REPORT
June 9, 2016

Prepared for:

Resolution Copper Mining

Results of Drilling, Construction, and Testing at Hydrologic Test Wells HRES-01, HRES-02, HRES-03, HRES-04, and HRES-05

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RESOLUTION COPPER MINING LLC, PINAL COUNTY, ARIZONA

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1 INTRODUCTION

Hydrologic test wells HRES-01, HRES-02, HRES-03, HRES-04, and HRES-05 were drilled and constructed during the period February 2 to March 11, 2004. The test wells were drilled evaluate lithologic and hydrogeologic conditions within the Apache Leap Tuff, and were terminated in the uppermost part of the Whitetail Conglomerate. Final test well construction was designed to permit hydrologic testing of the Apache Leap Tuff aquifer, and to provide access for long-term monitoring of groundwater level and groundwater quality for the aquifer. This report was prepared to provide construction details for the wells installed in 2004. Locations for the hydrologic test wells are shown on **Figure 1**. Schematic diagrams summarizing well construction details for each well are shown on **Figures 2 through 6**. Other data summarized on the schematic diagrams include: hydrogeologic units, fracture summary log, drilling penetration rate, water production during drilling operations, and borehole geophysical logs. Summary lithologic logs for the test wells are provided in **Appendix A**. Detailed description of hydraulic testing and results of analysis for hydraulic parameters are provided in **Appendix B**.

2 DRILLING OPERATIONS

The hydrologic test wells were drilled and constructed by Lang Exploratory Drilling (Lang) of Salt Lake City, Utah using a Lang LM-140 drill rig. The wells were drilled in accordance with technical specifications that were prepared by Resolution Copper Company (RCC) with technical input from Montgomery & Associates. Daily drilling reports were prepared by Lang personnel and were submitted to RCC personnel for review. RCC personnel coordinated drilling contractor activities and purchase of well construction materials, and prepared detailed lithologic descriptions for drill cuttings samples. Additional on-site monitoring was provided by Montgomery & Associates personnel during critical phases of drilling and construction for each well. Final completion of each well was designed by Montgomery & Associates based on review of lithologic and hydrologic conditions encountered during drilling operations, and results of borehole geophysical logs.

2.1 Drilling Method

Boreholes for the wells were drilled using the direct air-rotary drilling method for the surface casing borehole, and either the dual-wall, air reverse-circulation rotary method or the air-assisted, flooded reverse-circulation rotary method for the main exploration borehole. At each site, a 17-1/2-inch borehole was drilled to a depth of about 6 meters, and 12-inch blank steel surface casing was set and cemented. Drilling of the main borehole commenced using a 9-inch air hammer and the dual-wall reverse circulation drilling method. The change to an 8-3/4-inch tri-cone bit or to the flooded reverse-circulation rotary drilling method occurred when water entering the borehole from the formation impeded advancement of the borehole with the hammer bit or when management of water at the surface became an issue. Drilling methods are summarized by interval for each well in **Table 1**.

Table 1. Summary of Methods Used for Drilling of Hydrologic Test Wells HRES-01 through HRES-05

Drilling Method	Depth Interval (meters)				
	HRES-01	HRES-02	HRES-03	HRES-04	HRES-05
Direct Air Rotary	0-6	0-6	0-6	0-6	0-6
Dual-wall Air Reverse 9-inch Air Hammer Bit	6-423	6-211	6-472	6-231	6-295
Dual-wall Air Reverse 8-3/4-inch Tri-cone Bit	423-574.5	---	472-645	---	---
Flooded Reverse Rotary	---	211-483.8	---	231-532.5	295-349.6
Total Borehole Depth	**574.5**	**483.8**	**645.0**	**532.5**	**349.6**

2.2 Drilling Fluid Management

Air and water were the only drilling fluids used during drilling operations. Water for drilling operations was obtained from the Shaft No. 9 site water supply system. This water system is provided from pumping of water that drains from the Apache Leap Tuff aquifer into Shaft No. 9, and is collected at the tail-drift sump of the Neversweat Tunnel where the tunnel intersects Shaft No. 9. During drilling operations, drilling fluids were discharged to a cyclone to separate air from the fluid stream. The remaining water and cuttings then flowed through a vibrating screen to remove coarse cuttings, and the remaining fine material and water were contained in a portable mud pit and an excavated sump next to the drill rig. Sediments were allowed to settle before decanted drilling water was pumped to a 20,000 gallon mobile storage tank (Baker tank) for further settling of sediments.

At each drill site, water from the Baker tank was pumped to several large-capacity irrigation sprinklers for dispersal to surrounding countryside to prevent erosion and minimize runoff into nearby drainages. Water samples were collected from the sprinkler system during drilling at HRES-01 and submitted for laboratory chemical analyses for common constituents and selected trace constituents. Additional water samples were obtained from the discharge during open-borehole air-lift pumping tests at HRES-02 through HRES-05. With the exception of turbidity, results of laboratory chemical analyses indicated that water quality was excellent, and was similar to groundwater in the Apache Leap Tuff aquifer. The elevated turbidity was considered reasonable for land application and infiltration of the dispersed water.

2.3 Monitoring of Lithologic Conditions

During drilling operations, the drilling contractor recorded time interval to drill each 6-meter drill rod. Drill penetration rates for each well are summarized on **Figures 2 through 6.** Drill cuttings samples were collected at 3-meter intervals and placed in labeled plastic bags. Lithologic descriptions for each sample were prepared at the RCC core shed by a RCC geologist. Splits of each sample were placed in chip trays at the time of sample description and are stored by RCC. Lithologic logs are given in **Appendix A**. Logs summarizing interpretation of lithologic descriptions are shown on **Figures 2 through 6.** Lithologic units encountered at each well are summarized on **Table 2**.

Table 2. Summary of Lithologic Units Encountered at Hydrologic Test Wells HRES-01 through HRES-05

Lithologic Unit	Depth Interval (meters)				
	HRES-01	HRES-02	HRES-03	HRES-04	HRES-05
Apache Leap Tuff	0-513	0-456	0-612	0-513	0-324
Whitetail Conglomerate	513-574.5	456-382.8	612-627	513-532.5	324-349.6
Older Volcanic Units	---	---	627-645	---	---

2.4 Monitoring of Groundwater Conditions

When the dual-wall air reverse-circulation drilling method was used, it was possible to monitor for the presence of groundwater, and to determine approximately where groundwater inflow zones were encountered. The drilling contractor monitored groundwater production from the borehole using a methodology developed in cooperation with Montgomery & Associates field personnel. Observations of natural groundwater production were made after drilling out each 20-foot drill rod. Injection water was cut off from the air stream, and air circulation was continued for 5 to 15 minutes. Once water flow from the cyclone stabilized, a flow measurement was obtained from the outlet of the portable mud tank using a 5-gallon bucket and a stop watch, and results were recorded on the drillers' field log. These measurements are considered to represent qualitative changes in natural groundwater inflow into the borehole, and were useful for identifying approximate depths of groundwater inflow zones in the borehole. At wells HRES-02, HRES-04, and HRES-05, observations of groundwater inflow were not possible once change-over to the flooded reverse-circulation rotary drilling method occurred. Results of flow measurements made during drilling operations for each well are summarized on **Figures 2 through 6**.

3 BOREHOLE GEOPHYSICAL LOGGING

Once boreholes for the hydrologic test wells reached total depth, borehole geophysical logging was conducted using a variety of geophysical tools. Purpose of borehole geophysical logging was to identify important geologic contacts, to evaluate degree of fracturing encountered in the borehole, and to identify potential zones of groundwater movement and potential vertical flow in the borehole. Borehole geophysical logging services were provided by Southwest Exploration Services, LLC, Gilbert, Arizona.

A standard suite of borehole geophysical logs was conducted for all of the wells. These standard logs included: caliper, temperature, fluid resistivity, natural gamma ray, spontaneous potential, single point resistance, short-long normal resistivity, and sonic. Guard log resistivity logging was conducted at HRES-1 but was dropped from future logging suites because results were very similar to normal resistivity logs. Several borehole imaging logs were conducted at selected boreholes to evaluate effectiveness of these methods for delineating fractures that intersect the borehole, and for observing water entering the borehole above fluid levels in the borehole. These imaging logs included Acoustic Televiewer (ATV), Optical Borehole Imaging (OBI), and conventional dual-scan borehole video survey.

Results of borehole geophysical logging for hydrologic test wells HRES-01 through HRES-05 are shown on **Figures 2 through 6**. Maximum depth and depth intervals logged varied from borehole to borehole, and from tool to tool. Caliper and natural gamma can be run in both the unsaturated and saturated parts of a borehole, whereas temperature, fluid resistivity, spontaneous potential, single point resistance, normal resistivity, sonic, and ATV require a fluid-filled borehole. Borehole video and OBI logs can be run in both the unsaturated and saturated parts of the borehole, but any turbidity in the fluid-filled borehole can significantly limit visibility. Borehole geophysical logging conducted for each borehole is summarized on **Table 3**.

Table 3. Summary of Borehole Geophysical Logging Conducted for Hydrologic Test Wells HRES-01 through HRES-05

Log Type	HRES-01	HRES-02	HRES-03	HRES-04	HRES-05
<u>Standard</u>					
Caliper	X	X	X	X	X
Temperature	X	X	X	X	X
Fluid Resistivity	X	X	X	X	X
Natural Gamma Ray	X	X	X	X	X
Spontaneous Potential	X	X	X	X	X
Single-Point Resistance	X	X	X	X	X
Guard Log Resistivity	X				
8-inch Normal Resistivity	X	X	X	X	X
16-inch Normal Resistivity	X	X	X	X	X
64-inch Normal Resistivity	X	X	X	X	X
Sonic	X	X	X	X	X
<u>Borehole Imaging</u>					
Acoustic Televiewer	X	X			X
Optical Borehole Imaging	X				
Borehole Video	X	X	X		

A brief description of each logging parameter is provided below:

<u>Caliper:</u> The caliper log provides a continuous record of borehole diameter. For the HRES boreholes, a 3-arm caliper tool was used. This log is useful for evaluating location of washouts or open fractures in the borehole, and areas of potential borehole instability that should be considered during installation of well construction materials.

<u>Temperature:</u> The temperature log measures fluid temperature in the borehole. The log is most useful for identifying groundwater inflow zones, or for evaluating vertical flow within the wellbore under static or pumping conditions. In the absence of vertical flow in the borehole, fluid temperature typically increases with depth, following the geothermal gradient.

<u>Fluid Resistivity:</u> The fluid resistivity log measures the resistance of the borehole fluid to the flow of electrical current between two electrodes on the tool, and is continuously recorded in units of ohm-meters. Fluid resistivity is the reciprocal of electrical conductivity, which is a standard water quality parameter that gives a general indication of mineral content of the water. As with temperature logging, may be useful for identifying zones of groundwater inflow, if a sufficient contrast in water quality exists between the groundwater entering the borehole and ambient borehole fluid.

Natural Gamma Ray: The natural gamma ray (NGR) log provides a continuous measurement of the natural radioactivity (gamma radiation) of the rock units penetrated by the borehole (Keys, 1989). Source of gamma radiation is from natural radioisotopes that occur in rock minerals such as potassium feldspar and micas, uranium, and thorium.

Spontaneous Potential: Spontaneous potential (SP) logs measure the difference in DC voltage between an electrode in the borehole, and one temporarily installed at the surface adjacent to the wellhead (Keys, 1989). Most of the voltage results from electrochemical potentials that develop between dissimilar borehole and formation fluids. SP logs can be useful in defining contacts between distinctly different lithologies, where effects of electrochemical potentials may be locally enhanced.

Single-Point Resistance: Single-point resistance logs record the electrical resistance between electrodes in the borehole and an electrical ground at land surface. In general, resistance increases with increasing grain size and/or lithification and decreases with increasing borehole diameter, fracture density, and dissolved-solids concentration of the water. Single-point resistance logs can be useful in the determination of lithology, water quality, and location of fracture zones.

Normal Resistivity: Normal resistivity logs record the electrical resistivity of the borehole environment and surrounding rocks and water as measured by variably spaced potential electrodes on the logging probe. Typical spacing for potential electrodes is 16 inches for short-normal resistivity and 64 inches for long-normal resistivity. Normal-resistivity logs are affected by bed thickness, borehole diameter, and borehole fluid.

Sonic: Sonic logs, also known as acoustic velocity logs, provide a record of the travel time of an acoustic wave from one or more acoustic transmitters to receivers on the probe (Keys, 1989). The acoustic energy travels through fluids in the borehole and through adjacent rocks at velocities related to the degree of rock matrix lithification and porosity.

Acoustic Televiewer: The acoustic televiewer (ATV) log provides a magnetically-oriented, acoustically-generated image of the borehole wall. The ATV probe utilizes a rotating transducer that serves as both a transmitter and receiver (Keys, 1989). High-frequency acoustic signal is reflected from the borehole wall, and does not penetrate the formation. The resulting image provides a graphic representation of variations in acoustic reflective properties of the borehole wall. Features such as fractures, fracture fill material, changes in lithification, contrasts in clast hardness, etc. will often appear in an ATV log. Because the log is oriented, strikes and dips of fracture planes can be determined, and apertures can be measured. Because borehole fluids provide the transmission media for the acoustical signal, ATV logs can be run only in a fluid-filled borehole.

Optical Televiewer: The optical televiewer, or optical borehole imaging (OBI) log provides an oriented, optically scanned image of the borehole wall. Similar to ATV logging, the OBI tool utilizes a rotating optical scanner to develop the optical borehole image. The resulting image provides a more direct image of the borehole wall, and is useful for evaluating fracturing, rock texture, bedding features, fill materials, voids, etc. As with the ATV log, the oriented output from the OBI log can be used to measure strikes and dips of fracture planes or bedding planes. A distinct disadvantage is that the OBI log requires that borehole fluids be free of turbidity, which is not often the case in a freshly-drilled borehole.

Borehole Video Survey: The borehole video survey uses conventional optical video camera technology to record a continuous image of the borehole. The dual-scan down-hole camera is equipped with one fixed lens oriented vertically downward, and one lens installed on a rotating head that provides a 360-degree side-scan view of the borehole. The operator can switch back and forth between the two views. A light head is mounted below the vertical lens to illuminate the borehole below the vertical camera lens, and a set of lamps is installed around the side-scan lens to illuminate the borehole wall locally. Light intensity and lens focus are adjusted as needed to maximize visibility. This method is very useful in seeing real-time features within the borehole, and allows the opportunity to explore borehole features during logging without post-processing of data.

3.1 Interpretation of Borehole Geophysical Logs

3.1.1 Geologic Contacts

Depths for important geologic contacts were initially estimated based on drill rig action and drill cuttings description. Depths for these geologic contacts were refined using borehole geophysical logs. Resistivity, spontaneous potential, natural gamma, and sonic logs all clearly showed the upper and lower contact of a vitrophyre unit within the Apache Leap Tuff **(Figures 2 through 6)**. These logs were also useful in refining estimated depth to the contact with the underlying Whitetail Conglomerate.

3.1.2 Degree of Fracturing

Fracture summary logs were prepared using borehole video and geophysical logs including ATV, OBI, sonic, and electrical resistivity. Where available, the borehole video, ATV, or OBI logs were the primary sources for the fracture summary logs. If video, ATV, or OBI logs were not available, sonic logs were used to classify fractures. Electrical resistivity logs were used to confirm fracture zones. Fractures were qualitatively classified as minor, moderate, or major based on inspection of the logs. Minor fractures include joints and flow layer margins with no mineral filling generally less than 1 inch across. Moderate fractures include joints and faults with mineral filling or open voids ranging from about 1 to 6 inches across. Major fractures include faults or fault zones with mineral filling or open voids larger than about 6 inches across. Where borehole video, ATV, or OBI were not available, fractures zones were assigned using the sonic log to zones where acoustic travel time was larger than background. Intensity of the fracture was assigned based upon thickness of the anomalous zone. Major fractures were assigned to wide zones of slower acoustic travel.

3.1.3 Borehole Fluids

Borehole fluid characteristics were evaluated using the temperature and fluid resistivity logs, with the temperature log being most useful. In a typical borehole with little or no fluid circulation, temperature of stabilized borehole fluids would generally increase with depth following the regional geothermal gradient. In the case of test well HRES-03 **(Figure 4)**, fluid temperature steadily increased with depth, suggesting that there was little vertical movement of fluid in the borehole.

4 OPEN-BOREHOLE AIR-LIFT TESTING

Following borehole geophysical logging operations, the drill rods were lowered into the open borehole to a depth of about 300 meters, and a short-term air-lift test was conducted. Purpose of air-lift testing was to clean out and develop open fractures and voids intersected by the borehole, and to provide an initial indication of the hydraulic characteristics of the aquifer at each location. Test duration was limited to 2 to 4 hours due to limited on-site storage capacity for the discharged water.

During the drawdown period, water levels were monitored manually via a sounder access tube installed inside the drill pipe and extending below the bottom of the drill string. Use of dual-wall drill pipe permitted use of the drill pipe annulus as the air-line, and the inner tube as the eductor pipe. The connector sleeve for the inner drill pipe was removed at a pipe connection 12 meters above the bottom of the drill string to allow air to enter the inner tube and facilitate air-lift action. A custom-built air-lift head was constructed to accommodate injection of compressed air to the pipe annulus and discharge of air-lifted water out the inner tube, while also allowing simultaneous measurement of water level. Operational data for the open-borehole air-lift pumping tests conducted for the hydrologic test wells are summarized on **Table 4**. Results of data analyses for open-borehole air-lift tests are provided in **Appendix B**.

Table 4. Summary of Open-Borehole Air-Lift Testing Operational Data for Hydrologic Test Wells HRES-01 through HRES-05

Well Identifier	Test Duration (minutes)	Non-Pumping Water Level (meters)	Average Air-Lift Pumping Rate (liters/second)	Maximum Drawdown (meters)
HRES-01	240	267.9	5.7	>50
HRES-02	122	86.9	13.0	>112
HRES-03	120	90.0	1.5	>85
HRES-04	240	120.7	6.5	>125
HRES-05	240	96.5	3.7	>94

5 WELL CONSTRUCTION AND DEVELOPMENT

After completion of open-borehole air-lift testing, each well was constructed using 4 1/2-inch outside-diameter (1/4-inch wall thickness), blank and perforated, flush-threaded steel casing. Perforations are 1/8-inch wide by 4-inch long machine-cut slots. Flush-threaded steel caps were installed at the bottom of each casing string. Perforated casing was installed in several intervals at HRES-01, HRES-02, HRES-04, and HRES-05 to permit future testing of isolated aquifer zones. Because an existing well (USW UZP-4) was available at the HRES-3 site to monitor conditions in the upper aquifer, only one perforated zone was installed at well HRES-3. A summary of casing installation is provided in **Table 5**.

Materials installed in the annulus included 5/16-inch to 1/8-inch gravel pack, 3/8-inch bentonite chips or pellets, 1/4-inch silica sand, and cement-bentonite grout. All annular materials were installed using a tremie pipe. Annular bentonite seals were placed above and below each perforated zone to ensure isolation of the aquifer zones, and ranged from about 5 to 8 meters in thickness. Gravel pack outside each perforated zone was capped at the top and bottom of the interval with silica sand to minimize intrusion of bentonite from the seal into the gravel pack. Annular materials in the zones between the perforated intervals consisted of gravel with bentonite seals approximately every 30 meters. Schematic diagrams of well construction are shown on **Figures 2 through 6**.

Table 5. Summary of 4-inch Casing Installation Depths for Hydrologic Test Wells HRES-01 through HRES-05

	HRES-01	HRES-02	HRES-03	HRES-04	HRES-05
Perforated Interval(s) (meters)	321.5-328.1 414.4-427.7 480.8-486.9	199.9-206.6 312.7-319.4 383.8-399.3	443.9-457.2	178.1-190.3 220.8-233.0 391.4-397.5 432.6-438.9	117.3-129.5 178.3-184.4 309.4-315.5
Total Casing Depth (meters)	486.9	399.3	457.2	438.9	321.6

After construction was completed, each well developed by bailing and swabbing, and then by air-lift pumping. Well development was conducted to remove any sediment from the gravel pack adjacent to the perforated zones, and to remove any fill material that may have accumulated at the bottom of the 4-1/2-inch casing. Removal of sediment was important for minimizing potential damage to the submersible pump and packer assembly that was installed during subsequent testing operations, and for ensuring that the well is in communication with potential aquifer zones. The wells were bailed/swabbed for 5 to 16 hours, and then air-lifted and surged for 5 to 10 hours, until air-lifted water was substantially free of sediment.

6 HYDRAULIC TESTING

Hydrologic testing at the HRES wells after drilling and construction included short-term constant-rate pumping tests using air-lift and pump equipment. The hydraulic testing program comprised composite testing of multiple fracture zones intersected within the well, and detailed hydrologic characterization testing of isolated fracture zone(s) using inflatable packers. Detailed description of testing, analytical procedures, and results is given in **Appendix B**.

Aquifer properties were computed from data obtained during hydrologic composite and zone testing. These properties include transmissivity, hydraulic conductivity, and specific yield for the Apache Leap Tuff in the Oak Flat and Shaft No. 9 area that surrounds the well sites. Results of zone and composite transmissivities and hydraulic conductivities are shown in **Table 6.**

Table 6. Summary of Zone and Composite Pumping Test Results for Hydrologic Test Wells HRES-01 through HRES-05

Well Identifier	Description of Hydrologic Testing Zone	Aquifer Thickness (meters)	Transmissivity (m^2/d)[a]	Hydraulic Conductivity (m/d)[b]
HRES-01	Open Borehole	219.0	5.3	0.024
	A	23.8	0.07	0.003
	B	22.9	0.66	0.029
	C	22.3	0.22	0.010
HRES-02	Open Borehole	308.3	14	0.05
	A	14.0	18	1.3
	B	10.9	0.29	0.03
	C	17.4	0.27	0.02
HRES-03	Open Borehole	336.2	2.0	0.006
	A	17.7	--[c]	<0.001[d]
HRES-04	Open Borehole	318.0	122	0.4
	A	64.9	66	1.0
	B	54.0	--	<0.001
HRES-05	Open Borehole	223.6	89	0.4
	A	18.6	96	5.2
	B	11.8	--	<0.001
	C	11.3	--	<0.001

[a]m^2/d = square meters per day = cubic meters per day per meter width of aquifer at 1.1 hydraulic gradient

[b]m/d = meters per day = cubic meters per day per square meter of aquifer at 1:1 hydraulic gradient

[c]Pumping rate not sustainable; unable to complete test and analyze data for aquifer parameters

[d]Assume zone is less than 0.001 m/d

Lower hydraulic conductivity estimates are consistent with previously cited transmissivities and hydraulic conductivity values for the Apache Leap Tuff by the University of Arizona (Woodhouse, 1997). The range in estimates is consistent with computed aquifer parameters obtained from fractured volcanic aquifers (Freeze and Cherry, 1979) and analogous to Tertiary, fractured tuff aquifers in the area of the Nevada test site (Belcher and others, 2001).

The higher K zone estimates for the Apache Leap Tuff aquifer are reflective of the preponderance of higher permeability fractured rock intervals in the upper parts of the aquifer (Woodhouse,1997). At depth, K zone estimates are lower and are indicative of less permeable fracture intervals.

Estimates of specific yield derived from log-log type curve analysis of test data are indicative of unconfined aquifer conditions in the Apache Leap Tuff. However, tests were of short-duration and did not include observation wells; therefore computed specific capacities are approximate by order of magnitude.

7 REFERENCES CITED

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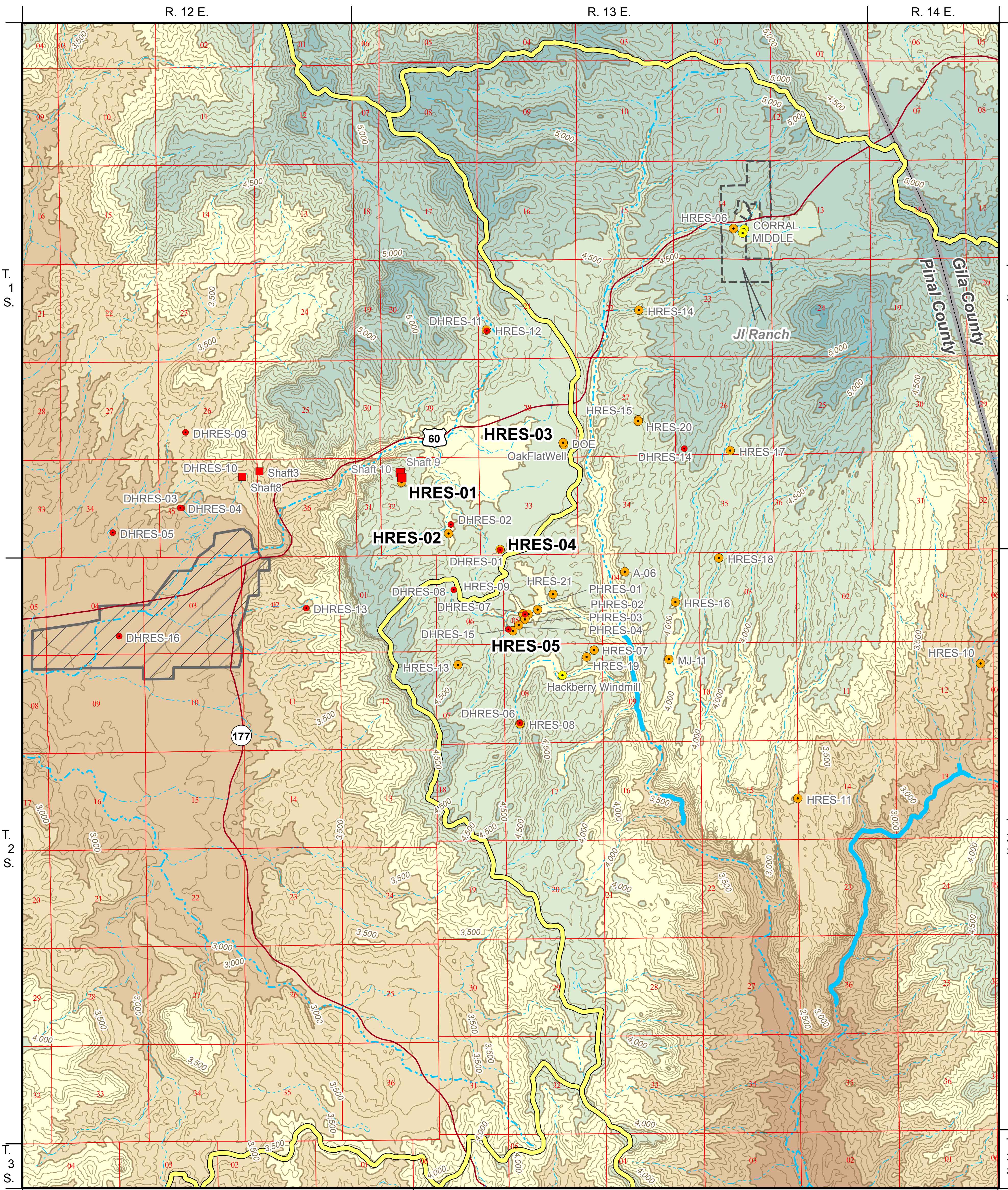


R. 12 E. R. 13 E.

EXPLANATION

Watershed Boundary

Perennial Reach

Groundwater Monitoring Sites

- Shallow Alluvial Aquifer Monitor Well
- Apache Leap Tuff Aquifer Monitor Well
- Deep Groundwater System Monitor Well
- Shaft

0 0.5 1 1.5 2
Miles

Resolution Copper Mining

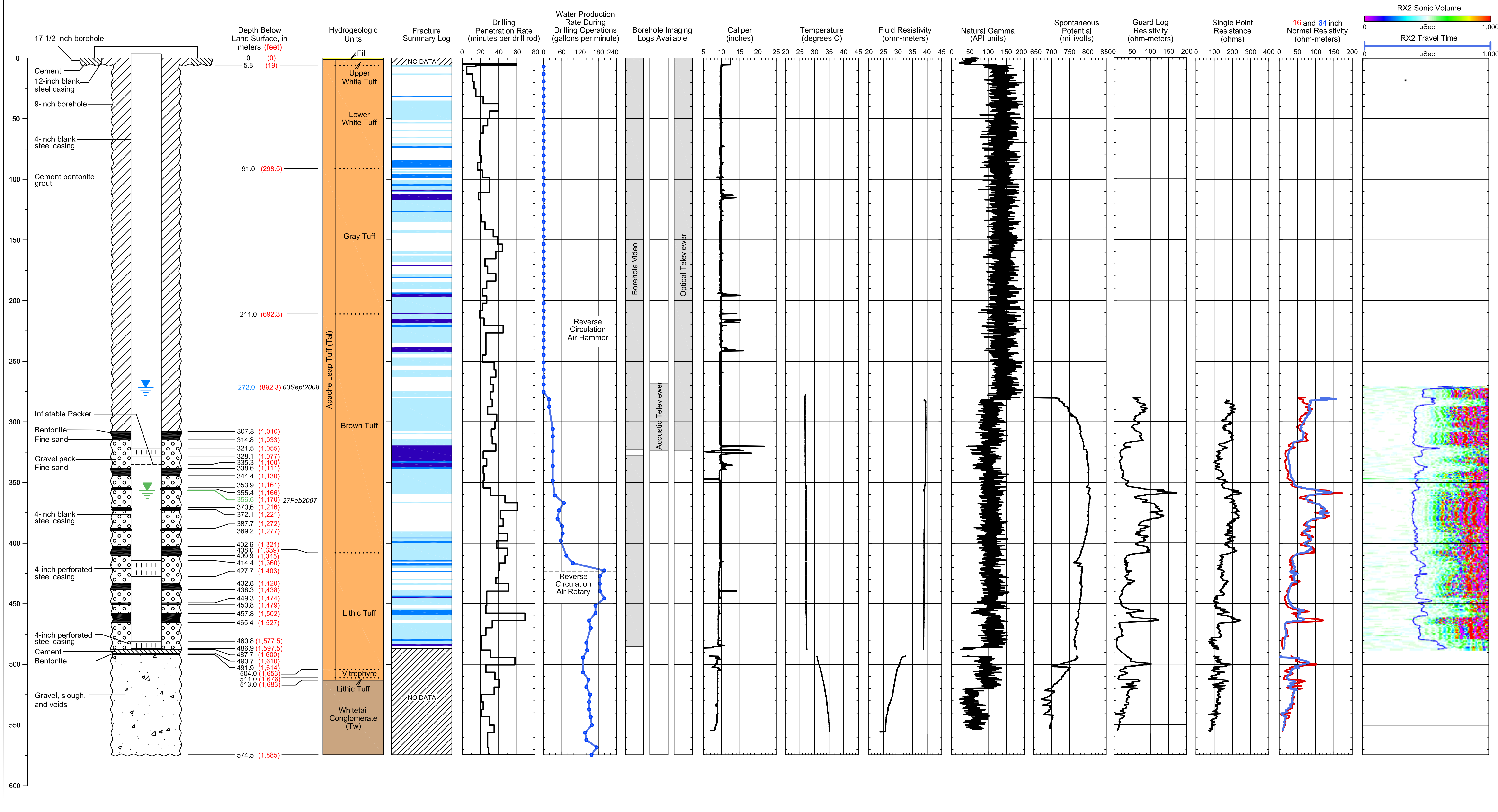
WELL LOCATIONS

MONTGOMERY & ASSOCIATES
Water Resource Consultants

2016

FIGURE 1

\GIS-Tuc\Projects\605\605.1501\Welloc_HRES1_5\07June2016



CADASTRAL: (D-1-13) 32bca	ADWR NO: 55-201852
NORTHING: 3684732.337	EASTING: 493714.748
LAND SURFACE ELEVATION: 1271.66	
DATUM: NAD 27 HORIZONTAL: UTM 12 VERTICAL: NGVD 29 METERS	

EXPLANATION

- No Fracturing Evident
- Minor Fracturing
- Moderate Fracturing
- Major Fracturing
- Shallow Non-pumping Water Level
- Deep Non-pumping Water Level

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HRES-01
SCHEMATIC DIAGRAM OF WELL CONSTRUCTION

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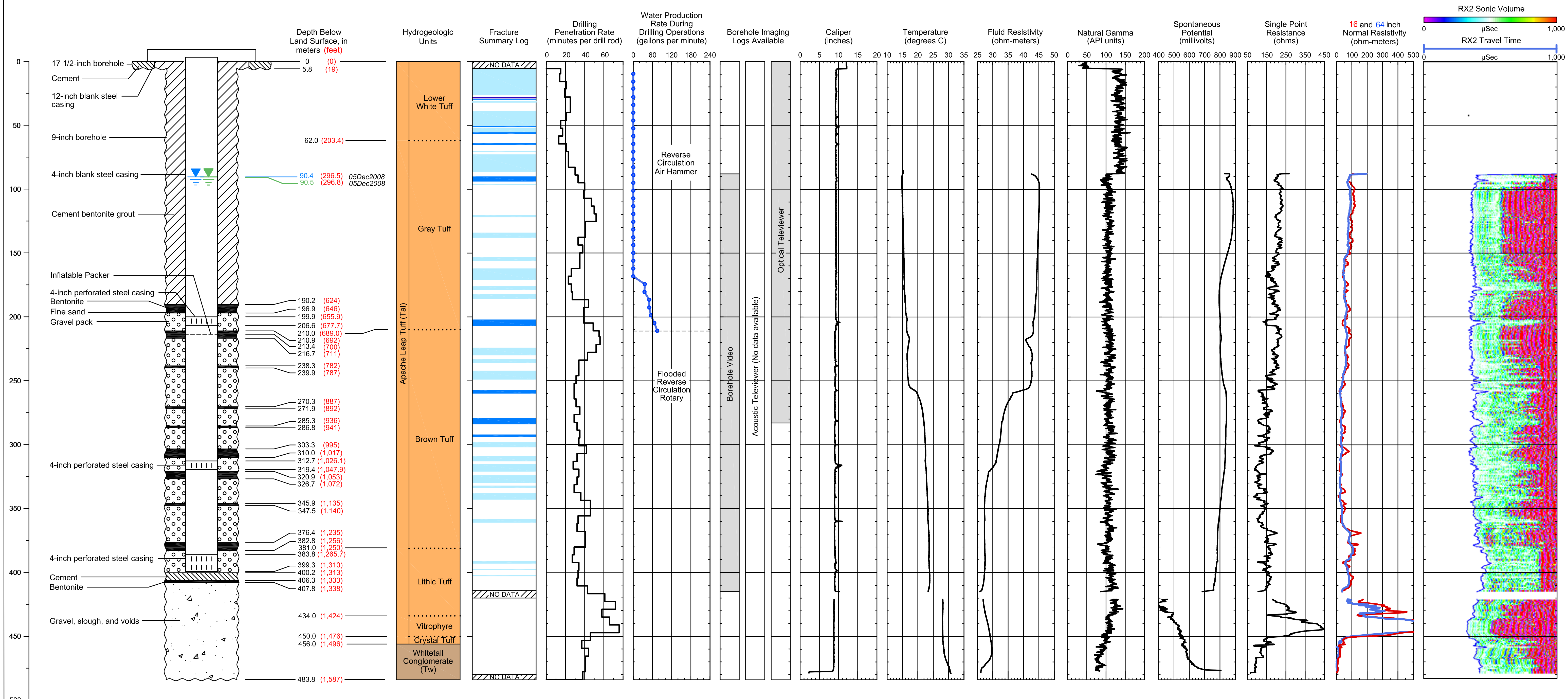
FIGURE 2

605.1501\HRES-1-WS-LOGS\06June2016



CADASTRAL: (D-1-13) 32dca	ADWR NO: 55-201850
NORTHING: 3683886.304	EASTING: 494479.323
LAND SURFACE ELEVATION: 1214.34	
DATUM: NAD 27 HORIZONTAL: UTM 12 VERTICAL: NGVD 29 METERS	

EXPLANATION

- No Fracturing Evident
- Minor Fracturing
- Moderate Fracturing
- Major Fracturing
- Shallow Non-pumping Water Level
- Deep Non-pumping Water Level

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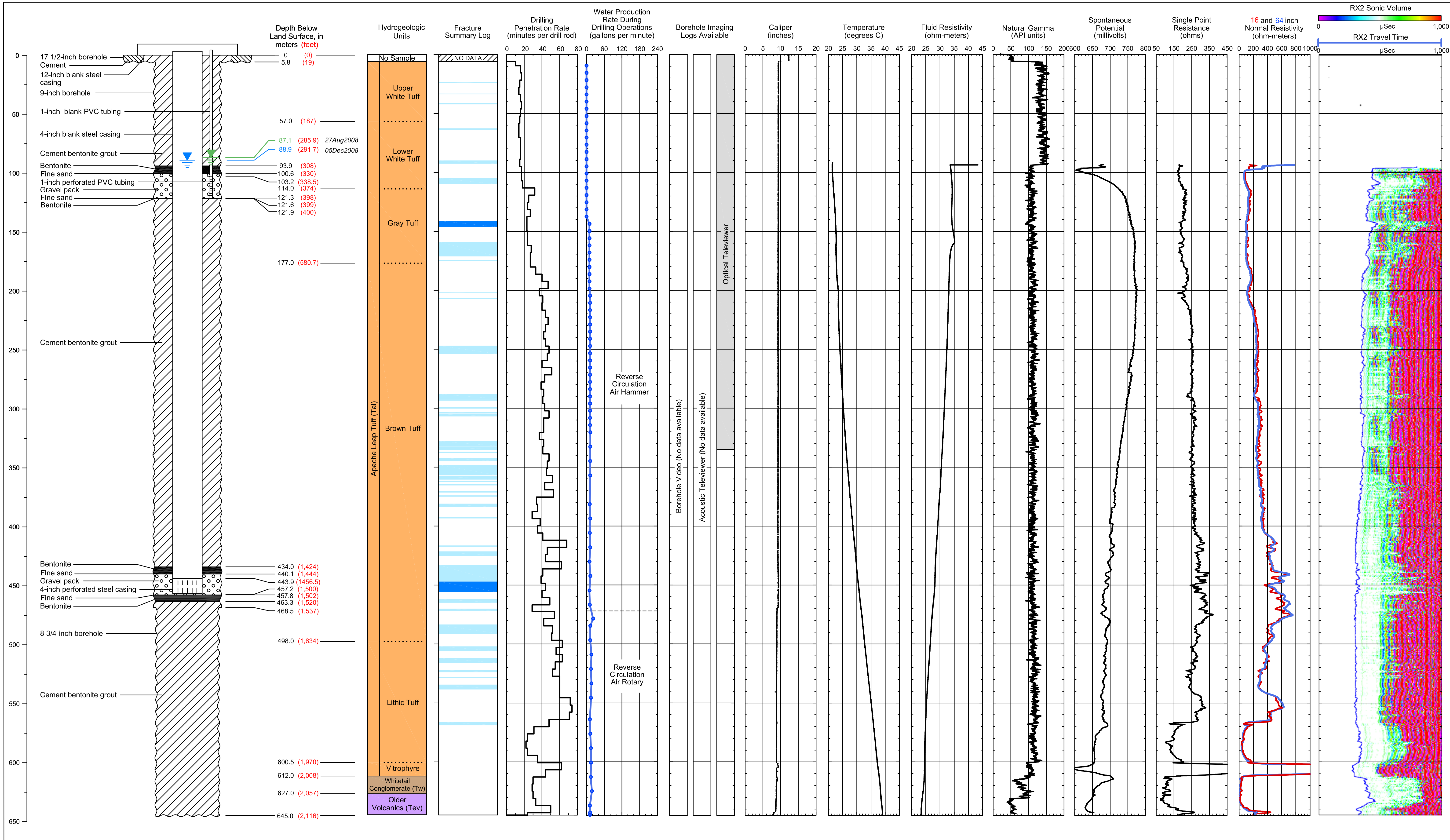
HRES-02
SCHEMATIC DIAGRAM OF WELL CONSTRUCTION

Version: June 9, 2016

FIGURE 3

605.1501\HRES-2-WS-LOGS\07June2016



CADASTRAL: (D-1-13) 28ddb	ADWR NO: 55-201851
NORTHING: 3685328.404	EASTING: 496381.896
LAND SURFACE ELEVATION: 1241.39	

DATUM: NAD 27
HORIZONTAL: UTM 12
VERTICAL: NGVD 29 METERS

EXPLANATION

- No Fracturing Evident
- Minor Fracturing
- Moderate Fracturing
- Major Fracturing
- Shallow Non-pumping Water Level
- Deep Non-pumping Water Level

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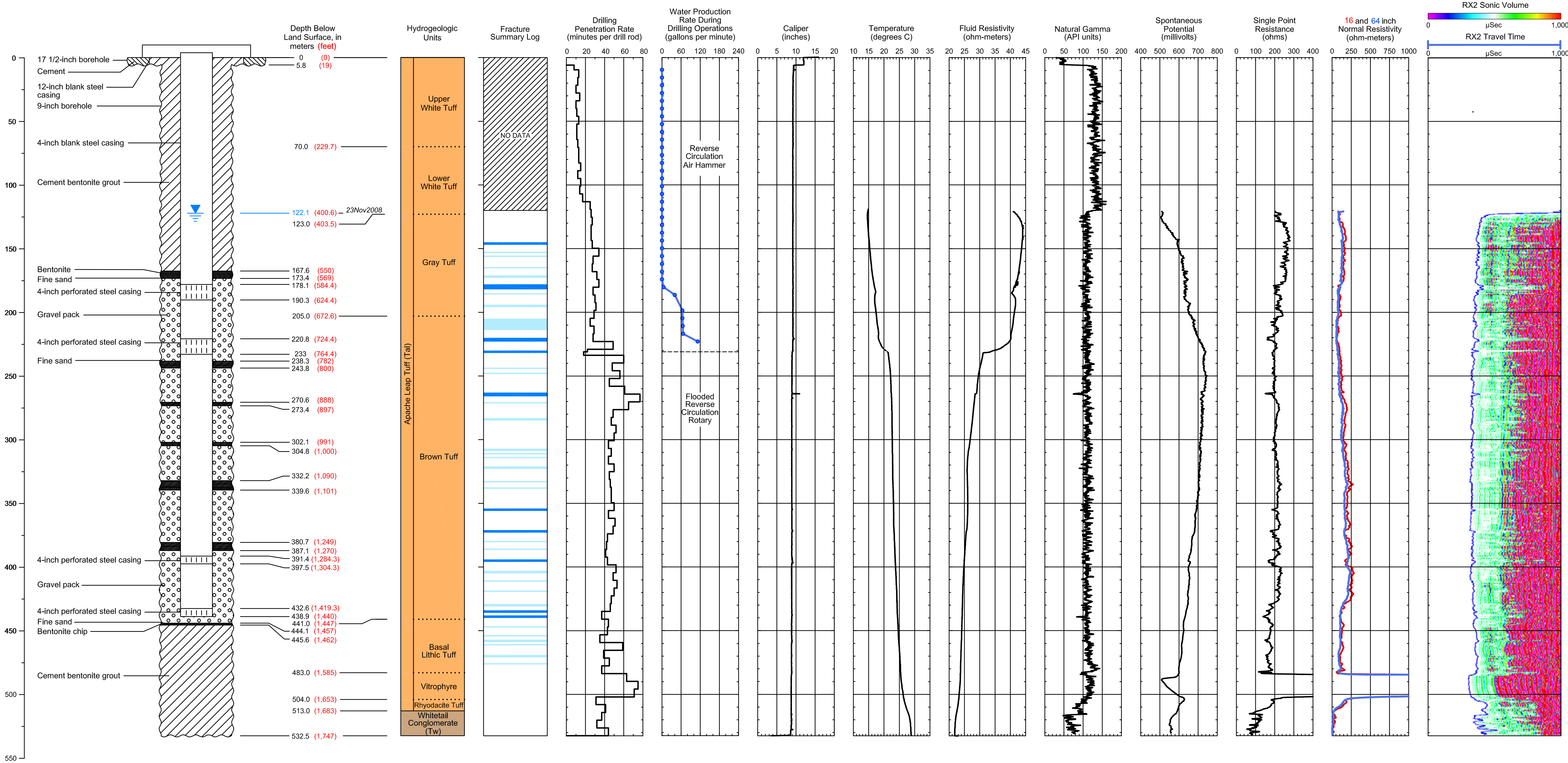
HRES-03
SCHEMATIC DIAGRAM OF WELL CONSTRUCTION

Version: June 9, 2016

FIGURE 4

605\.1501\HRES-3-WS-LOGS\07June2016



CADASTRAL: (D-1-13) 33ccd	ADWR NO: 55-201849
NORTHING: 3683616.170	EASTING: 495322.295
LAND SURFACE ELEVATION: 1243.49	
DATUM: NAD 27 HORIZONTAL: UTM 12 VERTICAL: NGVD 29 METERS	

EXPLANATION

- No Fracturing Evident
- Minor Fracturing
- Moderate Fracturing
- Major Fracturing
- Non-pumping Water Level

Resolution Copper Mining

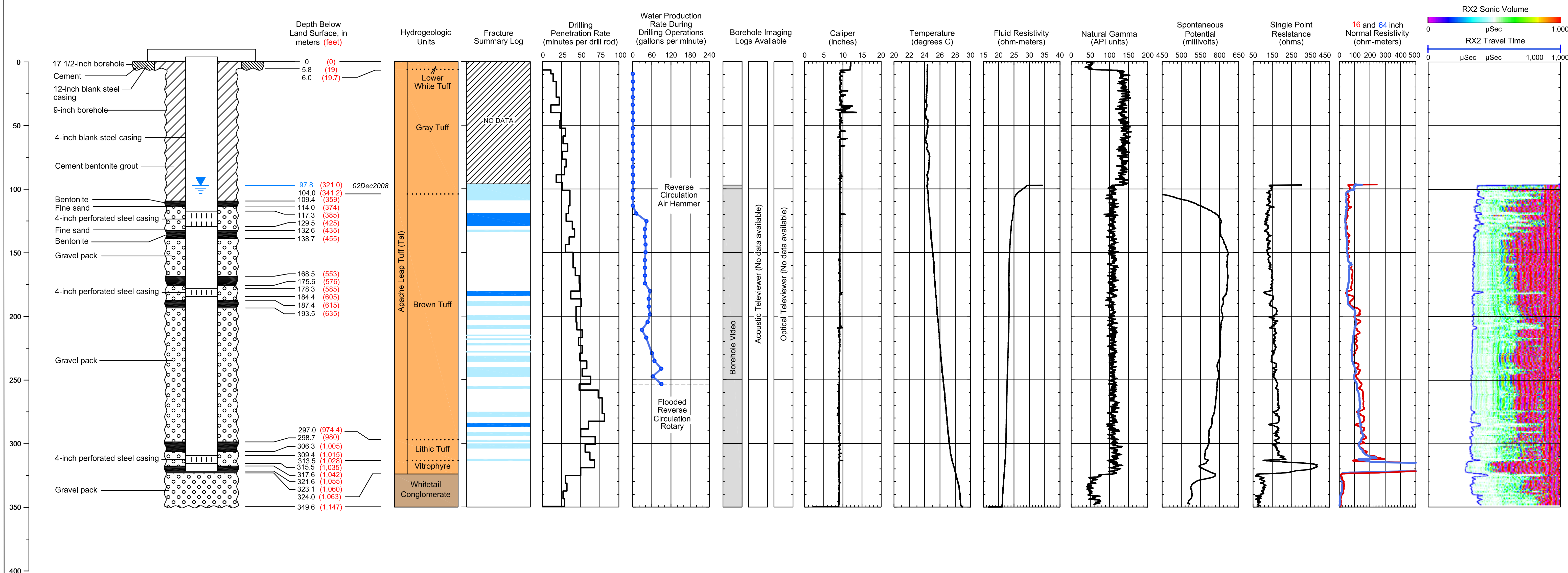
MONTGOMERY & ASSOCIATES Water Resource Consultants

HRES-04
SCHEMATIC DIAGRAM OF WELL CONSTRUCTION

Version: June 9, 2016

FIGURE 5

605.1501\HRES-4-WS-LOGS\07June2016



CADASTRAL: (D-2-13) 05ccb	ADWR NO: 55-201848
NORTHING: 3682274.632	EASTING: 495523.291
LAND SURFACE ELEVATION: 1218.30	
DATUM: NAD 27 HORIZONTAL: UTM 12 VERTICAL: NGVD 29 METERS	

EXPLANATION

- No Fracturing Evident
- Minor Fracturing
- Moderate Fracturing
- Major Fracturing
- Non-pumping Water Level

Resolution Copper Mining

MONTGOMERY & ASSOCIATES
Water Resource Consultants

HRES-05
SCHEMATIC DIAGRAM OF WELL CONSTRUCTION

Version: June 9, 2016

FIGURE 6

605.1501\HRES-5-WS-LOGS\07June2016

MONTGOMERY
& ASSOCIATES

Appendix A

Lithologic Logs for Test Wells

A-1. SUMMARY LITHOLOGIC LOG FOR HYDROLOGIC TEST WELL HRES-1[a]

Sample Interval (meters)						
Top	Bottom	Geologic Unit	General Description	Color	Fracturing	Remarks
0	1	Alluvium				
1	6	Upper White Tuff Apache Leap Tuff	dacite tuff			
6	91	Lower White Tuff Apache Leap Tuff	dacite tuff with abundant plagioclase, +/- sanidine, quartz, and biotite with trace magnetite and lithic fragments	white to light pink, light tan pink	open veinlets with calcite, 87 to 90 m	very weakly welded; eutaxitic texture; mostly devitrified
91	211	Gray Tuff Apache Leap Tuff	dacite tuff, crystal rich with plagioclase and biotite and minor lithic fragments	gray-pink to light gray-red	microfaults/veinlets with drusy chabazite- 108 to 123 m and 150 to 156 m; minor fault breccia gouge- 112.5 and 115.5 m; fault with slickensides and manganese oxide- 180 to 183 m	moderately welded; eutaxitic texture
211	408	Brown Tuff Apache Leap Tuff	dacite tuff, crystal rich with plagioclase, biotite, and quartz and trace lithic fragments	gray-brown to gray-red	fault zones at 241.5 m, 280.5 m, 283.5 m, 325 m, 331 m, 339 m, and 346 m; veinlets with drusy chabazite- 237 to 243 m, 258 to 261 m, 276 to 279 m, 351 to 363 m, 372 to 375 m, and 399 to 402 m; calcite veins- 318 to 342 m; weak calcite 381 to 408 m; weak manganese oxide in fractures- 372 to 375 m	moderate to locally strongly welded; minor eutaxitic texture
408	504	Lithic Tuff Apache Leap Tuff	dacite tuff	pale pink to yellow and pale pink gray at base	strong calcite- 414 to 420 m and 456 to 459 m; weak calcite- 429 to 434	weakly welded to strongly welded near base from 489 to 504 m
504	511	Vitrophyre Apache Leap Tuff	vitric tuff	black		strongly welded
511	513	Lithic Tuff Apache Leap Tuff	dacite tuff, vitric			weakly welded; glassy texture
513	574.5	Whitetail Conglomerate	conglomerate with interbedded sandstone and reddish clay			

[a] Lithology described by J. Wilkins, Resolution Copper Company; summarized from digital file "d_geol.xls" provided by J. Wilkins

A-2. SUMMARY LITHOLOGIC LOG FOR HYDROLOGIC TEST WELL HRES-2[a]

Sample Interval (meters)						
Top	Bottom	Geologic Unit	General Description	Color	Fracturing	Remarks
0	62	Lower White Tuff Apache Leap Tuff	dacite tuff with sanidine, quartz, biotite, and trace magnetite and lithic fragments	pinkish white, pink		weakly welded; increasing crystal content with depth
62	210	Gray Tuff Apache Leap Tuff	dacite tuff, crystal rich with feldspar, quartz, and biotite and trace lithic fragments	pink	fractures 62 to 70 m; minor fractures 70 to 149 m	crumbly from 62 to 78 m; moderately welded from 62 to 150 m; moderate to locally strongly welded from 150 to 210 m
210	381	Brown Tuff Apache Leap Tuff	dacite tuff, crystal rich with plagioclase and biotite, flattened pumice fragments, and trace lithic fragments	dark gray-pink, white, tan pink toward base	fractures with breccia, clay gouge, and/or slickensides- 256 m, 281 m, 301 m, 317 m, 337.5 m, 353 m, 360 m, 367 m, and 376.5 m; calcite veinlets- 168 to 180 m, 183 to 186 m, 202 to 213 m, 219 to 222 m, 228 to 231 m, and 306 to 309 m; calcite veins- 312 to 315 m, 321 to 333 m, and 374 to 381 m; chabazite veinlets- 231 to 234 m, 243 to 246 m, 303 to 306 m, and 333 to 336 m; weak manganese oxide- 336 to 348 m, 366 to 369 m, and 384 to 387 m; weak limonite- 336 to 354 m, 366 to 375 m, and 384 to 387 m	moderately welded; strongly welded- 258 to 309 m; moderate to locally strongly welded- 309 to 381m; eutaxitic texture
381	434	Lithic Tuff Apache Leap Tuff	dacite tuff with biotite and lithic fragments	dark gray-pink to pale gray-orange toward base	fault with slickensides- 385 m and 418 m; calcite veinlets 411 to 414 m; chabazite veinlets 405 to 408 m	moderate welded- 381 to 420 m; strongly welded- 420 to 434 m
434	450	Vitrophyre Apache Leap Tuff	vitric tuff with biotite and minor lithic fragments	black to amber brown at base		strongly welded; magnetic
450	456	Lithic Tuff Apache Leap Tuff	vitric dacite crystal tuff with biotite and broken plagioclase crystals	gray-pink to pale gray-yellow		weakly welded
456	483.8	Whitetail Conglomerate	siltstone, sandstone, and claystone	red-brown to gray-brown near base	calcite veinlets- 459 to 465 m	layered calcareous deposits of detrital to lacustrine origin

[a] Lithology described by J. Wilkins, Resolution Copper Company; summarized from digital file "d_geol.xls" provided by J. Wilkins

A-3. SUMMARY LITHOLOGIC LOG FOR HYDROLOGIC TEST WELL HRES-3[a]

Sample Interval (meters)						
Top	**Bottom**	**Geologic Unit**	**General Description**	**Color**	**Fracturing**	**Remarks**
0	6		NO SAMPLE			
6	57	Upper White Tuff Apache Leap Tuff	dacite tuff, crystal rich with biotite and oxidized magnetite	white to very light gray-pink	none	non-welded
57	114	Lower White Tuff Apache Leap Tuff	dacite tuff, crystal rich with biotite	very light gray-pink		weakly welded
114	177	Gray Tuff Apache Leap Tuff	dacite tuff with trace lithic fragments	gray-pink	calcite- 156 to 159 m	moderately welded- 114 to 144 m; weak to moderately welded- 144 to 177 m; eutaxitic texture
177	498	Brown Tuff Apache Leap Tuff	dacite tuff, crystal rich with biotite and quartz, flattened pumice fragments, and trace lithic fragments	reddish-gray-brown	weak calcite- 321 to 327 m, 338 to 342 m, 348 to 357 m, and 384 to 387 m; weak manganese oxide- 336 to 342 m and 354 to 357 m; quartz veinlets- 462 to 465 m	moderately welded 177 to 285 m; moderate to weakly welded- 285 to 408 m; strongly welded- 408 to 489 m; moderately welded- 489 to 498 m; eutaxitic texture; weakly magnetic
498	600.5	Lithic Tuff Apache Leap Tuff	dacite tuff with increasing lithic fragments toward central part of unit	gray-yellow to pale tan-gray toward base		weakly welded to moderately welded near base of unit
600.5	612	Vitrophyre Apache Leap Tuff	vitric tuff with biotite and minor lithic fragments	black		strongly welded; weakly magnetic
612	627	Whitetail Conglomerate	interbedded sandstone, conglomerate, and siltstone	reddish tan		
627	645	Older Volcanics	andesite to basaltic flow, very fine grained, with silica-filled amygdules with green celadonite rinds	dark greenish black		weak to moderately magnetic

[a] Lithology described by J. Wilkins, Resolution Copper Company; summarized from digital file "d_geol.xls" provided by J. Wilkins

A-4. SUMMARY LITHOLOGIC LOG FOR HYDROLOGIC TEST WELL HRES-4[a]

Sample Interval (meters)						
Top	Bottom	Geologic Unit	General Description	Color	Fracturing	Remarks
0	70	Upper White Tuff Apache Leap Tuff	dacite tuff	white to very pale pink	none	non-welded
70	123	Lower White Tuff Apache Leap Tuff	dacite tuff	pale pink, very light pink-gray		weakly welded
123	205	Gray Tuff Apache Leap Tuff	dacite tuff with flattened white pumice fragments	gray-pink, white	calcite veins- 177 to 186 m; weak calcite 192 to 198 m	weak to moderately welded; eutaxitic texture
205	441	Brown Tuff Apache Leap Tuff	dacite tuff, crystal rich with plagioclase and biotite		fault zone with chabazite- 219 to 222 m; calcite veins- 245 to 252 m, 327 to 330 m, and 356 to 357 m; weak calcite- 261 to 264 m, 375 to 378 m, and 399 to 411 m; chabazite veinlets- 270 to 276 m, 279 to 306 m, and 390 to 396 m; iron oxide banding- 301 to 304 m; weak iron oxide- 318 to 320 m; manganese oxide veinlets- 279 to 306 m	moderate to strongly welded- 205 to 309 m; strongly welded- 309 to 369 m; moderately welded- 369 to 441 m; very weakly magnetic
441	483	Lithic Tuff Apache Leap Tuff	dacite tuff with yellow ash fragments	pink grading to yellow-gray	chabazite veinlets 447 to 450 m	very weakly welded- 441 to 480 m; strongly welded- 480 to 483 m
483	504	Vitrophyre Apache Leap Tuff	vitric tuff	black to amber brown at base		strongly welded
504	513	Lithic Tuff Apache Leap Tuff	rhyodacite tuff, crystal bearing, trace biotite	light peach to light gray		non-welded
513	532.5	Whitetail Conglomerate	sandstone-siltstone, conglomerate, and mudstone	light yellow, brown		

[a] Lithology described by J. Wilkins, Resolution Copper Company; summarized from digital file "d_geol.xls" provided by J. Wilkins

A-5. SUMMARY LITHOLOGIC LOG FOR HYDROLOGIC TEST WELL HRES-5[a]

Sample Interval (meters)						
Top	Bottom	Geologic Unit	General Description	Color	Fracturing	Remarks
0	6	Lower White Tuff Apache Leap Tuff	dacite tuff	light gray-pink	clayey gouge- 5 m; minor manganese oxide on fractures- 3 to 6 m	very weakly welded
6	104	Gray Tuff Apache Leap Tuff	dacite tuff, crystal rich with plagioclase, quartz, biotite, trace hornblende, magnetite, and trace lithic fragments	gray-pink	fault- 47 m; slickensides- 70.5 m and 82 m; minor calcite veins- 72 to 84 m; trace chabazite filled vein/fault/cavity	moderately welded; trace to weak manganese oxide
104	297	Brown Tuff Apache Leap Tuff	dacite tuff, crystal rich	pale gray-brown, pink	fault with limonite and slickensides- 120 to 126 m; calcite veins- 186 to 192 m, and 198 to 201 m; calcite veinlets- 120 to 126 m, 147 to 150 m, 156 to 162 m, 165 to 168 m, 171 to 174 m, 204 to 207 m, 213 to 222 m, 225 to 228 m, and 237 to 243 m; chabazite veinlets- 108 to 111 m, 144 to 147 m; trace limonite 156 to 162 m	moderate to strongly welded
297	313.5	Lithic Tuff Apache Leap Tuff	dacite tuff, biotite rich with pale yellow-green pumice fragments and minor lithic fragments			weak to moderately welded; basal bowling ball clay horizon- 312.5 to 313.5 m
313.5	324	Vitrophyre Apache Leap Tuff	vitric tuff with localized lithic fragments and minor banding	black to dark amber brown		strongly welded
324	339	Whitetail Conglomerate	conglomerate, Paleozoic rich with minor quartzite		calcite vein- 336 to 342 m	sand to clay cement
339	349.5	Whitetail Lacustrine sediments	calcareous sandstone, poorly sorted, sub-angular to sub-rounded, minor pebble to cobble clasts	gray-brown		

[a] Lithology described by J. Wilkins, Resolution Copper Company; summarized from digital file "d_geol.xls" provided by J. Wilkins

Appendix B

Results of Hydrologic Testing at Wells HRES-01 through HRES-05

Contents

Tables

Illustrations

1 INTRODUCTION

The hydrologic testing program was conducted by Montgomery & Associates in 2004 at hydrologic test wells HRES-01 through HRES-05 on behalf of Resolution Copper Company (RCC). Results of hydrologic testing provided preliminary hydraulic parameters of the Apache Leap Tuff aquifer in the Oak Flat and Shaft No. 9 area, east of Superior, Arizona **(Figure 1)**. In addition to the characterization of hydraulic parameters, the testing program included characterization of hydraulic head and hydrochemistry of selected fracture intervals in the Apache Leap Tuff intercepted by HRES wells.

Analyses of the single well, short-term testing at HRES wells were completed in June 2004. Based on results of these analyses, we provided recommendations in July 2004 for long-term testing and multiple-well observation using the HRES wells to provide additional hydraulic characterization of the Apache Leap Tuff aquifer.

2 HYDROLOGIC TESTING STRATEGY

The hydrologic testing strategy at HRES wells included obtaining of vertical depth information pertaining to hydraulic properties, hydraulic head, and hydrochemical characteristics of the Apache Leap Tuff. Based on methodology for hydrogeologic site characterization outlined by Reidel and others (2002), two methods were recognized in order to obtain hydrologic data in the study area:

Test Method 1: "drill to total depth and log, test later," and

Test Method 2: "drill, log, and test as you go".

Each method has distinct advantages and disadvantages pertaining to characterization data quality and costs. Because of borehole conditions and need for subsequent water level and water quality monitoring, we used a variation of Test Method 1 for hydrologic testing at HRES wells. General approaches for Test Method 1 and Test Method 2 follow.

Principal approaches of Test Method 1 include conducting hydrologic test characterization elements only after the borehole is drilled to its completion depth (total depth), and logged for geology and fracture characterization using on-site geologist's interpretations of drill cuttings and wireline geophysical techniques. The primary focus of the Test Method 1 is assessment of the hydraulic characteristics of intersected fracture zones by conducting a testing program consisting of two basic test elements:

1. composite testing of multiple fracture zones intersected within the well using pumping test methods, and

2. vertical depth interval hydrologic characterization of selected fracture zone(s) using standard packers and pumping test methods.

The principal advantage of Test Method 1 is the lower overall equipment costs (i.e., drilling rig time, downhole test system rental) when compared to the other test strategies. A major disadvantage is that major pressure perturbations and groundwater incursions may be induced into the fractured rock surrounding the borehole during the extended, active borehole-drilling phase. These drilling-induced effects may require long test periods to obtain representative static hydraulic heads and hydrochemical samples.

The primary focus of the Test Method 2 is to provide detailed hydrologic characterization information at the time more intense zones of fractures are encountered during drilling. Once penetrating underlying denser, non-fractured zones, drilling is stopped and the newly drilled section of the borehole is then: (1) geophysically logged for fracture characterization, and (2) the zone is tested as in Test Method 1 using a packer test system to achieve test zone isolation from the overlying open borehole section. The principal advantages of Test Method 2 are shorter test times and higher quality of the hydraulic characterization data. Because the exposure time to drilling perturbations is minimized, test times required for acquiring representative static hydraulic heads and hydrochemical characteristics are reduced. However, standby drilling rig and test equipment costs incurred when either activity is not taking place is large.

The project considered Test Method 1 and Test Method 2 for hydrologic testing of the HRES wells completed in the Apache Leap Tuff in the Oak Flat and Shaft No. 9 study area. Based on review of logs from previous drilling activity in the area, poor stability of borehole walls was likely in areas of high fracture intensity. Because of reported occurrence of unstable, subsurface rock conditions in the Apache Leap Tuff, open borehole testing jeopardized use of packers and results of testing program. To reduce risk of borehole collapse and increase chances of economically successful hydrologic testing, the project opted to pursue a variation of Test Method 1 by using well construction techniques consisting of steel casing and annular seals to isolate fractured rock intervals intercepted by boreholes. Well construction techniques that stabilize boreholes also allowed for greater assurance that the well sites would be available for long-term monitoring of hydraulic head and chemical quality of groundwater.

3 HYDROLOGIC TESTING SEQUENCE

After drilling boreholes to total depth (approximate bottom of Apache Leap Tuff), geological and geophysical logging (e.g., televiewer, resistivity, sonic) identified zones of frequent rock fractures. After logging, open borehole airlift operations were conducted for development of the borehole prior to casing and for preliminary indication of specific capacity. Specific capacity is a measure of discharge rate and maximum groundwater level drawdown during pumping. Development is a term used to indicate procedures used by drillers for maximizing groundwater yield. Objectives of development are to repair well borehole damage caused by drilling processes smearing clays on the borehole wall, remove fines in the aquifer caused by drill cuttings, and enhance the physical characteristics of the borehole to allow free movement of groundwater (Driscoll, 1986).

After completing open borehole airlift operations, well construction started and consisted of installation of blank and perforated steel casing to isolate fracture intervals. Annular bentonite seals between the borehole wall and blank steel casing isolated fracture intervals, and perforated casing strings allowed for hydraulic testing and monitoring of isolated fractured rock intervals. The hydraulic testing program proceeded by composite testing of multiple fracture zones intersected within the well, and detailed hydrologic characterization testing of isolated fracture zone(s) using a submersible pump and inflatable packer.

A normal test sequence for hydrologic testing included the following elements:

- **Open Borehole Airlift Operations.** These operations provide: (1) development of the borehole to reduce impacts of drilling process; (2) specific capacity of the well prior to well construction; (3) an estimate of aquifer transmissivity based on constant-rate pumping and recovery analysis; and (4) an opportunity for collection of representative water samples for hydrochemical and isotopic analysis.

- **Constant-Rate Pumping Tests (Drawdown)**. Drawdown data obtained during constant-rate pumping tests is used to diagnostically evaluate operative aquifer conditions (e.g., leaky aquifer, unconfined aquifer, etc.), and detects the presence of nearby hydrogeologic features (e.g., boundaries such as faults, surface water, etc.). Pumping tests also provide opportunities for the collection of representative water samples for detailed hydrochemical and isotopic analysis, which are useful for assessing the source and origin of groundwater and evaluating hydrologic connection with surface water sources.

- **Constant-Rate Pumping Tests (Recovery)**. Analysis of groundwater level recovery data provides corroborative information (i.e., to drawdown response) during the constant-rate pumping test. The primary advantage for analysis of recovery data is its ease of application and its insensitivity to flow rate variations that might have occurred during the constant-rate pumping test phase.

An inflatable packer was used to isolate perforated zones in the well to test fracture intervals. Use of the packer aided in determining vertical hydraulic gradient in the well, testing of isolated fracture sets, and obtaining groundwater samples to identify hydrochemistry. Normal procedures with the packer assembly included:

- **Packer Inflation**. The down-hole assembly is positioned and the packer is inflated to isolate the test interval.

- **Water Level Stabilization**. Groundwater level is monitored above and below the packer until stablized.

- **Constant-Rate Pumping Test**. A constant-rate pumping test is conducted in order to determine aquifer parameters for the discrete fracture interval(s) open in the well to pumping.

Prior to pumping tests, short-duration pre-tests routinely occurred. Pre-testing was primarily for additional well development and for determining pumping rates for the constant-rate discharge test.

4 HYDROLOGIC TESTING EQUIPMENT

A down-hole assembly consisting of a submersible electric pump and inflatable packer was used for testing at wells HRES-01, 02, 04, and 05. For these wells, a 5-horsepower (hp) Grundfos submersible pump (Grundfos Model 16S50-38, 480V, 3 phase, 5-hp) pump was used for testing. Testing at HRES-03 used a 1-hp Grundfos submersible pump (Grundfos Model 5S10-22, 480V, 3 phase, 1-hp). Steel, 2-inch diameter column pipe held the pump and packer assembly.

An in-line flowmeter and a stopwatch used with a calibrated 15-gallon container measured discharge rates at land surface. Observations and recording flow rate and pressure gage measurements on the discharge assembly and manually adjusting a gate valve maintained a constant-rate discharge. Recording discharge readings during pumping occurred every 1 to 20 minutes. In-Situ, miniTROLL 100 psi and 300 psi, absolute pressure transducers measured and logged water levels in the pumping well and the nearby observation wells during testing. The transducers installed for monitoring groundwater level in wells were unvented; barometric pressure was monitored at the surface for atmospheric pressure fluctuations using a Geokon, 5 psi, absolute pressure transducer and Geokon, LC-1 datalogger. Dataloggers logged at 1-minute intervals. An electric water level sounder was used to take hand measurements of depth to water in the 1-inch diameter sounder access tube before, during, and after the pumping tests.

In order to test discrete fracture zone intervals isolated and screened in the well, a packer assembly was used that included a single, Baski Inc., 4-inch inflatable packer. The assembly had in-line adaptors installed above and below the packer to allow for the electrical cable of the pump to pass. In addition to measurement of water level below the packer for hydraulic analysis, measurement of water level above the packer was conducted during testing to verify integrity of packer setting, well annulus seals, and hydraulic communication between zones.

5 HYDROLOGIC TESTING METHODS AND PROCEDURES

Analysis of results of constant-rate pumping tests provided preliminary aquifer parameters for the Apache Leap Tuff. Testing procedures included regulating groundwater discharge at a uniform rate and measuring groundwater level response within the pumped well during the active pumping phase and during the subsequent recovery phase following end of pumping. Analytical methods of the drawdown and recovery water-level response within the pumping well provide estimates of hydraulic properties of the aquifer zones tested, as well as for discerning formational and non-formational flow conditions (e.g., wellbore storage, skin effects, presence of boundaries and leakage).

Routine analytical methods used for the analysis of constant-rate tests included log-log, type-curve matching and semi-log, straight-line methods. Type-curve-matching methods commonly used in the analysis of pumping test responses included those described in Theis (1935) and Neuman (1974). For straight-line analysis methods, the rate of change of water levels within the well during drawdown and/or recovery is analyzed to estimate hydraulic properties. Because well effects are constant with time during constant-rate tests, straight-line methods can be used to analyze quantitatively the water-level response at both pumping and observation wells. The semi-log, straight-line analysis techniques commonly used are based on either the Cooper and Jacob (1946) method (for drawdown analysis) or the Theis (1935) recovery method (for recovery analysis).

Theoretical type-curve matching developed by Neuman show three principal trends of water level response. The early trend conforms to behavior predicted by the Theis (1935) non-equilibrium equation. Water level decline during early time reflects elastic storage response of the aquifer. The middle trend shows a decreasing rate of water level decline corresponding to delayed response of water level in the aquifer and draining of pore spaces as water level declines. The late trend conforms to behavior predicted by the Theis non-equilibrium equation. However, unlike the early trend, the release of water from storage during late time is predominantly due to draining of pore spaces and lowering of the water table, rather than elastic response of the aquifer. Late trend results are analyzed for determination of specific yield of the aquifer; specific yield is usually an order of magnitude, or more, larger than storage coefficient.

Based on theoretical assumptions of the procedures, type-curve analyses restrict test responses for wells that fully penetrate nonleaky, homogeneous, isotropic, confined aquifers. Non-ideal well and aquifer conditions may be analyzed using straight-line methods if infinite-acting, radial flow conditions exist. Test data show infinite-acting, radial flow conditions when the change in pressure is proportional to the logarithm of time (Freeze and Cherry, 1979).

Log-log hydrographs of water level versus time are traditionally used for diagnostic analysis of pumping test data (Theis, 1935; Butler, 1990). Recent literature includes use of the derivative of the water level drawdown for diagnosing aquifer characteristics. Because of the sensitivity of the derivative of water level, the analytical graphing technique shows the validity for use of various hydrologic test analyses (Bourdet, 1989; Spane, 1993). Using derivative analysis, specific aquifer conditions can be examined such as nonleaky or leaky aquifers; fracture flow or dual porosity, confined or unconfined aquifers; and hydraulic positive or negative boundaries to subsurface groundwater flow. Derivative analysis also indicates when particular analytical techniques are appropriate for estimating aquifer parameters (Spane and Wurstner, 1993).

Figure B-1 shows characteristics of log-log hydrographs of drawdown derivative versus time responses for common aquifer conditions. Spane and Wurstner (1993) comment on the characteristics of the hydrographs:

> *"The early data, occurring before the straight-line approximation is valid or where wellbore storage is dominant, produce a steep, upward-trending derivative. The derivative normally decreases during transition from wellbore storage to radial flow and stabilizes at a constant value when infinite-acting, radial flow conditions are established. The stable derivative reflects the straight line on the semi log plot for infinite-acting radial flow. Unconfined and double-porosity aquifers may show two stable derivative sections at the same vertical position separated by a "valley" that represents the transition from one storage value to the other. A linear, no-flow boundary will result in a doubling of the magnitude of the derivative. If radial flow is established before the influence of the boundary is seen, a stable derivative will occur for a time followed by an upward shift to twice the original value. Constant-head boundaries display a downward trend in the derivative, which may be preceded by a stable derivative if radial flow conditions occur before the boundary effect becomes dominant. "*

Inherent in the analytical methods discussed above is the assumption that the test interval is homogeneous. A number of formation heterogeneities, however, can exert significant influence on pumping test response. Recognized heterogeneous formation conditions affecting pumping test response include multilayers of varying hydraulic properties within the well-screen section, dual porosity caused by fractured rock conditions, presence of linear boundaries, and radial variation of hydraulic properties with distance from the well (i.e., radial boundaries).

The effects of multi-layer conditions within the test interval have been examined previously by Butler and others (1994) and Butler (1997). These studies indicate that the presence of multi-layers of varying hydraulic properties cannot be distinguished from the pattern of the pumping test response. For well screens that fully penetrate a heterogeneous, multi-layer aquifer, the hydraulic conductivity estimated from the pumping test will be an arithmetic average of the thickness-weighted hydraulic conductivities of the individual layers. For well screens that partially penetrate the upper-part of a multi-layer aquifer, the hydraulic conductivity estimated from the test also will represent a thickness-weighted arithmetic average, as long as significant vertical leakage does not occur from layers underlying the test interval.

6 HYDROLOGIC TESTING RESULTS

Short-term, constant-rate pumping tests were conducted at the HRES well sites for preliminary hydrologic characterization and determination of aquifer parameters. Analysis of the drawdown and recovery test data at the pumped well provides local-scale hydraulic property estimates such as transmissivity (T) and hydraulic conductivity (K). Long-term testing and water level response at neighboring observation wells provide for regional-scale hydraulic property estimates that include T and S in addition to horizontal anisotropy (K_x and K_y) vertical anisotropy (K_z), storativity (S), and specific yield (Sy). Recommended long-term, multi-well hydrologic testing is required in order to obtain these latter, area-wide hydrologic parameters of K_{xyz}, S, and S_y.

The pumping test data were compiled in standardized spreadsheets using Microsoft Office Excel 2003. After organization and data verification in spreadsheets, pumping test data were imported to the computer-based, analytical aquifer test software AQTESOLV for Windows, version 3.50.008 (Glenn M. Duffield, HydroSOLVE, Inc., 2003). Standard AQTESOLV analysis output included type curve-matching graphs, description of analytical technique, and all parameters used for the analysis.

Analysis of constant-rate pumping-test data included diagnostic derivative analysis for identification of aquifer response and selection of the appropriate analysis method, and combined type curve and derivative plot analysis for hydraulic property determination. In general, drawdown data were representative for aquifer T analysis, however because of the disadvantageous effects caused by small variations in discharge rate during the test, straight-line recovery analysis techniques are judged to provide the best estimate of aquifer T. For the most part, the drawdown derivative pattern exhibited indicates unconfined aquifer conditions and that radial flow conditions establish in late time. However, because the pumping tests were short duration and observation well data were not available, the type-curve drawdown analysis is approximate for S_y derived from pumped well data.

The following sections provide descriptions of the performance and analysis of the constant-rate pumping tests conducted at each of the five well sites. **Table B-1** gives a summary of hydrologic testing at HRES wells. **Table B-2** provides results of pumping test analyses for HRES wells. **Figures B-2 through B-8** show drawdown graphs, recovery graphs, and results of analytical analyses.

6.1 Well HRES-01

Details of drilling and well construction for well HRES-01 are given in previous sections of this report. In summary, 4-inch blank and perforated steel casing is installed from land surface to a depth of 486.9 meters (m) below land surface (bls). Hydrologic testing zones are from depths of 314.8 to 338.6 m bls (zone A), 409.9 to 432.8 m bls (zone B), and 465.4 to 487.7 m bls (zone C). Bentonite seals in the annulus between the well casing and borehole wall hydraulically isolate these zones in the well.

Hydrologic testing included constant-rate pumping tests for: open borehole; composite zones A, B, and C (Test 1); composite zones B and C (Test 2), and zone C (Test 3).

6.1.1 Well HRES-01, Open Borehole Testing

The HRES-01 open borehole penetrated the Apache Leap Tuff and upper part of the Whitetail conglomerate. Based on interpretation of logs and groundwater level measurements, estimated aquifer thickness (b) was 219.0 m.

The constant-rate, air-lift pumping test for the HRES-01 open borehole was conducted on February 10, 2004. The average discharge rate was 86.7 gpm for the 240-minute pumping period. Depth to pre-pumping water level was 267.9 m bls. Bottom of drill pipe used for airlift operation was about 457 m bls. Submergence for airlift was about 189 m bls. **Figure B-2** shows the drawdown and recovery graphs for the test. The straight-line analysis of recovery data provided aquifer T computed to be 5.3 m^2/d.

6.1.2 Well HRES-01, Test 1

Test 1 at well HRES-01 was for zones A, B, and C. Based on interpretation of logs and construction reports, thickness of the zones hydraulically tested was 69.0 m.

Test 1 was conducted on March 12, 2004 at a pump setting of about 357 m bls. Average pumping rate for the 12-hour test was 10 gpm. Depth to pre-pumping water level was 293.01 m bls. **Figure B-2** shows the drawdown and graph for the test. The straight-line analysis of recovery data provided aquifer T computed to be 0.95 m^2/d.

Table B-1. Summary of Hydrologic Testing Intervals at HRES Wells

		Interval in Well for Hydrologic Testing			
Well	Cadastral Location	Identifier	Top (m, bls)	Bottom (m, bls)	Thickness (meters)
HRES-01	(D-1-13)32bca	open	267.9	486.9	219.0
		Zone A	314.8	338.6	23.8
		Zone B	409.9	432.8	22.9
		Zone C	465.4	487.7	22.3
HRES-02	(D-1-13)32dca	open	91.0	399.3	308.3
		Zone A	196.9	210.9	14.0
		Zone B	310.0	320.9	10.9
		Zone C	382.8	400.2	17.4
HRES-03	(D-1-13)28ddb	open	121.0	457.2	336.2
		Zone A	440.1	457.8	17.7
HRES-04	(D-1-13)33ccd	open	120.6	438.9	318.3
		Zone A	173.4	238.3	64.9
		Zone B	387.1	441.1	54.0
HRES-05	(D-2-13)05ccb	open	98.0	321.6	223.6
		Zone A	114.0	132.6	18.6
		Zone B	175.6	187.4	11.8
		Zone C	306.3	317.6	11.3

6.1.3 Well HRES-01, Test 2

Test 2 at well HRES-01 was for zones B and C. Based on interpretation of logs and construction reports, thickness of the zones hydraulically tested was 45.2 m. After completing Test 1, the packer on the pump column pipe was inflated on March 13, 2004 at a depth of about 354 m bls, effectively isolating the zones B and C with the pump assembly.

Test 2 started March 15, 2004 and pumping rate for the 12-hour test ranged from 9.5 gpm to 8.4 gpm; average was 9.0 gpm. Depth to pre-pumping water level was 307.86 m bls. **Figure B-3** shows the log-log drawdown and semi-log recovery graph for the test. The straight-line analysis of recovery data provided aquifer T computed to be 0.88 m^2/d.

Near the end of the pumping period, water level drawdown was 1.65 m above the packer. This amount of change in water level above the packer indicates an effective seal in the well, and moderate hydraulic communication between zones B and zone C in the aquifer near the well.

6.1.4 Well HRES-01, Test 3

Test 3 at well HRES-01 was for zone C. Based on interpretation of logs and construction reports, thickness of the zones tested was 22.3 m. After completing Test 2, the pump and packer assemble was lowered to about 440 m bls and the packer was inflated to isolate zone C.

Test 3 started March 17, 2004 and pumping rate for the 12-hour test was 8.5 gpm. Depth to pre-pumping water level was 303.25 m bls. **Figure B-3** shows the drawdown and recovery graph for the test. The straight-line analysis of recovery data provided aquifer T computed to be 0.22 m^2/d.

Near the end of the pumping period, water level drawdown was 0.08 m above the packer. This amount of change in water level above the packer indicates an effective seal in the well, and small hydraulic communication between zones B and zone C in the aquifer near the well.

Table B-2. Results of Pumping Test Analyses for HRES Wells

Well	Date Test Started	Test Description	Duration of Pumping (hours)	Average Pumping Rate (gpm)[a]	Theis Semi-Logarithmic Recovery Method Transmissivity (m^2/d)[b]	Neuman Log-Log Graphical Method		Operative Transmissivity[d] (m^2/d)
						Transmissivity (m^2/d)	Specific Yield[c]	
HRES-1	10-Feb-2004	Open Borehole	4	87	5.3	4.4	0.11	5.3
	12-Mar-2004	Test 1 (Zones A, B, C)	12	10	0.95	1.0	0.10	0.95
	15-Mar-2004	Test 2 (Zones B, C)	12	9.0	0.88	0.83	0.12	0.88
	17-Mar-2004	Test 3 (Zone C)	12	8.5	0.22	0.34	0.014	0.22
HRES-2	18-Feb-2004	Open Borehole	2	205	13	2.4	0.15	13
	6-Apr-2004	Test 1 (Zones A, B, C)	12	17	19	3.2	0.03	19
	8-Apr-2004	Test 2 (Zones B, C)	12	7.5	0.56	1.7	0.01	0.56
	10-Apr-2004	Test 3 (Zone C)	12	4.6	0.27	1.4	0.20	0.27
HRES-3	25-Feb-2004	Open Borehole	2	24	2.0	0.22	0.15	2.0
	16-Apr-2004	Test 1 (Zone A)	---[e]	---	---	---	---	---
HRES-4	3-Mar-2004	Open Borehole	4	105	122	5.4	0.30	122
	15-Apr-2004	Test 1 (Zones A, B)	12	23	66	48	0.04	66
	16-Apr-2004	Test 2 (Zone B)	---[e]	---	---	---	---	---
HRES-5	9-Mar-2004	Open Borehole	4	53	89	3.7	0.20	89
	2-Apr-2004	Test 1 (Zones A, B,C)	12	23	96	14	0.20	96
	4-Apr-2004	Test 2 (Zone B,C)	---[e]	---	---	---	---	---

[a] *gpm = gallons per minute*

[b] *m^2/d = cubic meters per day per meter width of aquifer at 1:1 hydraulic gradient*
[c] *Specific Yield = the volume of water released from storage per unit surface area of an unconfined aquifer per unit decline of the water table surface*

[d] *Operative Transmissivity = transmissivity derived from pumped well recovery analysis.*

[e] *Pumping rate not sustainable. Unable to complete test and analyze data for aquifer parameters.*

6.2 Well HRES-02

Details of drilling and well construction for well HRES-02 are given in previous sections of this report. In summary, 4-inch blank and perforated steel casing is installed from land surface to a depth of 399.3 m bls. Three fracture zones have casing screens ranging from depths of 196.9 to 210.9 m bls (zone A), 310.0 to 320.9 m bls (zone B), and 382.8 to 400.2 m bls (zone C). Bentonite seals in the annulus between the well casing and borehole wall hydraulically isolate these zones in the well. Hydrologic testing included constant-rate pumping tests for: open borehole; composite zones A, B, and C (Test 1); composite zones B and C (Test 2), and zone C (Test 3).

6.2.1 Well HRES-02, Open Borehole Testing

The HRES-02 open borehole penetrated the Apache Leap Tuff. Based on interpretation of logs and groundwater level measurements estimated b was 308.3 m. The constant-rate, airlift pumping test for the HRES-02 open borehole was conducted on February 18, 2004. The average discharge rate was 205 gpm for the 110-minute pumping period. Depth to pre-pumping water level was 88.49 m bls. **Figure B-4** shows the drawdown and recovery graph for the test. The straight-line analysis of recovery data provided aquifer T computed to be 13 m^2/d.

6.2.2 Well HRES-02, Test 1

Test 1 at well HRES-02 was for zones A, B, and C. Based on interpretation of logs and construction reports, thickness of the zones tested was 42.3 m. A pretest was conducted at well HRES-02 on April 5, 2004, for well development and for determining pumping rates for the constant-rate discharge test. The pump was set at 357 m below the top of casing. Test 1 was conducted on April 6, 2004. Average pumping rate for the 12-hour test was 17 gpm. Depth to pre-pumping water level was 90.54 m bls. **Figure B-4** shows the drawdown and recovery graph for the test. The straight-line analysis of recovery data provided aquifer T computed to be 19 m^2/d.

6.2.3 Well HRES-02, Test 2

Test 2 at well HRES-02 was for zones B and C. Based on interpretation of logs and construction reports, thickness of the zones tested was 28.3 m. After completing Test 1, the packer on the pump column pipe was inflated on April 7, 2004 at a depth of about 247 m bls, effectively isolating the zones B and C with the pump assembly. Test 2 started April 8, 2004. For the 12-hour pumping test, pumping rate ranged from 6.3 to 9.5 gpm; average was 7.5 gpm. Depth to pre-pumping water level was 90.52 m bls. **Figure B-5** shows the drawdown and recovery graph for the test. The straight-line analysis of recovery data provided aquifer T computed to be 0.56 m^2/d.

Near the end of the pumping period, water level drawdown was 0.03 m above the packer. This amount of change in water level above the packer indicates an effective seal in the well, and small hydraulic communication between zone A and zones B and zone C in the aquifer near the well.

6.2.4 Well HRES-02, Test 3

Test 3 at well HRES-02 was for zone C. Based on interpretation of logs and construction reports, thickness of the zones tested was 17.4 m. After completing Test 2, the pump and packer assemble was lowered to about 328 m bls and the packer was inflated to isolate zone C. Test 3 started April 10, 2004 and pumping rate for the 12-hour test was 4.6 gpm. Depth to pre-pumping water level was 95.70 m bls. **Figure B-5** shows the drawdown and recovery graph for the test. The straight-line analysis of recovery data provided aquifer T computed to be 0.27 m^2/d.

Near the end of the pumping period, water level drawdown was 0.09 m above the packer. This amount of change in water level above the packer indicates an effective seal in the well, and small hydraulic communication between zones B and zone C in the aquifer near the well.

6.3 Well HRES-03

Details of drilling and well construction for well HRES-03 are given in previous sections of this report. In summary, 4-inch blank and perforated steel casing is installed from land surface to a depth of 457.2 m bls. A deep fracture zone has casing screen from a depth of 440.1 to 457.8 m bls (zone A). Bentonite seals in the annulus between the well casing and borehole wall hydraulically isolate this zone in the well. Hydrologic testing included constant-rate pumping tests for open borehole and zone A (Test 1).

6.3.1 Well HRES-03, Open Borehole Testing

The HRES-03 open borehole penetrated the Apache Leap Tuff. Based on interpretation of logs and groundwater level measurements estimated b was 336.2 m. The constant-rate, air-lift pumping test for the HRES-03 open borehole was conducted on February 25, 2004. The average discharge rate was 24 gpm for the 120-minute pumping period. Depth to pre-pumping water level was 89.96 m bls. **Figure B-6** shows the drawdown and recovery graph for the test. The straight-line analysis of recovery data provided aquifer T computed to be 2.0 m^2/d.

6.3.2 Well HRES-03, Test 1

Test 1 at well HRES-01 was for zone A. Based on interpretation of logs and construction reports, thickness of the zone tested was 18.0 m. The pump was set at 182 m below the top of casing. Pre-testing at well HRES-03 was on April 15 and 16, 2004. Pumping rates larger than 1 gpm could not be maintained during the pretest. Because of low and variable pumping rate, plans were abandoned for Test 1.

6.4 Well HRES-04

Details of drilling and well construction for well HRES-04 are given in previous sections of this report. In summary, 4-inch blank and perforated steel casing is installed from land surface to a depth of 438.9 m bls. Two fracture zones have casing screens ranging from depths of 173.4 to 238.3 m bls (zone A) and 387.1 to 441.1 m bls (zone B). Bentonite seals in the annulus between the well casing and borehole wall hydraulically isolate these zones in the well. Hydrologic testing included constant-rate pumping tests for: open borehole; composite zones A and B (Test 1); and zone B (Test 2).

6.4.1 Well HRES-04, Open Borehole Testing

The HRES-04 open borehole penetrated the Apache Leap Tuff. Based on interpretation of logs and groundwater level measurements estimated b was 318.3 m. The constant-rate, air-lift pumping test for the HRES-04 open borehole was conducted on March 3, 2004. The average discharge rate was 105 gpm for the 240-minute pumping period. Depth to pre-pumping water level was 120.6 m bls. **Figure B-7** shows the drawdown and recovery graph for the test. The straight-line analysis of recovery data provided aquifer T computed to be 122 m^2/d.

6.4.2 Well HRES-04, Test 1

Test 1 at well HRES-04 was for zones A and B. Based on interpretation of logs and construction reports, thickness of the zones tested was 119 m. Test 1 was conducted on April 15, 2004. The pump was set at 250 m bls. Average pumping rate for the 12-hour test was 22.5 gpm. Depth to pre-pumping water level was 96.50 m bls. **Figure B-7** shows the drawdown and recovery graph for the test. The straight-line analysis of recovery data provided aquifer T computed to be 66 m^2/d.

6.4.3 Well HRES-04, Test 2

Test 2 at well HRES-04 was for zone B. Based on interpretation of logs and construction reports, thickness of the zones tested was 54 m. After completing Test 1, the packer on the pump column pipe was inflated on April 16, 2004 at a depth of about 245 m bls, effectively isolating the zone B with the pump assembly. Pre-testing at well HRES-04 started and pumping rates larger than 1 gpm could not be maintained during the pretest. Because of low and variable pumping rate, plans were abandoned for Test 2.

6.5 Well HRES-05

Details of drilling and well construction for well HRES-05 are given in previous sections of this report. In summary, 4-inch blank and perforated steel casing is installed from land surface to a depth of 321.6 m bls. Two fracture zones have casing screens ranging from depths of 117.3 to 129.5 m bls (zone A), 178.3 to 184.4 m bls (zone B), and 309.4 to 315.5 m bls. Bentonite seals in the annulus between the well casing and borehole wall hydraulically isolate these zones in the well. Hydrologic testing included constant-rate pumping tests for: open borehole; composite zones A, B, and C (Test 1); and composite zones B and C (Test 2).

6.5.1 Well HRES-05, Open Borehole Testing

The HRES-05 open borehole penetrated the Apache Leap Tuff. Based on interpretation of logs and groundwater level measurements estimated b was 223.6 m. The constant-rate, air-lift pumping test for the HRES-05 open borehole was conducted on March 9, 2004. The average discharge rate was 53 gpm for the 240-minute pumping period. Depth to pre-pumping water level was 96.50 m bls. **Figure B-8** shows the drawdown and recovery graph for the test. The straight-line analysis of recovery data provided aquifer T computed to be 89 m^2/d.

6.5.2 Well HRES-05, Test 1

Test 1 at well HRES-05 was for zones A, B, and C. Based on interpretation of logs and construction reports, thickness of the zones tested was 24 m. Test 1 was conducted on April 2, 2004. The pump was set at 201 m bls. Average pumping rate for the 12-hour test was 23 gpm. Depth to pre-pumping water level was 88.60 m bls. **Figure B-8** shows the drawdown and recovery graph for the test. The straight-line analysis of recovery data provided aquifer T computed to be 96 m^2/d.

6.5.3 Well HRES-05, Test 2

Test 2 at well HRES-05 was for zones B and C. Based on interpretation of logs and construction reports, thickness of the zones tested was 12 m. After completing Test 1, the packer on the pump column pipe was inflated on April 3, 2004 at a depth of about 197 m bls, effectively isolating the zones B and C with the pump assembly. Pre-testing at well HRES-05 started and pumping rates larger than 1 gpm could not be maintained during the pretest. Because of low and variable pumping rate, plans were abandoned for Test 2.

7 SUMMARY AND CONCLUSIONS

Wells HRES-01 through HRES-05 were drilled in 2004 as hydrogeologic characterization wells in the Apache Leap Tuff. These wells provide a preliminary assessment of hydrogeologic conditions and a means of long-term monitoring of hydraulic head and chemical quality of groundwater. Hydrologic testing at the HRES wells after drilling and construction included short-term constant-rate pumping tests using air-lift and pump equipment.

Aquifer properties were computed from data obtained during hydrologic composite and zone testing. These properties include transmissivity, hydraulic conductivity, and specific yield for the Apache Leap Tuff in the Oak Flat and Shaft No. 9 area that surrounds the well sites. By subtraction, transmissivity by zone is computed by using the composite results shown in **Table B-2**. Results of zone and composite transmissivities and hydraulic conductivities are shown in **Table B-3.**

Hydraulic conductivity estimates are calculated by dividing transmissivity by aquifer thickness for open boreholes tests and by vertical thickness of the zone open to the aquifer **(Table B-3)**. Lower estimates are consistent with previously cited transmissivities and hydraulic conductivity values for the Apache Leap Tuff by the University of Arizona (Woodhouse, 1997). The range in estimates is consistent with computed aquifer parameters obtained from fractured volcanic aquifers (Freeze and Cherry, 1979) and analogous to Tertiary, fractured tuff aquifers in the area of the Nevada test site (Belcher and others, 2001).

The higher K zone estimates for the Apache Leap Tuff aquifer are reflective of the preponderance of higher permeability fractured rock intervals in the upper parts of the aquifer (Woodhouse,1997). At depth, K zone estimates are lower and are indicative of less permeable fracture intervals.

Estimates of specific yield derived from log-log type curve analysis are shown in **Table B-2.** These values are indicative of unconfined aquifer conditions in the Apache Leap Tuff. However, tests were of short-duration and did not include observation wells, therefore computed specific capacities are approximate by order of magnitude.

In designing and analyzing the single-well pumping tests, we idealized the aquifer as an equivalent porous medium with uniform hydraulic properties. This approach assumes that a large-scale volume of fractured rock controls groundwater movement. The fractures form a network of interconnected conduits, similar to magnified connected pore spaces in sedimentary, granular media. Results of hydraulic test analyses provide, in general terms, the local-scale hydraulic properties of the Apache Leap Tuff aquifer. Hydrologic testing indicates at the HRES well locations shows no hydraulic boundaries or response characteristics indicative of detachment or perched-water conditions. Results so far suggest that the saturated fractured rock aquifer at these locations is part of the larger, area-wide unconfined aquifer system.

Additional work would be useful in attaining a better understanding of our fractured-rock hydrology conceptual model of the Apache Leap Tuff aquifer, especially in terms of dual-porosity or small-scale fracture controlled groundwater movement. Hydraulic tests in the Oak Flat area during the 2004 study were done in wells that served multi-purposes for the project. Because higher density fracturing tended to be tested, results may be biased toward higher estimates of the hydraulic properties of the aquifer. Single-well tests may also bias hydraulic test results, higher or lower, to near borehole aquifer conditions. Based on other studies in fractured rock, there is some evidence that wells in the vicinity of high density lineaments (rock joints and faults expressed at land surface) are likely to yield larger quantities of groundwater than rocks drilled away from the lineament pattern. Therefore, recommend hydraulic testing is required to better define these larger-scale aquifer characteristics.

Table B-3. Summary of Zone and Composite Pumping Test Results

Well Identifier	Description of Hydrologic Testing Zone	Aquifer Thickness (meters)	Transmissivity (m^2/d)[a]	Hydraulic Conductivity (m/d)[b]
HRES-01	Open Borehole	219.0	5.3	0.024
	A	23.8	0.07	0.003
	B	22.9	0.66	0.029
	C	22.3	0.22	0.010
HRES-02	Open Borehole	308.3	14	0.05
	A	14.0	18	1.3
	B	10.9	0.29	0.03
	C	17.4	0.27	0.02
HRES-03	Open Borehole	336.2	2.0	0.006
	A	17.7	--[c]	< 0.001[d]
HRES-04	Open Borehole	318.0	122	0.4
	A	64.9	66	1.0
	B	54.0	--	< 0.001
HRES-05	Open Borehole	223.6	89	0.4
	A	18.6	96	5.2
	B	11.8	--	< 0.001
	C	11.3	--	< 0.001

[a] *m^2/d = square meters per day per meter width of aquifer at 1:1 hydraulic gradient*

[b] *m/d = meters per day per meter width of aquifer at 1:1 hydraulic gradient*

[c] *Pumping rate not sustainable. Unable to complete test and analyze data for aquifer parameters.*

[d] *Assume zone is less than 0.001 m/d.*

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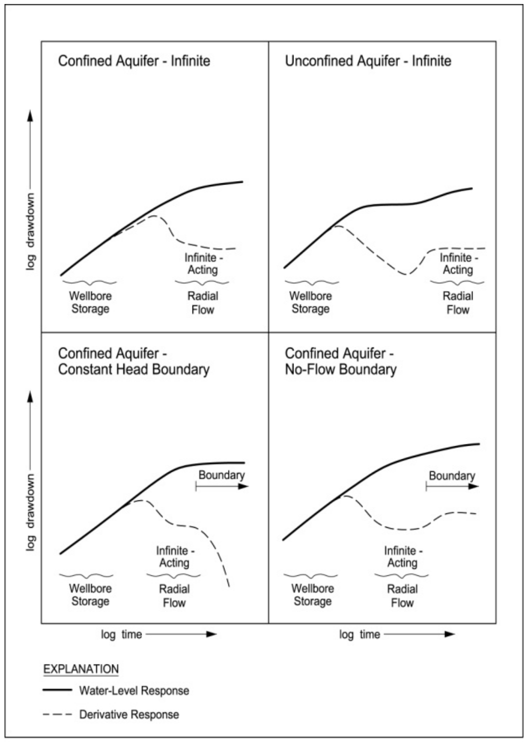
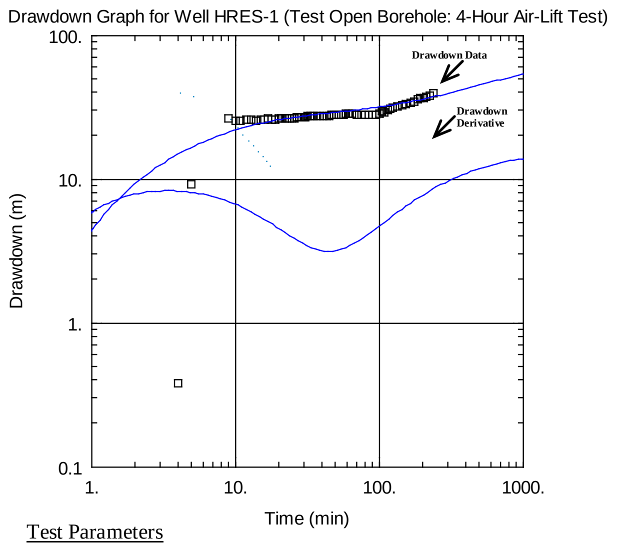
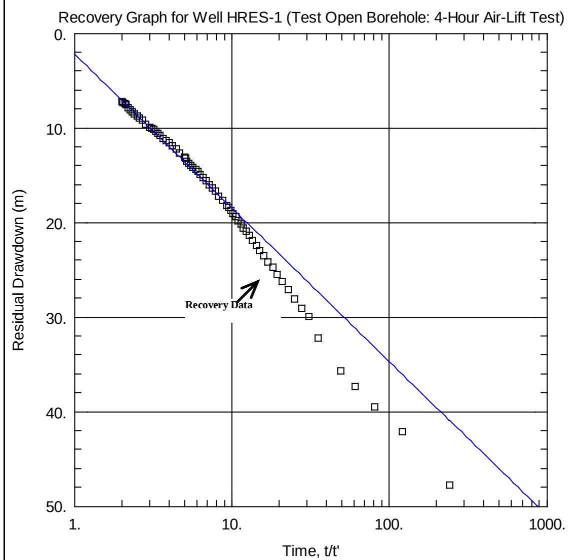


Figure B-1. Schematic Log-Log Hydrographs of Drawdown and Drawdown Derivative versus Time for some Common Aquifer Conditions (after Spane, 1993)



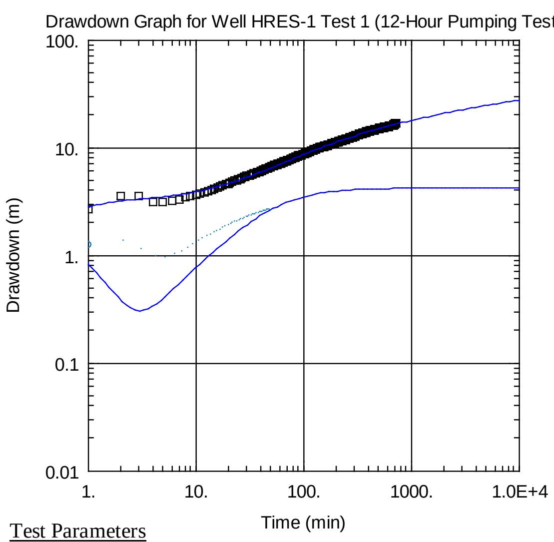
<u>Test Parameters</u>
Non-Pumping Water Level 267.85 m bls (Open Borehole)
Pumping Started 1214 February 10, 2004
Pumping Stopped 1614 February 10, 2004
Average Pumping Rate 86.7 gpm

<u>Analysis Parameters</u>
Aquifer Analytical Model = Neuman (Unconfined)
Transmissivity = 4.4 m^2/d
Storage Coefficient = 0.012
Specific Yield = 0.11



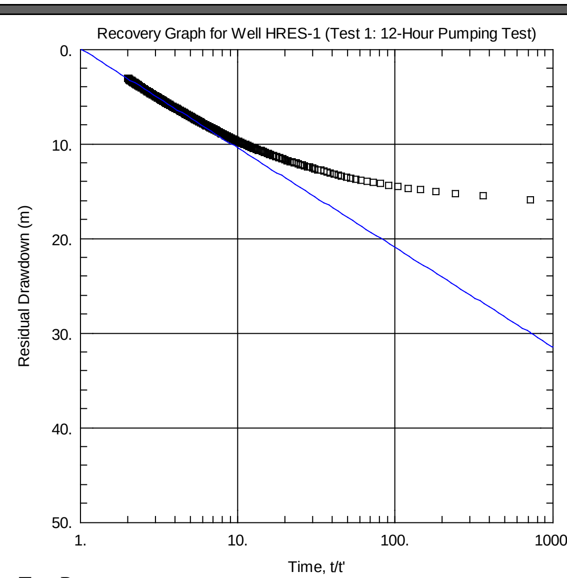
<u>Test Parameters</u>
Non-Pumping Water Level 267.85 m bls (Open Borehole)
Pumping Started 1214 February 10, 2004
Pumping Stopped 1614 February 10, 2004
Average Pumping Rate 86.7 gpm

<u>Analysis Parameters</u>
Aquifer Analytical Model = Theis (Recovery)
Transmissivity = 5.3 m^2/d



<u>Test Parameters</u>
Non-Pumping Water Level 293.01 m bls (Zones A, B, and C)
Pumping Started 0800 March 12, 2004
Pumping Stopped 2000 March 12, 2004
Average Pumping Rate 10.0 gpm

<u>Analysis Parameters</u>
Aquifer Analytical Model = Neuman (Unconfined)
Transmissivity = 1.0 m^2/d
Storage Coefficient = 0.0020
Specific Yield = 0.10



<u>Test Parameters</u>
Non-Pumping Water Level 293.01 m bls (Zones A, B, and C)
Pumping Started 0800 March 12, 2004
Pumping Stopped 2000 March 12, 2004
Average Pumping Rate 10.0 gpm

<u>Analysis Parameters</u>
Aquifer Analytical Model = Theis (Recovery)
Transmissivity = 0.95 m^2/d

Figure B-2. Drawdown and Recovery Graphs of Drawdown Data and Drawdown Derivative, Recovery Data, and Fitted Line for Analysis of Testing at Well HRES-01, Open Borehole Test and Test 1

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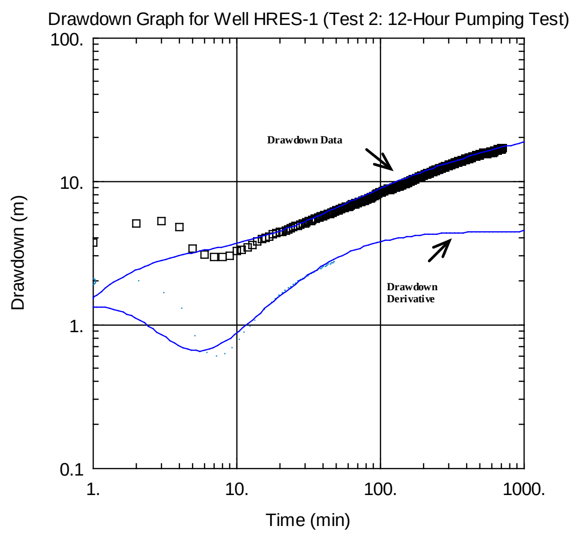
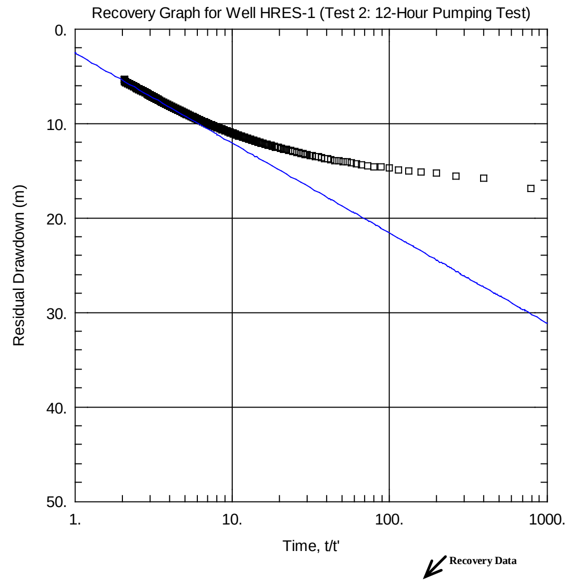


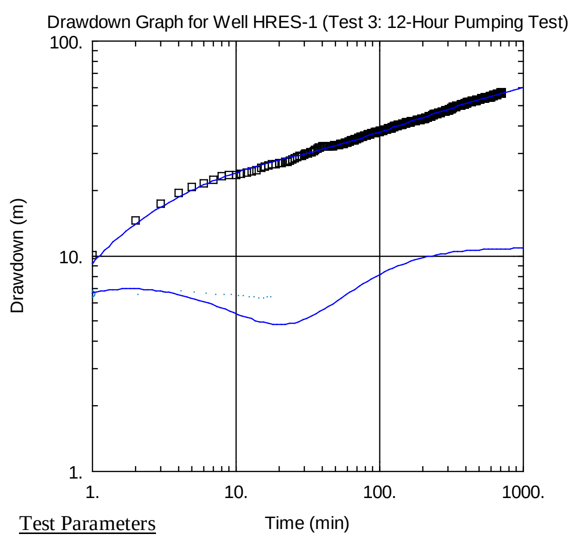
Test Parameters
Non-Pumping Water Level 307.86 m bls (Zones B and C)
Pumping Started 0750 March 15, 2004
Pumping Stopped 1950 March 15, 2004
Average Pumping Rate 9.0 gpm

Analysis Parameters
Aquifer Analytical Model = Neuman (Unconfined)
Transmissivity = 0.83 m^2/d
Storage Coefficient = 0.010
Specific Yield = 0.12



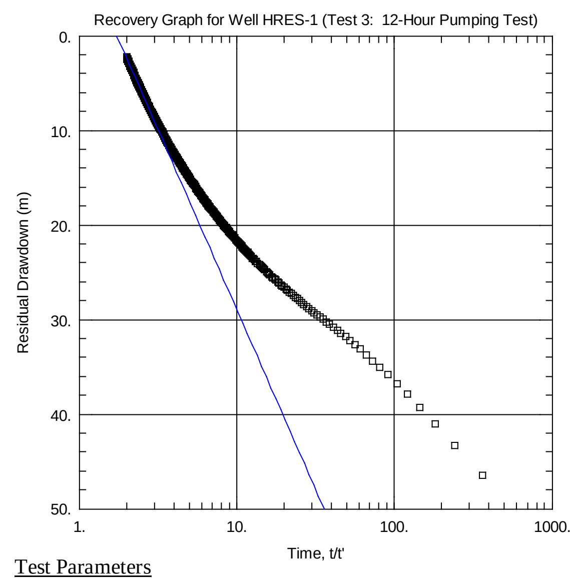
Test Parameters
Non-Pumping Water Level 307.86 m bls (Zones B and C)
Pumping Started 0750 March 15, 2004
Pumping Stopped 1950 March 15, 2004
Average Pumping Rate 9.0 gpm

Analysis Parameters
Aquifer Analytical Model = Theis (Recovery)
Transmissivity = 0.88 m^2/d



Test Parameters
Non-Pumping Water Level 303.25 m bls (Zone C)
Pumping Started 0700 March 17, 2004
Pumping Stopped 1900 March 17, 2004
Average Pumping Rate 8.5 gpm

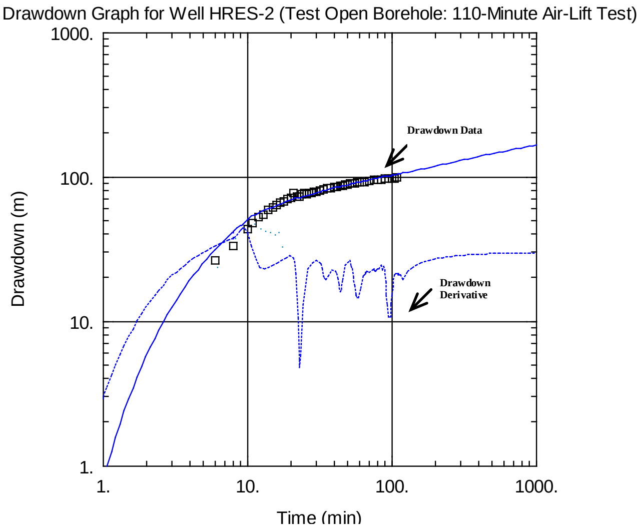
Analysis Parameters
Aquifer Analytical Model = Neuman (Unconfined)
Transmissivity = 0.34 m^2/d
Storage Coefficient = 0.0031
Specific Yield = 0.014



Test Parameters
Non-Pumping Water Level 303.25 m bls (Zone C)
Pumping Started 0700 March 17, 2004
Pumping Stopped 1900 March 17, 2004
Average Pumping Rate 8.5 gpm

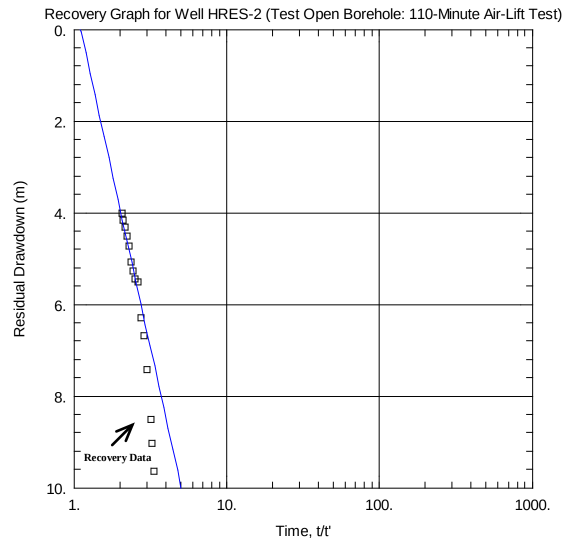
Analysis Parameters
Aquifer Analytical Model = Theis (Recovery)
Transmissivity = 0.22 m^2/d

Figure B-3. Drawdown and Recovery Graphs Showing Drawdown Data and Drawdown Derivative, Recovery Data, and Fitted Line for Analysis of Testing at Well HRES-01, Test 2 and Test 3



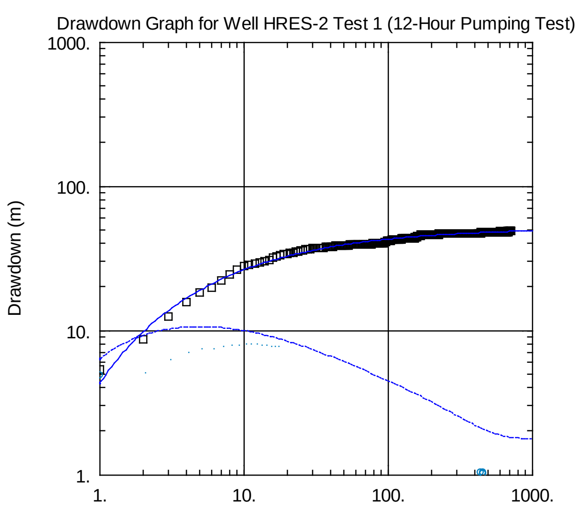
<u>Test Parameters</u>
Non-Pumping Water Level 88.49 m bls (Open Borehole)
Pumping Started 0300 February 18, 2004
Pumping Stopped 0450 February 18, 2004
Average Pumping Rate 205 gpm

<u>Analysis Parameters</u>
Aquifer Analytical Model = Neuman (Unconfined)
Transmissivity = 2.4 m^2/d
Storage Coefficient = 0.08
Specific Yield = 0.15



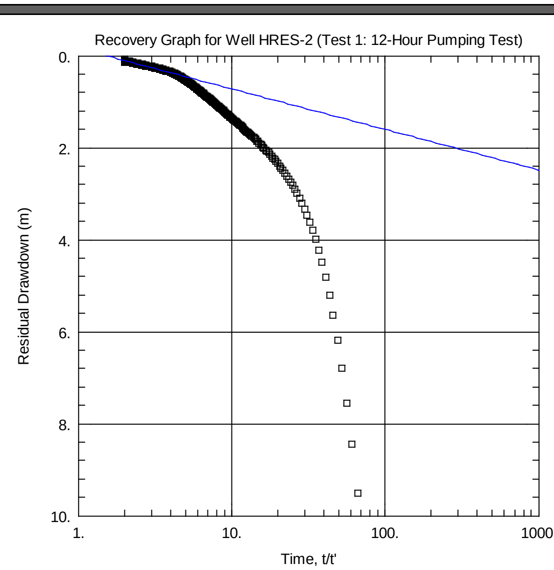
<u>Test Parameters</u>
Non-Pumping Water Level 88.49 m bls (Open Borehole)
Pumping Started 0300 February 18, 2004
Pumping Stopped 0450 February 18, 2004
Average Pumping Rate 205 gpm

<u>Analysis Parameters</u>
Aquifer Analytical Model = Theis (Recovery)
Transmissivity = 13 m^2/d



<u>Test Parameters</u>
Non-Pumping Water Level 90.54 m bls (Zones A, B, and C)
Pumping Started 0715 April 6, 2004
Pumping Stopped 1915 April 6, 2004
Average Pumping Rate 16.7 gpm

<u>Analysis Parameters</u>
Aquifer Analytical Model = Neuman (Unconfined)
Transmissivity = 3.2 m^2/d
Storage Coefficient = 0.020
Specific Yield = 0.031



<u>Test Parameters</u>
Non-Pumping Water Level 90.54 m bls (Zones A, B, and C)
Pumping Started 0715 April 6, 2004
Pumping Stopped 1915 April 6, 2004
Average Pumping Rate 16.7 gpm

<u>Analysis Parameters</u>
Aquifer Analytical Model = Theis (Recovery)
Transmissivity = 19 m^2/d

Figure B-4. Drawdown and Recovery Graphs Showing Drawdown Data and Drawdown Derivative, Recovery Data, and Fitted Line for Analysis of Testing at Well HRES-02, Open Borehole Test and Test 1

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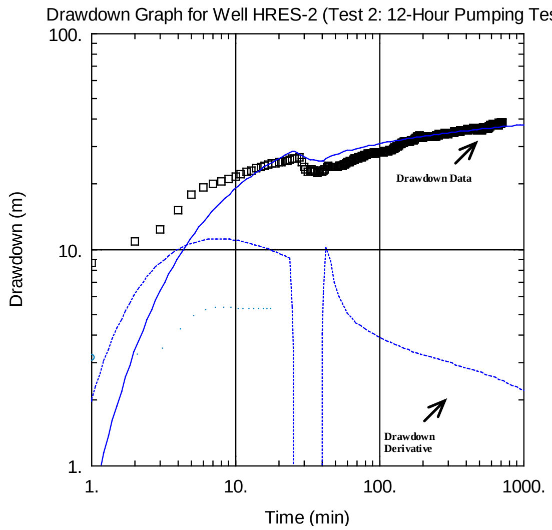
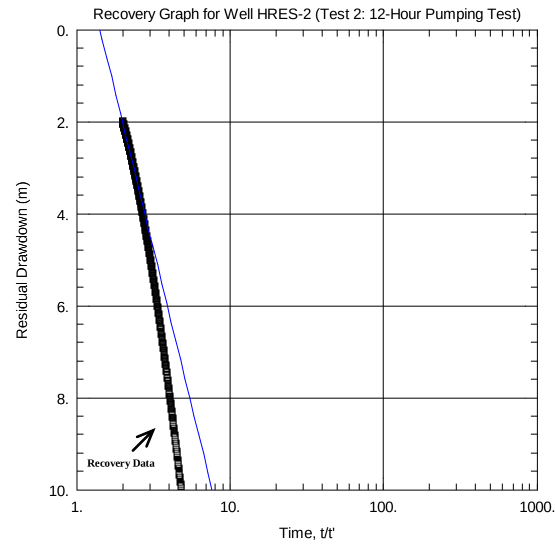
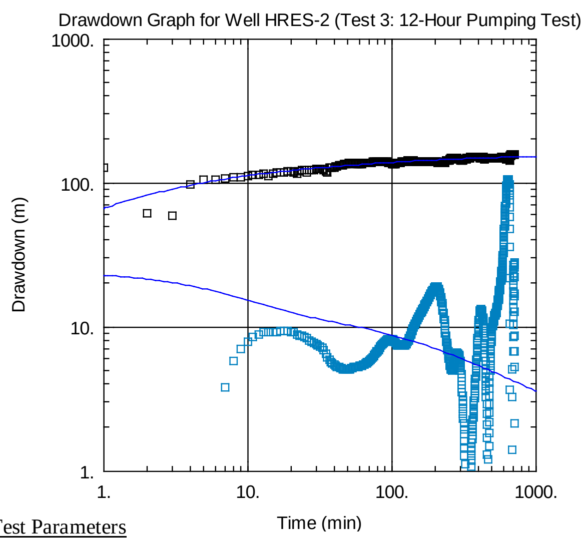


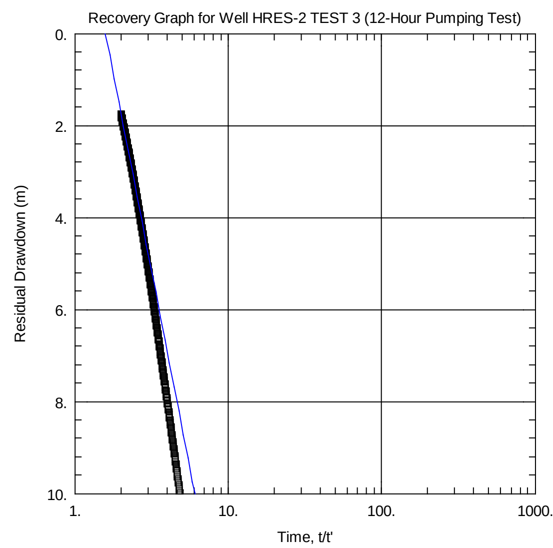
Test Parameters
Non-Pumping Water Level 90.52 m bls (Zones B and C)
Pumping Started 0730 April 8, 2004
Pumping Stopped 1930 April 8, 2004
Average Pumping Rate 7.5 gpm
Analysis Parameters
Aquifer Analytical Model = Neuman (Unconfined)
Transmissivity = 1.7 m^2/d
Storage Coefficient = 0.046
Specific Yield = 0.010



Test Parameters
Non-Pumping Water Level 90.52 m bls (Zones B and C)
Pumping Started 0730 April 8, 2004
Pumping Stopped 1930 April 8, 2004
Average Pumping Rate 7.5 gpm
Analysis Parameters
Aquifer Analytical Model = Theis (Recovery)
Transmissivity = 0.56 m^2/d

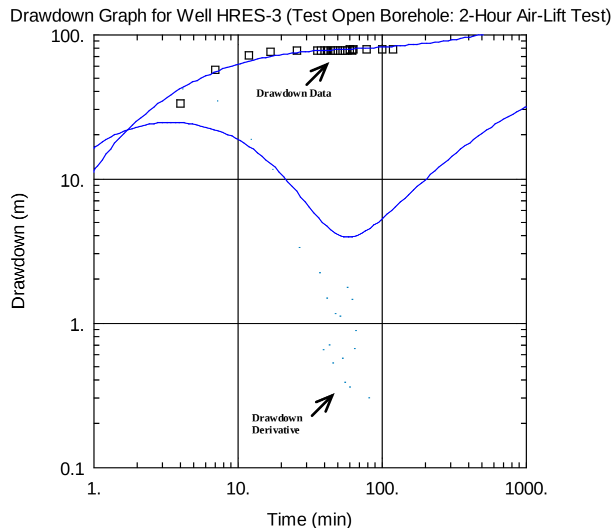


Test Parameters
Non-Pumping Water Level 95.70 m bls (Zone C)
Pumping Started 0655 April 10, 2004
Pumping Stopped 1855 April 10, 2004
Average Pumping Rate 4.6 gpm
Analysis Parameters
Aquifer Analytical Model = Neuman (Unconfined)
Transmissivity = 1.4 m^2/d
Storage Coefficient = 0.00068
Specific Yield = 0.20



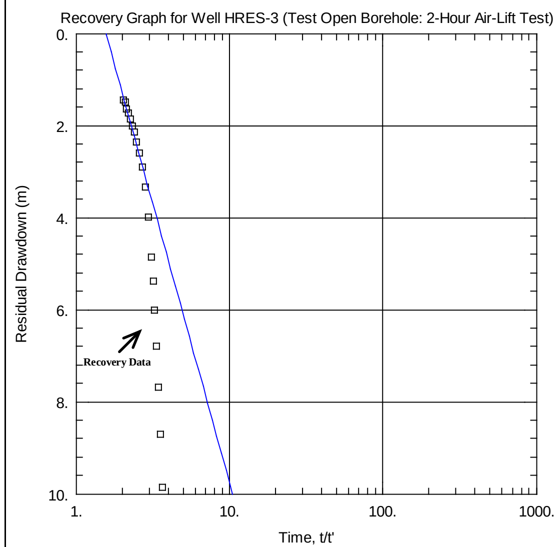
Test Parameters
Non-Pumping Water Level 95.70 m bls (Zone C)
Pumping Started 0655 April 10, 2004
Pumping Stopped 1855 April 10, 2004
Average Pumping Rate 4.6 gpm
Analysis Parameters
Aquifer Analytical Model = Theis (Recovery)
Transmissivity = 0.27 m^2/d

Figure B-5. Drawdown and Recovery Graphs Showing Drawdown Data and Drawdown Derivative, Recovery Data, and Fitted Line for Analysis of Testing at Well HRES-02, Test 2 and Test 3



Test Parameters
Non-Pumping Water Level 89.96 m bls (Open Borehole)
Pumping Started 1400 February 25, 2004
Pumping Stopped 1600 February 25, 2004
Average Pumping Rate 24.1 gpm

Analysis Parameters
Aquifer Analytical Model = Neuman (Unconfined)
Transmissivity = 0.22 m^2/d
Storage Coefficient = 0.0021
Specific Yield = 0.15



Test Parameters
Non-Pumping Water Level 89.96 m bls (Open Borehole)
Pumping Started 1400 February 25, 2004
Pumping Stopped 1600 February 25, 2004
Average Pumping Rate 24.1 gpm

Analysis Parameters
Aquifer Analytical Model = Theis (Recovery)
Transmissivity = 2.0 m^2/d

Figure B-6. Drawdown and Recovery Graphs Showing Drawdown Data and Drawdown Derivative, Recovery Data, and Fitted Line for Analysis of Testing at Well HRES-03, Open Borehole Test

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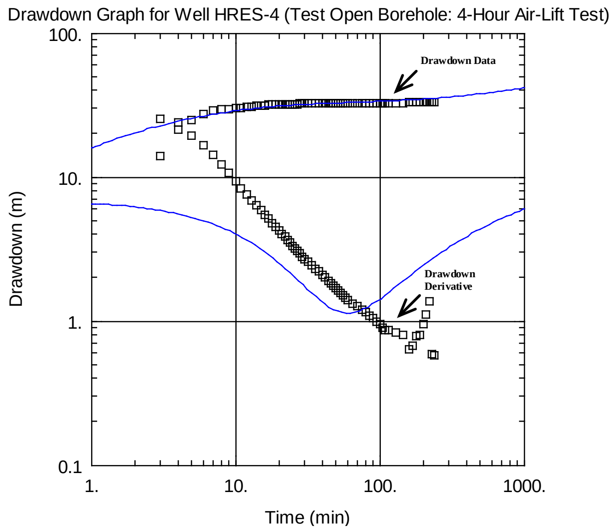
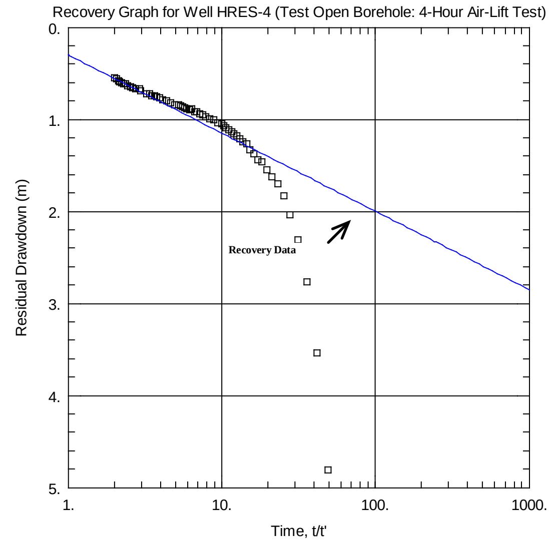
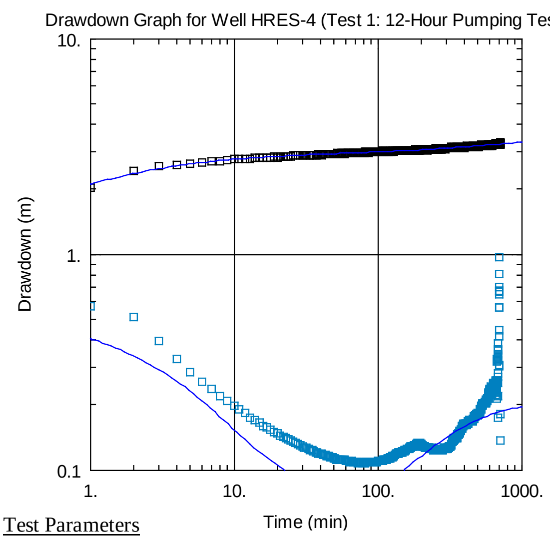


<u>Test Parameters</u>
Non-Pumping Water Level 120.6 m bls (Open Borehole)
Pumping Started 1350 March 3, 2004
Pumping Stopped 1750 March 3, 2004
Average Pumping Rate 104.5 gpm
<u>Analysis Parameters</u>
Aquifer Analytical Model = Neuman (Unconfined)
Transmissivity = 2.4 m^2/d
Storage Coefficient = 0.08
Specific Yield = 0.15

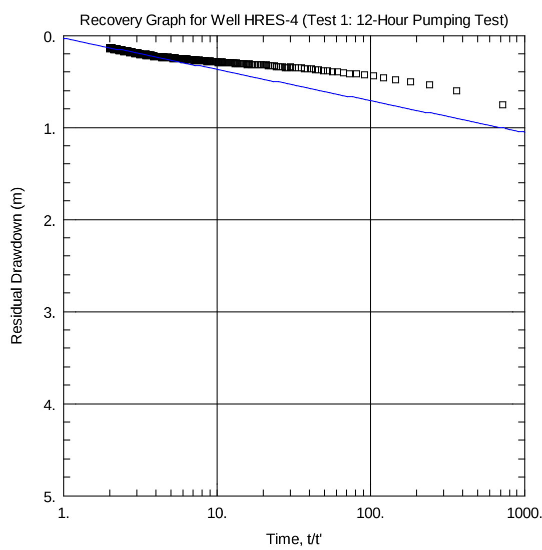


<u>Test Parameters</u>
Non-Pumping Water Level 120.6 m bls (Open Borehole)
Pumping Started 1350 March 3, 2004
Pumping Stopped 1750 March 3, 2004
Average Pumping Rate 104.5 gpm
<u>Analysis Parameters</u>
Aquifer Analytical Model = Theis (Recovery)
Transmissivity = 121.9 m^2/d



<u>Test Parameters</u>
Non-Pumping Water Level 96.5 m bls (Zones A and B)
Pumping Started 0600 April 15, 2004
Pumping Stopped 1800 April 15, 2004
Average Pumping Rate 22.5 gpm

<u>Analysis Parameters</u>
Aquifer Analytical Model = Neuman (Unconfined)
Transmissivity = 47.8 m^2/d
Storage Coefficient = 0.0053
Specific Yield = 0.040



<u>Test Parameters</u>
Non-Pumping Water Level 96.5 m bls (Zones A and B)
Pumping Started 0600 April 15, 2004
Pumping Stopped 1800 April 15, 2004
Average Pumping Rate 22.5 gpm

<u>Analysis Parameters</u>
Aquifer Analytical Model = Theis (Recovery)
Transmissivity = 66.0 m^2/d

Figure B-7. Drawdown and Recovery Graphs Showing Drawdown Data and Drawdown Derivative, Recovery Data, and Fitted Line for Analysis of Testing at Well HRES-04, Open Borehole Test and Test 1

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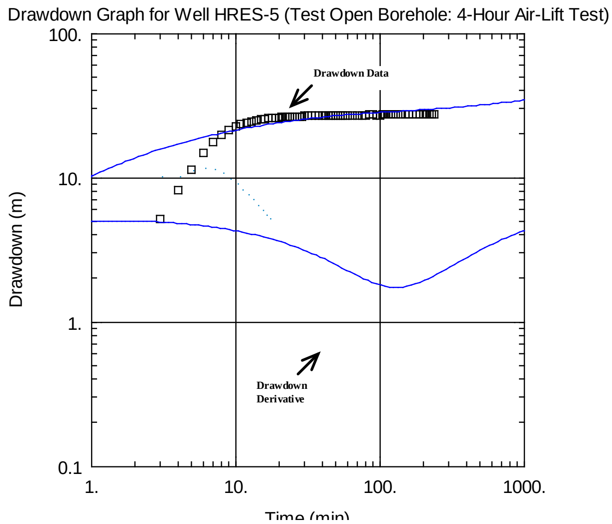
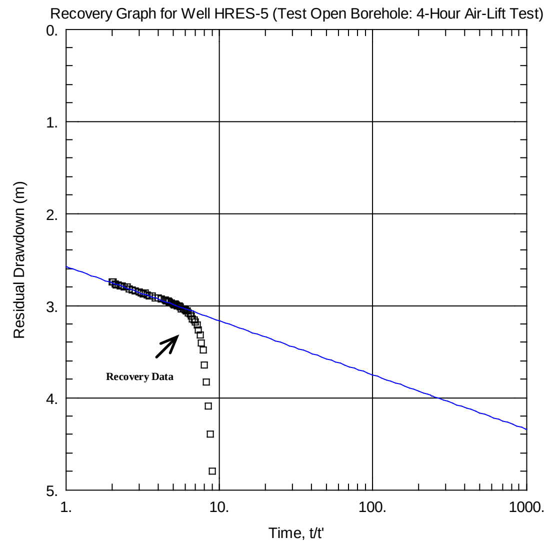
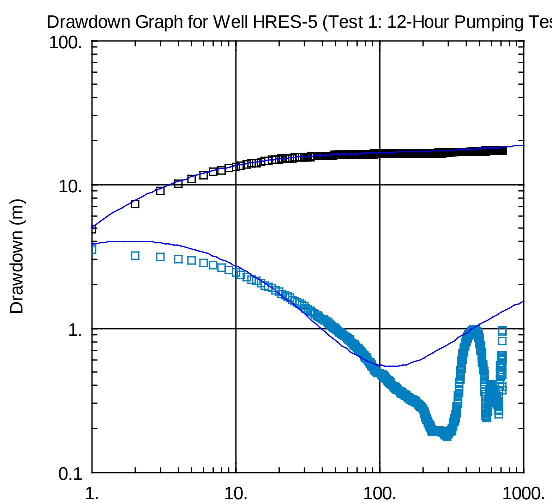


Test Parameters
Non-Pumping Water Level 96.5 m bls (Open Borehole)
Pumping Started March 2130 March 9, 2004
Pumping Stopped March 0130 March 10, 2004
Average Pumping Rate 52.5 gpm
Analysis Parameters
Aquifer Analytical Model = Neuman (Unconfined)
Transmissivity = 3.7 m^2/d
Storage Coefficient = 0.0045
Specific Yield = 0.20

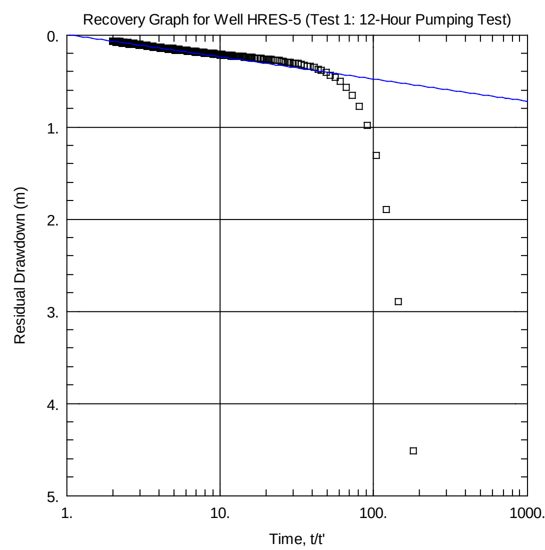


Test Parameters
Non-Pumping Water Level 96.5 m bls (Open Borehole)
Pumping Started March 2130 March 9, 2004
Pumping Stopped March 0130 March 10, 2004
Average Pumping Rate 52.5 gpm
Analysis Parameters
Aquifer Analytical Model = Theis (Recovery)
Transmissivity = 89.1 m^2/d



Test Parameters
Non-Pumping Water Level 88.60 m bls (Zones A and B)
Pumping Started 0925 April 2, 2004
Pumping Stopped 2125 April 2, 2004
Average Pumping Rate 23.1 gpm

Analysis Parameters
Aquifer Analytical Model = Neuman (Unconfined)
Transmissivity = 13.5 m^2/d
Storage Coefficient = 0.045
Specific Yield = 0.2



Test Parameters
Non-Pumping Water Level 88.60 m bls (Zones A and B)
Pumping Started 0925 April 2, 2004
Pumping Stopped 2125 April 2, 2004
Average Pumping Rate 23.1 gpm

Analysis Parameters
Aquifer Analytical Model = Theis (Recovery)
Transmissivity = 95.6 m^2/d

Figure B-8. Drawdown and Recovery Graphs Showing Drawdown Data and Drawdown Derivative, Recovery Data, and Fitted Line for Analysis of Testing at Well HRES-05, Open Borehole Test and Test 1

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