GEOTHERMAL DIRECT-USE WELL FOR COMMERCIAL GREENHOUSES RADIUM SPRINGS, NEW MEXICO

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Editor's Note: This report is a condensed version of the Final Report of a U.S. DOE cost-shared contract submitted by Alex R. Masson, Inc., of Linwood, KS, to the Idaho Operations Office, February 2001, titled: "Deep Production Well for Geothermal Direct-Use Heating of a Large Commercial Greenhouse, Radium Springs, Rio Grande Rift, New Mexico." This project is part of the cost-shared direct-use drilling program that also funded a well for a district heating project in Canby, CA, reported in Vol. 21, No. 4 of the *GHC Quarterly Bulletin* (December 2000), titled: "Drilling Geothermal Well ISO."

INTRODUCTION

Background

Expansion of a large commercial geothermally-heated greenhouse is underway and requires additional geothermal fluid production. This report discusses the results of a cost-shared U.S. Department of Energy (DOE) and A. R. Masson, Inc. drilling project designed to construct a highly productive geothermal production well for expansion of the large commercial greenhouse at Radium Springs. The well should eliminate the potential for future thermal breakthrough from existing injection wells and the inducement of inflow from shallow cold water aquifers by geothermal production drawdown in the shallow reservoir. An 800-ft deep production well, Masson 36, was drilled on a U.S. Bureau of Land Management (BLM) Geothermal Lease NM-3479 at Radium Springs adjacent to the A. R. Masson Radium Springs Farm commercial greenhouse 15 miles north of Las Cruces in Dona Ana County, New Mexico, just west of Interstate 25 near the east bank of the Rio Grande. (Figure 1). The area is in the Rio Grande rift, a tectonically-active region with high heat flow, and is one of the major geothermal provinces in the western United States (Seager and Morgan, 1979; White and Williams, 1975).

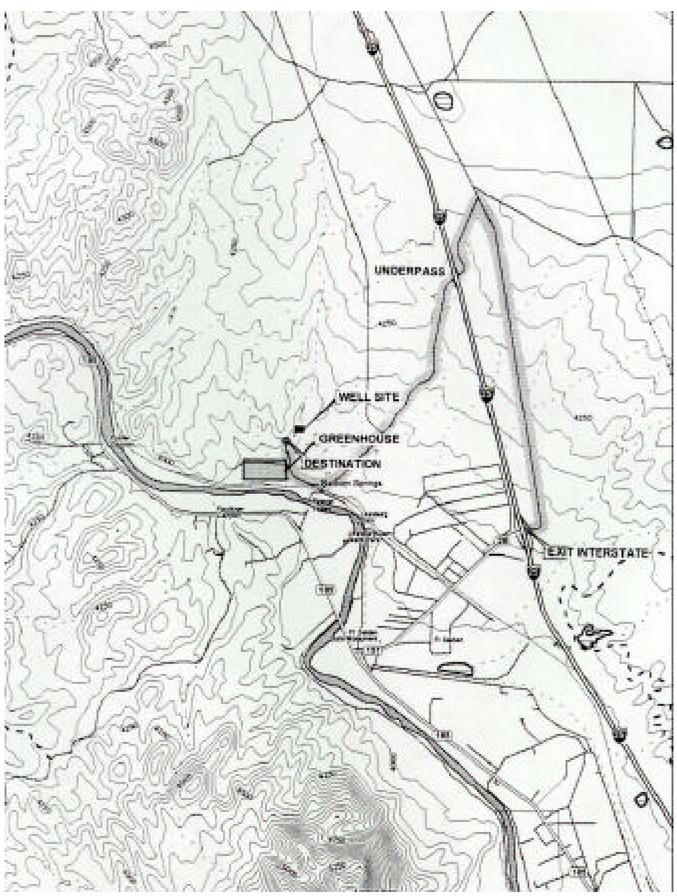

Figure 1. Location map of the Masson 36 Well.

Objectives

The major objective of the Masson 36 well was to obtain 190°F fluids at 1,500 gallons per minute (gpm) from a deep-confined reservoir. The objective of producing from the deep reservoir which is confined by a thick, clay-rich aquitard, is to practically eliminate direct communication with the shallow cold water aquifers and the Rio Grande from geothermal production pumping in the future. Current geothermal production and injection forms a probable flow couplet that is contained in a shallow and fractured rhyolite intrusion. The couplet and intrusion are hydraulically-connected with nearby shallow cold water aquifers. Therefore, the third primary objective is to avoid drilling across the shallow rhyolite reservoir or seal it off during well construction, if it is encountered, so that only deeper water is produced. All of these objectives were apparently achieved with the Masson 36 well.

Site Selection and Well Design Considerations

The currently produced shallow reservoir at Radium Springs is a fractured rhyolite intrusion of Oligocene age and of limited areal extent and volume. The rhyolite intrudes a thick Eocene aquitard, the Palm Park Formation (Seager, 1975). The fractured rhyolite is in hydraulic communication with nearby cold alluvial aquifers (Gross, 1987).

With the current shallow production-injection well couplet, decreases in temperature are experienced in late winter and early spring as the greenhouse facility has grown from four acres to about 17 acres since 1987. This decrease in temperature is probably from the combined affects of drawdown that encourages infiltration of cold water from the Rio Grande and sub-adjacent aquifers and from cool injected fluids via the injection wells.

The shallow reservoir contains 150 to 162°F sodium chloride water with a variable total dissolved solids (TDS) of around 3,300 milligrams per liter (mg/L)(Witcher, 1988). Current production is from two wells less than 300 feet depth, completed in fractured rhyolite. These wells were drilled by rotary air hammer. Two injection wells, approximately 1,000 feet distance from the production wells, accommodate about 400 gpm of 100°F water. The injection wells are located in the local outflow plume of the fractured rhyolite host, while the production wells are located over the local upflow plume. The upflow plume is a "geohydrologic window" of rhyolite that acts as a conduit across the Palm Park aquitard and allows upflow out of a deeper much larger reservoir (Witcher, 1988; Ross and Witcher, 1998).

Two (8,000- and 9,000-ft) wells drilled by Hunt Energy north of the Masson greenhouses in the early 1980s, provide insight into the nature of the deep reservoir. A fractured, composite Precambrian granite and Paleozoic carbonate reservoir is capped or confined by the Eocene Palm Park Formation aquitard. Laramide Orogeny compressional (Late Cretaceous to early Eocene) and Rio Grande rift extensional (Oligocene to present day) fault zones and fractures host the deep-seated reservoir in Precambrian and Paleozoic rocks (Seager, et al., 1984 and 1986).

Temperature gradient information in the area indicates a broad area of 12.6 to 14.3°F /100-ft temperature gradients over the area from Hunt well 53-27 and southward to the Masson greenhouse facility (Witcher, unpub. data). These temperature gradients are likely to continue into the Palm Park aquitard cap to the top of fractured and possible karst Paleozoic carbonate units. The carbonate rocks were first encountered at 675 to 960 feet depth in the Hunt wells 25-34 and 53-27, respectively (files, New Mexico Bureau of Mines and Mineral Resources). A temperature log of well 53-27 shows that the well becomes isothermal below 1,000 feet at a temperature of about 185°F (Witcher, unpub data). If the top of the deep reservoir is about 175 to 190°F over a broad area, then the temperature gradients also broadly define the depth to the top of the reservoir between 600 and 1,000 feet depth, provided the Palm Park aquitard has no large lateral variations in thermal conductivity.

A north-northwest trending Quaternary normal fault delimits the western surface extent of the shallow rhyolite reservoir host at Radium Springs and the westward extent of the highest temperature gradients to the footwall side of the fault zone (Seager, 1975 and Witcher, unpub data). This fault crosses the eastern part of the Masson greenhouse complex.

The final site selected for drilling is on surface land owned by Masson that has an associated BLM geothermal lease that is held by Masson. This site is about 500 feet east of the northwest-striking fault zone on the foot wall and is situated in an area with no rhyolite outcrops. The selected site is closest to the fault zone, has the best access, and is just north of the greenhouse complex in an area with good security.

Participants

The Masson 36 production well project was administered by the Idaho Operations Office of the U.S. Department of Energy. The project was cost-shared by A. R. Masson, Inc. and the U.S. Department of Energy. The drilling contractor for the project, K. D. Huey Drilling of Capitan, New Mexico, was selected on the basis of sealed competitive bid. Well site geotechnical services, permit coordination, and reporting was performed by Witcher and Associates of Las Cruces, New Mexico. The Resource Group, Palm Desert, California provided engineering assistance. Permitting and regulatory oversight was with the New Mexico State Engineer Office (NMSEO) and the BLM.

DRILLING AND SITE OPERATIONS

Drill Site Layout

The Masson 36 well is within the Radium Springs Known Geothermal Resource Area (KGRA) and is located on private surface, owned by Masson, adjacent a local arroyo flood control dike, trending east to west about 600 feet north of the Masson greenhouse complex.

Drill Rig Specifications

A truck-mounted Mobile Equipment Service SR35 rig was used for constructing the Masson 36 well. The SR35 is a top drive rig that is equipped with a 1,350 cfm/350 psi Sullair air compressor. An auxillary 1,150 cfm/350 psi Ingersol Rand air compressor was also used in tandom with the rig compressor as needed. The SR35 utilizes hydraulic drives for the drill motors, pumps, and hoist, allowing excellent variable controls. The rig has a 110,000 pound pullback with the hoist, a rotary torque of 12,000 pounds, and a 700-hp diesel engine on the deck.

Well Control

In the event that pressured fluids, gas, or rapidly boiling or flashing super-heated water entered the Masson 36 well while drilling, several steps were taken to insure that well discharges would be controlled. Well control consisted of blowout prevention (BOPE) equipment, valved flow and kill line ports, an auxiliary water tank with a minimum of 275 bbls (11,550 gallons) of water on site, and the monitoring of bottom-hole temperatures (BHT) and blooie line temperatures. The BOPE stack consisted of a Hydril GK 13 5/8 -3M annular preventer installed on a 13-5/8 in. wellhead spacer spool with flow and kill line ports. A rotating head was installed over the annular BOPE. The kill line port was connected to the auxiliary water tank via a pump. The BOPE was activated by a pneumatic accumulator and was function tested to 2,700 psi. The BOPE and casing was tested to 500 psi for 15 minutes with only 10 psi bleed off. The pressure tests were witnessed by Masson and BLM representatives.

Well Site Geology and Operations Monitoring

Well site geotechnical operations included making field geologic logs of cuttings and archiving cuttings for future reference or study. Samples were taken at the blooie line over 10-ft intervals. Cuttings will be sent for storage and archival at the New Mexico Bureau of Mines and Mineral Resources in Socorro, New Mexico.

Geophysical and temperature logs completed the geotechnical operations. Several temperature logs were taken after overnight breaks in drilling in order to gain information on the temperature gradient and bottom hole conditions. Because cement is exothermic as it cures, an additional temperature log was obtained several hours after the surface casing was cemented. Determination of the cement top in the annulus, facilitated calculation of how much cement to order to fill the backside of the casing to the surface. Geophysical logs were run prior to running surface casing and after reaching total depth (TD), but prior to running the production casing string.

Operations monitoring included daily report log, daily cost tabulation, and a well history log. The daily report log was used to document footage per shift, blooie temperature measurements, all drilling activities, and materials used in drilling. A well history log complemented the daily report log. The well history log was used to record chronologically important events at the well site such as visitors, drilling miles-tones, or any other events not recorded by daily report log.

Drilling Summary and Analysis

Drilling and casing depths in this report are referenced to the drill table (DF) at 4-ft elevation above the ground surface (Table 1). All drilling was done with air foam, using either an air hammer above 672 feet depth or rotary tri-cone bit below 672 feet depth.

On the basis of a competitive bid, the Masson 36 drilling contract was awarded to K. D Huey Drilling a water well driller from Capitan, New Mexico in May 2000. The Huey drill rig did not move on to the site until August 2000. On August 7, the borehole was spudded. The drilling assembly included 17-1/2-in. stabilizers for a straight and gauge hole along with the air hammer and bit. Drilling progressed smoothly until August 9, when the air hammer bit was shanked or in other words broken at the splines inside the air hammer and left at the bottom of the hole when the drill string was tripped or brought out of the hole. On August 22, the "fish" or air hammer bit was recovered. Options were discussed and geophysical logging was performed. It was decided to run and cement surface casing. On August 28 and 29, 465 (DF) feet of 13-3/8-in. surface casing was run in the hole. On August 31, Dowell/Schlumberger arrived on site from Artesia, New Mexico, and ran 144 bbls of cement. Cementing across the ryholite zone was done in stages to insure that fractures and washout zones were sealed. A temperature log ran several hours after Schlumberger demobilized showed the cement at the top of the rhyolite interval. A backside cement job by a local contractor was performed on September 1, to complete the cementing of the surface casing annulus to the surface. This additional 17 bbls of cement filled the hole with overflow at the surface. Between September 2 and 16, the drilling rig top drive was overhauled and the BOPE was installed and tested. Pressure testing was witnessed by the BLM and Masson's consultants on site. On September 16, drilling operations resumed with a 12-1/4-in. drilling assembly. It took an additional ten days to drill a 12-1/4-in. hole to 800 feet, and run and hang a 9-5/8-in. production casing string. A drilling assemblage change was necessary due to formation fluid production at 672 feet. The air hammer and bit was replaced with a tricone bit and rotary air operations resumed and the hole reached total depth (TD) of 800 feet on September 22.

All operations from start to finish were daytime only and usually with only a two man crew. Analysis of drilling operations time indicates that only about 40 hours was actually spent drilling. A nearly equal amount of time or 37 hours was spent tripping in and out of the hole. Installing and uninstalling the BOPE took 47 hours. A much larger amount of time was spent repairing equipment or recovering the 17-1/2 in. air hammer bit at the bottom of the hole. However, the bulk of time between the contract award and the completion of the well involved waiting on drilling personnel, equipment and supplies.

Well Completion

A total depth of 800 feet was reached on September 22, 2000, within the Permian Hueco Formation, a mostly limestone unit with some interbedded shale. The Hueco Formation was an important drilling target. However, the hole only encountered 12 feet of this unit. Much greater production and possibly 10 to 15°F higher temperatures are likely within this unit and underlying carbonate units at a few hundred feet greater depth. However, the well construction and completion provides a contingency for re-entering the hole at a later time in order to drill at least to 2,300 ft depth if desired (Table 2).

Table 1. Daily Footage and Activity Log of the Masson 36 Well

Date	Footage (ft/day)	Remarks
6/29	24	Auger conductor hole, run conductor casing and cement
6/30-8/6	0	Construct cellar and begin moving equipment on site
8/7	120	Finish rigging up, drill 17 1/2 in surface hole with air hammer
8/8	180	Continue 17 1/2 in surface hole with air hammer and foam
8/9	150	Ran temp log, continue 17 1/2 in surface hole with air foam
8/10	0	Ran temp log, trip out, shanked bit in air hammer, bit fish on bottom
8/11-8/21	0	Attempt to recover fish
8/22	0	Ran BHT (186 ^{o}F), successfully recovered fish, decide to run casing
8/23	0	Ran geophysical logs
8/24-8/27	0	Casing delivered
8/28	0	Begin to run surface casing with shoe and float collar
8/29	0	Finish run of 461 ft 13 3/8 in surface casing, haul water
8/30	0	Haul water, prepare for cementers, rig maintenance
8/31	0	Cement surface casing, ran temp log to evaluate cement job
9/1	0	Top job cement backside and WOC
9/2-9/5	0	Repair rig top drive
9/6	0	Clean cellar, cut top surface casing, prepare to install BOPE
9/7-9/11	0	Continue repair of rig top drive
9/12	0	Ran temp log, installed rig top drive, wait on BOPE
9/13	0	Unload BOPE, installed well head flange and set spool with side ports
9/14	0	Nipple up annular, rotating head, accumulator and test, install H_2S monitor
9/15	0	Install kill and choke lines, install blooie line, make up drill tools
9/16	51	Trip in, tag cement at 423 ft, drill out cement and float collar, drill ahead
9/17	0	Repair auxiliary air compressor
9/18	147	Drill ahead using 12 1/4 in air hammer with foam
9/19	0	Trip out, wait on 12 1/4 in tricone bit
9/20	0	Wait on 12 1/4 in tricone bit
9/21	68	Make up drill tools, trip in, drill air rotary foam
9/22	60	Drill ahead, TD 800 ft, producing 1175 gpm 196 ^{o}F water while drilling air
9/23	0	Trip out, break down BOPE
9/24	0	Unload casing, run geophysical logs
9/25	0	Finish removing BOPE, prepare to run 9 5/8 in production liner
9/26	0	Ran 9 5/8 in production liner to 793 ft, turn off hanger, trip and laydown rig

Table 2. Masson 36 Well Completion Specifications

Item	Hole Size (inches)	Top (ft)	Bottom (ft)	Type (grade)	ID (inches)	Weight (lbs/ft)	Cement (bbls)
conductor casing	24	surf	28	H-40	20	78	3
surface casing	17 1/2	surf	465	N-80 btc	13 3/8	72	157
production liner	12 1/4	395	793	N-80 btc	9 5/8	47	(hung)
production perf	12 1/4	562	793	3/8 rnd	9 5/8	40 h/ft	(punch)

Geophysical and Temperature Logging

The Masson 36 was geophysically logged several times before the well was completed (Table 3) (Figures 2, 3, 4 and 5). A suite of temperature logs was performed with the New Mexico State University (NMSU) temperature logging system. Southwest Geophysical Services of Farmington, New Mexico was contracted to perform additional temperature logs and various other geophysical logs to include caliper, gamma, neutron and electric logs. The NMSU and Southwest Geophysical Services temperature logs were performed with wireline tools that were outfitted with thermister probes which have an accuracy of between 0.005 and 0.05^{o}F.

A caliper tool was run in the open hole prior to installing surface casing. The caliper log shows variation in borehole size which allows calculation of the amount of cement needed to insure a good surface casing seal. The gamma and neutron logs were also obtained. Maximum sampling radius for the gamma and neutron logs is about 1 to

2 feet into the formation. A logging rate of 20 feet per minute is used. As with temperature logs, the wireline signal is digitally converted into ASCII files for analysis and interpretation.

The gamma log measures gamma radiation from naturally occurring uranium, thorium, and potassium. Because different rock types have different radioactivity levels, the gamma log is a very useful lithology correlation tool. For instance, shales and clay may have higher natural radioactivity than sandstone and sand. The neutron tool contains an active radioactive source that emits neutrons and a detector that spaced on the tool about two feet from the neutron source. Neutrons emitted by the tool are principally slowed to low energies by hydrogen (i.e., water and hydrocarbons) in the formation, resulting in less signal for the detector if porosity is high. Where hydrogen content is low (low porosity) the neutrons diffuse much greater distances (closer to the detector) before slowing to low energies. Because of hydrogen sensitivity, the neutron log has use as an indicator of relative formation porosity.

Electric logs can also measure the amount of porosity. Because salty water is a good conductor of electricity compared to rock or drilling mud, electric logs can have much value in well evaluation. The electric logs measure voltage potential and they are reported as a difference as in the SP log or resistance as in the single point "resistance" log or as resistance per unit length as in the normal (long 64 inch - short 16 inch) "resistivity" logs.

CONCLUSIONS AND RECOMMENDATIONS

The Masson 36 well is completed in the top of a deep confined reservoir at Radium Springs. Production temperatures of 210 to 212 ºF are likely. It is believed that the well will sustain long-term production in excess of 1,500 to 2,000 gpm.

A long-term flow test should be performed to determine production and final pump design. The pump test should begin as a step-test and end with a steady-state drawdown test for at least 48 hours. As important as measuring drawdown in Masson 36, drawdown should also be

Table 3. Summary Geologic Log of Masson 36 Well

4 to 14 feet **ALLUVIUM**	Unconsolidated fluvial sand and gravel; arroyo deposits and drill pad base.
14 to 120 feet **PALM PARK FM**	Altered and slightly-to moderately indurated purple brown and blue green, clayey andesitic volcanolitharenite and volcanolithrudite; mostly interbedded andesitic breccia mudflow or lahar deposits.
120 to 222 feet **ROBLEDO RHYOLITE**	Grey porphyritic rhyolite. Highly fractured with brown and red brown oxidized fracture and breccia fragment surfaces. Rhyolite dike with shallow north dip.
222 to 495 feet **PALM PARK FM**	Altered and indurated brown andesitic volcanolitharenite and volcanolithrudite with intervals of strong blue green chlorite, epidote and clay alteration; mostly interbedded with andesitic breccia mud flow or lahar deposits.
495 to 635 feet **PALM PARK FM**	Altered purple brown, maroon and brown, indurated andesitic volcanolitharenite and volcanolithrudite with intervals of strong blue green chlorite, epidote, and clay alteration; mostly interbedded with andesitic breccia mud flow or lahar deposits.
635 to 710 feet **PALM PARK FM**	Interbedded light gray to brown arkosic litharenite and purple brown andesitic volcanolitharenite with some strong blue green alteration; very minor disseminated hydrothermal pyrite mineralization below 690 feet.
710 to 788 feet **LOVE RANCH FM**	Granule, fine to medium arkosic lithic sandstone with some clastic chert and minor disseminated hydrothermal pyrite mineralization.
788 to 800 feet **HUECO FM**	Limestone with gray sticky clay.

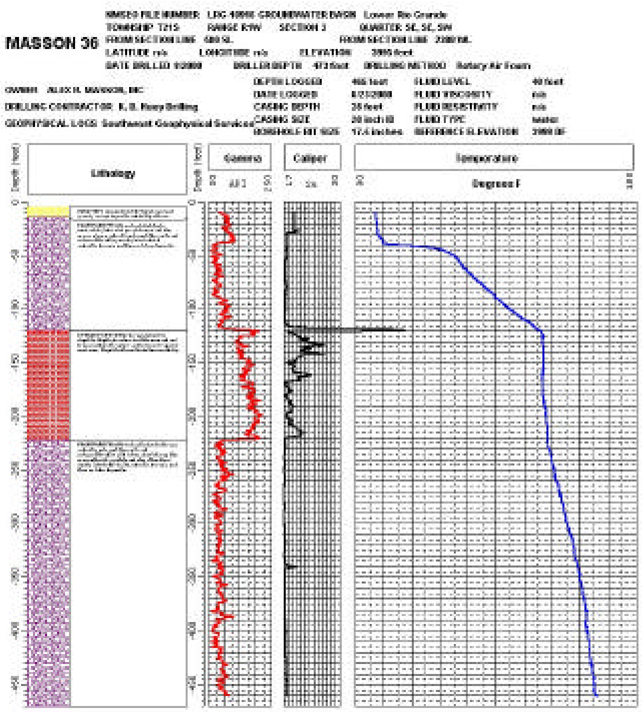

Figure 2. Pre-surface casing temperature and geophysical logs.

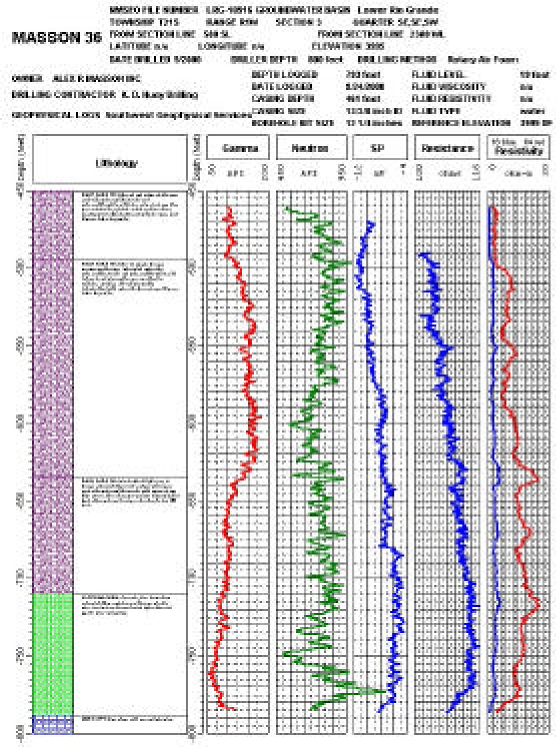

Figure 4. Electric logs of the 460- to 793-ft interval.

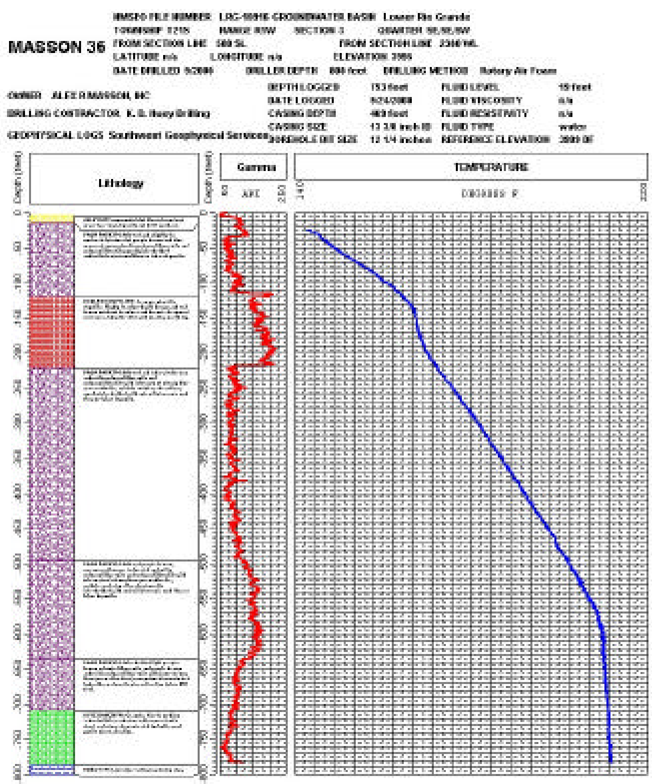

Figure 3. Post-drilling gamma and temperature logs.

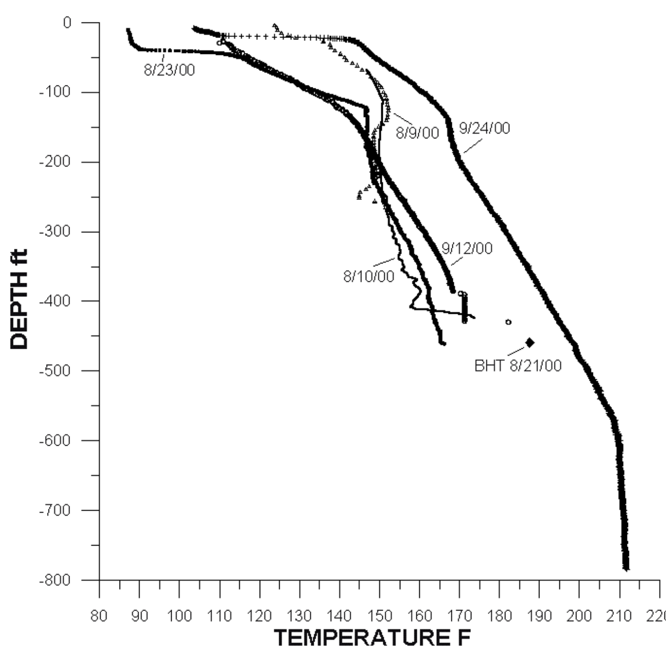

Figure 5. Composite graph of temperature logs and BHT measurements.

measured in several of the current shallow production wells. Drawdown should also be observed in at least one nearby cold wells. Ideally, drawdown should also be monitored in the Hunt 25-37 well while the pump test is conducted. This will require BLM approval. If step-tests indicate it is possible, Masson 36 should be pumped at 3,000 gpm for the steady-state drawdown test in order to stress the reservoir and determine any hydraulic connection with shallower reservoirs or with the deep reservoir to the north where the Hunt wells were drilled. The test should be planned and managed by a qualified engineer or geologist and not by a local southern New Mexico water well driller.

This well is configured in such a way that a very large pump can be installed. Also, the well could be deepened several thousand feet in the future if higher temperature or additional production is desired for either the greenhouse or for small-scale binary electrical power generation or both.

It is also recommended that Masson undertake a disciplined and regular monitoring of selected wells including the Masson 36 well. This would include chemistry, temperature, and water level measurements taken at regular and periodic times. As a part of such an effort, all of the wells to be monitored should be surveyed so that a precise elevation is known. If any shallow production or injection wells are to be abandoned, I would also recommend modifying the well constructions to create dedicated monitor wells or piezometers rather than plugging and abandoning the wells. This would require BLM and or NMSEO approval; but, I believe the agencies would be supportive of a proper monitor well design and use plan.

Without a monitoring program, the reservoir will probably not be understood. Monitoring also provides baseline data and procedure that can provide a measure of foresight into reservoir behavior and also "early warning" of impacts from any overly aggressive development on the Radium Springs KGRA immediately north of the greenhouse.

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