
Q = discharge rate, in gpm
s = drawdown observed in pumped well at time t_c, in ft

In some instances, it may be possible to eliminate casing storage effects by setting an inflatable packer above the tested screen interval prior to conducting the test. Therefore, this option has been implemented for the R-well testing program, including the R-23i pumping test. Using the packer was successful in eliminating casing storage effects in the R-23i pumping test.

TIME-DRAWDOWN METHODS

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

$$s = \frac{114.6Q}{T} W(u) \qquad (3)$$

where,

$$W(u) = \int_u^\infty \frac{e^{-x}}{x} dx \qquad (4)$$

and

$$u = \frac{1.87r^2 S}{Tt} \qquad (5)$$

and where,

s = drawdown, in ft
Q = discharge rate, in gpm
T = transmissivity, in gpd/ft
S = storage coefficient (dimensionless)
t = pumping time, in days
r = distance from center of pumpage, in ft

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

$$T = \frac{114.6Q}{s} W(u) \tag{6}$$

$$S = \frac{Tut}{2693r^2} \tag{7}$$

where,

T = transmissivity, in gpd/ft
S = storage coefficient
Q = discharge rate, in gpm
$W(u)$ = match point value
s = match point value, in ft
u = match point value
t = match point value, in minutes

An alternative solution method applicable to time-drawdown data is the Cooper-Jacob method (1946), a simplification of the Theis equation (1935) that is mathematically equivalent to the Theis equation for most pumped well data. The Cooper-Jacob equation describes drawdown around a pumping well as follows:

$$s = \frac{264Q}{T} \log \frac{0.3Tt}{r^2 S} \tag{8}$$

where,

s = drawdown, in ft
Q = discharge rate, in gpm
T = transmissivity, in gpd/ft
t = pumping time, in days
r = distance from center of pumpage, in ft
S = storage coefficient (dimensionless)

The Cooper-Jacob equation is a simplified approximation of the Theis equation and is valid whenever the u value is less than about 0.05, where u is defined as follows:

$$u = \frac{1.87r^2S}{Tt} \tag{9}$$

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

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

$$T = \frac{264Q}{\Delta s} \tag{10}$$

where,

T = transmissivity, in gpd/ft
Q = discharge rate, in gpm
Δs = change in head over one log cycle of the graph, in ft

Because the R-wells are severely partially penetrating, an alternate solution considered for determining aquifer parameters is the Hantush equation for partially penetrating wells (1961a, b). The Hantush equation is as follows:

$$s = \frac{Q}{4\pi T}\left[W(u) + \frac{2b^2}{\pi^2(l-d)(l'-d')}\sum_{n=1}^{\infty}\frac{1}{n^2}\left(\sin\frac{n\pi l}{b} - \sin\frac{n\pi d}{b}\right)\left(\sin\frac{n\pi l'}{b} - \sin\frac{n\pi d'}{b}\right)W\left(u, \sqrt{\frac{K_z}{K_r}}\frac{n\pi r}{b}\right)\right] \tag{11}$$

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

b = aquifer thickness
d = distance from top of aquifer to top of well screen in pumped well
l = distance from top of aquifer to bottom of well screen in pumped well
d' = distance from top of aquifer to top of well screen in observation well
l' = distance from top of aquifer to bottom of well screen in observation well
K_z = vertical hydraulic conductivity
K_r = horizontal hydraulic conductivity

In this equation, W(u) is the Theis well function and W(u,β) is the Hantush well function for leaky aquifers where:

$$\beta = \sqrt{\frac{K_z}{K_r}} \frac{n\pi r}{b} \tag{12}$$

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

RECOVERY METHODS

Recovery data were analyzed using the Theis Recovery Method. This is a semi-log analysis method similar to the Cooper-Jacob procedure.

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

$$T = \frac{264Q}{\Delta s} \tag{13}$$

The recovery data are particularly useful compared to time-drawdown data. Because the pump is not running, spurious data responses associated with dynamic discharge rate fluctuations are eliminated. The result is that the data set is generally "smoother" and easier to analyze.

The Theis curve matching method and the Hantush equation also can be applied to recovery data, provided they are limited to the early data. In order to apply these methods to later data, it is necessary to compute what is called "calculated recovery" – the difference between extrapolated drawdown and the observed residual drawdown. However, because this computation requires extrapolating the original drawdown trend, it can introduce errors into the data and, actually, simply incorporates the perceived drawdown trend into the calculated recovery, rather than providing an independent analysis.

SPECIFIC CAPACITY METHOD

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

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

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

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

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

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

To apply this formula, a storage coefficient value must be assigned. Storage coefficient values for confined conditions can be expected to range from about 10^{-5} to 10^{-3}, depending on aquifer thickness (the thicker the aquifer, the greater the storage coefficient). Typically, a value of 5 x 10^{-4} may be assigned for calculation purposes (Driscoll, 1986). The calculation result is not particularly sensitive to the choice of storage coefficient value, so a rough estimate of the storage coefficient is adequate to support the calculations. The piezometric levels for screens 2 and 3 were well above the tops of the screens, suggesting possible confined conditions. For the purposes of the calculations in this report, confined conditions were assumed, although there was no certainty that the producing zones actually were confined.

The analysis also requires assigning a value for the saturated aquifer thickness, b. In R-23i, calculations were based on an assumed aquifer thickness of 100 ft – the distance from the screen 2 water level at 450 ft to the bottom of the screen 3 porous interflow zone at 550 ft.

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

R-23i DATA ANALYSIS

This section presents the data obtained from the R-23i pumping test and the results of the analytical interpretations. Analyses were applied to pre- and post-development water levels, recovery data following trial 1, pumping and recovery data from trial 2, the 24-hour constant-rate pumping data, and the subsequent recovery data. There also is a discussion of the background data recorded before and after the constant-rate pumping test.

Well Development

The combined water from both screens in the 4.5-in. well was developed between November 13 and 16. A packer was installed and the bottom screen was developed between November 16 and December 5. The bottom screen was aquifer-tested between December 8 and 11. The middle screen was developed later, from December 17 through 20. The total volume of water pumped from the 4.5-in. well only was 32,059 gallons or about 4,285 cubic ft, with about 25,800 gallons of this coming from screen 3. Prior to development, the static water level in the well (with both screens 2 and 3 open) was 449.74 ft bgs. On December 8, 3 days following the completion of the bottom screen development, the observed water level was 454.08 ft, or 4.34 ft lower.

This information was used to estimate a possible range for the size of the perched zone affected by pumping. If the perched area is visualized as a square of length dimension, L, the following equation can be derived to estimate this dimension:

$$L = \sqrt{\frac{V}{sS}} \qquad (16)$$

where,

L = length dimension along one side of square area, in ft
V = volume pumped, in cubic ft
s = decline in water level, in ft
S = storage coefficient

Note that this equation is based on the assumption that the perched zone head declined by a magnitude, s, everywhere. For areally extensive perched zones, this assumption will be violated and the equation will underestimate the size of the perched area.

For storage coefficients of 10^{-4} and 10^{-5}, this calculation yields L values of 2,900 ft and 9,300 ft, respectively, suggesting possibly a laterally extensive perched zone at R-23i. Assumption of unconfined conditions (greater storage coefficient) would yield far lower estimates for L. Unfortunately, there was no way to determine whether the zone was confined or unconfined from the available data, although the assumption of confined conditions seems reasonable because of the massive basalt flow covering the porous interflow zones.

Background Data

Water level data were plotted along with barometric pressure data for each of the three screen zones in R-23i and nearby regional well R-23. Figure 1 shows the apparent water level hydrograph for R-23i screen 3 and the barometric pressure data recorded before, during, and after the constant-rate pumping test. Apparent on the hydrograph is that water levels continued to show recovery from the trial tests and the extended pumping test throughout the monitoring period.

The data on Figure 1 show a subtle correlation between barometric pressure and the apparent hydrograph. This can be seen in three barometric pressure drops – one overnight from December 13 to 14, one at midday on December 14, and one at midday on December 15. Corresponding to each pressure drop, the slope of the water level recovery curve flattened slightly. This effect may be easier to see on the expanded-scale plot on Figure 2, on which a rolling-average hydrograph has been plotted to reduce data scatter. A visual examination of the plots suggests that the barometric effect on water levels was probably no more than 10 to 30 percent of the barometric pressure change, thereby suggesting a high barometric efficiency of about 70 to 90 percent. Because of the ongoing water level rebound from pumping, it was not possible to quantify the barometric efficiency exactly.

Figure 3 shows a comparison of the screen 2 hydrograph and the barometric pressure signal. A rolling average hydrograph was used to reduce data scatter. The "ripple" effect in the hydrograph on the right side of the graph showed a subtle flattening of the data trace whenever there was a noticeable drop in barometric pressure, similar to the response observed for screen 3. This suggested a high barometric efficiency for screen 2, but strictly less than 100 percent, i.e., there was some noticeable response to barometric pressure changes. The ongoing water level rebound precluded an exact determination of barometric efficiency for screen 2.

Figure 4 shows a comparison of the screen 1 hydrograph and the change in barometric pressure. On this figure, the barometric pressure change signal has been reduced by a factor of 0.69, corresponding to a barometric efficiency of 31 percent. Based on the good correlation between the two curves, this is a reasonable estimate of the barometric efficiency of the perched screen 1 zone. There was no observable response in the screen 1 zone to pumping screens 2 and 3. It was concluded that these zones are not hydraulically connected.

Figure 5 shows a comparison of the R-23 hydrograph and the barometric pressure signal. Note that a decline in barometric pressure caused a rise in groundwater elevation of a similar magnitude. The only explanation for this response was that the water levels must have been measured using a vented transducer and the screen zone was essentially 100 percent barometrically efficient. There was no observable response in R-23 to pumping screens 2 and 3. It was concluded that these zones are not hydraulically connected.

In summary, the background data indicated barometric efficiencies of 31 percent for the uppermost perched zone (screen 1), perhaps around 70 to 90 percent for the two intermediate perched zones (screens 2 and 3) and near 100 percent for the regional aquifer (R-23). This means barometric pressure effects reach the uppermost zone effectively, have much less effect on the intermediate perched zones, and do not seem to penetrate to the regional aquifer at all – a reasonable scenario that is consistent with previous observations on the Plateau. Water level data showed that the screen 2 and 3 zones are hydraulically connected to each other, but hydraulically isolated from the screen 1 perched zone and the top of the regional aquifer.

Trial Testing

Following pump installation, the well was pumped briefly (trial testing) to evaluate well capacity, fill the drop pipe in preparation for subsequent testing, and generate some useful data. Trial 1 was conducted with the packer deflated, at a discharge rate that varied from more than 10 gpm down to 2.1 gpm by the end of the trial. Pumping continued for 60 minutes from 1:00 P.M.

until 2:00 P.M. and was followed by 90 minutes of recovery until 3:30 P.M. Leaving the packer deflated permitted obtaining pumping performance data for the combined screen 2 and 3 zones.

Following trial 1, the packer was inflated, hydraulically separating the screen 2 and screen 3 zones. After an equilibration period of 105 minutes, trial 2 was conducted for 105 minutes from 5:15 P.M. until 7:00 P.M. The discharge rate for trial 2 began at 2.6 gpm, but declined to 1.95 gpm by the end of the test. Following shutdown, recovery was monitored for 37.5 hours until 8:30 A.M. on December 10.

Trial 1

Figure 6 shows drawdown recorded during trial 1. When the pump first started, it likely produced in excess of 10 gpm because of the low starting head. As the drop pipe filled, the rate declined until water was produced at the surface after 10 minutes. At that time the rate was 6.3 gpm, having averaged 7.8 gpm over the first 10 minutes of pumping. The rate was maintained at 6.3 gpm for an additional 10 minutes and then adjusted downward to just over 2 gpm.

The initial portion of the curve suggests a profound storage effect. This was confirmed during the flow rate reduction, because the water levels didn't "spike" upward when the rate was cut, as would normally be expected. This muted response suggested a casing-storage-like buffer that prevented rapid changes in water level. It was suspected that the storage effect was greater than what would have been expected from just the annular space between the 4.5-in. ID well casing and the 2-in. drop pipe.

Figures 7 and 8 show the residual drawdown and recovery data from the trial 1 test. Again the data traces suggested a large storage response. The late pumping data and early recovery data were used to try to estimate the size of the storage feature.

Two equations were set up to describe the late pumping and early recovery response by computing the rate at which water entered the well. For the late pumping data, the following expression was derived:

$$Q_{fill} = Q_m + \frac{7.48As_r}{t} \qquad (17)$$

where,

Q_{fill} = the rate at which water entered the casing, in gpm
Q_m = the measured discharge rate, in gpm (2.1 gpm)
A = effective cross section area of the storage feature, in square ft
s_r = ft of recovery over time t (0.09 ft over the last 9 minutes of pumping)
t = time over which recovery, s_r, was observed (9 minutes)

For the early recovery data, this expression for Q_f was derived:

$$Q_f = \frac{7.48As_r'}{t'} \qquad (18)$$

where,

s_r' = recovery in time t', in ft (0.31 ft over first minute of recovery [Figure 8])
t' = recovery time, in minutes (1 minute)
Combining these two equations and solving for A yielded a cross sectional area of the storage feature of 0.936 square ft (ft^2). This corresponded to a circular area having a diameter of about 13 in., coincidentally about the same size as the borehole drilled for this well. The drill bit used was 12.25 in. in diameter, but generally the finished borehole is slightly larger than the nominal bit size. This result could have been a coincidence, or could indicate the presence of a void between the borehole and the well casing at the elevation where the water level was changing – about 465 ft bgs.

During well construction, the volume of annular fill material required between 463 and 550 feet was five times the calculated amount (95 versus 19 cubic ft) because of bridging and cleanout attempts that occurred after TD was reached. During construction, slough filled the annulus between 504 and 469 ft bgs, with the latter depth being the approximate depth of the bridge that had developed in the open borehole. It is possible that a void formed in this interval, although the screened interval was swabbed to settle the native formation across the middle screened interval.

An alternate explanation relates to the presence of a large washout zone between 463 and 469 ft bgs. The actual volume of annular fill materials required from 463 to 469 ft bgs far exceeded the calculated volume (34 versus 2 cubic ft), indicating a very large washout zone exists at that depth, and possibly deeper. It is possible that during the trial test the annulus remained filled, but that the washout zone contributed enough storage volume to show the observed effect. (This explanation would require that the drained porosity of the filter pack in this interval was coincidentally equal in volume per foot to the volume of the original gauge borehole.)

Trial 2

Figure 9 shows time-drawdown data from the trial 2 test. The early data from the test, corresponding to a pumping rate of 2.6 gpm, suggest a transmissivity for the screen 3 zone of 55 gallons per day per foot (gpd/ft) and a hydraulic conductivity of 2.39 gallons per day per square foot (gpd/ft^2), or 0.32 ft per day. The late data, after the discharge rate had been adjusted to 1.95 gpm, yielded an overall transmissivity of 117 gpd/ft and a hydraulic conductivity of 1.17 gpd/ft^2, or 0.16 ft per day, based on a saturated zone thickness of 100 ft. Recall that if the assumed thickness is 78 ft, the average conductivity would increase by 28 percent to 0.2 ft per day, and if just the porous interflow zone thickness of 38 ft is used in the calculation, the corresponding conductivity would increase by 163 percent to 0.41 ft per day – presumably representative of the porous interflow zone.

Note that in these calculations, the second slope on Figure 9 was analyzed independent of the antecedent pumping at the greater discharge rate – as though the entire pumping rate had been constant. This approach ignored the lingering effects of the greater discharge rate. However, because the greater discharge rate lasted for only 4 minutes, separate calculations (not included here) showed that the effect of the greater rate was negligible and could be ignored.

Figure 10 shows the drawdown data measured in screen 2 caused by pumping screen 3. Because of the likelihood of an annular void or formation void contributing significant storage to this zone, it was concluded that all of the measured response was storage-affected and the data were not analyzed.

Figure 11 shows the screen 3 recovery following trial 2 pump shutoff. The early data describe a steep slope, likely reflecting the properties of just the screened interval, while the late data show a flatter slope consistent with vertical expansion of the cone of depression.

The early data were analyzed using Theis curve matching as shown on Figure 12. The analysis revealed a transmissivity of 48 gpd/ft and a hydraulic conductivity of 2.09 gpd/ft^2, or 0.28 ft per day for the screen 3 interval.

Figure 13 shows analysis of the late recovery data, yielding an overall transmissivity of 125 gpd/ft and a saturated zone average hydraulic conductivity of 1.25 gpd/ft^2, or 0.17 ft per day. If the conductivity is increased by 28 percent and 163 percent, as discussed earlier, the results are 0.21 ft per day average conductivity and 0.44 ft per day for the combined porous interflow zones. Note on Figure 13 the abrupt increase in slope at late time. This is a strong indication of boundary conditions, i.e., a lateral limit to the perched zone in the vicinity of the pumped well.

Figure 14 shows trial 2 recovery data collected from the screen 2 interval. It is probable that much of the early data were storage-affected. An attempted analysis of later data was performed as shown on Figure 15. The line of best fit was applied to late data, but avoided the steep portion of the curve that coincided with the boundary-affected data from screen 3 noted on Figure 13. The resulting transmissivity from this analysis was 101 gpd/ft, yielding a hydraulic conductivity of 1.01 gpd/ft^2, or 0.14 ft per day. Increasing the conductivity by 28 percent and 163 percent produced an average conductivity value of 0.17 ft per day and a combined porous interflow conductivity value of 0.36 ft per day, respectively.

24-Hour Constant-Rate Pumping Test

The constant-rate pumping test was started at 12:00 P.M. on December 10 and continued for 24 hours until 12:00 P.M. on December 11. The discharge rate varied from less than 1 gpm to more than 2 gpm, averaging 1.53 gpm. Following shutdown, recovery/background measurements were recorded for more than 115 hours until 7:15 A.M. on December 16.

Time-Drawdown Analysis

Figure 16 shows the screen 3 time-drawdown data for the 24-hour constant-rate pumping test. As is evident on the graph, the discharge rate fluctuated significantly during the test, precluding analysis of the data.

Figure 17 shows the drawdown data recorded in screen 2 during the screen 3 test. As shown on the graph, analysis of the late data revealed a transmissivity of 220 gpd/ft and a hydraulic conductivity of 2.2 gpd/ft^2, or 0.29 ft per day – nearly double previous results. Applying the increases of 28 and 163 percent to the conductivity yielded an overall average saturated zone value of 0.38 ft per day and a combined porous interflow zone value of 0.77 ft per day, respectively.

Because screens 2 and 3 both partially penetrated the saturated zone, the time-drawdown data were analyzed using the Hantush Method. Figures 18, 19 and 20 show log-log curve matching results for assumed vertical anisotropy ratios of 0.1, 0.01, and 0.001, respectively. All calculations were performed for an arbitrary assigned aquifer thickness of 100 ft. The results were similar from all three graphs, suggesting a transmissivity of about 41 ft^2/day and a hydraulic conductivity of 0.41 ft per day. Increasing this value by 28 and 163 percent yielded an overall average saturated zone conductivity of 0.53 ft per day and a combined porous interflow zone value of 1.08 ft per day. Unfortunately, the similarity of the results for all assigned values of anisotropy precluded estimating this parameter.

Recovery Analysis

Figure 21 shows the recovery data for screen 3 following the 24-hour test. The early data describe a steep slope, likely reflecting the properties of just the screened interval, while the late data show a flatter slope consistent with vertical expansion of the cone of depression. The very late data showed a slope increase indicative of boundary conditions associated with the lateral limits of the perched zone.

Figure 22 shows Theis curve matching analysis of the early screen 3 recovery data, yielding a transmissivity of 46 gpd/ft and a hydraulic conductivity of 2.0 gpd/ft^2, or 0.27 ft per day for the screen 3 porous interflow zone.

Figure 23 shows analysis of the late screen 3 recovery data, yielding a transmissivity of 132 gpd/ft and a hydraulic conductivity of 1.32 gpd/ft^2, or 0.18 ft per day. Applying the increases of 28 and 163 percent to this conductivity yielded an overall average saturated zone value of 0.23 ft per day and a combined porous interflow zone value of 0.46 ft per day.

Figure 24 shows analysis of the screen 2 recovery data, yielding a transmissivity of 254 gpd/ft and a hydraulic conductivity of 2.54 gpd/ft^2, or 0.34 ft per day. Applying the increases of 28 and 163 percent to this conductivity yielded an overall average saturated zone value of 0.43 ft per day and a combined porous interflow zone value of 0.89 ft per day.

Because screens 2 and 3 both partially penetrated the saturated zone, the screen 2 recovery data were analyzed using the Hantush method. Figures 25, 26, and 27 show log-log curve matching results for assumed vertical anisotropy ratios of 0.1, 0.01, and 0.001, respectively. All calculations were performed for an arbitrary assigned aquifer thickness of 100 ft. The results were similar from all three graphs, suggesting a transmissivity of about 38 ft^2/day and a hydraulic conductivity of 0.38 ft per day. Increasing this value by 28 and 163 percent yielded an overall average saturated zone conductivity of 0.49 ft per day and a combined porous interflow zone value of 1.0 ft per day. Unfortunately, as was the case with the drawdown data, the similarity of the results for all assigned values of anisotropy precluded determining this parameter from the test data.

Specific Capacity Data

Specific capacity data were used along with well geometry to estimate lower-bound conductivity values for the screen 2 and 3 intervals. In addition to specific capacity, other input values used in the calculations included well screen lengths of 10 ft and 23 ft for screens 2 and 3, respectively, a saturated zone thickness of 100 ft, a storage coefficient of 5 x 10^{-4}, and a borehole radius of 0.51 ft.

During trial 1 with both screens 2 and 3 open, R-23i produced 2.1 gpm with a drawdown of 10.82 ft after 60 minutes of pumping, for a specific capacity of 0.194 gallons per minute per foot of drawdown (gpm/ft). During trial 2 with the packer inflated, screen 3 pumping alone produced 1.95 gpm with a drawdown of 27.6 ft after 60 minutes of pumping, for a specific capacity of 0.071 gpm/ft. This was 36.6 percent of the combined specific capacity, meaning that screen 2 contributed 63.4 percent of the specific capacity, or about 1.7 times the specific capacity produced by screen 3.

During the 24-hour pumping test, screen 3 produced 1.53 gpm with a drawdown of 27.9 ft after 1,440 minutes. Applying the Brons & Marting equation to these data yielded a lower-bound hydraulic conductivity of 0.31 ft per day for the screen 3 porous interflow zone. The conventional pumping test analyses for this zone had produced an average estimated conductivity of 0.3 ft per day. While the lower-bound value was slightly greater, the two agreed fairly well suggesting that the conventional results were reasonable.

The combined screen 2 and 3 specific capacity of 0.194 gpm/ft was used to compute a lower-bound hydraulic conductivity value of 0.77 ft per day for the combined porous interflow zones. Conventional analyses produced one cluster of conductivity values averaging 0.42 ft per day and another cluster of significantly greater values averaging 0.94 ft per day. The lower-bound value was consistent with this latter grouping of values, but contradicted the other values. Nevertheless, it was similar in magnitude to the overall average of the conventionally derived values of 0.68 ft per day.

SUMMARY

The following information summarizes the results of the pumping and recovery tests on R-23i screen 3:

1. The barometric efficiency of R-23i screens 1, 2, and 3, and the R-23 screened interval, increased with depth, ranging from a low of 31 percent for R-23i screen 1 to near 100 percent for R-23.

2. The static water level measured in screen 3 was 10.4 ft lower than that in screen 2, indicating a strong downward gradient between screens 2 and 3 and suggesting a low vertical hydraulic conductivity for the intervening rock. Some of the observed head difference might have been attributable to antecedent development pumping of the screen 3 zone.

3. Development pumping of more than 25,000 gallons of water from screen 3 over a 3-week period caused an observed decline of 4.34 ft in the static water level measured 3 days following cessation of pumping, compared to that measured prior to pump development.

4. The specific capacity produced from screen 2 was about 70 percent greater than that produced from screen 3.

5. When pumping from the open well (both screens 2 and 3 exposed), the pumping and recovery data were profoundly storage-affected. The size of the storage feature

coincidentally matched the size of the borehole drilled for the well, suggesting the possibility of an open annulus outside the 4.5-in. OD well casing at around 465 ft bgs.

6. The hydraulic conductivity of the screen 3 porous interflow zone was estimated to be about 0.3 ft per day. The lower-bound value obtained from the specific capacity for this zone was 0.31 ft per day, in good agreement with the conventionally derived value.
7. The hydraulic conductivity of the combined screen 2 and 3 porous interflow zones showed one cluster of values averaging 0.42 ft per day and another cluster averaging 0.94 ft per day, for an overall average of 0.68 ft per day. The lower-bound value obtained from the specific capacity of the combined zones was 0.77 ft per day, suggesting that the larger conventionally derived value may be more representative of formation properties.
8. It was not possible to quantify the vertical anisotropy ratio of the perched zone because it proved to be an insensitive parameter with respect to testing and analysis.

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Figure 1. Comparison of R-23i Screen 3 Apparent Hydrograph and Adjusted TA-54 Barometric Pressure

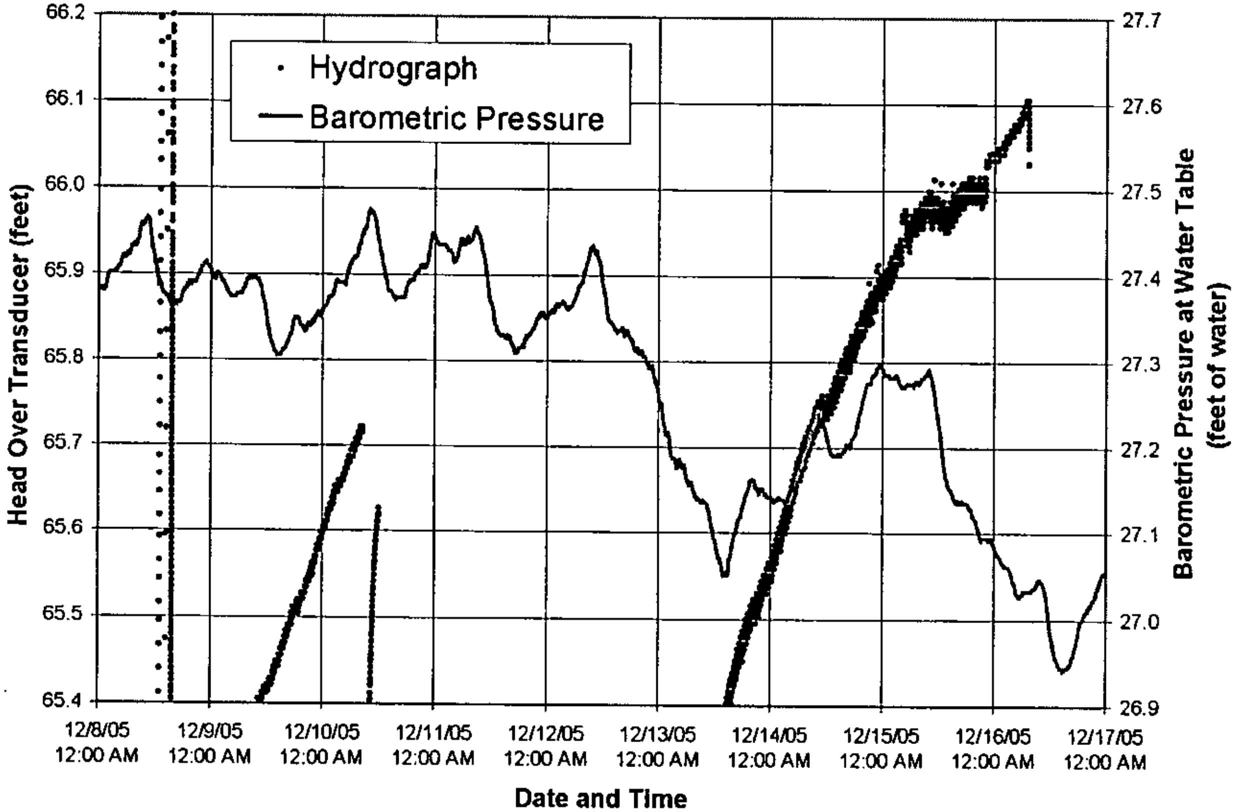


Figure 2. Comparison of R-23i Screen 3 Rolling Average Hydrograph and Adjusted TA-54 Barometric Pressure - Expanded Scale

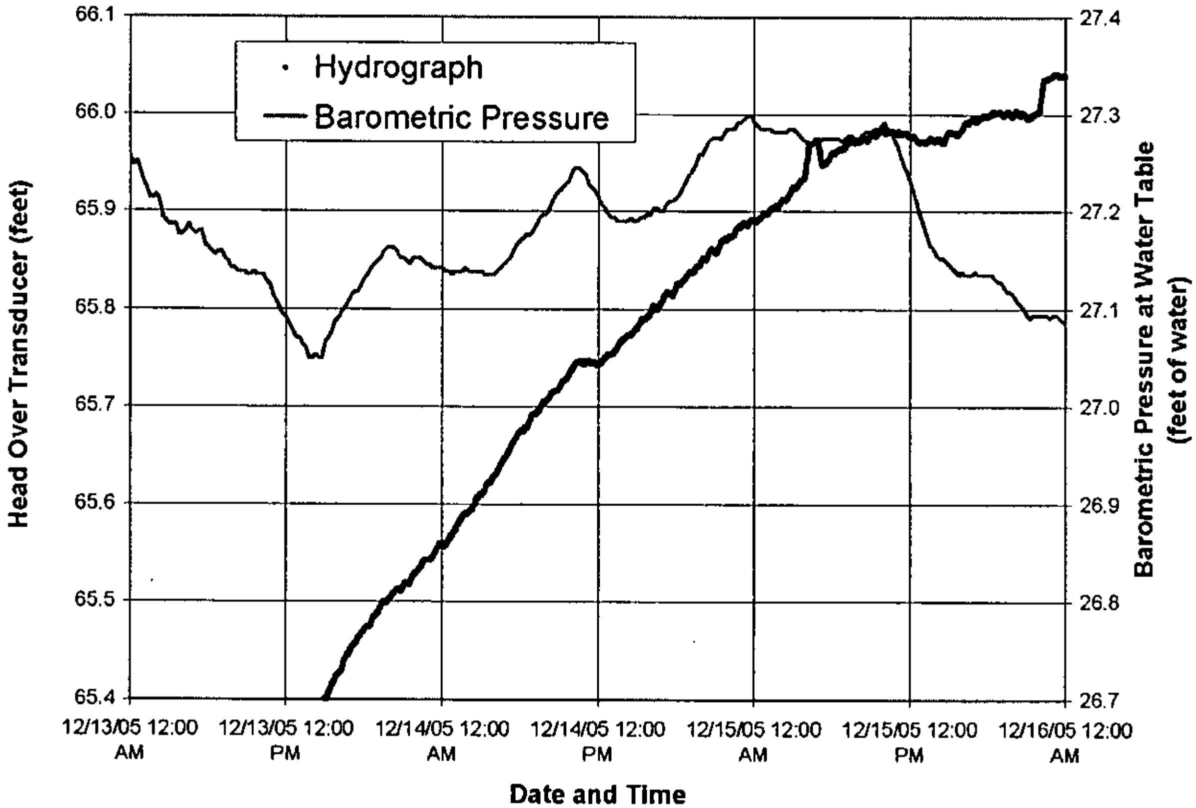


Figure 3. Comparison of R-23i Screen 2 Rolling Average Apparent Hydrograph and Adjusted TA-54 Barometric Pressure

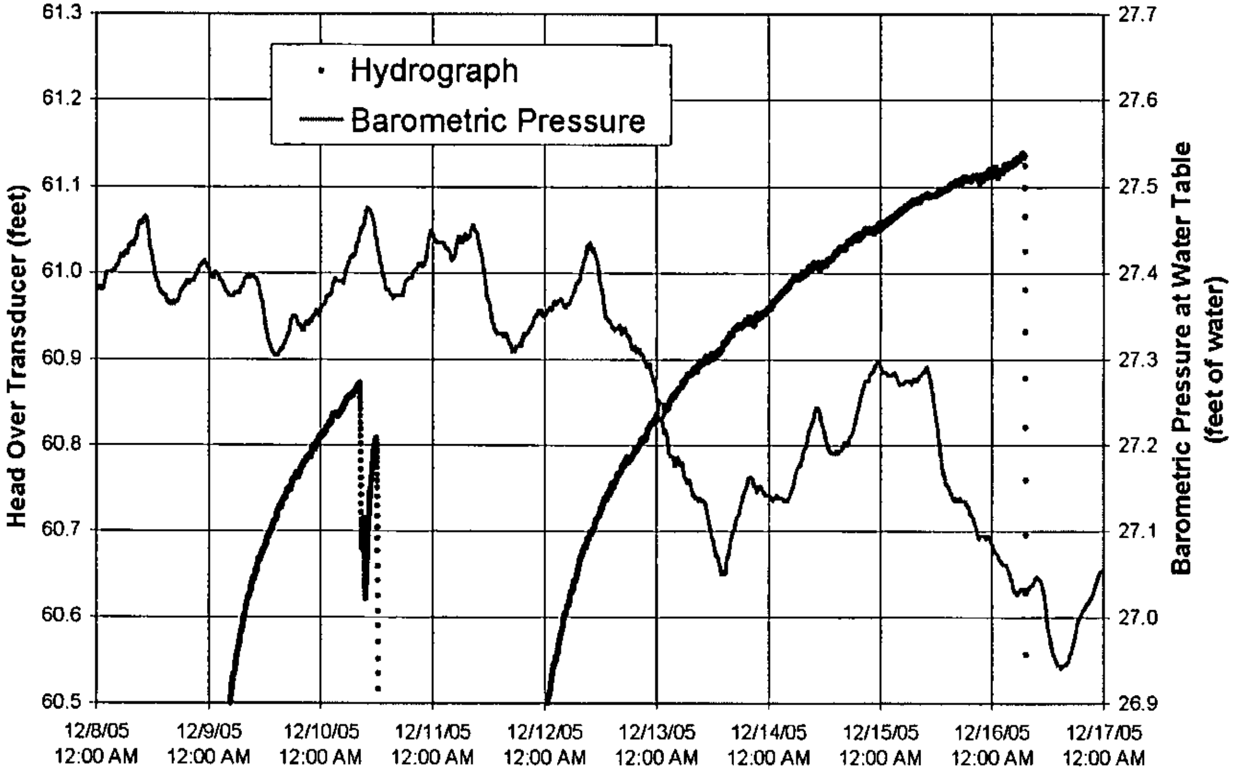


Figure 4. Comparison of R-23i 2-Inch Piezometer Hydrograph and TA-54 Barometric Pressure Change Adjusted For 31 Percent Barometric Efficiency

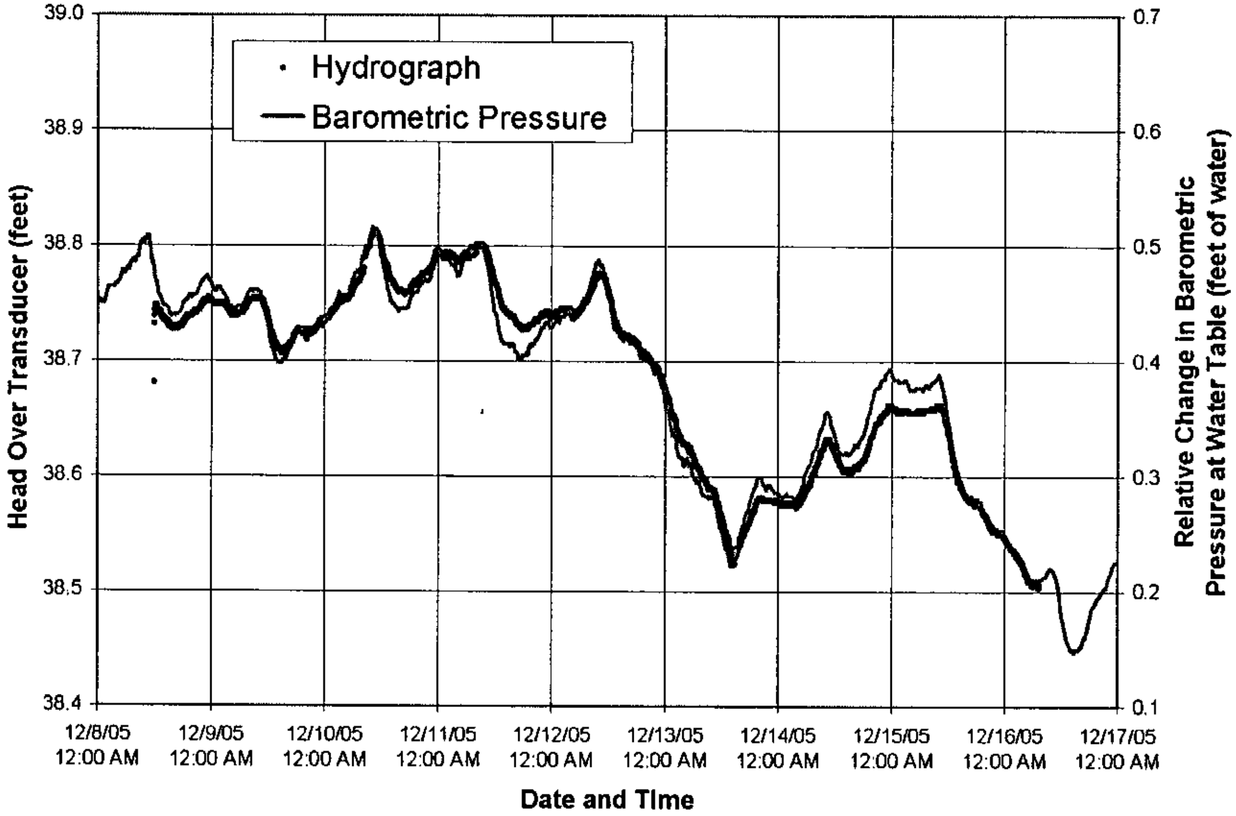


Figure 5. Comparison of R-23 Apparent Hydrograph and Adjusted TA-54 Barometric Pressure

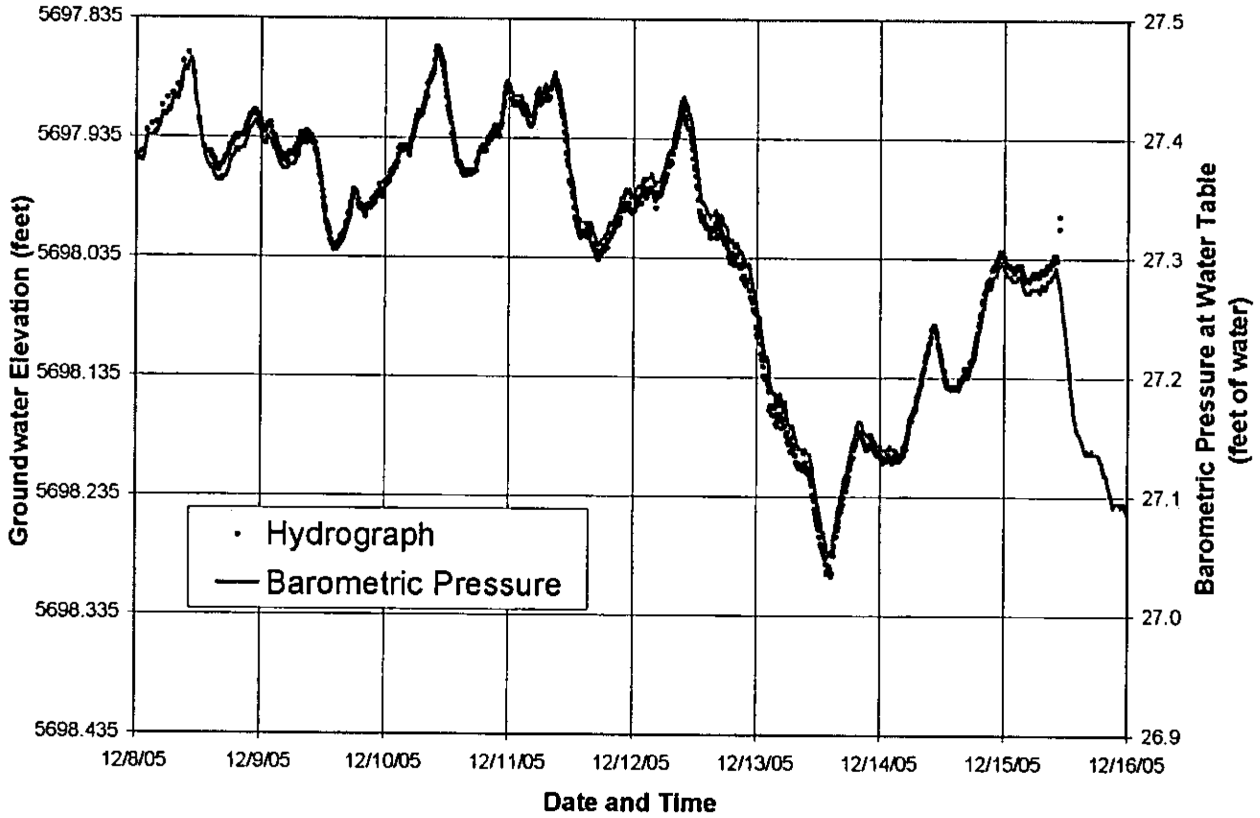


Figure 6. Well R-23i Both Screens Trial 1 Drawdown

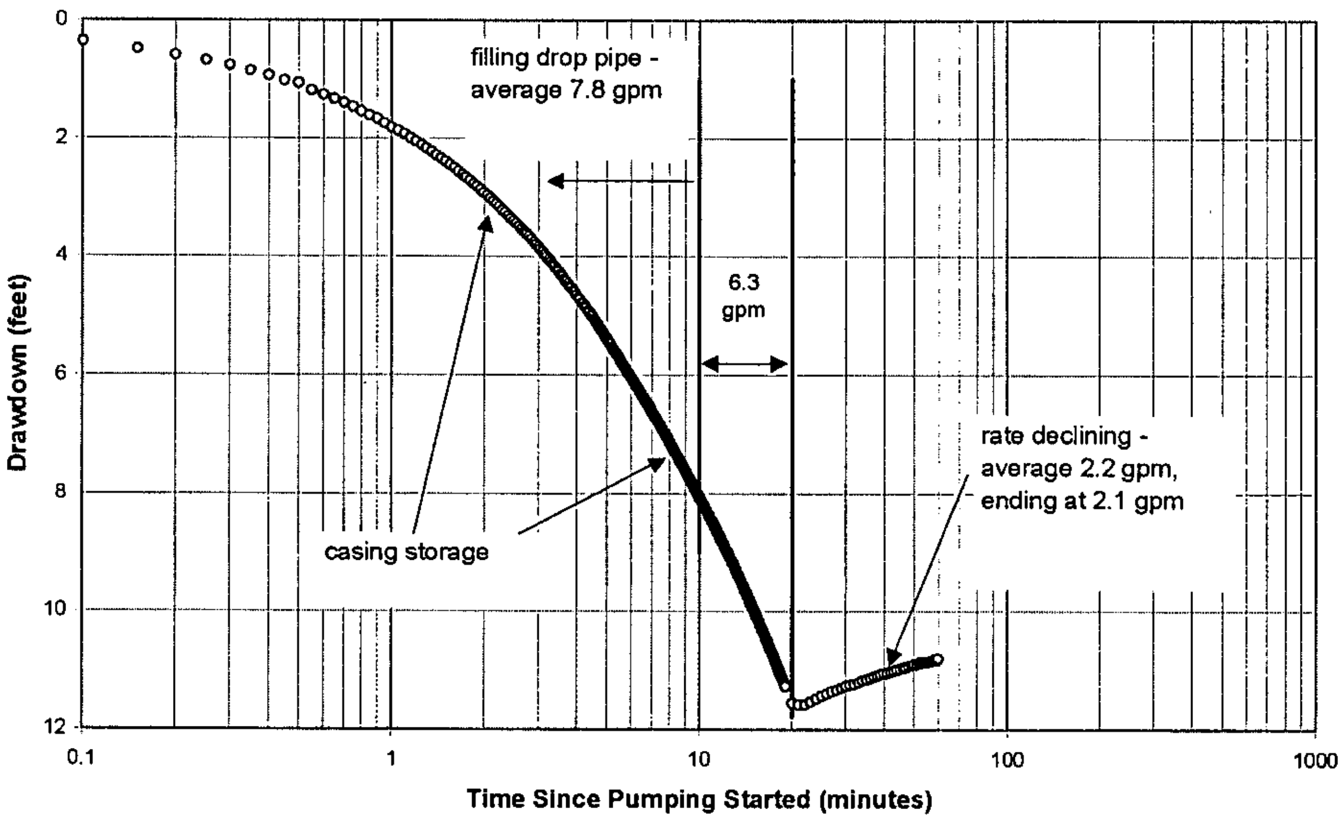


Figure 7. Well R-23i Trial 1 Residual Drawdown With Both Screens Open

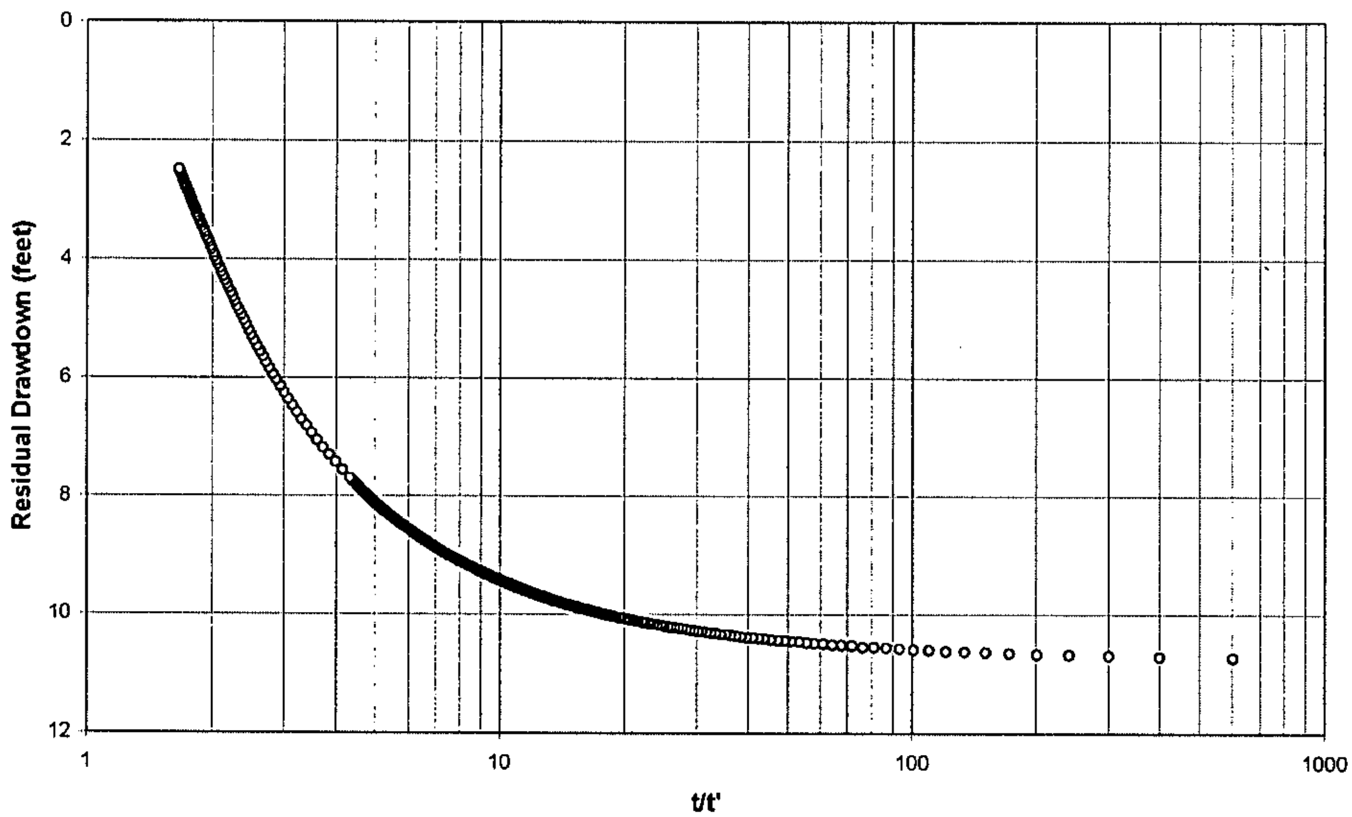


Figure 8. Well R-23i Trial 1 Recovery With Both Screens Open

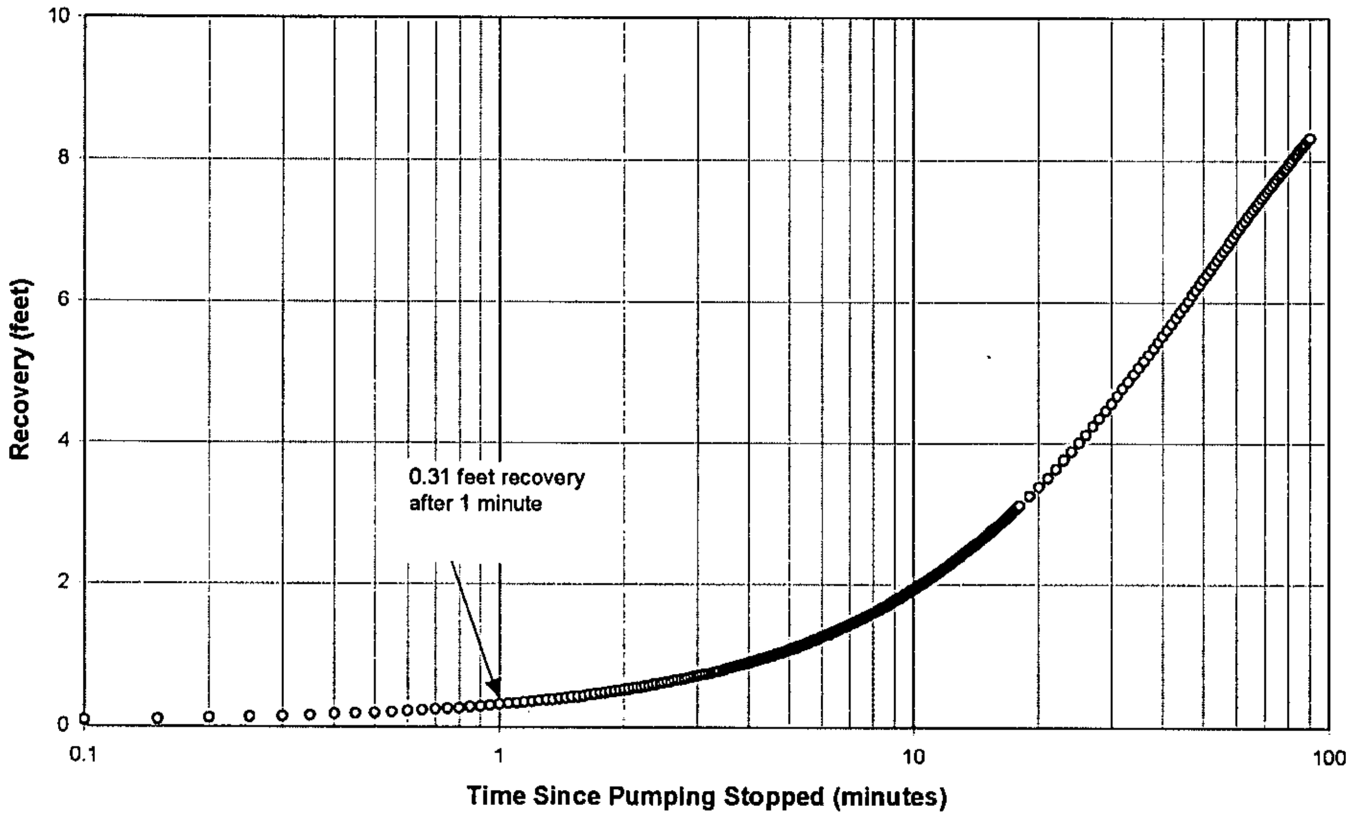


Figure 9. Well R-23i Screen 3 Trial 2 Drawdown

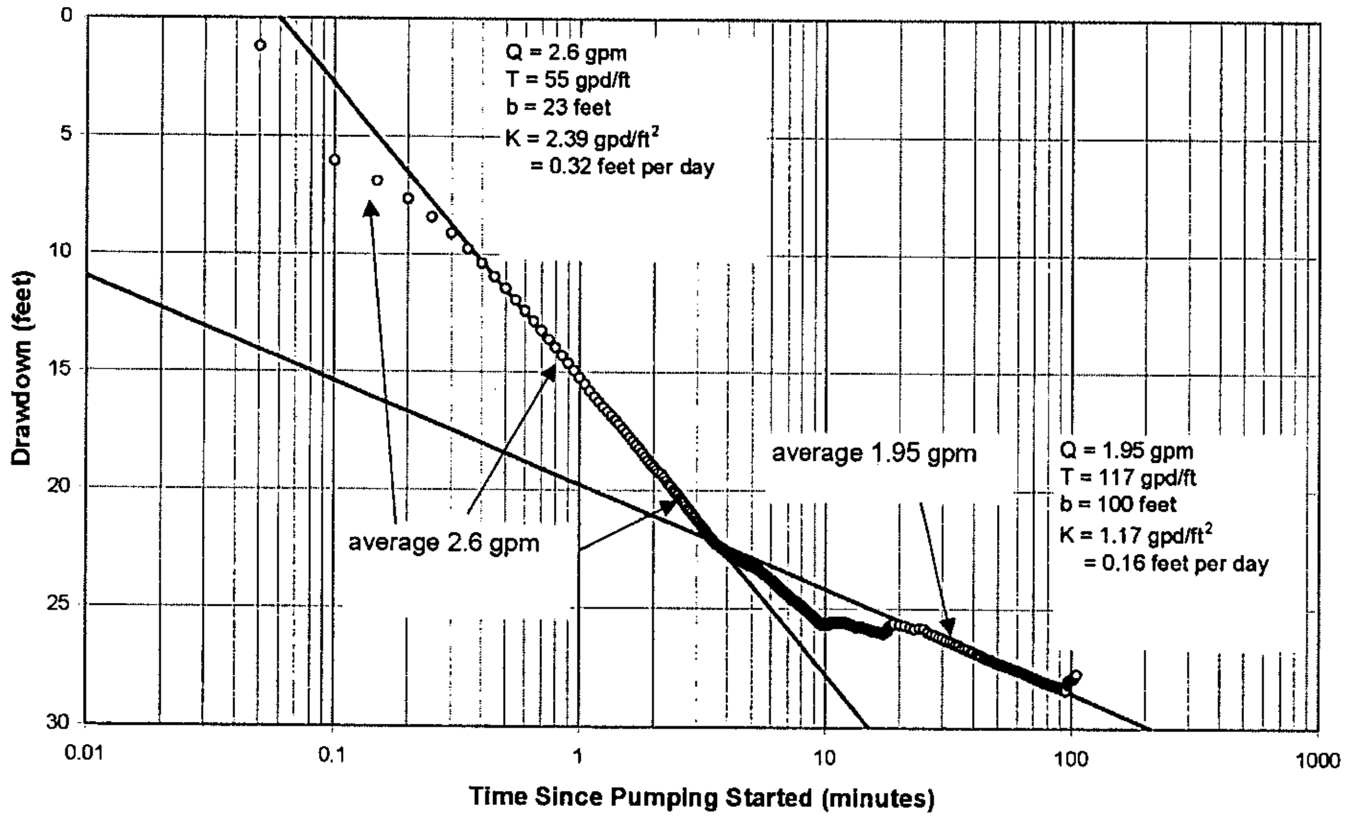


Figure 10. Well R-23i Screen 2 Trial 2 Drawdown

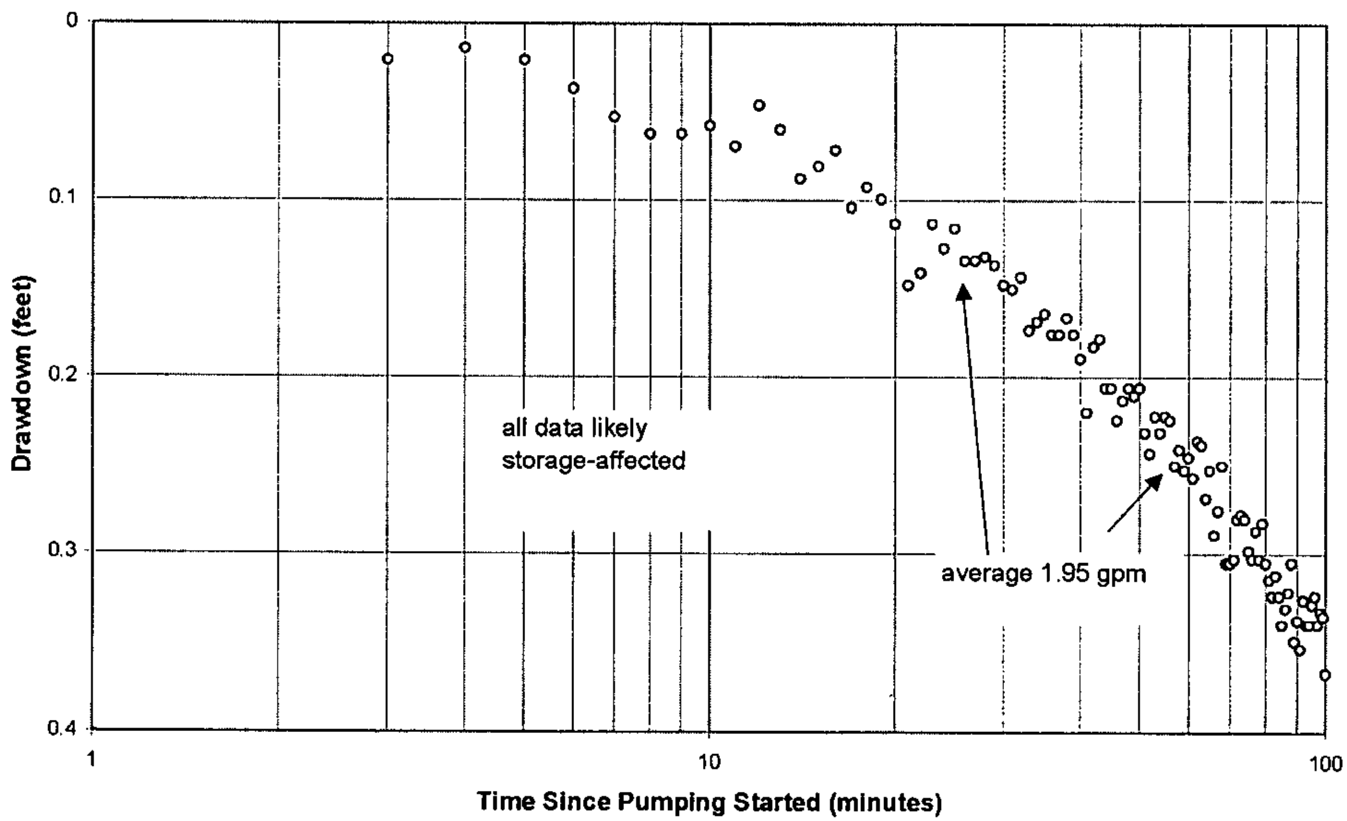


Figure 11. Well R-23i Screen 3 Trial 2 Recovery

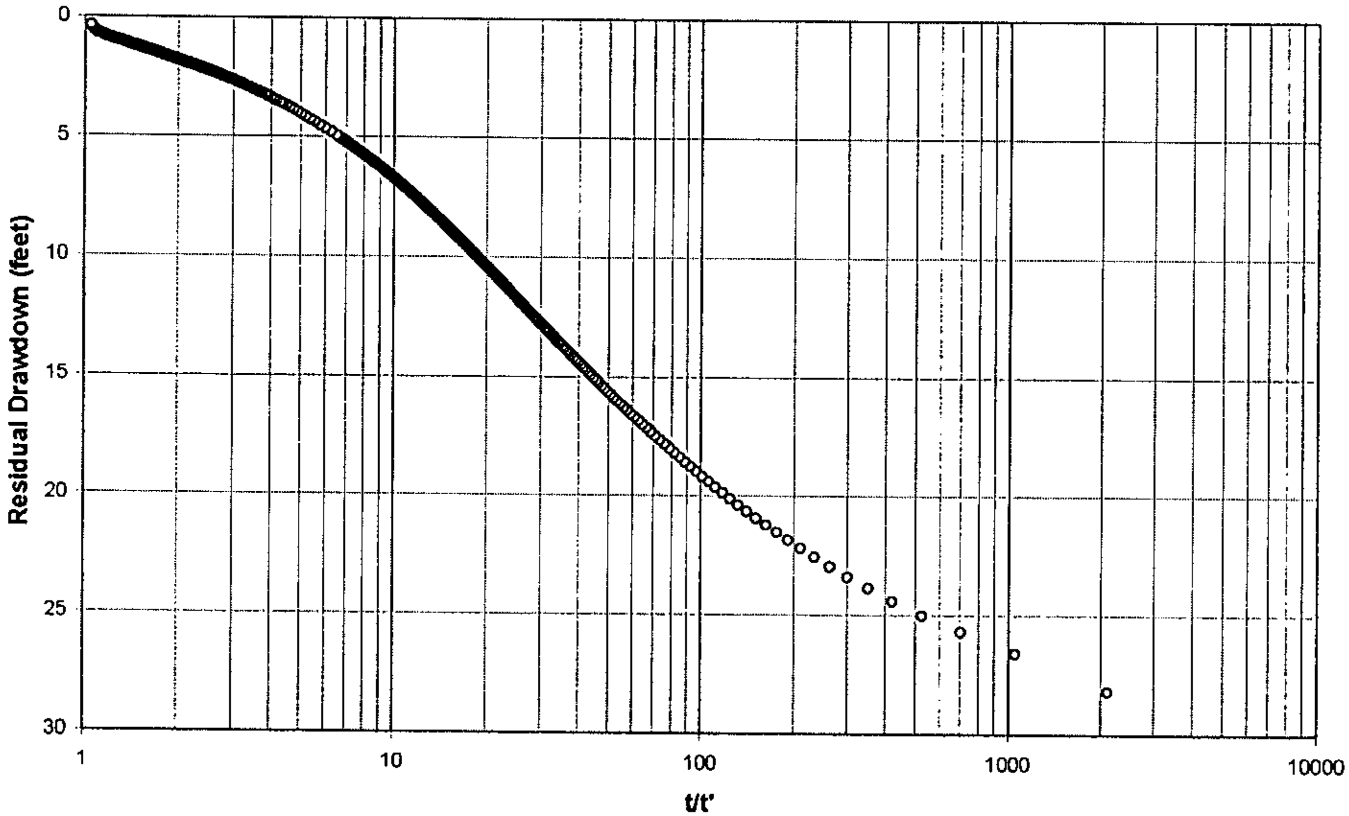


Figure 12. Well R-23i Screen 3 Trial 2 Recovery - Early Data

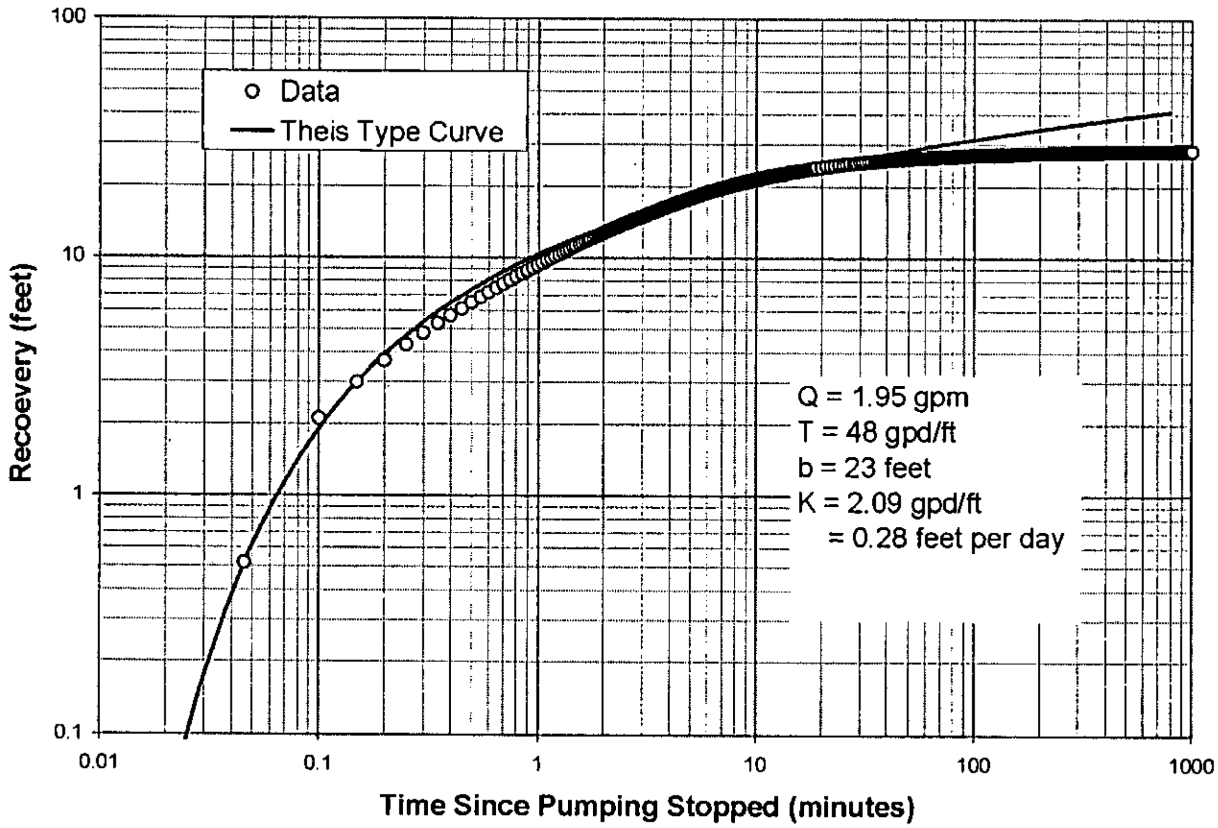


Figure 13. Well R-23i Screen 3 Trial 2 Recovery - Late Data

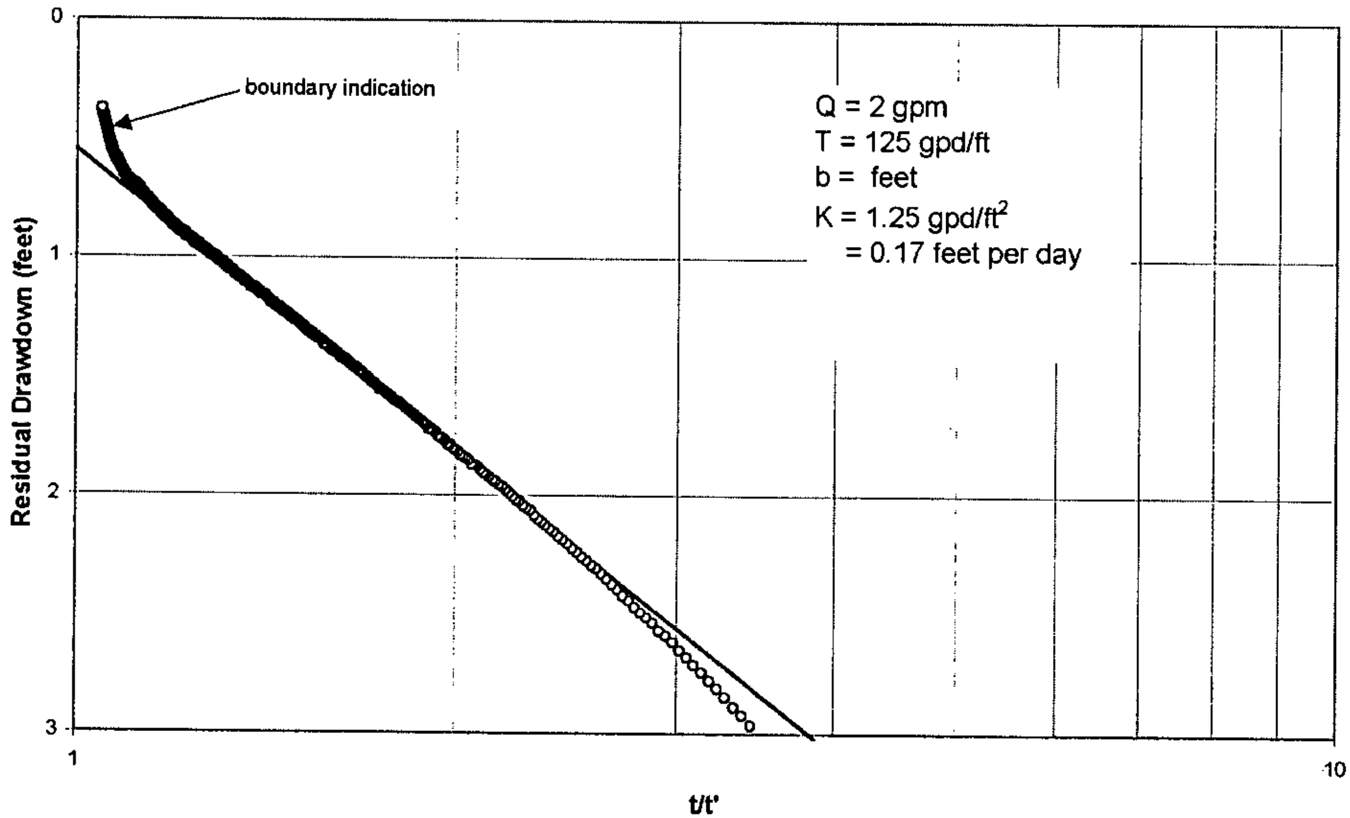


Figure 14. Well R-23i Screen 2 Trial 2 Recovery

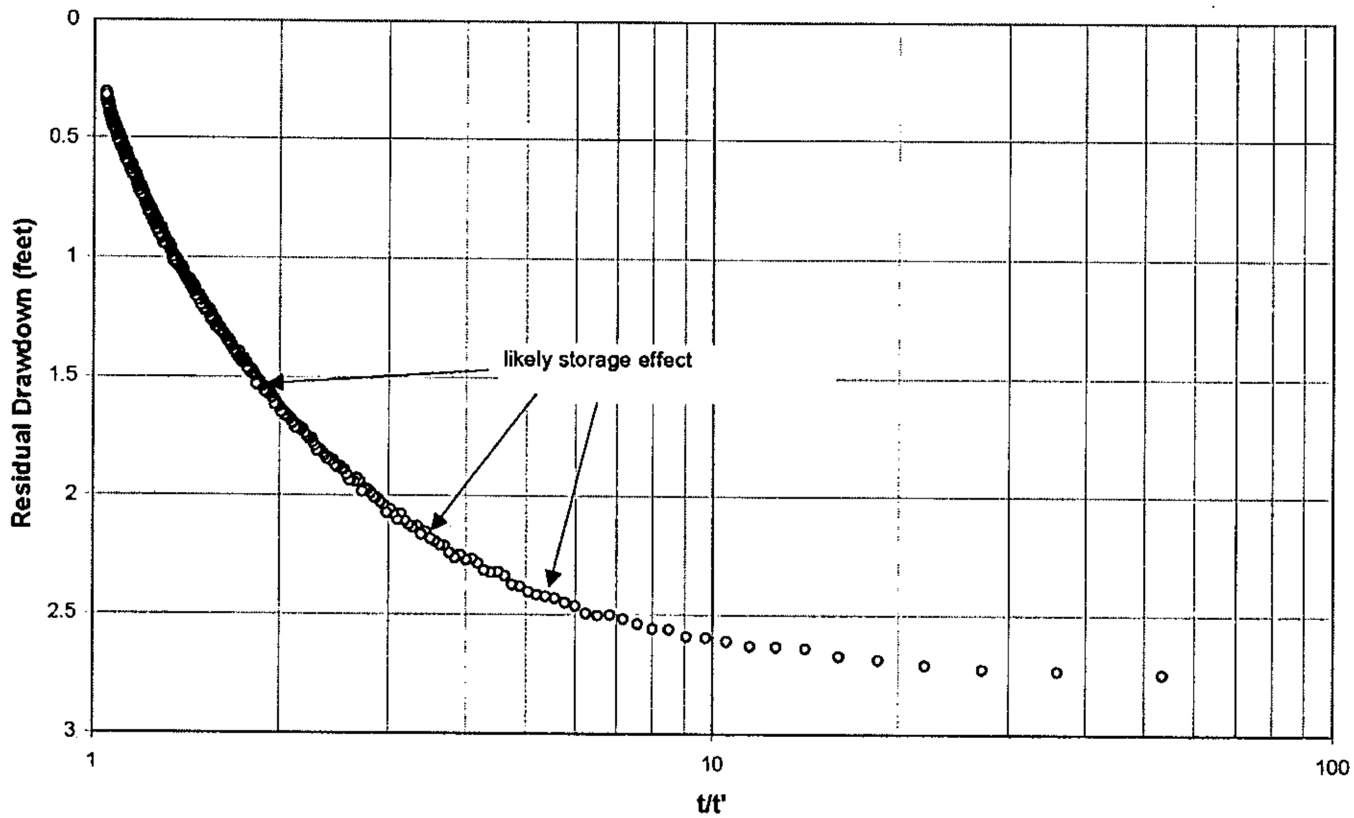


Figure 15. Well R-23i Screen 2 Trial 2 Recovery - Expanded Scale

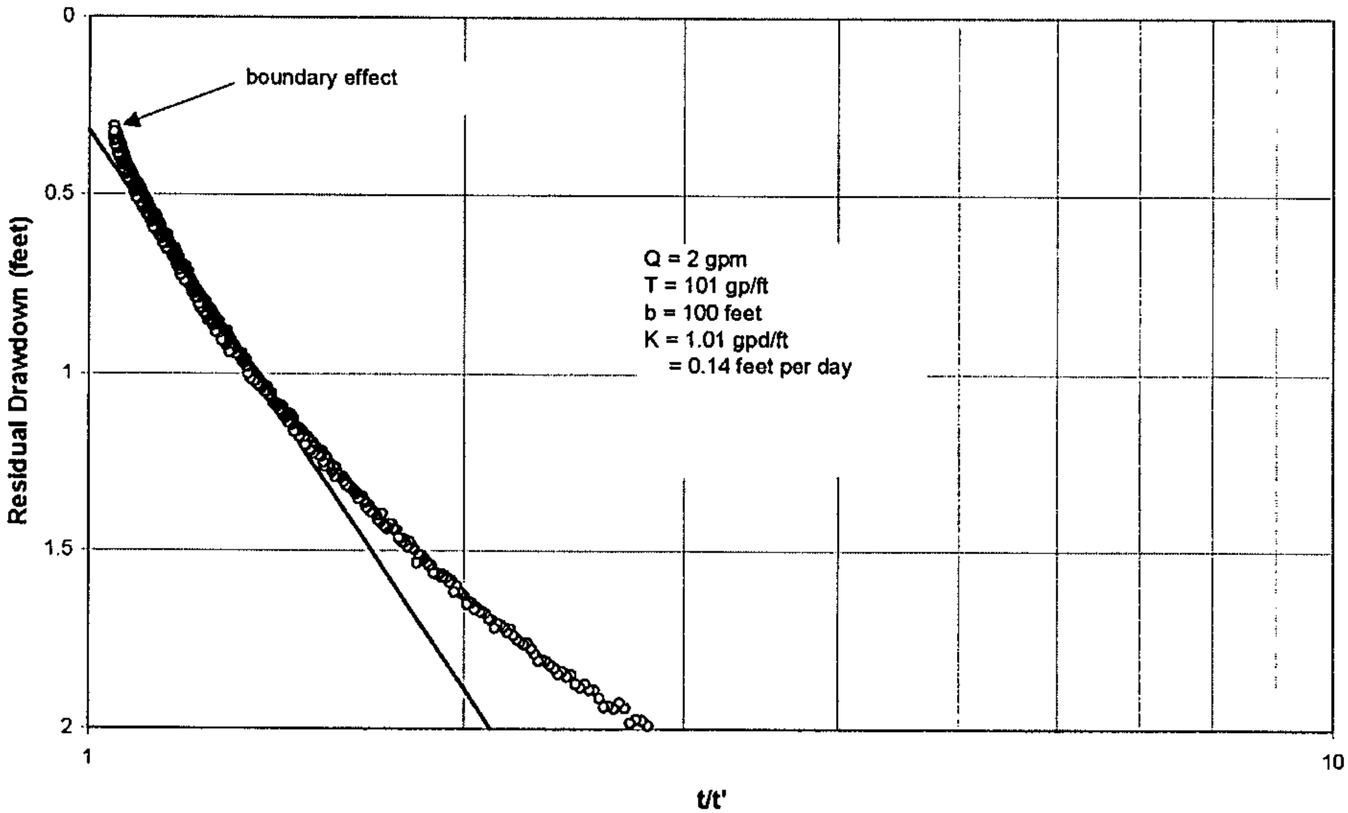


Figure 16. Well R-23i Screen 3 Drawdown

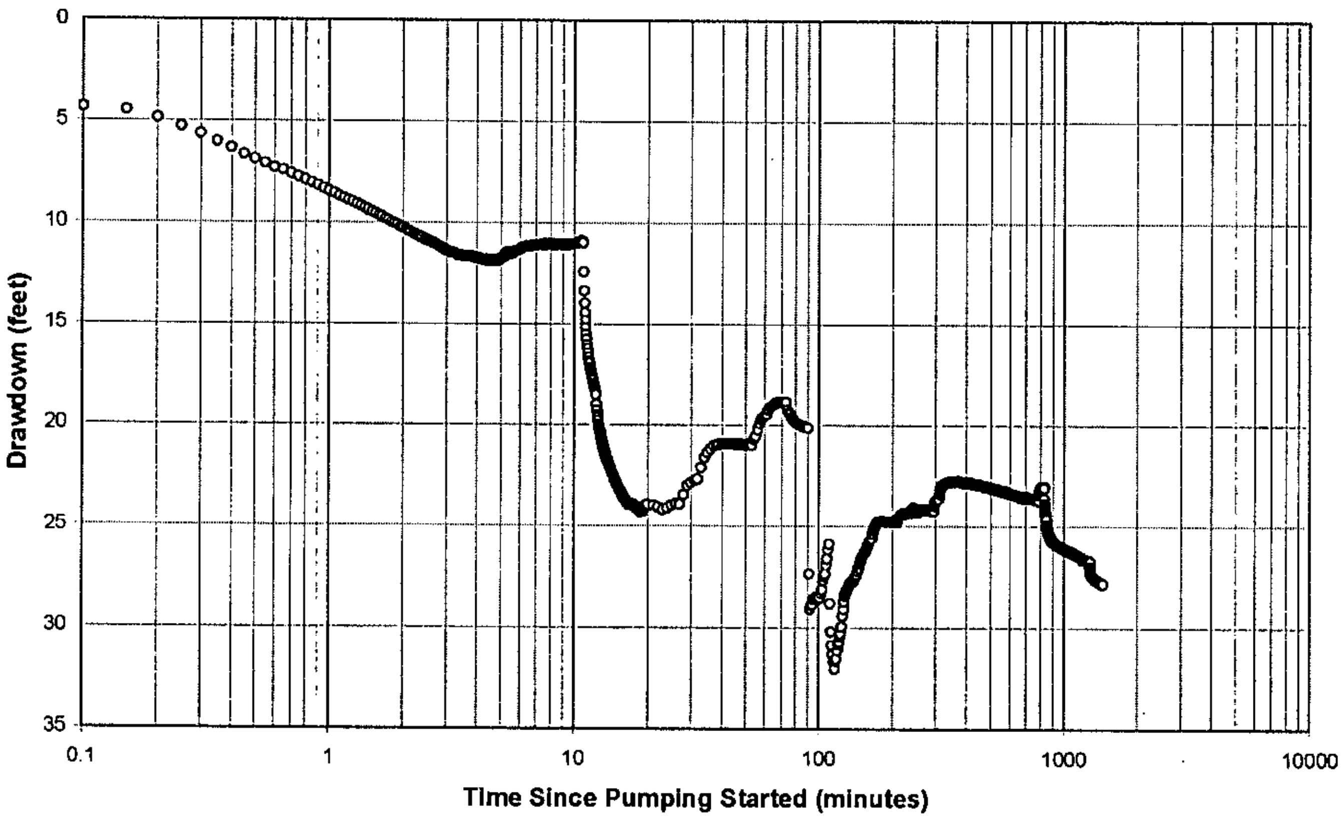


Figure 17. Well R-23i Screen 2 Drawdown

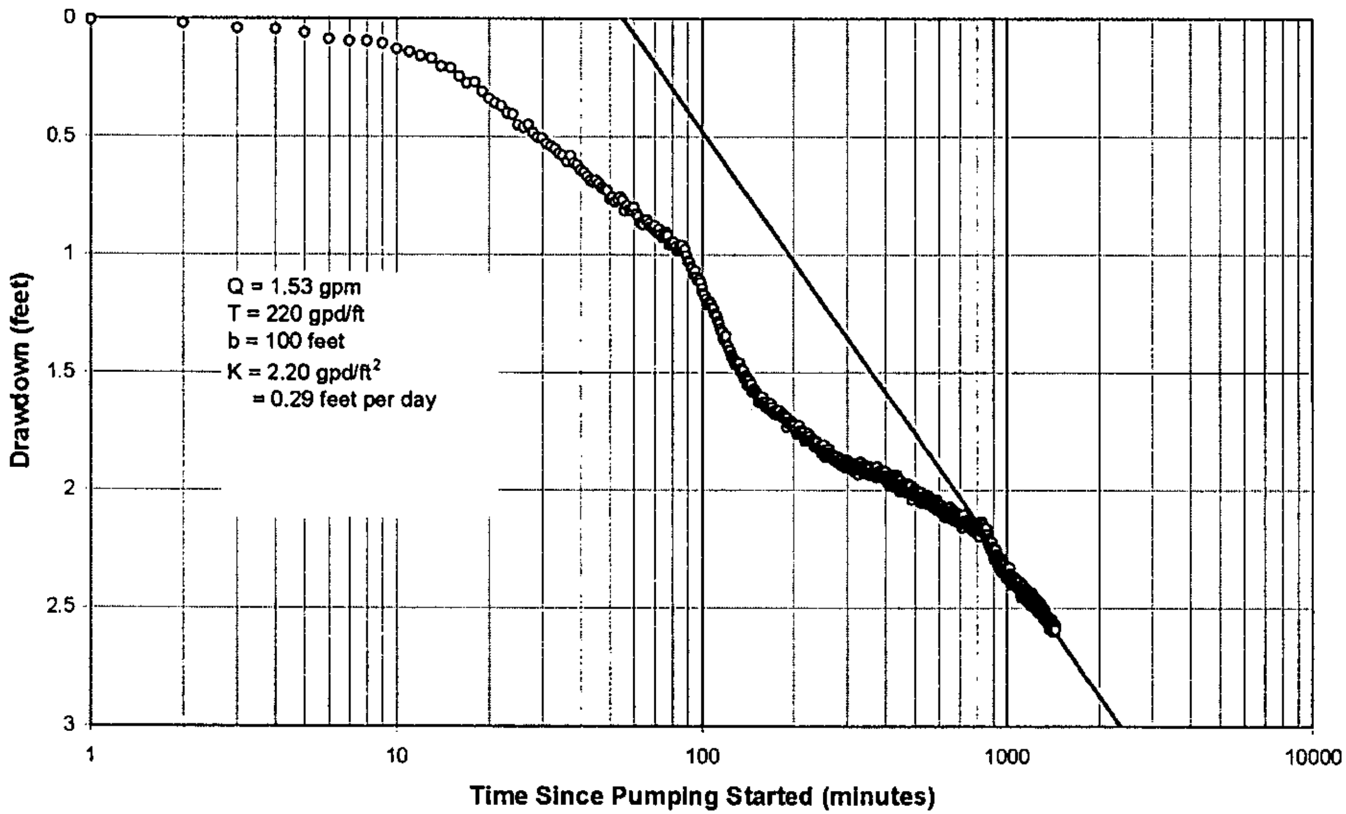


Figure 18. Well R-23i Screen 2 Drawdown Hantush Solution For Anisotropy of 10

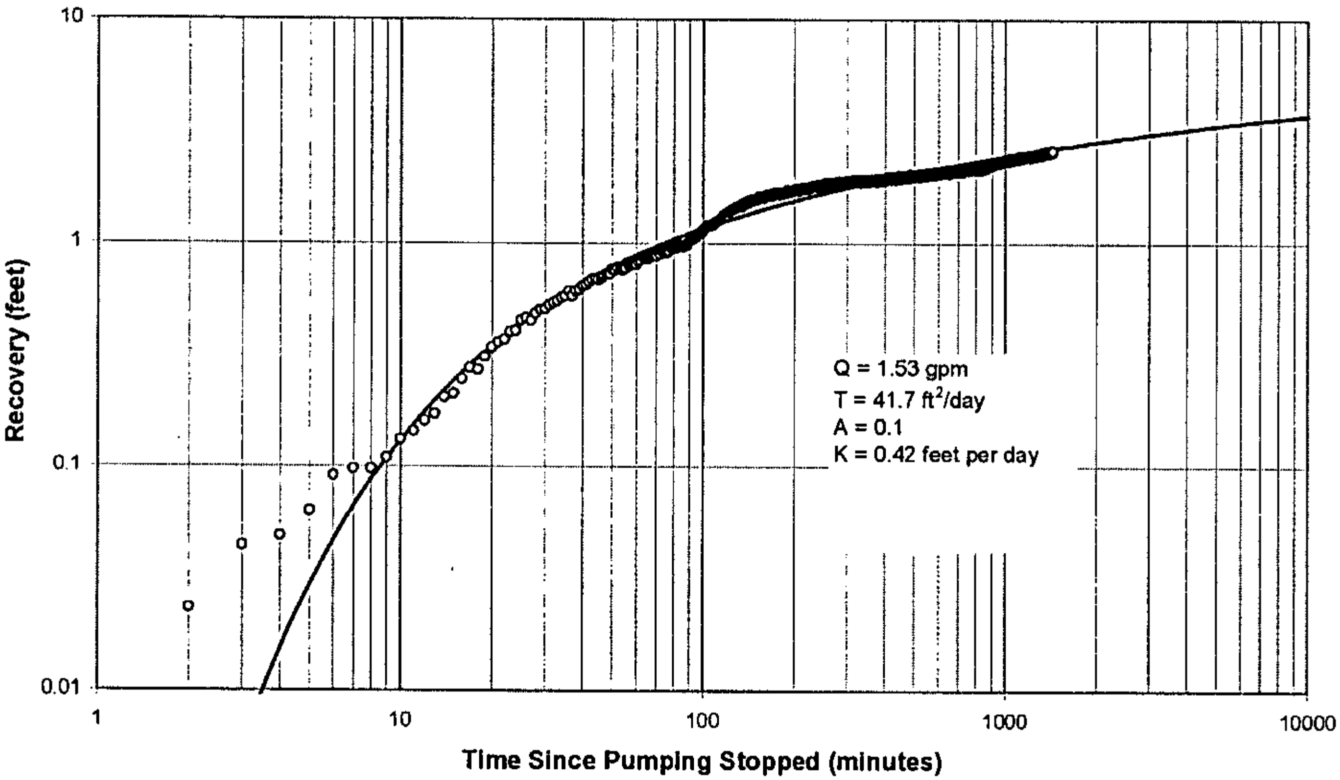


Figure 19. Well R-23i Screen 2 Drawdown Hantush Solution For Anisotropy of 100

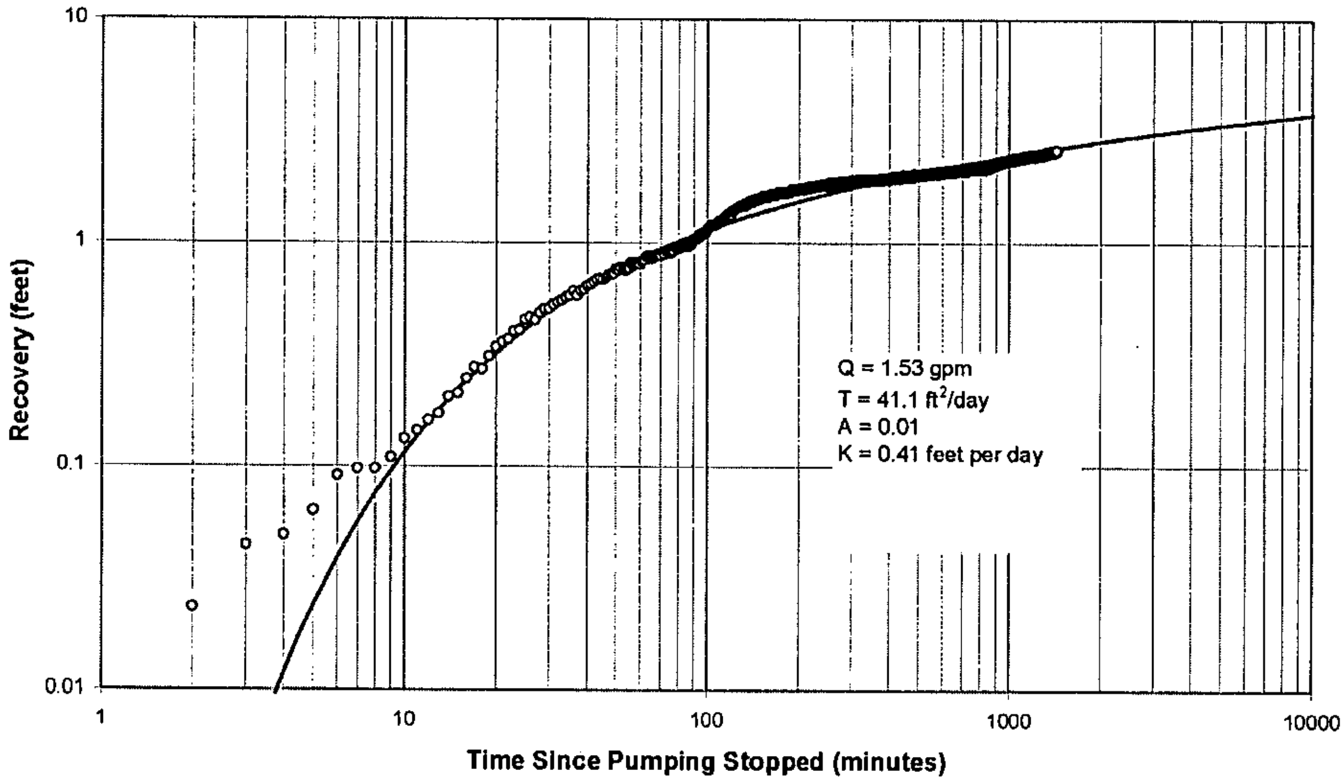


Figure 20. Well R-23i Screen 2 Drawdown
Hantush Solution For Anisotropy of 1000

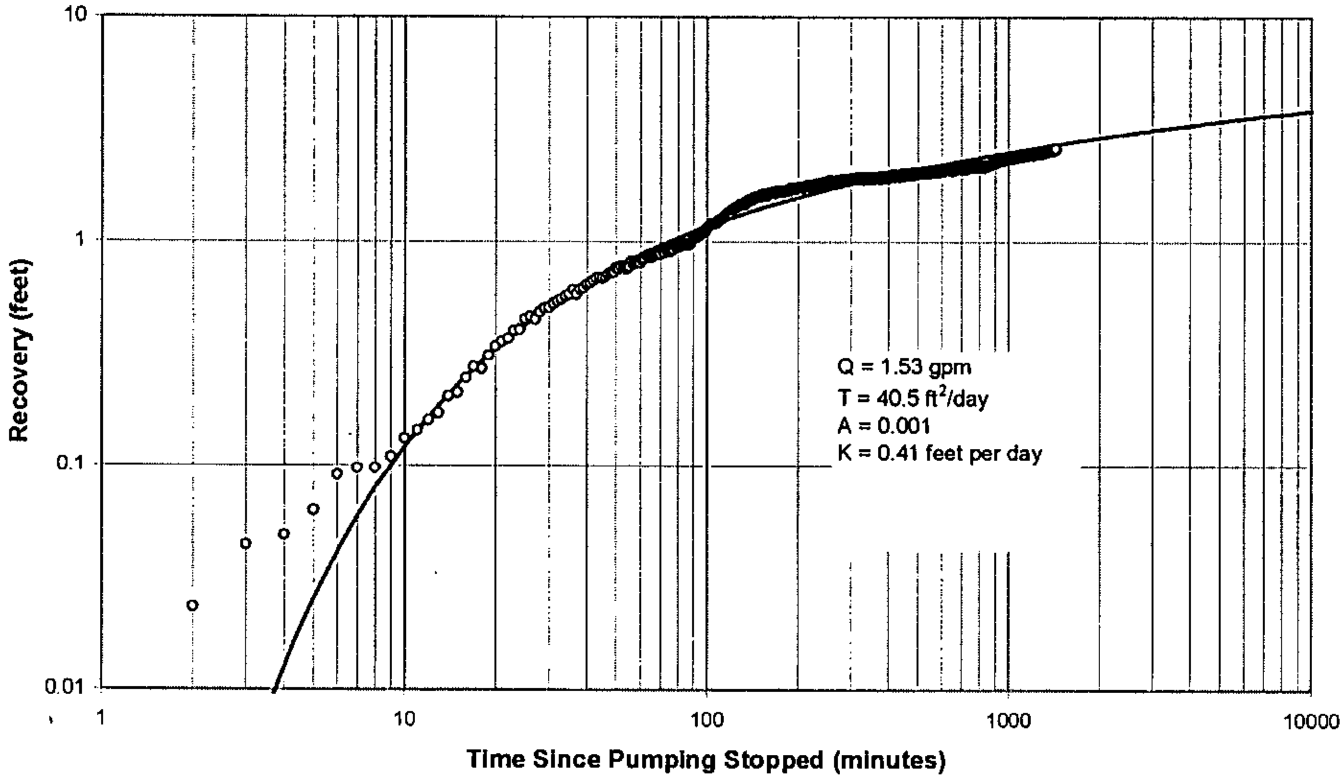


Figure 21. Well R-23i Screen 3 Recovery

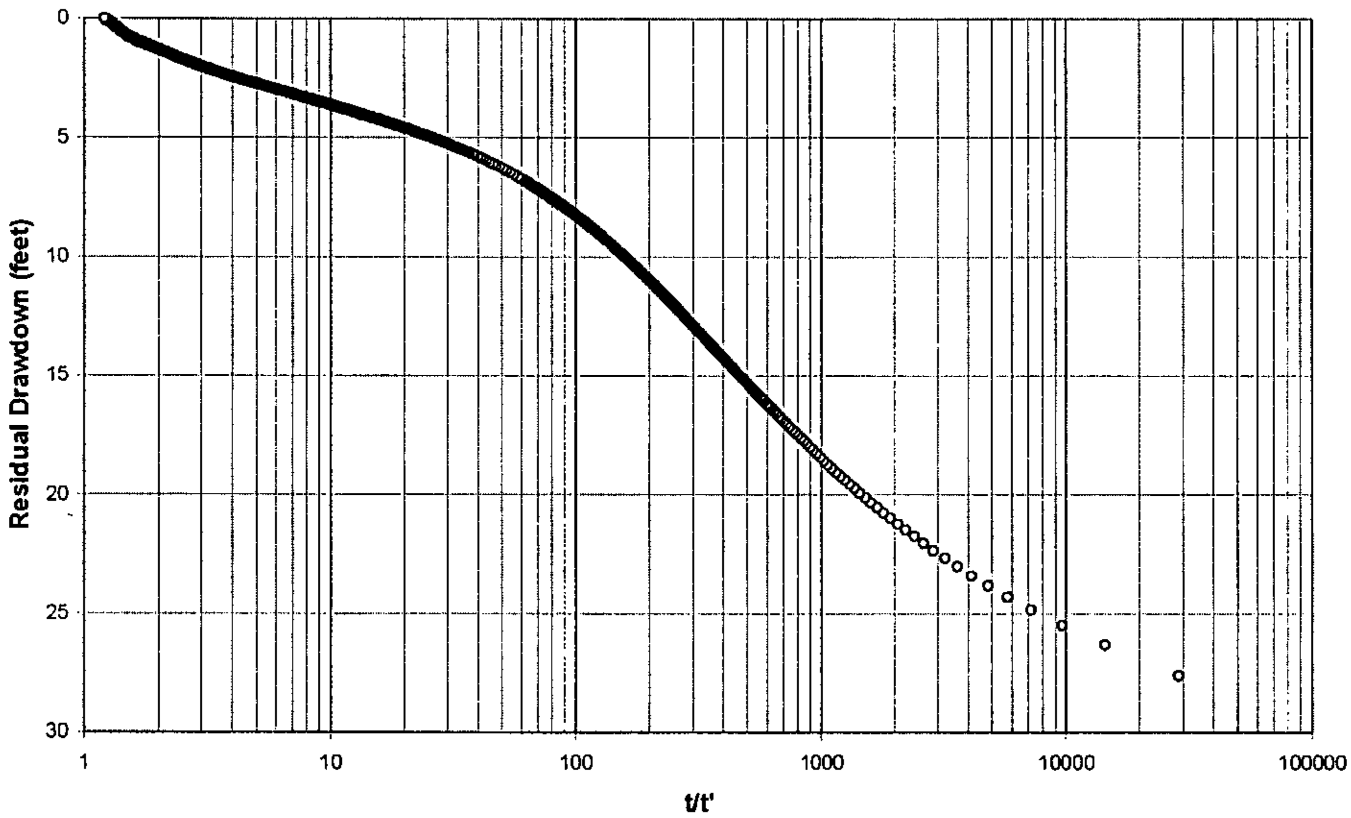


Figure 22. Well R-23i Screen 3 Recovery - Early Data

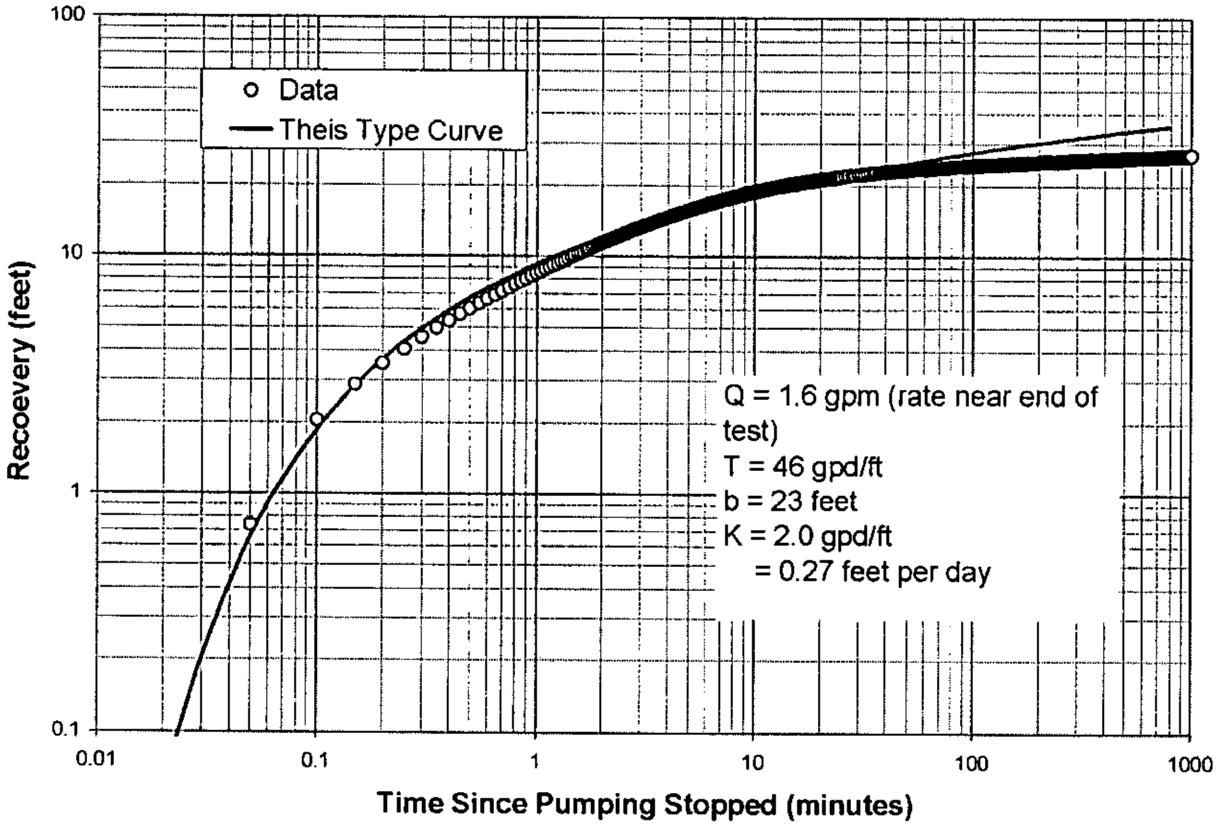


Figure 23. Well R-23i Screen 3 Recovery - Late Data

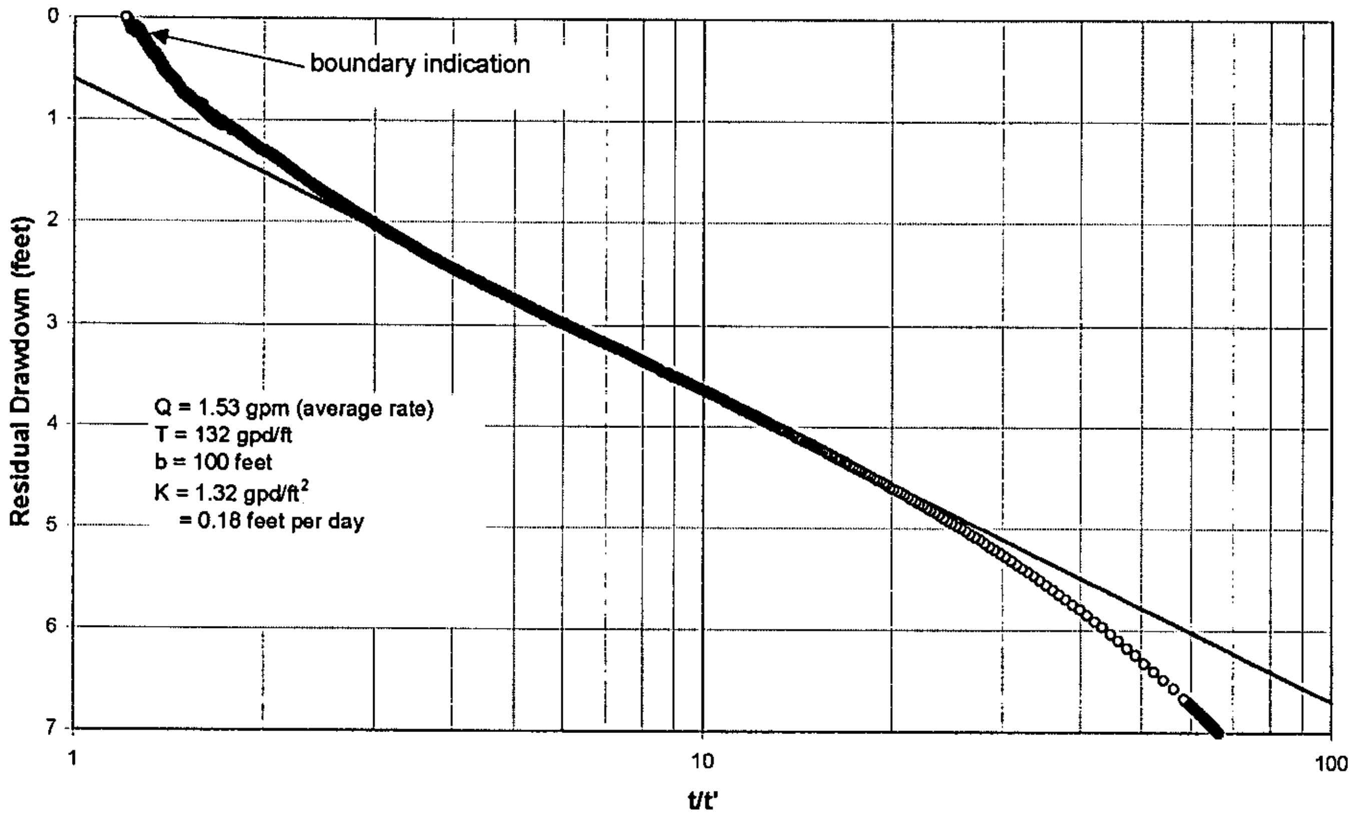


Figure 24. Well R-23i Screen 2 Recovery

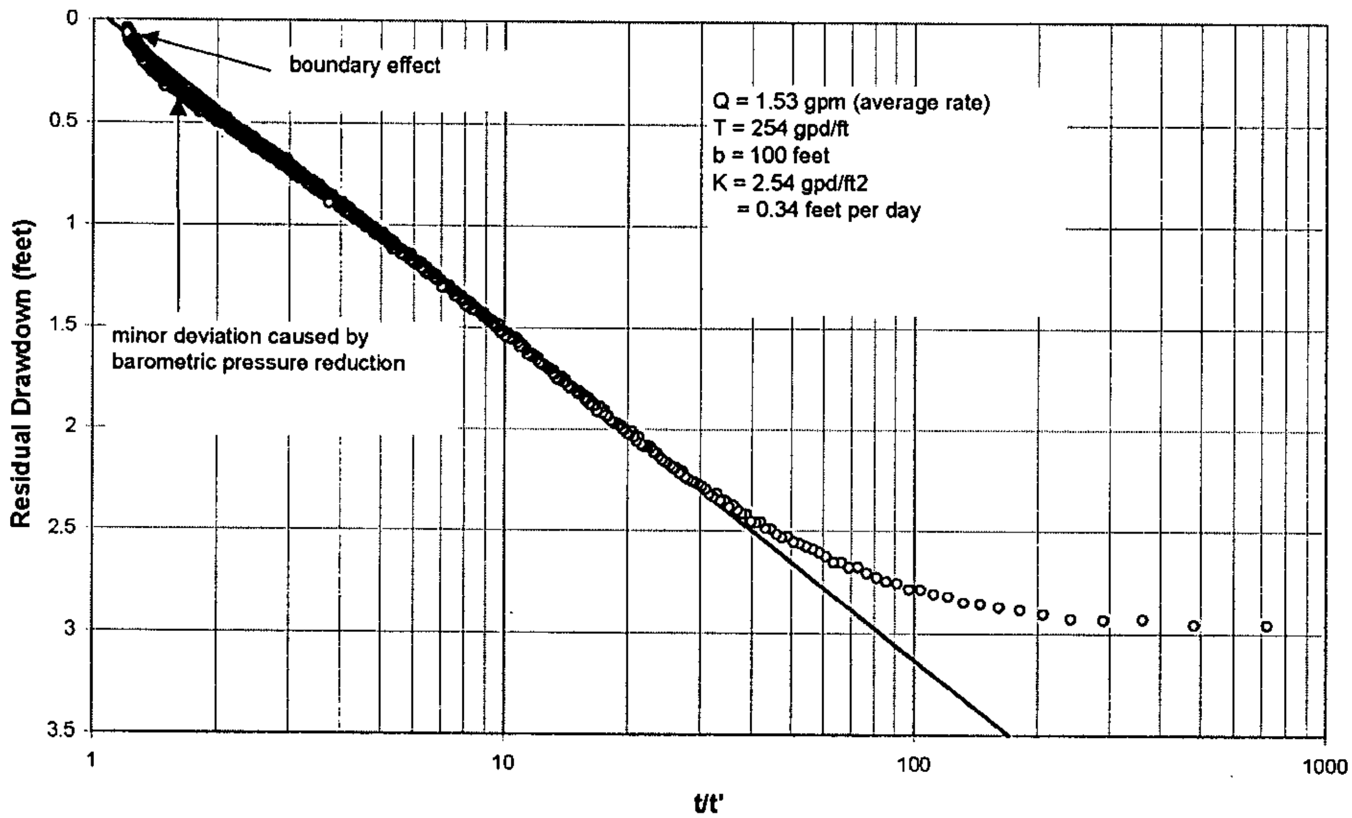


Figure 25. Well R-23i Screen 2 Recovery
Hantush Solution For Anisotropy of 10

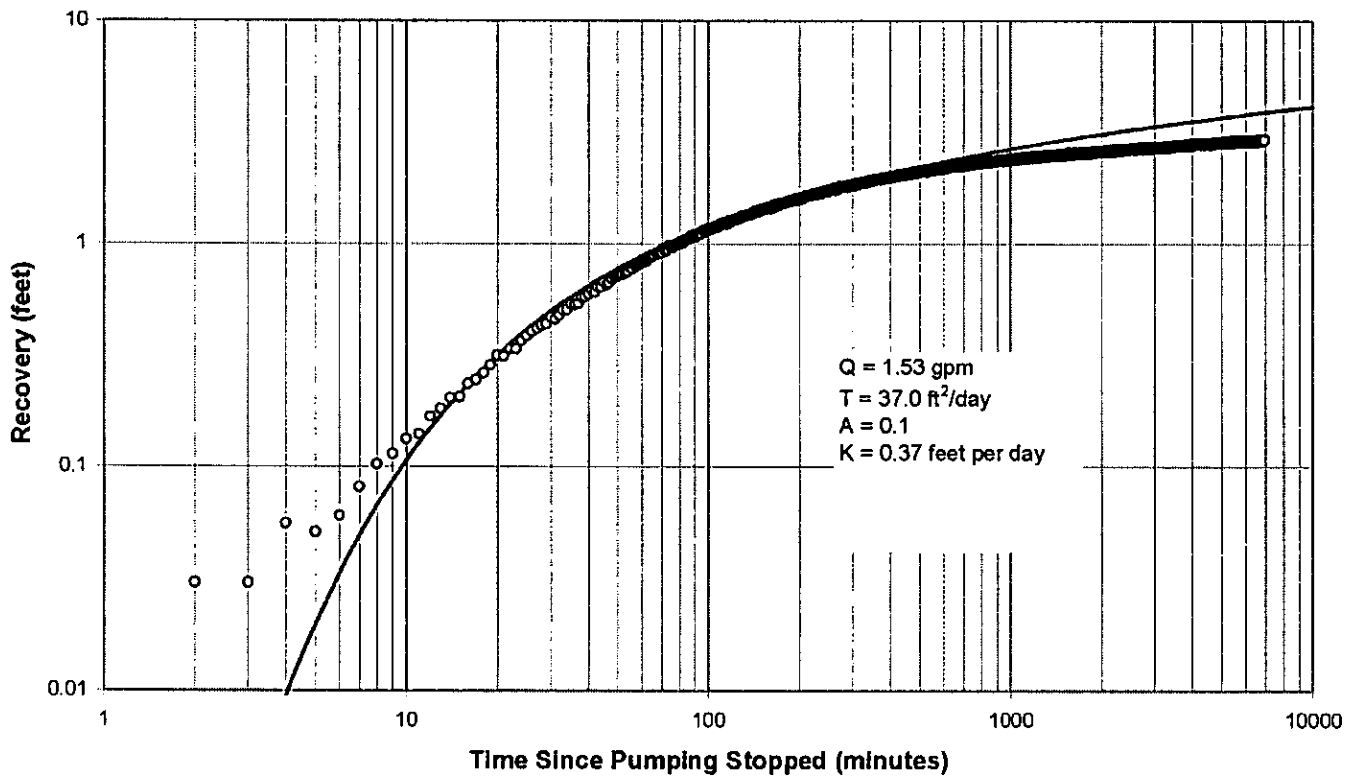


**Figure 26. Well R-23i Screen 2 Recovery
Hantush Solution For Anisotropy of 100**

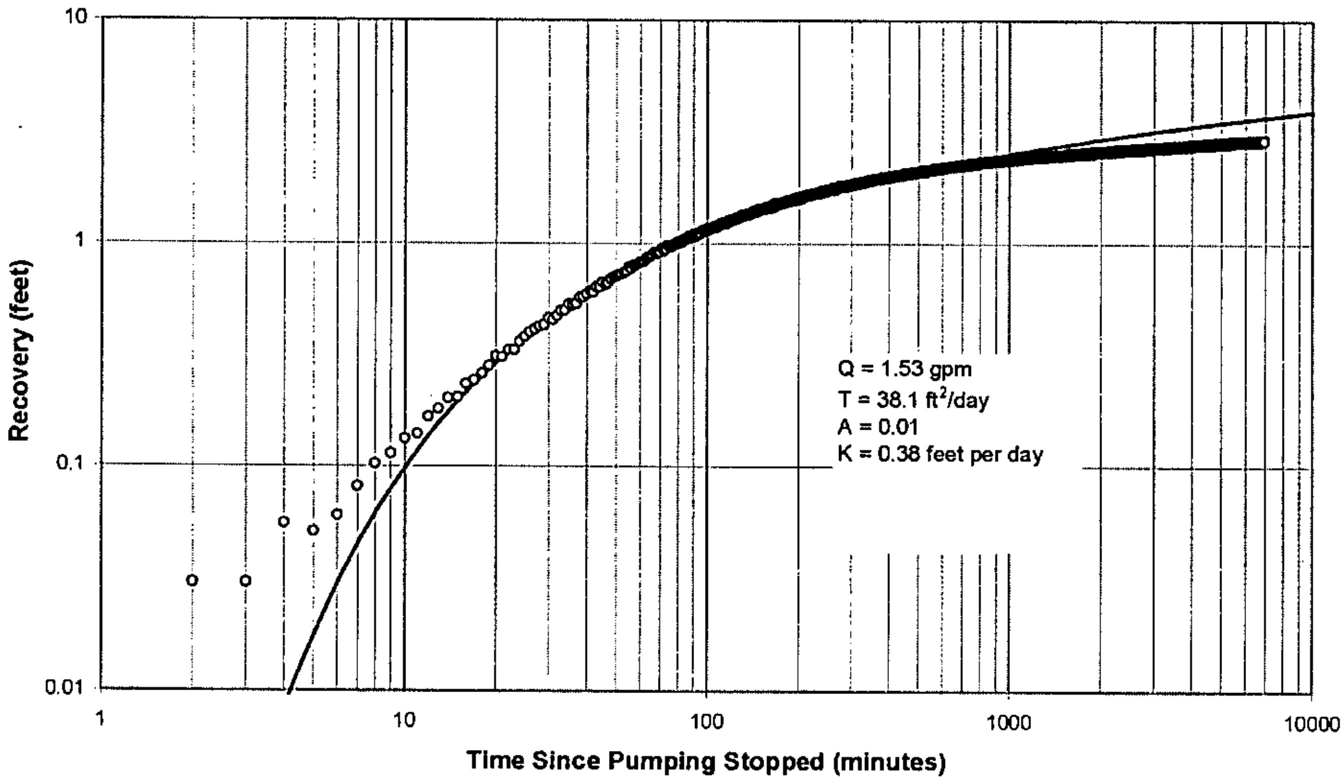
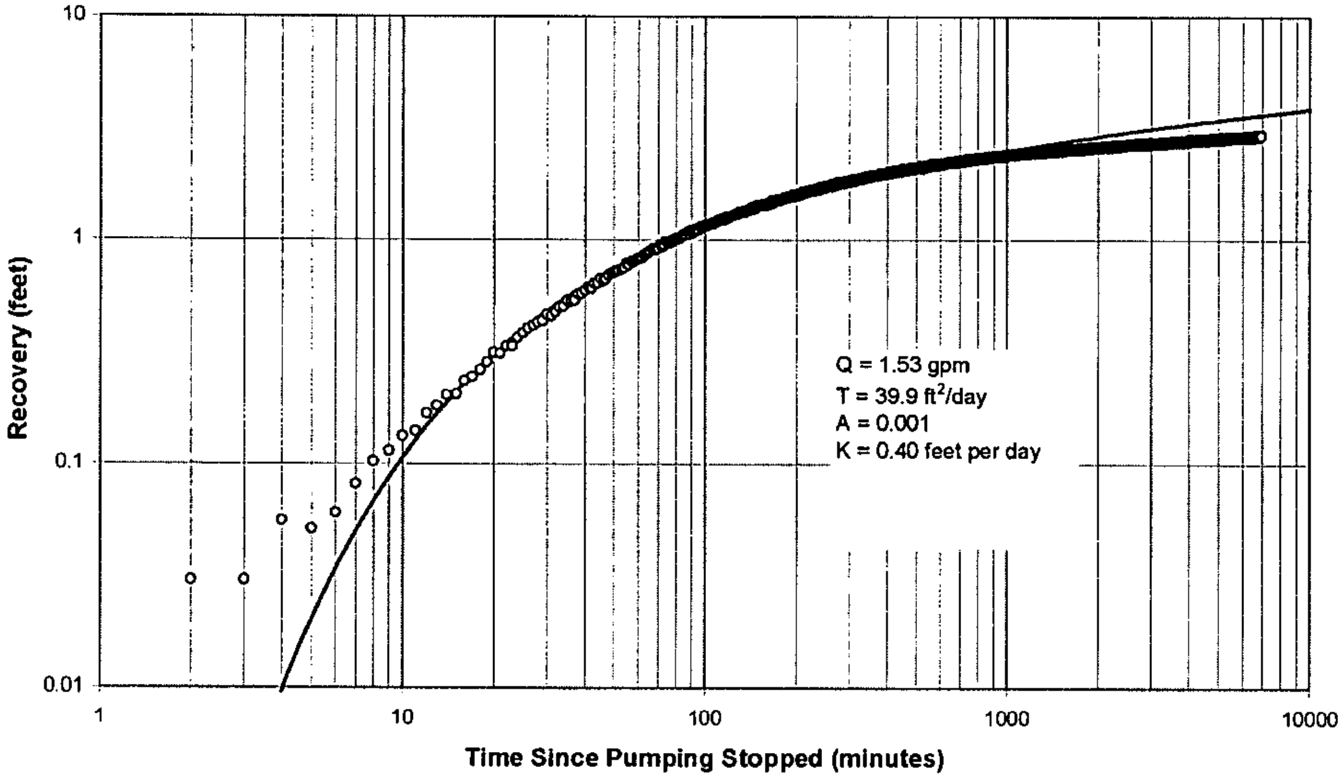


Figure 27. Well R-23i Screen 2 Recovery
Hantush Solution For Anisotropy of 1000



Appendix F

Deviations from Planned Activities

Activity	Drilling Work Plan for R-23i (Kleinfelder 2005a)	R-23i Actual Work
Cuttings Sampling	The work plan called for cuttings to be collected and sieved at 5-foot (ft) intervals beginning at 550 ft below ground surface (bgs)	LANL scientists requested that samples be collected at 5-ft intervals beginning at 400 ft bgs and that request was followed.
Water Sample Analyses	The work plan called for groundwater samples to be analyzed for perchlorate, anions, cations, and metals.	Screening and final groundwater samples were submitted for analysis of anions, cations, metals, and perchlorate. Additionally, one of the final samples was submitted for high explosives analysis.
Primary Filter Pack, Bottom Screened Interval	The work plan called for 5 ft of primary filter pack sand below each screened interval.	There is 3 ft of filter pack sand beneath the bottom screened interval.
Primary Filter Pack, Middle Screened Interval	The work plan called for 10/20 silica sand to be installed as a primary filter pack to 5 ft above and below the screened interval.	During well construction, formation slough accumulated across the majority of the middle screened interval, precluding the installation of the primary filter pack.

TARGET PAGE

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RECORD TYPE: CD/DVD

DATE: March 2006

SYMBOL: Project 494320

SUBJECT: R-23i Final Well completion Report

Appendix A - R-23i Bore hole Video Log

October 20, 2005 0-476 ft bgs

TARGET PAGE

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ER ID # 092495

RECORD TYPE: CD

DATE: 4 March 2004

SYMBOL: Project 49436

SUBJECT: Information & Table of contents Appendices A through F & Geophysical Files