Pilgrim Hot Springs Flow Testing

PS 13-1 Air Lifted Flow Testing September 15-17, 2014

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INTRODUCTION

The Alaska Center for Energy and Power (ACEP) led an extensive geothermal exploration effort at Pilgrim Hot Springs between 2010 and 2014. During this time period, a variety of geophysical surveys were conducted in conjunction with drilling efforts that took place during the summers of 2011, 2012, and 2013. The efforts culminated in the drilling of a large diameter well capable of high flow rates in the fall of 2013. Flow testing of this well, called PS 13-1, during September 2014 was the first time that controlled flow rates greater than the naturally occurring artesian rates were sustained and measured at the site. Previous testing had investigated the subsurface temperatures but had not closely examined the aquifer's production capability. Downhole temperatures and pressures were measured in PS 13-1 while the well was flowing at 60 gpm, and while the well was airlifted at rates of 172 gpm and 300 gpm. The pressure changes that were measured led researchers to conclude that the well has the ability to sustainably provide thermal fluid for on-site power generation and district heating applications.

FLOW TESTING OF PS 13-1

Well PS 13-1 was briefly flow tested twice with air lifting assistance between Sept. 15 and 17, 2014. The airlift was accomplished utilizing thin wall 1" diameter aluminum tubing with a dispersion head on the bottom and a small Atlas Copco trailer mounted rental compressor rated at 100 PSI and 185 CFM. This hardware was supplied by Howard Trott of Potelco. A six inch Krohne magnetic flow meter (magmeter), supplied by ACEP, was used to measure the flow rates. The surface equipment is shown on Figure 1. The 5" diameter dispersion head was backed up with 1/8 inch aircraft cable to prevent accidental loss of the downhole equipment in the well. The air water mixture flowed into the first tank on Figure 1 with considerable turbulence. As the water flowed into the second tank there was no turbulence and the tank provided adequate head to push the water through the magmeter and out a 240 foot-long 6" PVC pipeline to the flow through hot spring pond.

The first airlift only lasted about an hour as the flow was limited by a constriction in the flow line downstream of the second tank. Expansion of the flow line caused a short flexible hose to partially collapse and reduce the flow rate out of the second tank. This first test was more of a test of the equipment than a test of the resource. The aluminum tubing was run to a depth of 40 feet below the top of the standpipe (29 feet below ground level). The average air lift flow rate during the first test was 172 gpm and the magmeter readings were confirmed by measuring that it took 18 seconds to fill a 55 gallon drum in the discharge of the pipeline into the flow through hot springs pond. This equates to 183 gpm. Pumping at a higher air rate increased the flow rate to 177 gpm but resulted in the water bubbling out the top of the wellhead standpipe.

Figure 1. Surface equipment utilized for airlift of PS 13-1. The magmeter is in the silver spool between the black and white parts of the flow line. The black heavy large diameter hose serving as a standpipe on the top of the wellhead was needed to prevent water from flowing out the top of the wellhead. The clamp holding the aluminum tubing is visible on top of the standpipe. The blue hoses are the air lines coming from the trailer mounted air compressor.

Once the well was being airlifted and the wellhead appeared to be stable a Kuster tool was run to a depth of 30 m below the top of the master gate with the heavier aircraft cable used as a backup in case the small 1/16 inch diameter cable normally used on the reel was cut. The Kuster tool was run into the well for a little over a half hour before the air was cut off. Once the air was cut off the well resumed its natural artesian flow at 55 gpm and the Kuster tool remained hanging in the well overnight to record the pressure buildup. There was no wing valve on the flow line to allow the well to be shut-in with the aluminum tubing and Kuster tool hanging in the well.

On the morning of Sept. 16 some additional parts were obtained in Nome and the flow line was modified to remove the constriction. The aluminum tubing in the well was deepened from 40 to 72' below the top of the standpipe on the wellhead (61 feet below ground level). This depth was about the maximum practical depth for one person on a large A frame ladder to raise and lower the downhole equipment. It also was the maximum depth to also allow use of the on hand larger diameter aircraft cable to hold and protect the Kuster tool.

In the second test there was adequate confidence to run the Kuster tool into the well under artesian flow conditions before starting the air lift. The air volume was quickly increased in 3 steps to find the maximum air lift rate that would not flow water out the top of the wellhead. This flow rate was about 300 gpm. The highest flow rate reported briefly by the magmeter was about 350 gpm. The 300 gpm air lifted flow rate was held for about 7.5 hours, until the air compressor was almost out of diesel fuel at 0100 hours on Sept. 17. After the compressor was shut off the well continued to flow artesian until after the Kuster tool was retrieved late in the morning on Sept. 17. The downhole hardware was pulled out of the well on the morning of Sept. 17 as Howard Trott had to fly out of Nome that evening.

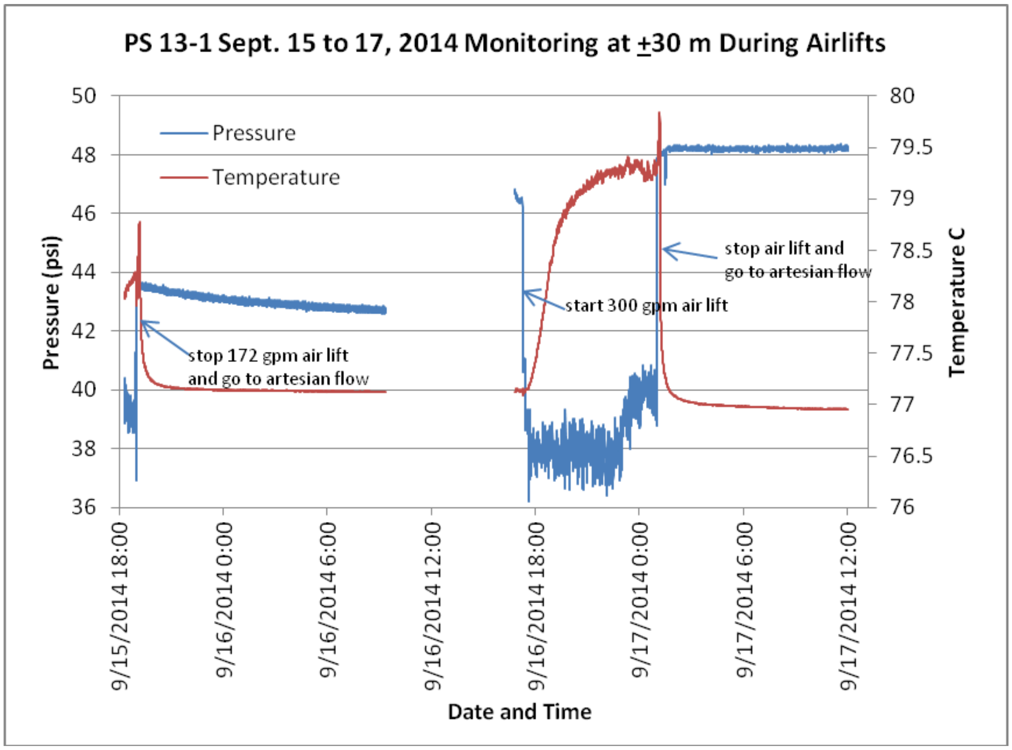

Figure 2. Downhole pressure and temperature record during the two air lifts of PS 13-1.

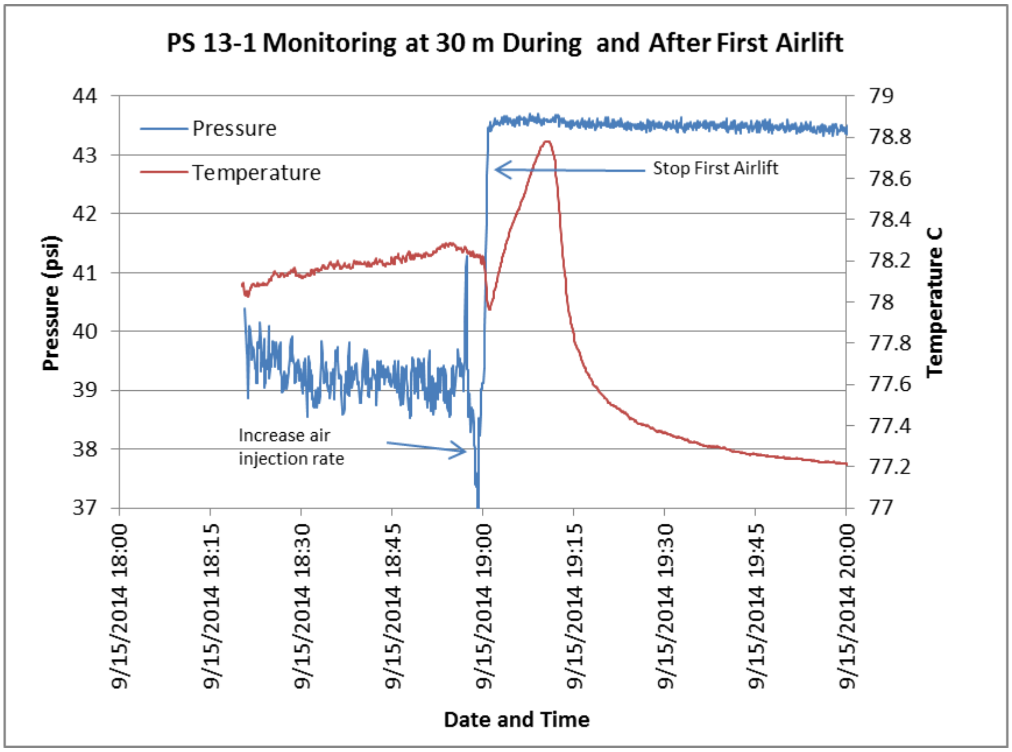

Figure 3. Downhole pressure and temperature record just before and after stopping the first air lift at 1902 hours.

The air lifting increased the scatter in the pressure and temperature data as compared to the unassisted artesian flow (Figures 2 and 3). During the first air lift it is unclear if there was any decline trend in the downhole pressure. The first 15 minutes of downhole data indicate a decline but perhaps this was simply the tool equilibrating to the downhole conditions (Figure 3). During the second 15 minutes there is no evident decline. At 7 pm the amount of air being pumped was increased for 2 minutes to assess the plumbing system at higher flow rates and was then shut off (Figure 3). The amount flowing through the meter increased by only about 5 gpm to 177 gpm but water was occasionally spilling out the top of the wellhead. There was a constriction in the soft 6 inch hose between the two tanks that was limiting the flow that could go through the meter.

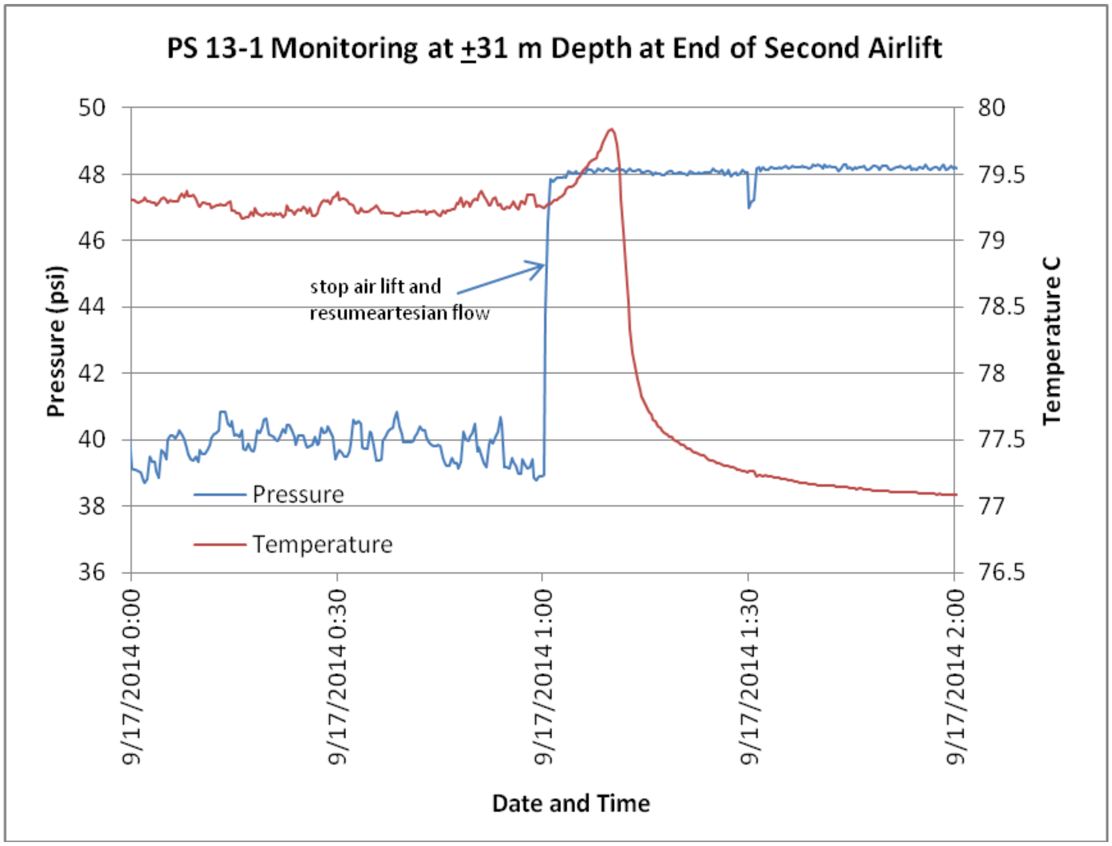

Figure 4. Downhole pressure and temperature record just before and after stopping the second air lift at 1902 hours.

The downhole flowing temperatures were measured below the air injection depth and therefore can not be cooled by the air injection, as the surface measured temperatures were. The maximum downhole temperature measured during the first airlift was 78.28 °C (Figure 3). Immediately upon shutting off the air, the temperature took a 0.2 °C decline and then quickly climbed for the next 13 minutes to its maximum value of 78.8 °C and then quickly cooled. The temperature was down to 77.1 °C when the tool was removed the following morning and showed a range of 1.7 °C during this logging. During the air lift the temperatures slightly increased. After the air lifting ceased the bulk of the temperature change occurred. First with a short 0.2 °C decrease that was probably related to the short increased volume air lift. Then there was a 0.8 °C increase followed by a long decline until temperatures were about 1 °C lower than during the airlifting. During this decline the well was flowing under natural artesian conditions. This variation of temperatures with flow rates demonstrates that there is more than one

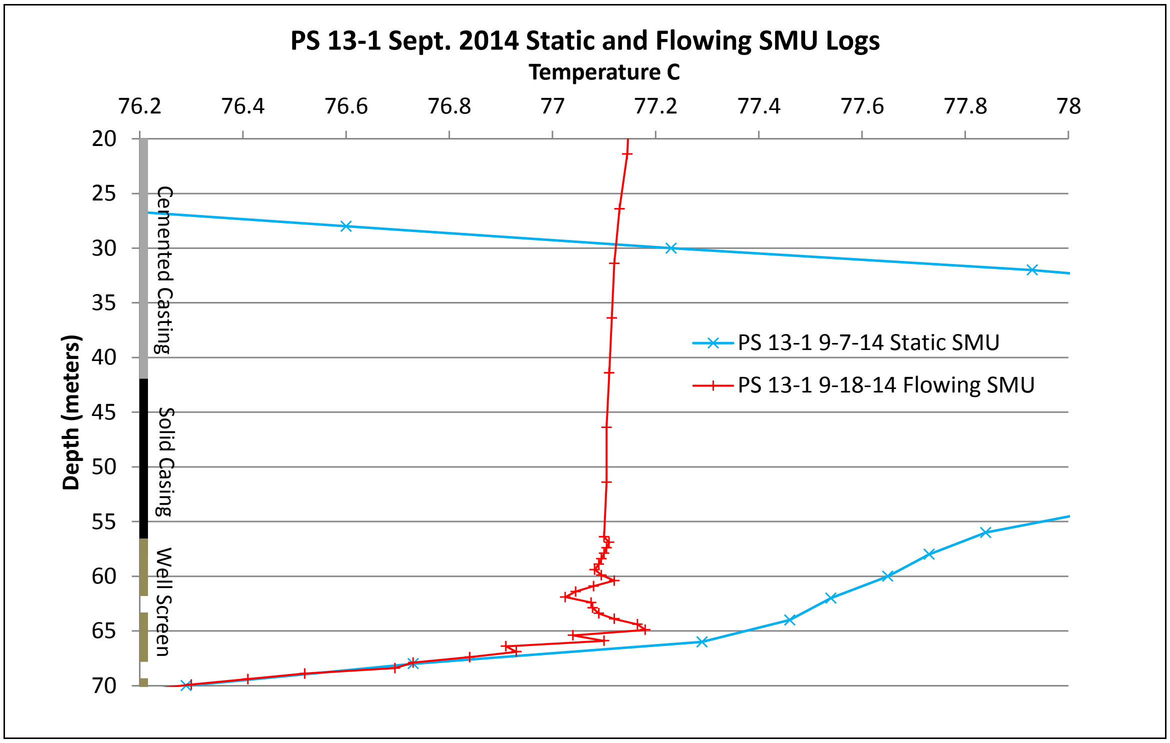

Figure 5. Detailed flowing and static logs from PS 13-1 run in Sept. 2014 with precision SMU logging equipment. The flowing log depths were increased by 1.4m to have exactly the same bottom hole depth as the static log as this is the most important part of the hole for this discussion.

feed zone for this well with differing temperatures. Higher temperatures coincide with higher flow rates.

A similar response was seen upon stopping the second airlift (Figure 4), however this response lacked the sharp initial drop in temperature as seen at the end of the first airlift (Figure 3).

The maximum temperature recorded after stopping the second airlift was 79.8 ^{o}C or 1.0 ^{o}C hotter than seen after stopping the first airlift (Figure 2). After the second airlift was finished the artesian flowing tempeature declined to 76.95 ^{o}C, about 0.25 ^{o}C cooler than seen after the the end of the first airlift.

All of this temperature variability points to a fairly complex interplay between two or more feed zones with differing temperatures. This led to a very detailed flowing log being run on the morning of Sept. 18 before the well was shut in and the artesian flow was stopped. This artesian flowing log and a static log run on Sept. 7, 2014 show some of the details of the fluid entry points (Figure 5).

The flowing SMU log shows multiple sharp reversals in temperature gradient between depths of 56 and 67 m which define all the possible fluid entry points. The top of the screen in the wells is at 57.3m which is in good agreement with the flowing temperature log. Due to the minimal divergence between the flowing and static logs between depths of 65 and 67 m, any fluid entry points in that interval are suspect as the temperature readings were not very stable in that and shallower intervals. The deepest significant fluid entry is at a depth near 65 m and the shallowest major entry as defined by temperature is near 60 m. All of the defined fluid-entry tempeatures are between 77.02 and 77.18 ^{o}C on the flowing log. However the static temperatures in this interval range from 77.4 to 77.7 ^{o}C. During the airlifting temperatures as high as 78.25 to 79.3 ^{o}C were measured which had to come from shallower depths in the well, perhaps as shallow as 35 or 40 m. This fluid would then have to flow down the outside of the uncemented 14" casing and enter the screened interval between 57.3 and 72.5 m. The maximum temperature measured during the airlifting operations was the 79.8 ^{o}C spike shortly after ceasing the air lift. This is only 0.18 ^{o}C hotter than the maximum measured tempeature of 79.62 ^{o}C during the static log prior to flowing the well. Thus we now have a good idea as to the origin of the fluid producing the temperature spike.

It was decided that during the air lift the internal wellbore conditions were probably too severe for the small SMU tool and its delicate electrical cable. The primary use of the Kuster tool was for the pressure monitoring so it was not moved during the airlifting. However, during any future air lifting a traversing Kuster survey should be run.

Four major flow rate changes were monitored with downhole pressure changes in PS 13-1 during September 2014. The first was done on Sept 15, prior to the airlifting and involved opening up the well so it could artesian flow. During this flow the rate is somewhere between 60 and 75 gpm as it was measured with a 5 gallon bucket. Three major flow rate changes were monitored during the airlifting with the Kuster tool downhole (Figure 2, Table 1) and the magmeter providing the flow rate data. The first was the cessation of the first airlift, the second was the start of the second airlift, and the third was the end of the second airlift. All of these changes had natural artesian flow either before or after. None of the changes involved the larger change in going from a static condtion to the airlift.

TABLE 1 PRODUCTIVITY DATA

	Start Artesian Flow	Stop First Airlift	Start Second Airlift	Stop Second Airlift
Starting Flow Rate	0	172	65	300
Ending Flow Rate	60 – 75?	55	300	60?
Change in Flow Rate	60 – 75?	117	235	240
Pressure Before Change	103.40	38.27	46.45	39.4
Pressure After Change	100.46	43.54	37.91	48.23
Change in Pressure	2.94	5.27	8.54	8.83
Productivity (gpm/psi)	20.4 – 25.5	22.2	27.5	27.2

The productivity measurement involving the lowest flow rate and smallest downhole pressure change was between 20.4 and 25.5 gpm/psi. The next largest flow rate change was at the end of the first airlift and it produced a productivity value of 22.2 gpm/psi, the same as the average value of the cessation of artesian flow. The two largest flow rate changes at the start and stop of the second airlift give virtually identical and higher productivity values of 27.5 and 27.2 gpm/psi. These are quite encouraging as the well did not give lower productivity values as higher flow rate changes occurred. This indicates that the well is capable flow at significantly higher rates. However, it does not indicate that the temperatures seen during testing are sustainable over the long term.

The pressure record in PS 13-1 shows a 2 psi increase after 2230 hours (figure 2). This is a reflection of the thin cable holding the tool breaking and the tool moving part of a meter downhole until it was held by the thicker aircraft cable. It turned out to be very useful to back up the support for the Kuster tool.

TEMPERATURE AND PRESSURE MONITORING IN PS 13-2

Two hours after the first airlift a Kuster tool was hung in well PS 13-2 near a depth of 30m to monitor its downhole temperature and pressure for a few days during the expected longer and more voluminous second airlift. This PS 13-2 record is exceptionally complex for a well that was not flowing (Figure 6). The start and stop of the second airlift is marked by sharp pressure changes of about 0.2 psi. There was no net longer-term pressure change between the pressure prior to the airlift and pressures near the end of the monitoring period.

During the airlift there was a curious temperature increase and decline that requires a much deeper understanding of the hydrology to try to explain (Figure 6). Equally large or larger temperature changes occurred when the airlift was not in progress.

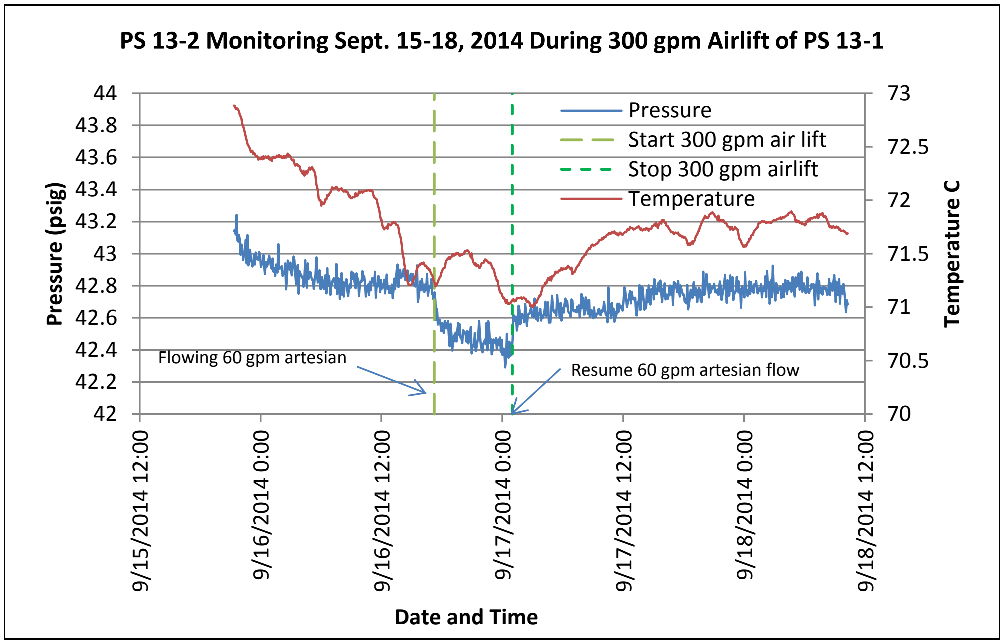

Figure 6.

TEMPERATURE AND PRESSURE MONITORING IN PS 13-3

A Kuster tool was also hung in PS 13-3 after the first airlift to document the downhole pressure and temperature changes (Figure 7). This record shows a sharp 0.2 psi reaction to both the start and stop of the airlift. There is no longer-term net pressure change from the start of monitoring to the end. There was a tiny .05 °C temperature rise associated with the higher flow that did not reverse after the airlift. There are also three tiny temperature spikes that occur after 8 pm very close to one day apart that are not understood.

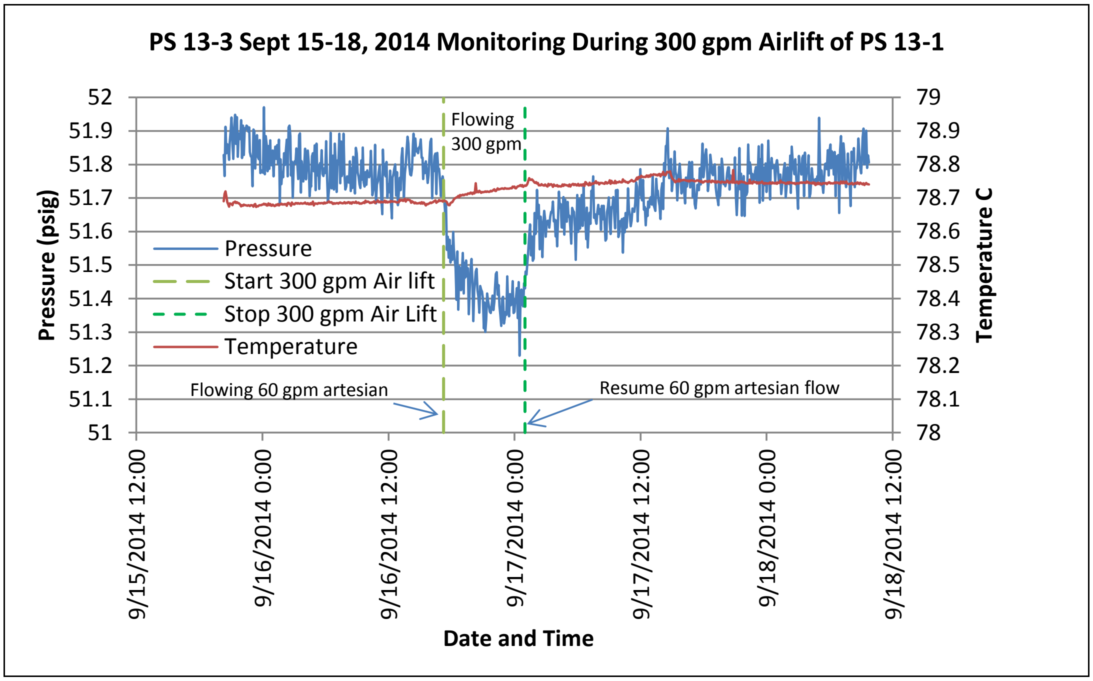

Figure 7.

HISTORIC HOT SPRINGS TEMPERATURE MONITORING

A small Hobo brand temperature monitoring probe was placed in the discharge area in the historic hot spring pool at Pilgrim Hot Springs during the testing of the wells. The pool is located 750 feet northeast of well PS13-1. During the testing period, the sensor was placed in the northwest corner of the pool about 2 feet below the water surface (figure 8).

Figure 8.

Researchers Chris Pike and Dick Benoit also used a presision temperature measuring probe owned by Southern Methodist University to measure the maximum temperatures in the pool. This was done by inserting the probe several inches into the sandy bottom of the pool and recording the temperatures. The maximum temperature of 73 °C (163 °F) was encountered in the extreme eastern edge of the pool.

The water temperature of the pool was monitored between September 9th and September 18th 2014 with a brief interuption during the early morning hours of September 16th to download data. During the time that the temperature was being recorded, the hot spring pool was being used by the public for soaking and relaxation activities. ACEP staff member Chris Pike monitored the temperature probe on a nightly basis to ensure that it was still in position. There was a brief period on September 12th when the probe was removed from the spring. The data collected show that the pool temperature varied for unknown reasons and mostly stayed between 100 and 110 degrees F (figure 9).

During the 300 GPM flow testing, the pool temperature dropped. It did not stabalize and begin to rise again until after air lifting pumping was stopped. During this time period, the pool dropped to its coolest recorded temperature, below 94 degrees F (figure 9). Further testing is needed to draw a difinitive correlation between the temperature of the hot spring pool and the flow of the wells, however the pumping of water from the shallow thermal aquifer likely impacts the flow of hot water that flows into the pool.

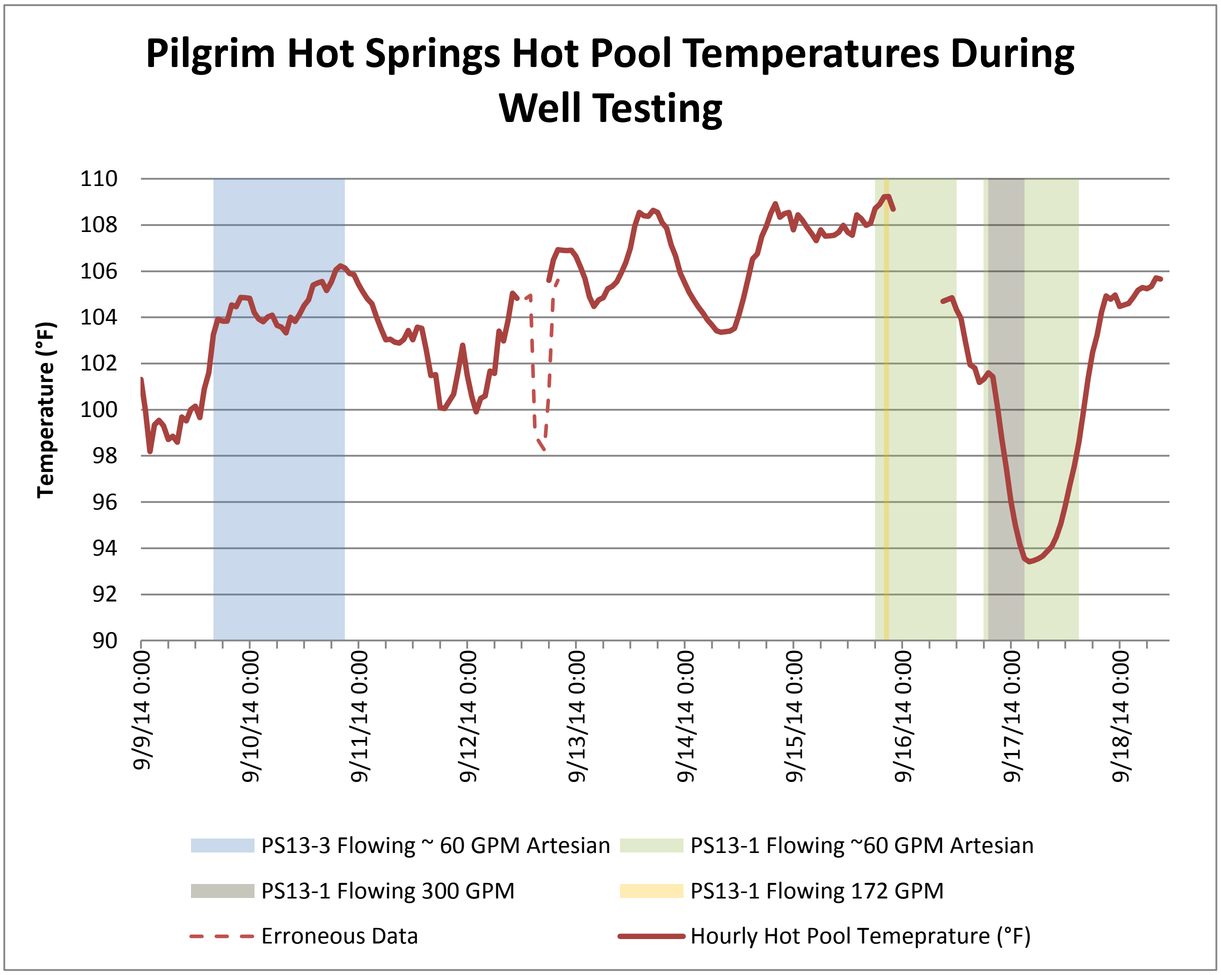

Figure 9.

CONCLUSIONS

The PS 13-1 well was successfully airlifted for over 7 hours at an average rate of 300 gpm. This probably represented about the largest flow that could have been achieved with the available equipment. Repeated productivity measurements with flow rate changes of 60 to 240 gpm all gave values of 20.4 to 27.5 gpm/psi which indicates a good productive well. It is encouraging that the productivity values associated with the higher flow rates had the highest values. During the airlift most of the fluid must have entered the wellbore in the main shallow thermal aquifer and flowed down the blank casing to enter the screened part of the well below 57.3m.

The airlift test impacted the nearby PS 13-2 and PS 13-3 wells with a 0.2 psi pressure decline. There apparently also were temperature impacts but these are not convincingly explicable with the available data.