FINAL TECHNICAL REPORT

EXPLORATION OF THE UPPER HOT CREEK RANCH GEOTHERMAL RESOURCE, NYE COUNTY, NEVADA

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EXECUTIVE SUMMARY

The Upper Hot Creek Ranch (UHCR) geothermal system had seen no significant exploration activity prior to initiation of this GRED III project. Geochemical geothermometers calculated from previously available but questionable quality analyses of the UHCR hot spring waters indicated possible subsurface temperatures of $\pm$320 °F. A complex Quaternary and Holocene faulting pattern associated with a six mile step over of the Hot Creek Range near the UHCR also indicated that this area was worthy of some exploration activity.

Permitting activities began in Dec. 2004 for the temperature-gradient holes but took much longer than expected with all drilling permits finally being received in early August 2005. The drilling and geochemical sampling occurred in August 2005.

Ten temperature gradient holes up to 500' deep were initially planned but higher than anticipated drilling and permitting costs within a fixed budget reduced the number of holes to five. Four of the five holes drilled to depths of 300 to 400' encountered temperatures close to the expected regional thermal background conditions. These four holes failed to find any evidence of a large thermal anomaly surrounding the UHCR hot springs. The fifth hole, located within a narrow part of Hot Creek Canyon, encountered a maximum temperature of 81 °F at a depth of 105' but had cooler temperatures at greater depth. Temperature data from this hole can not be extrapolated to greater depths. Any thermal anomaly associated with the UHCR geothermal system is apparently confined to the immediate vicinity of Hot Creek Canyon where challenges such as topography, a wilderness study area, and wetlands issues will make further exploration time consuming and costly.

Ten water samples were collected for chemical analysis and interpretation. Analyses of three samples of the UHCR thermal give predicted subsurface temperatures ranging from 317 to 334 °F from the Na-K-Ca, silica (quartz), and Na-Li geothermometers. The fact that all three thermometers closely agree gives the predictions added credibility.

Unfortunately, the final result of this exploration is that a moderate temperature geothermal resource has been clearly identified but it appears to be restricted to a relatively small area that would be difficult to develop.

INTRODUCTION AND BACKGROUND

This final report submitted to the Department of Energy Golden Field Office reviews the geothermal geology of the Upper Hot Creek Ranch geothermal prospect and presents the results of temperature-gradient hole drilling, geochemical analyses of hot and cold waters in the area, and integrates these into a preliminary conceptual model of the geothermal resource.

One of the primary objectives of the Department of Energy's Geothermal Technologies Program is to increase the economically viable geothermal resource in the United States to 40,000 megawatts by 2040. This can be done by both increasing the amount of geothermal energy produced from existing operating fields in the United States and by increasing the number of resources producing this electricity. A stated goal of the Department of Energy is to locate 20 new geothermal fields by 2010.

This project, Exploration of the Upper Hot Creek Ranch Geothermal Resource, Nye County, Nevada is one of eleven fiscal year 2004 projects in the GRED III Program. With a total budget of $105,760 it is by far the smallest of the eleven GRED III projects. The next largest project has a budget almost three times that of this project.

The exploration of the Upper Hot Creek Ranch (UHCR) Geothermal Resource was intended to demonstrate that the brine geothermometers predict this resource has a subsurface temperature significantly above 300 °F and that the size and location of the thermal anomaly and its total heat loss would encourage additional exploration, such as slim holes. Publicly available geological and geothermal data are integrated with the results of the temperature-gradient holes and the geochemistry to develop a conceptual model of the resource that can be utilized as a guide for additional or deeper future exploration.

The UHCR Geothermal Resource is located within a regional area covering ten thousand or more square miles identified as the Eureka heat flow low. This, along with its relatively remote location, has inhibited previous geothermal exploration to the point that this can be considered one of the very few geothermal prospects in Nevada with some evidence of temperatures over 300 °F but has seen no significant previous exploration. Should this project provide encouraging results in a previously unexplored region it may result in additional geothermal exploration in a large part of Nevada that has been more or less ignored for the past 3 decades.

The exploration program in this GRED III project was developed by Dick Benoit and David Blackwell with a focus on utilizing geothermal exploration tools (shallow temperature-gradient holes and water geochemistry) that have a proven track record in the Basin and Range Province and are quick and low in cost. These two exploration tools are widely regarded as providing the least ambiguous data of all the geothermal exploration tool possibilities available. Dick Benoit and David Blackwell have over 60 years of combined experience working in the geothermal industry with emphasis on Basin and

Range range-front geothermal systems (Dixie Valley, Roosevelt, and Beowawe) that at this stage appear structurally similar to Upper Hot Creek Ranch.

REGIONAL SETTING AND GEOLOGY

The Upper Hot Creek Ranch geothermal prospect is located in the north-central part of Nye County and is centered on the mouth of Hot Creek Canyon in T 7 and 8 N, R 50 E MDB&M (Figures 1and 2). It is approximately midway between the towns of Tonopah and Ely. Hot Creek Canyon drains into the Hot Creek valley or graben which lies to the east of the Hot Creek Range. Hot Creek Canyon cuts completely through the Hot Creek Range as a scenic gorge with up to 2600' of relief. It allows surface and subsurface waters from the northern part of Stone Cabin Valley and Little Fish Lake Valley to flow into the Hot Creek Valley which in turn drains into Railroad Valley. Little Fish Lake Valley lies at an elevation of 6300' and much of Hot Creek Valley lies between 5300 and 5500' in elevation. Peaks on either side of Hot Creek Canyon are between 7500 and 8843' in elevation. The area is very scenic with a number of historical sites such as the ghost town of Tybo, scattered mining relics, and charcoal kilns.

The local area is very sparsely populated with only 3 inhabited ranches along wet portions of Hot Creek Canyon. In Hot Creek Valley very low brush and grass are present. At higher elevations near the range front sagebrush becomes abundant and the mountains are covered with sage, pinion, and juniper. Surface water is present only in parts of Hot Creek Canyon and a few reaches of the other major canyons draining the east side of the Hot Creek Range.

Regional Geology

There are several published maps of the regional geology at a scale of 1:250,000 or greater (Schell, 1981, Kleinhampl and Ziony, 1985, Whitebread and John, 1992, and Sawyer and Anderson, 1998). Unfortunately, while published maps of 15" Quadrangles at a scale of 1:62,500 to the north (Moore Station) and south (Tybo) of Hot Creek Canyon are available; the Morey Peak Quadrangle map covering Hot Creek Canyon has not been published. The previously cited maps focus on different aspects of the geology. Perhaps the most complete overall map is by Kleinhampl and Ziony (1985) as it has reasonable detail in both the valleys and ranges (Figure 3). The Whitebread and John (1992) map focuses solely on the bedrock geology but even within the ranges it lacks much of the finer detail of Kleinhampl and Ziony (1985). Only young faults are shown on the Sawyer and Anderson (1998) map at a regional scale not particularly suitable for purposes of geothermal exploration (Figure 4). Faulting and lineaments within the Quaternary units are the focus of the map by Schell (1981) but a review of some of the photos utilized by Schell shows that details of this map are questionable (Figure 5) and additional lineaments are easily visible on air photos.

Regional Stratigraphy

There are no outcroppings of pre Cambrian crystalline or granitic rocks in the Hot Creek Range. The oldest exposed rocks are a fairly complete Paleozoic marine sedimentary sequence several thousand feet thick ranging in age from Cambrian to Permian (Figure 3). There are abundant carbonate units with numerous caves and dissolution features that serve as part of the regional Eastern Nevada carbonate aquifer. Mesozoic rocks are absent in the Hot Creek area. A sequence of Tertiary volcanic rocks, primarily intermediate to silicic ash flow tuffs several thousand feet thick, unconformably overlie the Paleozoic sedimentary units. Within the Hot Creek Valley, Quaternary alluvium is present, again up to several thousand feet thick.

The youngest volcanic rocks in the region are the Quaternary and Recent Lunar Crater complex of basaltic cinder cones and lava flows. The closest of these features is about 11 miles southeast of the UHCR hot springs and the bulk of this complex is located within the Pancake Range to the east of the Hot Creek Valley (Figure 3). It seems unlikely that the Lunar Crater volcanic field is a heat source for the UHCR hot springs.

An oil exploration well, the Hot Creek Federal 24-13 was drilled by Apache Corporation in 1981 within Hot Creek Valley in the SW ¼ SW ¼ of Section 24, T 8 N, R 50 E (about 3 1/2 miles east-northeast of the UHCR) to a depth of 11,060'. This now abandoned well penetrated 7060' of Quaternary and Tertiary valley fill and 2690' of Tertiary volcanic tuffs. Between depths of 9750' and 11,060' Paleozoic carbonate rocks were the dominant lithology. Very limited temperature data from this well are described later.

Regional Structure

The Hot Creek Range and Hot Creek Valley are separated by a long down-to-the-east zone of range-bounding normal faults (Figures 3 and 4). This fault zone extends from north of Moores Station to the south end of the Kawich Range a distance of over 50 miles. While being a major element of the north-trending structure and physiography in this region of the Basin and Range province, this fault zone is by no means exceptional for any of its characteristics when compared with other major range-bounding fault zones in central Nevada (Figure 4). The fault zone is indicated to be up to 3 or 4 miles wide, involving up to four different strands, and extends from two to three miles within the range to two to three miles east of bedrock exposures out into the valley (Figure 4). The offset across the range front in Hot Creek Valley can be large as demonstrated by the Apache Corporation well which encountered 7060' of Quaternary and Tertiary valley fill deposits.

The Upper Hot Creek Ranch (UHCR) geothermal prospect is located in an area of abnormal regional structural complexity. To the south of Hot Creek Canyon the Hot Creek Range is a relatively simple uplifted north-south trending structural block eight to nine miles wide (Figure 3*)*. North of Hot Creek Canyon the width of the Hot Creek Range rapidly increases to about 12 miles with the development of an eastward six mile offset or step over of the entire range. This step over is completed in a north-south distance of about six miles. South of Hot Creek Canyon the great majority of faults trend north-south and Paleozoic rocks comprise about 1/3 of the outcrop. North of Hot Creek Canyon there is a 6 to 8 mile interval where the Paleozoic rocks do not crop out and most of the faults shown by trend east-west. North of this, where the range once again trends north-south, Paleozoic rocks are again present with dominantly northerly trending mapped structures. No east west trending structures are present within Hot Creek Canyon.

Local Structure and Active Faulting

Unfortunately, there are no published maps of the geology at a smaller scale than 1:250,000 in the vicinity of Hot Creek Canyon and the two most credible mapping efforts of recent faulting (Kleinhampl and Ziony (1975) and Schell (1981)) do not agree very closely (Figures 3 and 5). Therefore, the air photos of Schell (1981), available at the Nevada Bureau of Mines and Geology library were examined to provide an independent check on the range-front fault patterns. The review of the photos indicated several recent lineaments offsetting Quaternary alluvium, most likely Quaternary and/or Holocene fault traces, within a few miles of the mouth of Hot Creek Canyon that were not noted by Schell (1981) (Figure 5). Unfortunately, given the discouraging drilling results of the shallow temperature-gradient holes there is no reason to discuss these features in detail in this report.

North of Mountain View Canyon (the canyon about 1 mile south of Hot Creek Canyon and shown upstream from temperature-gradient hole J on Figure 2) the range-front fault loses its topographic definition as it enters the south side of Hot Creek Canyon (Figure 6). It also offsets hydrothermally altered silicic Tertiary volcanic rocks against Paleozoic rocks, suggesting a northward diminishing offset. There is a thin veneer of unaltered alluvium overlying much of the Tertiary volcanic rocks demonstrating this alteration occurred before the alluvium was deposited.

The range-front fault lacks topographic expression as it crosses the bottom of Hot Creek Canyon and appears to terminate beneath Quaternary alluvium a few hundred yards north of the UHCR house (Figure 3). However, a north-south trending, hundred foot wide calcite vein was found cutting through Quaternary alluvium at an elevation of 6200’ on a ridge 2600’ north of the UHCR house (Figure 2). This vein is more or less on strike with the range-front fault trend and demonstrates recent hydrothermal activity along the range-front fault trend north of the UHCR. This vein can only be accessed by foot in the steep and rugged terrain and was first noted during the drilling of the temperature-gradient holes.

The Upper Hot Creek Ranch hot springs are located about 600 to 1000 feet west of the range-front fault where it crosses onto the north side of Hot Creek Canyon. This proximity suggests the hot spring water utilizes the north end of the range-front fault as its primary channel to the surface. As the Hot Creek Valley crossing represents the lowest elevation of the surface trace of the range-front fault it is logical that the hot springs crop out in the canyon bottom.

North of the mouth of Hot Creek Canyon the topographic offset defining the range-front is confined to a single northeasterly to northerly trending fault that offsets older Quaternary alluvium against younger Quaternary alluvium (Figures 2 and 3). The offset along this fault segment gradually decreases toward the north or northeast (Figure 2) and it does not appear to intersect at the surface with the large displacement easterly trending fault that defines the south boundary of Morey Peak, which separates Tertiary volcanic rocks from Quaternary alluvium (Figure 3). Kleinhampl and Ziony (1985) provide a more credible mapping of this fault than Schell (1981). However, both previous mappers missed a northerly-trending west-dipping probable fault scarp about one half mile east of the south step over fault that defines a very prominent graben like feature on Figures 2 and 7. This graben, with beheaded channels in the alluvium clearly shown on the air photo, extends about 3 miles south from the mouth of Water Canyon to the main Hot Creek stream channel. No work has been done to date the age of the scarps defining this graben.

SEISMIC ACTIVITY

The UHCR geothermal prospect is located outside of all the known seismic belts in Nevada. It is in an area of low to very modest seismic activity (de Polo and dePolo, 1999). Near the mouth Hot Creek Canyon only two events with magnitudes less than 4.0 have been located. No events exceeding magnitude 6.0 have been recorded within 90 miles of the prospect.

GRAVITY AND SEISMIC LINES

A regional scale Bouguer gravity map of the Tonopah 1° by 2° quadrangle (Healey, et al., 1981) defines the major regional features. Unfortunately the individual stations are only located along the major roads and are spaced from 1 to 3 miles apart, not providing the level of detail needed to improve the structural understanding of the local Hot Creek area.

There are a number of existing seismic lines in Hot Creek Valley related to the Apache Corporation oil and gas exploration program but these are not discussed here due to the absence of a thermal anomaly in the valley.

TEMPERATURE-GRADIENT HOLES

The project originally intended to drill up to 10 temperature-gradient holes a maximum of 500 feet deep but due to unexpected permitting costs, rapidly increasing drilling prices, and drilling problems on one hole only five holes were drilled (Figures 6 and 7).

The holes were specifically sited at least a mile or so from the UHCR thermal springs to explore a relatively large area. Drilling relatively close to the UHCR thermal springs would undoubtedly define an intense shallow thermal anomaly but all of the major producing geothermal fields with 10 or more megawatts in output in the Basin and Range province to date are associated with large thermal anomalies covering at least several square miles. Therefore, this drilling program was designed to explore for a thermal anomaly covering several square miles and hopefully being at least partially located in an area where topographic and political constraints would not seriously constrain future project developments.

Drilling began on August 5, 2005 with a single crew. A second crew arrived late on August 6 for round the clock activity and the last hole was completed on August 12. The only problems encountered during drilling were hard rock, circulation losses and caving problems at site S, the rig becoming stuck while moving off of site S, and one water truck/pipe truck breaking down and needing to be towed to the last two sites. The drilling contractor provided more ancillary equipment such as a light plant for night drilling, a trailer mounted mud shaker system, a forklift, and a welding unit that significantly lengthened the moving time between holes over what was originally anticipated.

Temperature Gradient Hole Site Descriptions and Geology

Site T

This site was the first drilled and is located on the south side of the mouth of Hot Creek Canyon, about 1.2 miles southeast of the UHCR hot springs (Figures 2, 6, and 7). This hole penetrated Quaternary alluvium ranging from coarse sand to coarse gravel throughout its 400 foot length. This hole was picked as the most likely to obtain evidence of any subsurface flow of hot water down Hot Creek Canyon.

Site S

This site was drilled second and is located about ¾ miles northwest of the UHCR hot springs. It was the only available site located on Bureau of Land Management land in the lower part of Hot Creek Canyon. It is located in a narrow section of Hot Creek Canyon and encountered 120' of coarse alluvial material overlying limestone bedrock. There were lost circulation, hard drilling, and caving problems that limited this hole to a drilled depth of 205' and a completed depth of 176'. This hole was sited to evaluate the thermal regime within bedrock in the mountain range. A vigorous shallow subsurface flow of water should be present at this site. The canyon walls adjacent to this site are heavily karsted.

Site J

This site was drilled third and is located one mile south of the UHCR hot springs. It is located a few hundred feet east of the range-front fault below the mouth of Mountain View Canyon. This hole was specifically sited to gather evidence of abnormally high heat flow along the range-front south of the hot springs. This hole encountered alluvium to its total depth of 400' but the alluvium in the bottom half of the hole was finer grained and had more clay than the alluvium in the top half of the hole.

Site O

This site is located 2 1/3 miles northeast of the hot springs just east of the mouth of Fourmile Canyon. It was located to check for evidence of high heat flow along both the recent fault extending NNE from the mouth of Hot Creek Canyon and the east-west trending fault extending east from Fourmile canyon. It was not possible to site a hole in this area closer to the Upper Hot Creek Ranch hot springs due to an absence of roads, a Wilderness Study Area, and U. S. Forest Service management of lands. This hole penetrated coarse Quaternary alluvium to its total depth of 400'.

Site M

This site was drilled toward the middle of Hot Creek Valley to provide background information away from the eastern front of the Hot Creek Range. It is located about four miles east of the hot springs. This hole encountered relatively fine grained Quaternary alluvium to its total depth. This was the last hole drilled and was terminated at a depth of 300' for budget considerations.

Temperature Profiles

At least two temperature logs were run in each hole, some as soon as half a day after drilling was completed (Figures 8, 9, 10, 11, and 12). Temperature logs under thermal equilibrium conditions were run in all five holes on Aug. 21 and 22 (Figure 13). This allowed each hole to thermally equilibrate for between 10 and 15 days prior to obtaining the final log. Key data for the temperature gradient holes are shown on Table 1.

Table 1

Hole Name	Location	Elev.	Total Depth	BHT	Max Temp	Depth Interval	Gradient
		feet	feet	(ºF)	(ºF)	feet	(ºF/100 feet)
T	NE of SE Sec.33	5590	400	66.9	66.9	250-	3.1
	T 8 N, R 50 E					381	
S	SW of NW Sec.29	5700	205	76.8	80.1	20-	24.4
	T 8 N, R 50 E					98	
S	same					>98	Negative
J	NE of SE Sec. 32	5920	400	65.1	65.1	105-	2.12
	T 8 N, R 50 E					394	
O	NW of NE Sec. 22	5985	400	65.1	65.1	105-	1.37
	T 8 N, R 50 E					400	
M	NW of NE Sec. 1	5525	300	60.4	60.4	138-	1.99
	T 7 N, R 50 E					295	

Only the hole at site S in Hot Creek Canyon shows evidence of temperatures above regional background values with a temperature of 80 ºF being reached at a depth of 105'. The Old Dugan Place warm spring is located about 1 ½ miles upstream of site S and discharges a few hundred gallons per minute of 90 to 97 ºF water. Perhaps this or another large weakly thermal flow is impacting site S at shallow depths. It is possible that site S is within the thermal anomaly surrounding the UHCR hot springs. The temperatures at site S decrease below a depth of 105' so it is impossible to predict temperatures at greater depths (Blackwell, 2005).

Sites J, O, and M have nearly identical temperatures at a depth of 300 feet and linear temperature gradients that range from 1.4 to 2.1 ºF/100'. The similarity suggests that these holes represent the local background thermal conditions in the area.

Site T has the lowest temperatures and a fairly irregular temperature profile indicating some possible convective movement of cold water down Hot Creek Canyon. It also has the highest temperature gradient deep in a hole, 3.1 °F/100'. Whether the higher gradient in the bottom section of the hole indicates a higher gradient condition projecting to depth or merely reflects a return to the temperatures and gradients similar to the M, O, and J holes cannot be established with the data available.

Some limited temperature measurements from the Hot Creek Federal 24-13 well drilled by Apache Corp. in 1981 tend to confirm the shallow temperature gradient holes. The 24-13 well is located just over two miles north of TG hole M and 1.5 miles east-southeast of TG hole O (Figure 7). During a flow test at the completion of the well, a single maximum reading thermometer recorded a temperature of 375 °F at a depth of 8842'. Making the bold assumption that the 375 °F value is an accurate representation of the true formation temperature at a depth of 8842' and assigning a 60 °F surface temperature gives a linear temperature gradient of 3.57 °F/100'. This is modestly above the measured shallow temperature gradients. However, other data from the Apache well such as a Schlumberger temperature of 207 °F at a depth of 7600' (Seeley, 1981) give an average temperature gradient of 1.93 °F/100' which is virtually identical to the measured shallow temperature gradients.

The average gradients in the valley fill wells are somewhat lower than the Basin and Range norm. Assuming a typical valley fill thermal conductivity of 1.4 W/m/K, the heat flow for the wells would be 35-56 mW/m^2 compared to the Basin and Range average of 80±10 mW/m^2. These limited data are not very favorable for the geothermal development of this area without access to the immediate vicinity of the hot springs or to the rugged terrain north and south of Hot Creek Canyon. The data available from the drilling program are not sufficient to direct an intermediate depth drilling program.

The shallow temperature gradients and the deeper Apache Corporation temperatures are disappointing from a geothermal exploration perspective, demonstrating that there is not a large thermal aureole associated with the UHCR hot spring and that there is no large subsurface thermal outflow from the vicinity of the UHCR hot springs or the range-front fault. In fact, the UHCR geothermal system may potentially have the smallest thermal anomaly in Nevada of any geothermal system which has credible geothermometers exceeding 320 °F. There must be an intense shallow thermal anomaly in the immediate vicinity of the UHCR hot springs, but this anomaly must either be very restricted in size or extends to the north where access and data are lacking. The presence of the calcite vein ½ mile north of the UHCR house (Figure 2) offers some small possible support for the geothermal system extending north of the UHCR hot springs.

HOT SPRING DESCRIPTIONS

There are three known hot spring areas in Hot Creek Canyon, Upper Hot Creek Ranch, the Old Dugan warm spring, and Upper warm spring. The hottest and easternmost is at Upper Hot Creek Ranch where dozens of orifices produce water as high as 196 °F when measured in October 2003. In August 2005 the highest temperature measured was 191 °F. Different thermocouples were used in the different years but this 5 °F difference seems rather large to be explained by the equipment. The thermocouple used in 2005 was within 1 °F of the

SMU temperature probe at a temperature of 152 °F. Perhaps some or all of this cooling was due to the abnormally wet winter of 2004-2005 allowing greater amounts of cold shallow groundwater to flow into the UHCR area.

The UHCR hot springs occur in a heavily vegetated meadowland at the north edge of the bottom of Hot Creek Canyon (Figure 14). The entire hot spring area has been fenced to protect people and animals and is contained within the taller vegetation and fencing shown at the base of the hill on Figure 14. The hot spring area covers about one acre and is elongated in an east-west direction. A 67 °F stream flows east into the thermal area at a rate near 50 - 100 gpm and mixes with hot water. There is also ample opportunity for the thermal fluid to mix with cold shallow groundwater prior to the thermal water reaching the surface. Downstream of the hot springs there is a 250 to 300 gpm surface flow of mixed cold and hot spring water. Immediately below the thermal area the creek has a temperature of 153 °F. At the bridge across Hot Creek to the Upper Hot Creek Ranch the creek temperature is 102 °F, being reduced by other cold springs located east of the hot springs. The highest creek temperature measured in the thermal area was 156 °F.

Most, if not all, of the dozens of individual orifices do not exceed a few gpm in flow rate. The one major exception is a large orifice in the creek bottom in the east central part of the thermal area that warms the creek temperature from 142 °F to 154 °F. Temperatures within individual orifices vary substantially in all three dimensions. Many orifices at the level of the creek can not be sampled as the stream water readily flows into these orifices. Hot and relatively cool orifices can often be found within a few feet of each other. The overall thermal fluid flow from the hot springs is on the order of 150 to 200 gpm.

There are a few small patches of sulfur and salt crusted ground in the eastern part of the thermal area indicating that in the past or at certain times of the year shallow subsurface boiling occurs (Figure 15).

The Old Dugan Warm Spring is a large volume spring in the central part of Hot Creek Canyon 2.3 miles above the Upper Hot Creek Ranch hot springs. A temperature of 90 °F was measured in August 2005 while a temperature of 97 °F was measured in October 2003. This spring has recently been filled in and the flow diverted through a pipeline to operate a Pelton wheel. Flow from this spring is used for irrigation so some of this water probably becomes part of the groundwater system flowing downstream to the UHCR.

The Upper Warm Spring is a six to eight gpm 95 °F spring located about 4 miles upstream of the Old Dugan Warm Spring. This spring had the same temperature in October 2003 and August 2005 and supports a population of small fish.

About 20 miles south of Hot Creek Canyon a geothermal system crops out at Warm Springs for which basic chemistry and stable isotope data are available (Mariner et al., 1974, 1975). This hot spring has precipitated large amounts of travertine.

Hose and Taylor (1974) reported interesting Na-K-Ca predicted temperatures of 161 °C and 282 °C for a hot spring located near the center of Hot Creek Valley in Sec. 30, T 7 N, R 51 E. Unfortunately, no hot spring exists at this location and the reported 142 °F measured temperature is inconsistent with any of the thermal springs in Hot Creek Canyon. Apparently this spring named Hot Creek Valley is the result of a location error.

COLD SPRING DESCRIPTIONS

Cold springs occur at multiple places in Hot Creek Canyon upstream of the UHCR. There are many springs, seep, and marshy areas in the large meadow near UHCR that produce on the order of 100 gpm of cool water. Flows from individual orifices or collections of orifices are difficult to determine as significant parts of this large meadow are marshy. Upstream of this large meadow Hot Creek Canyon is dry for a mile or so but there are at least two or three other major meadow areas with springs and seeps further up Hot Creek Canyon.

There is one very low volume cold spring located about ½ mile downstream of UHCR that is utilized as a drinking water source for the Hot Creek Ranch. It was not sampled as part of this study. There is only one spring in Hot Creek Valley, Blue Jay Spring located several miles southeast of UHCR. It has a discharge of only a few gpm.

GEOCHEMISTRY

Prior to 2003 the only published chemical analyses of the Hot Creek Canyon thermal waters were some questionable and incomplete analyses (Garside and Schilling, 1979).

In October 2002 six water samples were collected from the Hot Creek Canyon area (Benoit, 2003) as a reconnaissance evaluation of the chemistry and to obtain some better documented predicted subsurface temperature data. Unfortunately, a series of analytical problems and questionable laboratory reporting compromised the quality of these data requiring a resampling of the waters as part of this project. These earlier data are not presented in this report as it requires a lengthy and ultimately unproductive discussion of possible errors and discrepancies.

Nine water samples were collected for a complete geothermal water analysis of cations and anions. One water sample was collected for a partial geothermal water analysis. Three diluted samples of the hottest waters were collected for colorimetric silica analysis. Eight samples were collected for stable isotope analyses (Table 2).

UHCR Hot Spring Sample Descriptions

Three samples of thermal water were collected from the three hottest orifices of the UHCR hot springs which did not have creek water flowing into or through them.

Sample UHCR-1a was collected from a pool along the north bank of the creek in the eastern part of the thermal area (Figure 15). The pool had a maximum temperature of 191 °F and a flow rate of 3 to 5 gpm. Immediately west of this pool there is some sulfur and salt encrusted ground but at the time of sampling shallow subsurface temperatures here were well below boiling temperatures.

Sample UHCR-2a was collected from a small 184 ºF to 188 ºF pool at the far western edge of the thermal area and south of the creek. This pool is on a small mound and did not have visible surface overflow but must have been discharging to the shallow subsurface for the temperatures to be this high.

Sample UHCR-8a was collected from a 187 ºF hot pool about 20' south of the creek in the central part of the thermal area. It is adjacent to a larger and cooler pool and was flowing at 1 to 2 gpm.

Mixed Hot and Cold Sample Descriptions

Sample UHCR-3a was collected from the 153 ºF creek at the east end of the culvert immediately above the UHCR bathhouse about 500 feet downstream from the east end of the thermal springs. This sample should be representative of the total flow from the hot springs and the cold surface flow down Hot Creek Canyon. The flow rate at this point is on the order of 200 gpm.

Sample UHCR-10a was collected from the bridge crossing Hot Creek to the UHCR. This sample point is another 500 feet downstream from the UHCR-3a sample location. The temperature of the stream here is 102 ºF and the flow is on the order of 300 gpm. There has been approximately 100 gpm of cold water added to Hot Creek by springs on the south side of the valley bottom between the UHCR-3a and UHCR-10a sites. This is a marshy area that is difficult to sample so no samples were obtained of this cold water source.

Cold Water Sample Descriptions

Sample UHCR-6a was collected from the 67 ºF stream a few hundred yards west and upstream of the UHCR hot springs. The stream was flowing about 50 to 100 gpm at this point.

Sample UHCR-7a was collected from a cold seep area on the south edge of the canyon near BM 5705 shown on the 7 ½" Hobble Canyon topographic maps. It is about 1800 feet west of the UHCR hot springs. This seep had a temperature of 69 ºF on the afternoon of August 10 however; this temperature is not particularly meaningful.

Sample UHCR-9a was collected from the 67 ºF pool immediately above the diversion box for the water system for the UHCR. It is located on the north edge of the canyon at the toe of an alluvial fan about 1600 feet upstream of the hot springs. The flow rate of this spring area is unclear.

Other Warm Spring Sample Descriptions

Sample UHCR-4a was collected from the ±50 gpm overflow of 90 ºF water from the Old Dugan Place hot spring in the bottom of Hot Creek Canyon approximately 2.4 miles west-northwest of the UHCR. This is flow that was not going to the Pelton wheel at the Kerbel (Old Dugan Place) Ranch. Flow of this spring has all been diverted into a pipe and the formerly large pool at this site no longer exists. The flow must exceed 100 gpm, perhaps significantly. After passing through the Pelton Wheel this water is used for irrigation and some of it must percolate into the ground and flow as groundwater toward the UHCR.

Sample UHCR-5a was collected from the 95 °F Upper warm springs which was flowing about 3 gpm. This hot spring is located on the bottom of Hot Creek Canyon about 5 ¾ miles west to west-northwest of the UHCR.

The USGS sample from Warm Springs, about 20 miles south of UHCR is also shown on Table 2 for comparative purposes. It has an overall composition reasonably similar to the UHCR thermal waters, presumably because the subsurface rocks in both of these areas are similar.

Basic Chemistry Results

All the analyzed samples are relatively dilute bicarbonate waters with filed pHs ranging from 6.5 (?) to 8 (from papers) and lab pHs ranging from 7.59 to 8.89 (Table 2). Total carbonate as a percentage of the anions ranges from 63 to 78%. Chloride ranges from 8 to 12% of the total anions. Sulfate ranges from 11 to 24% of the total anions. The balances for all nine completely analyzed samples are good, ranging from 0 to 4% with the total cation amounts consistently being higher than the anions. The most saline waters, by a small amount, are the UHCR hot springs and the cold seep on the south side of the Hot Creek Canyon (UHCR-7A). By far the most dilute sample is the Upper Warm Spring.

The UHCR hot springs are quite anomalous in having 4.79 to 5.2 ppm of magnesium, given the sampling temperatures of 184 to 191 °F. Normally springs this hot have magnesium contents of 0.5 ppm or less in Nevada.

The three cold water samples contain substantially more sulfate than the Upper Hot Creek Ranch hot spring waters and approximately equal amounts of chloride (Table 2). This permits these cold spring waters, which are all hydraulically up gradient of the hot springs to contain a large fraction of cooled geothermal water. However, the sulfate and chloride contents are greater than those in the Upper Warm Spring and Old Dugan Place thermal waters so this may be evidence of another previously unknown geothermal fluid in Hot Creek Canyon. Also, the silica contents are modestly elevated, giving predicted temperatures of 170 to 178 °F (Table 3). However, in terms of sodium, fluoride, lithium, and boron contents these cold waters do not resemble the UHCR thermal waters so they can not come directly from the UHCR geothermal system.

Stable Isotope Results

The eight stable isotope analyses show the two cold waters and the two warm spring samples defining a probable local meteoric water line (Figure 16). The Upper Hot Creek Ranch hot springs show the classical oxygen shift seen in geothermal systems throughout the world, although this shift is rather modest in magnitude, being approximately half a per mil. The USGS sample from Warm Springs is also shown on Figure 16 and is quite similar to the UHCR thermal waters in terms of its stable isotope composition and offset from the local meteoric water line.

Geothermometry

The three colorimetric silica analyses of the Upper Hot Creek Ranch hot springs agree closely with the silica ICP analyses (Table 2). The Fournier quartz geothermometer based on the silica ICP analyses predicts subsurface temperatures of 327 to 334 °F for the Upper Hot Creek Ranch thermal waters (Table 3).

The Na-K-Ca geothermometer predicts temperatures of 323 to 325 °F for the UHCR geothermal waters, just slightly lower than the silica predicted temperatures.

The Na-K geothermometer predicts higher temperatures but these are most likely abnormally high due to the relatively high calcium contents in the UHCR thermal fluid. The Na-K predicted temperatures are unbelievably high for the mixed, cold, and warm spring waters.

TABLE 3
Geothermometers

Sample	Na-K-Ca (F)	Na-K-Ca (Mg corr.) (F)	Na-K (Fournier) (F)	Quartz (Fournier) (F)	Li/Mg (Kharaka and Mariner) (F)
UHCR Hot Springs					
1A (east)	325	170	371	327	320
2A (west)	325	175	369	332	321
8A (central)	323	166	365	334	317
Mixed Waters					
3A (Hot Creek at bath house)	323	218	377	314	350
Cold Waters					
9A (cold water for UHCR)	144	44	429	170	472
7A (seep on S side of valley)	154	61	449	178	472
6A (Hot Creek above hot springs)	140	37	406	174	469
Warm Springs					
5A (Upper Warm Spring)	103	-21	234	198	468
4A (Old Dugan Spring)	131	0	478	189	502

If the magnesium correction is made to the Na-K-Ca geothermometers the predicted subsurface temperature of the UHCR thermal fluid decreases to approximately 170 °F, which is lower than the measured temperatures. This correction should not apply to the UHCR thermal fluids because the independent silica predicted temperature based on quartz solubility is very close to the Na-K-Ca predicted temperatures. This correction would be invalid if the magnesium were added to the UHCR fluid by dilution with shallow groundwater shortly before the sample was collected.

Interestingly, the Li-Mg geothermometer, a seldom used geothermometer, predicts subsurface temperatures of 317 to 321 °F for the UHCR geothermal waters. It also predicts unbelievably high subsurface temperatures for all the other water types.

Overall the geothermometers in Table 2 are in close agreement with a predicted temperature of 317 to 334 °F for the UHCR geothermal system.

Mixing Relationships

Graphs of boron and sodium versus lithium (Figures 17 and 18), and chloride versus sulfate (Figure 19) most clearly show the general relationships between the various water types in Hot Creek Canyon. The UHCR hot spring fluid mixes with the cold ground water to produce the mixed flow of Hot Creek below the hot springs. Immediately below the UHCR hot springs the mixture contains 75 to 85% UHCR thermal water. If the surface total flow at this point is 200 gpm then the amount of thermal water being discharged to the surface is on the order of 150 to 170 gpm. There is an old weir just below the bath house at the UHCR but it is full of debris and not usable for quantifying the flow rates.

The graph of chloride versus sulfate (Figure 19) allows the possibility that all of the sampled waters might be part of two mixing trends. A fairly saline cold groundwater might mix with other more dilute shallow waters upstream of the UHCR. In the vicinity of the UHCR hot springs the thermal water mixes with an already mixed ground water to produce the overall chemistry of Hot Creek downstream of the UHCR hot springs.

CONCEPTUAL MODEL OF THE UHCR GEOTHERMAL SYSTEM

The stable isotope data indicate that the water in the UHCR geothermal system either fell as precipitation at higher elevations or is a paleowater recharged during the last ice age (Figure 16). This is the standard interpretation for most or all Nevada geothermal systems. Three chemical geothermometers consistently and convincingly suggest that the deep geothermal resource temperature is approximately 325 °F (Table 3).

It is unclear as to where this recharge water migrated down to be heated at depth. There is abundant Paleozoic limestone in the area so it is possible that fluid flows could be through karsted limestone as well as along extensional normal faults. Assuming a temperature gradient of 2 °F/100’, a surface temperature of 60 °F, and a subsurface temperature of 325 °F, the recharge water must have descended to at least a depth of 13,250’ to access the geochemically predicted temperatures.

The proximity of the UHCR hot springs to the range-front fault defining the eastern margin of the Hot Creek Range to the south of Hot Creek Canyon strongly suggests a portion of this fault is the conduit by which the thermal water rises from depth (Figures 2 and 3). The UHCR thermal springs occur at or near the northern end of this particular fault. Temperature gradient hole J clearly shows that the fault one mile south of the UHCR has background thermal conditions so this part of the fault is not hosting the geothermal system. A lack of drilling north of Hot Creek Canyon allows the possibility that the fault extends some distance north of the canyon and might be transmitting hot water as indicated by the calcite vein high on the ridge above UHCR (Figure 2).

The geothermal system is discharging on the order of 150 to 200 gpm of hot water to the surface with a maximum measured temperature of 191 to 196 °F. This flow may include a couple of tens of gpm of magnesium rich shallow ground water that has mixed with the thermal water near the surface. There is obvious evidence of mixing (both visual and geochemical) of the thermal water with surface water at the hot springs and downstream of the hot springs. Temperature gradient hole T strongly suggests that there is no large subsurface flow of thermal water down Hot Creek Canyon.
The cold spring and stream samples collected upstream of UHCR contain elevated chloride, fluoride, and sulfate contents which suggest they were thermal waters in the recent past.

SUMMARY AND CONCLUSIONS

The UHCR geothermal system is located at the eastern margin of the Hot Creek Range in an area of abnormal structural complexity where the range begins to "step over" about six miles to the east. It is located at the north end of a major range-front fault segment that terminates in or near the bottom of Hot Creek Canyon. The area is tectonically active with several fault splays displacing Quaternary alluvium. There is no evidence of thermal activity along any of these fault splays. The geothermal system discharges on the order of 150 to 200 gpm from Paleozoic sedimentary rocks in a one acre sized area in the bottom of the Hot Creek Canyon.

The quartz, Na-K-Ca, and Mg-Li geothermometers are all in close agreement, indicating that the fluid discharging from the UHCR geothermal system has been as hot as 317 to 334 °F. Abnormally high magnesium contents of the thermal fluid indicate that there has been some mixing with a magnesium rich groundwater shortly before the fluid reaches the surface. The UHCR geothermal waters show the classical oxygen shift of stable isotopic values.

Four temperature-gradient holes up to 400 feet deep located south, east, and northeast of the UHCR hot springs produced temperature gradients of 1.4 to 3.1 °F/100'. These are within the range of regional background values. A fifth hole located upstream of the UHCR hot springs in the bottom of Hot Creek Canyon produced an irregular temperature profile with a maximum temperature of 81 °F. There is no large thermal anomaly or subsurface thermal plume of hot water associated with the UHCR geothermal system. The aerial extent of the geothermal system in the immediate vicinity of UHCR is not known however, it appears that the UHCR geothermal system has an exceptionally small shallow thermal anomaly given its geochemically predicted temperatures.

Any geothermal development in the immediate vicinity of the UHCR hot springs would face several challenges including serious topographic constraints, a wilderness study area designation of land north of the canyon bottom, and wetlands access and permitting issues.

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APPENDIX 1

UHCR Temperature Logs