Direct Use of Geothermal Water at the Solage Calistoga Resort, Napa County, California

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ABSTRACT

Direct utilization of low to moderate geothermal resources for bathing, balneology or space heating started growing since the end of the 20th century in California and the U.S.

Calistoga, in California, became one of the major towns for spas and resorts since the mid 1980s when several new resorts opened. Most waters used come from shallow wells (~200 feet) with temperatures from 170°F to 200°F, but recently, higher temperature were measured in a deeper reservoir, increasing the estimated size and longevity of the Calistoga geothermal reservoir.

The Solage Calistoga Resort, opened in 2007 currently uses fluid from one of the two shallow wells that were drilled on the property in 2006. Fluids at temperatures of 204-212 °F heat swimming pools and other spas as well as heating the facility.

1. Introduction

The Solage Calistoga resort is located immediately northeast of the town of Calistoga in the Napa Valley, California (Figure 1). The Calistoga area has been known for several decades as an area where geothermal fluids occur in the shallow subsurface over a relatively wide area. These fluids have been used for various spa and bathing purposes since the early 1860s (Youngs et al, 1980). Current usage of the geothermal fluids include spas, mud baths, balneology, mineral water production and other various uses at individual residences.

The general temperature of the geothermal fluids within the Calistoga area range from ambient water temperatures of 50-60°F to the hottest known subsurface temperature of approximatively 275°F at approximatively 1 mile northwest of the town of Calistoga (Youngs et al., 1980).

To supply its property with hot geothermal fluids, the Solage Calistoga facility drilled two wells: Palisades #1 and Palisades #2, to total depths of 397 and 852 feet respectively. Fluid temperature and flow rates obtained in these wells were higher than expected and brought new understanding of the Calistoga geothermal resource expanding its known depth of occurrence to the deeper fractured tuffs, previously limited to the overlying alluvial formations.

For the spa and heating use of the resort, Palisades #1 is used as a producer and Palisades #2 reinjection of the fluids to insure the reservoir longevity.

Figure 1. Location map of Calistoga.

2. Geologic Setting

The Calistoga geothermal area is at the southern end of the Mayacamas Mountains. The geologic framework of these Mountains is characterized by a series of northwest-trending folded, faulted blocks and thrust plates. The mountains are typically broken into corresponding series of northwest-trending ridges and valleys. Present in the area are rocks of the Franciscan assemblage of Cretaceous age, marine sedimentary rocks of Tertiary age, southeast of Clear Lake; the Sonoma Volcanics, of Pliocene age, near and south of Mount St. Helena; and numerous scattered exposures of non-marine sedimentary rocks of Pliocene to Holocene age (Figure 2).

2.1 Geologic Formations

Franciscan Formation and Sedimentary Rocks of Cretaceous Age

Rock units, assigned to the Franciscan assemblage by Blake and others (1971), occur in major portions of the Mayacamas Mountains. The Franciscan assemblage contains an abundance of sheared rock characterized by high clay content and low permeability. Areas where these rocks are exposed in the Mayacamas Mountains have large numbers of landslides.

Although the Franciscan assemblage comprises the bedrock within the Calistoga study area, actual outcrops of Franciscan rocks occur as small isolated exposures, confined to the north and northeastern margins of the valley. Typically, these outcrops are comprised of graywacke or greenstone, although an extensive body of serpentinite is exposed northwest of Kimball Reservoir (Youngs et al., 1980).

Sonoma Volcanics

Tertiary volcanic rocks are exposed on the surface over all of the marginal area of the Napa Valley. These rocks are composed almost entirely of material of volcanic origin, and are considered to constitute a part of the Sonoma Volcanics of upper Pliocene age. They constitute a thick and highly variable series of andesite, basalt, and minor rhyolite flows with interbedded and discontinuous layers of tuff, tuff breccia, agglomerate and scoria. Tuff, by far the most common and widely distributed rock in the Sonoma Volcanics, is a fragmental rock made up entirely of volcanic material.

Alluvium

In this paper, deposits described as alluvium include the older alluvium, terrace deposits, older alluvial-fan deposits, and younger alluvium as mapped and described by Kunkel and Upson (1960) and Fox and other (1973).

The older alluvium of Napa Valley is composed of lenticular deposits of unconsolidated and poorly sorted clay, silt, sand, and gravel. Where exposed at the surface, it is predominantly a reddish-brown color and exhibits cross-bedding.

Terrace deposits include numerous isolated bodies of unconsolidated clay, sand, gravel, and cobbles that cap hilltops and benches or border the base of steep hills and mountain slopes. All these bodies are thin and of small extent. No fossils have been found in these deposits, but their stratigraphic position indicates an age from late Pleistocene to Holocene. They may be equivalent

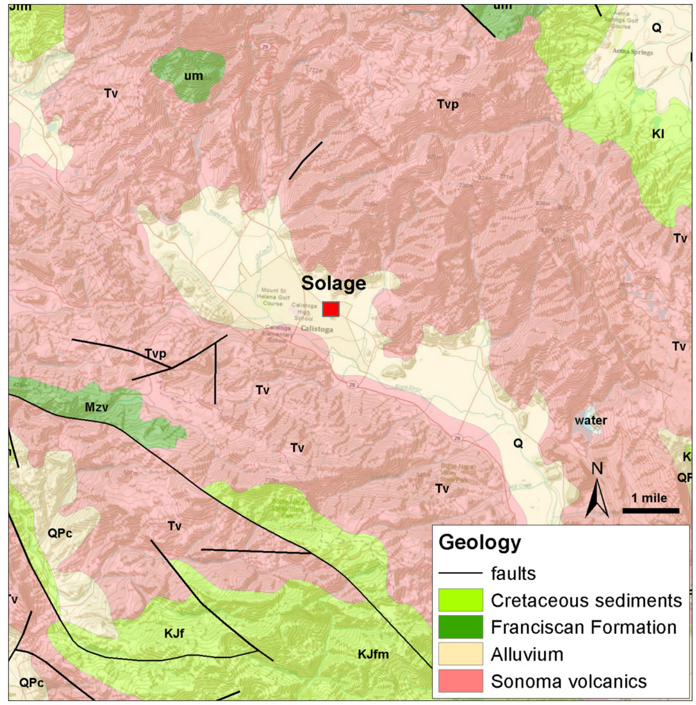

Figure 2. Geologic map of the Napa Valley.

in part to the older alluvium. These deposits are unconsolidated. Although in most places they contain a large proportion of sand and gravel, they are mainly non-waterbearing, because generally they are thin and occur above the water table.

The younger alluvium consists of interbedded unconsolidated gravel, sand, silt, clay, and peat in beds comprising channel, flood plain, and alluvial fan deposits. These deposits overlie or overlap all other formations in the Napa Valley.

The floor of the Napa Valley consists of channel deposits and flood-plain deposits composed predominately of well-sorted gravels and sand interbedded with silts. This material is not well exposed in section; and for the most part is indistinguishable from the older alluvium. However, typically, these deposits are less than 30 feet thick.

The thickness of the alluvium increases progressively from north to south, and from the periphery of the valley toward the Napa River. The alluvium nearly everywhere thins toward the edges of the valley, except in the area immediately east and southeast of St. Helena.

2.2 Structure

The geologic structure for much of the Mayacmas Mountains area is characterized by the northwest trends of the Jurassic and Cretaceous rock sequences and the fault zones that separate them into tilted and folded blocks Folding and faulting that has affected the Franciscan rocks is difficult to document in the Calistoga area due to lack of outcrops and reliable attitudes. That folding and faulting have occurred in the Franciscan rocks is evidenced by sharp attitude changes within short distances and near-vertical to vertical bedding. Some major northwest trending faults zones have been mapped to the northwest of Napa Valley (Fox and others, 1973).

The rocks of the Sonoma volcanic that cover most of the Franciscan rocks south of Mt St Helena were gently folded and faulted by compressional forces from the northeast or southwest after their deposition. Two relatively short faults north of Calistoga as well as some larger ones occurring 3 to 5 miles south and southeast have been mapped by Fox (1983).

3. Resource Characteristics

3.1 Temperature Distribution

A comparison of temperature logs by Murray (1986) for all wells within the Calistoga geothermal system indicates that maximum temperatures are reached at depths of approximatively 200 feet below the surface. Wells deeper than 200 feet generally produce water at cooler temperatures. This is characteristic of lateral hot-water flow and conductive heat losses to the confining sedimentary layers (Bodvarsson et al., 1982).

3.2 Flow Rates

Of all the parameters, flow rates are the most difficult to predict. This is primarily because the actual flow from each well is dependent on the immediate permeability characteristics in the vicinity of that well. In addition, while temperature and chemical characteristics are not complicated to measure, determining accurate flow rates requires comprehensive well test programs, not normally completed on most wells.

In the Calistoga area only two wells are known to have had true pump tests, CHS-1 and CHS-2. For CHS-1 two stabilized rates with acceptable drawdown were obtained: 78 gpm and 46 gpm. For CHS-2 the flow rate was estimated at less than 20 gpm.

Other wells in the area have various flow rates reported which range from up to 200 gpm to less than 5 gpm. However these rates are reported on well drillers summary reports submitted to the California Division of Oil, Gas and Geothermal Resources and as such are not necessarily truly representative of well capabilities due mostly to their unknown test length and other testing parameters.

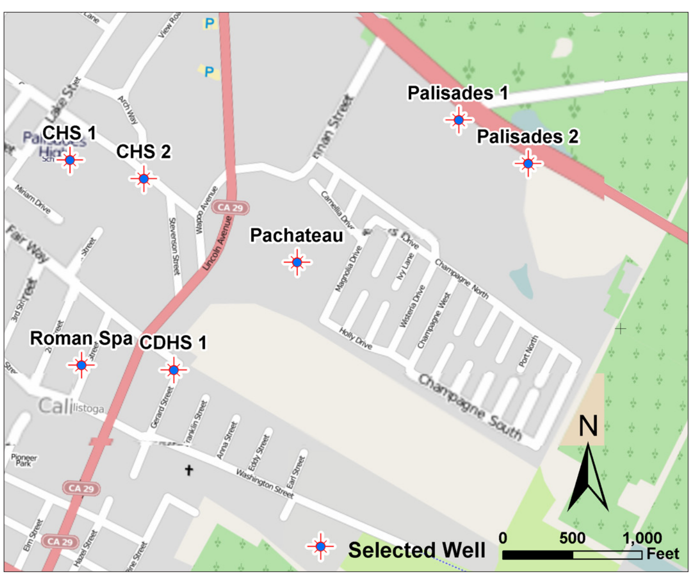

Figure 3. Selected Geothermal Well Map of the Calistoga area.

3.3 Reservoir Model

Previous studies of the geothermal resource underlying the city of Calistoga determined that it is made up of four separate zones (Youngs et al., 1980, Murray, 1986).

Zone 1 is comprised of alluvial sediments extending from the surface to about 120 feet deep, which contain low temperature water (less than 75 degrees Fahrenheit). Although saturated, only a few isolated wells produce waters in excess of 77° F from a depth less than 120 feet in the Calistoga area.

Zone 2 is considered the main sequence of alluvium with an average thickness of 640 feet and a maximum inferred thickness of 1,400 feet. Youngs et al. (1980) interpreted Zone 2 to be the primary geothermal aquifer in the Calistoga area. Murray (1986) stated that the longevity of use of geothermal fluids from Zone 2, assuming no recharge to the system, is expected to be approximately 100 years.

Zone 3 is a sequence of volcanic ash and ash flow tuffs below Zone 2 that contain little or no interstitial water. This section forms an impermeable barrier to vertical ground water migration between Zones 2 and 3.

Zone 4 consists of volcanic ash flow tuff capable of producing high volumes of hot water. The tuff breccia, scoriaceous material, and sedimentary deposits that compose a relatively small part of the Sonoma Volcanics generally are more permeable than the older ultra-basics Franciscan, and sedimentary Cretaceous rocks and yield, on the average, greater quantities of water to wells.

Previously thought to contain an upper unit that was welded and virtually impermeable, Zone 4 produced a large amount of hot water upon penetration of the permeable volcanic material. This zone may represent a major addition to the geothermal resource in the Upper Napa Valley. Estimates of reservoir longevity (100 years) made by Youngs et al. (1980) and Murray (1986) assumed that the alluvial sequence in Zone 2 represented the only zone that could produce geothermal water. They based their assumption on the interpretation that the underlying volcanic ash in Zone 3 and the lower Zone 4 was impermeable and geothermal fluids could only be extracted from the overlying alluvium in Zone 2.

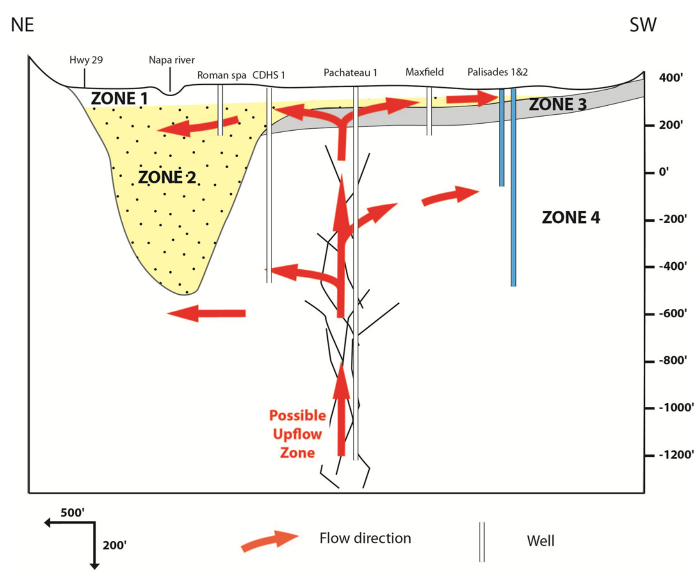

Figure 4. Conceptual model of the Calistoga resource.

Geochemical and hydrological analyses have demonstrated that the resource is being charged along a central fault or fracture system (Figure 7) (Youngs et al., 1980). The rate of natural charge and the rate of downstream discharge (surplus water) currently leaving the system, however cannot be accurately determined.

4. Solage Calistoga Production Wells

4.1 History

A first geothermal well, Palisades #1, was drilled in 2005 on the Solage property to a total depth of 397 feet. The 8 5/8" casing was installed to 352 feet with louvered screen sections after series of logs were run. The second well, Palisades #2 was drilled in 2006 about 500 feet southeast of Palisades #1 to a total depth of 852 feet to evaluate injection options (Figure 5).

4.2 Lithology Encountered

The Palisades #1 well encountered a sequence of volcanoclastic deposits, mostly welded tuffs beneath approximatively 45 feet of alluvium. This sequence is similar to the volcanic identified in other areas of Calistoga as part of the Sonoma volcanic. An increase in the hardness of the volcanics was noted below depth of 352 feet corresponding to the change from predominantly welded tuffs to lithic tuffs.

Palisades #2 also encountered a thick sequence of welded tuff, observed to the total depth of the well cut by thin alluvial formations (10 to 50 feet) composed of silt, sand, sandy clay or gravels.

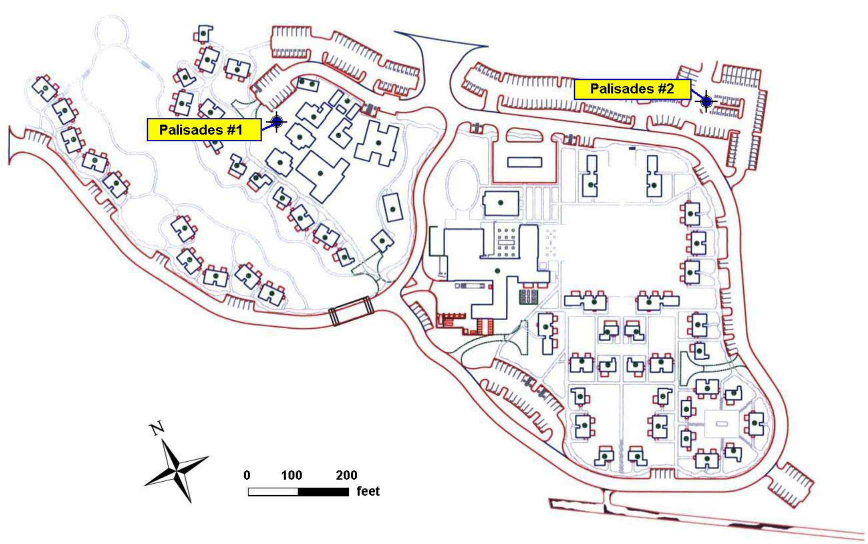

Figure 5. Solage Calistoga Facility Map and Well Locations.

4.3 Well Testing

Palisades #1 well was flow tested and was estimated to be capable of a flow rate of 22-25 gpm at a water temperature of 196°F (Figure 6). At this flow rate, the drawdown should be 193 feet, which is less than the maximum safe drawdown of 255 feet estimated by the pump contractor to ensure a prudent margin for operations. During the test the well flow rate decreased from 30 gpm to 21 gpm, resulting from a lower hydraulic head on the pump as the fluid level drops in the well. The pumping rate was adjusted to have a flow rate of 22-25 gpm. The flowing temperature of 196°F indicates that much of the flow is coming from the lower portion of the well.

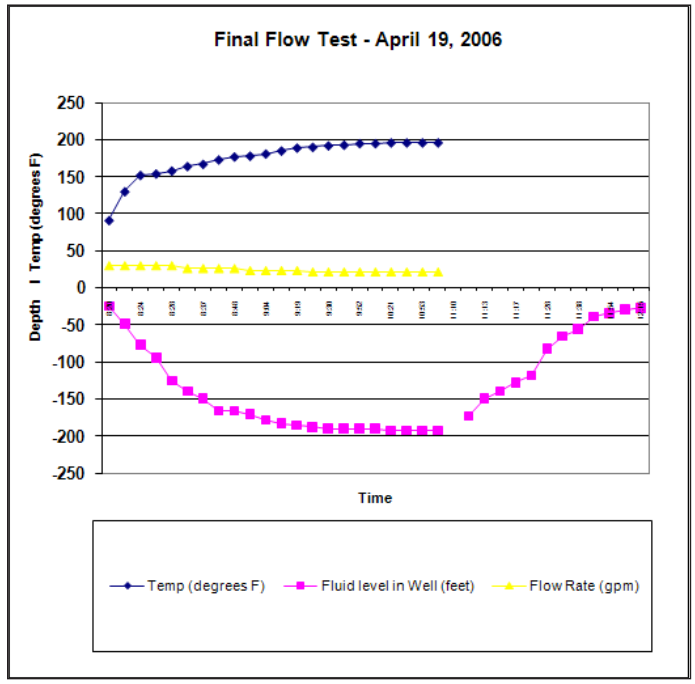

Figure 6. Flow Test Results in Well Palissades #1.

During flow testing there was some "surging" of the flow. Since the highest measured temperature in the well was 221°F at 350 feet the surging was a result of flashing occurring in the well. The Palisades #2 wells produced an estimated 30-35 gpm of geothermal fluid at approximately 204°F. The water was of similar quality as in Palisades #1.

Both wells produced fluids suitable for use at the facility but Palisades #1, with a slightly lower production is currently used as the primary production well and Palisades #2 would eventually be used as an injection well in the future.

4.4 Well Logging

Logs run in the Palisades #1 well included temperature, gamma ray, resistivity, self potential (SP) and a directional survey.

Because the temperature tool had a limited temperature range, the continuous temperature survey was run only to a depth of 270 ft. Temperature recorded at 270 ft was 153°F (Figure 7)

The well is subvertical, the inclination angle does not exceed 5°. The resistivity log shows 4 distinguishable lower resistivity zones (at 180', 230', 280' and 340') which correspond on the lithologic log of the well to zones described as having moderately altered silicic fine grained matrix and/or an increase feldspar to clay alteration. These zones are also visible on the SP log with the addition of an anomaly at 305'.

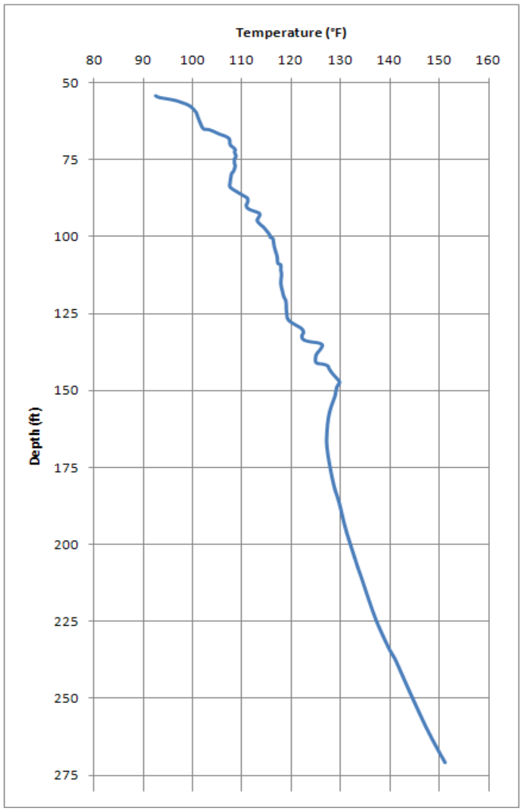

Figure 7. Temperature profile in well Palisades #1.

Constituent		Palisades No. 1	Palisades No. 2
	units		
Ca	mg/L	18	9.3
Li	mg/L	0.69	1.6
K	mg/L	10	11
Na	mg/L	150	270
SiO2	mg/L	77	86
Sb	mg/L	<0.15	<0.15
As	mg/L	<0.30	<0.30
Ba	mg/L	0.088	0.28
Be	mg/L	<0.01	<0.01
Cd	mg/L	<0.01	<0.01
Cr	mg/L	<0.01	<0.01
Co	mg/L	<0.05	<0.05
Cu	mg/L	<0.05	<0.05
Pb	mg/L	<0.05	<0.05
Mo	mg/L	<0.05	<0.05
Ni	mg/L	<0.05	<0.05
Se	mg/L	<0.20	<0.20
Ag	mg/L	<0.01	<0.01
Tl	mg/L	<0.40	<0.40
V	mg/L	<0.05	<0.05
Zn	mg/L	0.58	<0.05
B	mg/L	9.4	9.3
Hg	ug/L	<0.50	<0.20
F	mg/L	5.9	11
Cl	mg/L	190	180
SO4	mg/L	2.9	12
HCO3	mg CaCO3/L	150	110
Total Alk	mg CaCO3/L	150	110
TDS	mg/L	540	580
pH			7.88

Table 1. Chemical analyses results from well fluid samples.

4.5 Geothermal Fluids

Analytical data from well testing indicated that the produced fluids in both wells are consistent with geothermal fluids from other locations within the area and did not include any constituent levels that would prevent its use at the Solage Calistoga facility. Results of the sampling are presented in Table 1 and show that the geothermal fluids are relatively benign with total dissolved solids of 540mg/L which could classify the water as mineral water. The boron concentration is above the limit allowed for surface disposal which is an important factor for a well in an area of intense vineyard cultivation. The high barium levels are due to residual presence of drilling mud in the fluids.

5. Use System for Geothermal Fluids

The geothermal fluids are being pumped from Palisades #1 using a lineshaft pump located at 340 feet. Fluids are piped in a pressurized line from the well to two separate equipment buildings where heat is extracted and some geothermal water is diverted to direct use.

5.1 Heating and Distribution System

The geothermal fluid used in Solage Calistoga is pumped from the Palisades #1 well and is used in the two main parts of

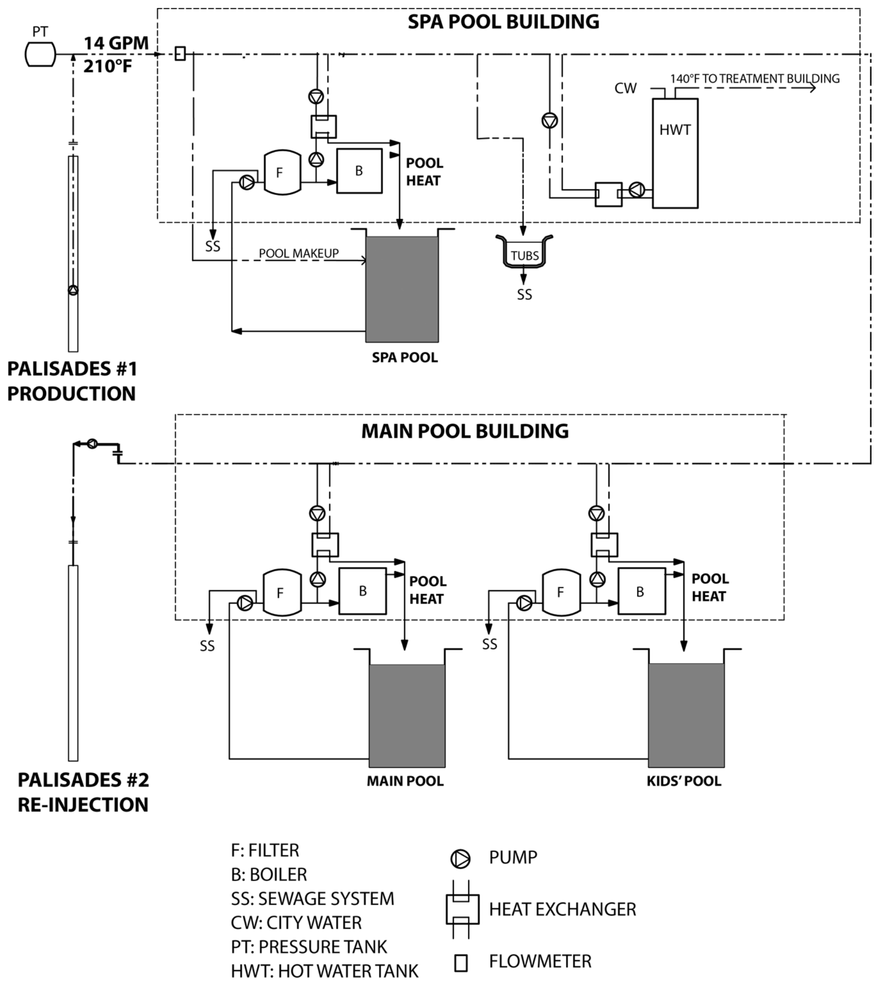

Figure 8. Flow chart for use of geothermal water at Solage Calistoga.

the facility: the Spa Pool area and the Main Pool area. A facility flow diagram is presented in Figure 8.

The geothermal pool in the Spa Pool area is filled exclusively with geothermal water. Its temperature is maintained at 98°F by extracting the heat from the geothermal water through the heat exchanger. The water of the geothermal pool is changed only in case of necessity. The spas are emptied and refilled as needed with geothermal water at night and allowed to cool down during closed hours, their temperature is then maintained at 104°F.

Part of the hot fluids is also cooled down separately with city water in a tank to be used in treatment soaking tubs.

In the Main Pool area, two pools (Main and Kids) and several spas, filled with city water are maintained at a temperature of 80°F using two heat exchangers extracting the heat from the geothermal fluid.

5.2 Sustainability of the Resource

The system installed at Calistoga Solage has been in use for approximately five years and is currently produced at a constant flow rate of approximately 14 gpm sufficient for facility demand. almost constant temperature ranging from 208 to 213°F. Depending on the need of hot geothermal water in the facilities, the re-injection temperature varies from 89 to 190°F.

6. Summary and Conclusion

As evidenced by drill logs, an increase in temperature and water volume upon penetration at depth, while drilling into deeper volcanics produced large volumes of hot water. The geothermal reservoir in the deeper volcanic rocks (Zone 3 and 4) is probably larger with a greater depth and more extensive recharge area compared to the alluvial reservoir in Zones 1 and 2.

The drilling of the two Palisades wells on the Solage Calistoga property brought new information regarding Calistoga geothermal resource. Temperatures as high as 221°F and maybe higher, at shallow depth (~400 feet) can be expected; the drawdown during production is limited indicating that the reservoir size is consequent and the fluid chemistry is suitable for geothermal use, with a low TDS classifying it as a mineral water.

References

Blake, M.C., Smith, J.T., Wentworth, C.M., Wright, R.H., 1971. Preliminary geologic map of western Sonama County and northernmost Marin County, California. In U.S.G.S. Department of Housing and Urban Development Basic Data Contribution 12.

Bodvarsson, G.S., Benson, S.M., Witherspoon, P.A., 1982. Theory of the Development of Geothermal Systems Charged by Vertical Faults. Journal of Geophysical Research, vol. 87, n°B.11.

Fox, K., Sims, J., Bartow, J., Helley, E., 1973. Preliminary geologic map of eastern Sonoma county and western Napa county, California. U.S. Geological Survey Basic Data Contributions, n°561.

Hsu, K.J., 1969. Preliminary report and geologic guide to Franciscan mélanges, Morro Bay – San Simeon Area, California: California Division of Mines and Geology Special Publication 35, 46p.

Kunkel, F., Upson, J.E., 1960. Map and ground water in Napa and Sonoma Valleys, Napa and Sonoma Counties, California. USGS Water supply Paper 1498, 252p.

Murray, K.S., 1986. A Geothermal Resource Assessment for the City of Calistoga, Final Report. California Energy Commission. 76p.

Taylor, Gary C., 1981. Drilling Addendum to Resource Assessment of Low and Moderate Temperature Geothermal Waters in Calistoga.

Youngs , L. Bacon, C., Chapman, R., Higgins, C., Majmunder, H. and Taylor, G., 1980. Resource Assessment of Low- and Moderate- temperature geothermal waters in Calistoga, Napa County, California, OFR 81-13 SAC. California Division of Mines and Geology, 168 p.